TESIS DOCTORAL POR COMPENDIO DE PUBLICACIONES

NEW PLATFORM FOR INTELLIGENT CONTEXT-BASED DISTRIBUTED INFORMATION FUSION

VNiVERSiDAD
D SALAMANCA

Departamento de Informática y Automática

Facultad de Ciencias

AUTOR

Gabriel Villarrubia González

DIRECTORES

Dr. D. Juan Francisco De Paz Santana

Dr. D. Javier Bajo Pérez

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Índice

1 Solicitud Presentación Tesis.

Estimada Coordinadora del Programa de Doctorado:

*Gabriel Villarrubia González con DNI: 71932845-T, y alumno del programa "*DOCTORADO EN INGENIERÍA INFORMÁTICA*" matriculado en el plan de estudios: INGENIERÍA INFORMÁTICA (R.D.99/2011) y con número de expediente 11:*

Solicita que se tenga en consideración la información aportada en este documento con el objetivo de poder presentar la tesis con título *"NEW PLATFORM FOR INTELLIGENT CONTEXT-BASED DISTRIBUTED INFORMATION FUSION" mediante el formato de compendio de artículos/publicaciones*. La información aportada se corresponde con lo establecido en el *Procedimiento para la presentación de la tesis doctoral en la Universidad de Salamanca en el Formato de Compendio de Artículos/Publicaciones*:

A continuación se detallan los documentos adjuntos en esta solicitud:

- Página Inicial especificando que la tesis corresponde a un compendio de trabajos previamente publicados detallando para cada uno de ellos: referencia de la revista, editorial, DOI y afiliaciones de cada uno de los miembros autores.
- Autorización del director o codirector para la presentación de la tesis mediante el formato de compendio de artículos/publicaciones.
- Tema objeto de estudio (Introducción).
- Estado del Arte.
- Apartado en castellano que refleje la coherencia y relación directa entre los artículos/publicaciones presentados. Dicho apartado incluirá al menos una introducción con los antecedentes del tema objeto de estudio, la hipótesis de trabajo y los objetivos así como las principales conclusiones.
- Copia completa de las publicaciones originales que conformarán la Tesis Doctoral (artículos, capítulos de libro, libro o libros aceptados o publicados).
- Para cada uno de los 3 artículos presentados, un resumen en castellano en el cual se especifican: los objetivos de la investigación, la metodología utilizada, los resultados alcanzados, y las conclusiones finales.

1.1 *Compendio de trabajos publicados.*

La tesis con título "*NEW PLATFORM FOR INTELLIGENT CONTEXT-BASED DISTRIBUTED INFORMATION FUSION*" corresponde a un compendio de trabajos previamente publicados. A continuación se detalla el nombre y afiliación de cada uno de los autores, la referencia completa de la revista o editorial y el DOI de cada uno de ellos.

Autores (**p.o. de Firma**)**:** Gabriel Villarrubia[1], Juan F. De Paz[1], Javier Bajo[2], Juan M. Corchado[1]
Titulo**:** Ambient Agents: Embedded Agents for Remote Control and Monitoring Using the PANGEA Platform
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Afiliaciones:
(1) Departamento de Informática y Automática, Universidad de Salamanca, Plaza de la Merced s/n 37008 Salamanca, Spain; E-Mails: gvg@usal.es (G.V.); fcofds@usal.es (J.F.P) ; corchado@usal.es (J.M.C.)
(2) Departamento de Inteligencia Artificial, Universidad Politécnica de Madrid, Madrid, Spain: E-Mails: jbajo@fi.upm.es (J.B.)
Lugar de Publicación: Basel (Switzerland)
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31/74 → Chemistry, Analytical — Segundo Tercio (2º Cuartil)
14/28 → Electrochemistry — Tercer Tercio (3º Cuartil)
Revisión por al menos dos expertos independientes

Autores (p.o. de Firma): Gabriel Villarrubia[1], Javier Bajo[2], Juan F. De Paz[1], Juan M. Corchado[1]
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(1) Departamento de Informática y Automática, Universidad de Salamanca, Plaza de la Merced s/n 37008 Salamanca, Spain; E-Mails: gvg@usal.es (G.V.); fcofds@usal.es (J.F.P) ; corchado@usal.es (J.M.C.)
(2) Departamento de Inteligencia Artificial, Universidad Politécnica de Madrid, Madrid 28660, Spain; E-Mails: jbajo@fi.upm.es (J.B.)
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Afiliaciones:
(1) Departamento de Informática y Automática, Universidad de Salamanca, Plaza de la Merced s/n 37008 Salamanca, Spain; E-Mails: srg@usal.es (S.G.); fcofds@usal.es (J.F.P) ; gvg@usal.es (G.V.); carol_zato@usal.es (C.Z.); corchado@usal.es (J.M.C.)
(2) Departamento de Inteligencia Artificial, Universidad Politécnica de Madrid, Madrid 28660, Spain; E-Mails: jbajo@fi.upm.es (J.B.)
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1.2 *Autorización del Director.*

Dr. Juan Francisco De Paz Santana

Profesor Titular de Universidad

Dpto. de Informática y Automática

VNiVERSiDAD
D SALAMANCA

Facultad de Ciencias

Plaza de la Merced, s/n.

37008 Salamanca, Spain

Tfno.: +34 923 294400 (Ext. 5478)

email: fcofds@usal.es

web: http://bisite.usal.es/

Dr. ***Juan Francisco De Paz Santana*** *DNI 76125754D profesor Titular de Universidad del Departamento de Informática de la Universidad de Salamanca*

HAGO CONSTAR:

Que como director de la tesis doctoral de Gabriel Villarrubia González con DNI 71932845T autorizo a presentar la tesis doctoral *"NEW PLATFORM FOR INTELLIGENT CONTEXT-BASED DISTRIBUTED INFORMATION FUSION"* mediante la modalidad de compendio de artículos al disponer de los siguientes artículos publicados*:*

1. *Gabriel Villarrubia, Juan F. De Paz, Javier Bajo, Juan M. Corchado, Ambient Agents: Embedded Agents for remote control and monitoring using the PANGEA platform, Sensors, 14, 13955-13979, (2014). JCR 2.245 Instruments & instrumentation (10/56) Q1.*
2. *Gabriel Villarrubia, Juan F. De Paz, Javier Bajo, Juan M. Corchado, Monitoring and detection system to track anomalous behavior applied to elderly care, Sensors, 14, 9900-9921, (2014). JCR 2.245 Instruments & instrumentation (10/56) Q1.*
3. *Sara Rodríguez, Juan F. De Paz, Gabriel Villarrubia, Carolina Zato, Javier Bajo, Juan M. Corchado, Multi-Agent Information Fusion System to manage data from a WSN in a residential home, Information Fusion. 23, 43-57, (2015). JCR. 3.681 Computer science, theory & methods (3/102) Computer Science, Artificial Intelligence (9/121) Q1.*

Por todo ello fimo esta carta de autorización

Fdo.: Juan Francisco De Paz Santana
Salamanca a 23 de Noviembre de 2015

1.3 *Aceptación por escrito y con firma original de los coautores para que el doctorando presente el trabajo.*

AUTORES **(P.O. DE FIRMA):** GABRIEL VILLARRUBIA[1], JUAN F. DE PAZ[1], JAVIER BAJO[2], JUAN M. CORCHADO[1]
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AFILIACIONES:

(1) DEPARTAMENTO DE INFORMÁTICA Y AUTOMÁTICA, UNIVERSIDAD DE SALAMANCA, PLAZA DE LA MERCED S/N 37008 SALAMANCA, SPAIN; E-MAILS: GVG@USAL.ES (G.V.); FCOFDS@USAL.ES (J.F.P) ; CORCHADO@USAL.ES (J.M.C.)
(2) DEPARTAMENTO DE INTELIGENCIA ARTIFICIAL, UNIVERSIDAD POLITÉCNICA DE MADRID, MADRID 28660, SPAIN; E-MAILS: JBAJO@FI.UPM.ES (J.B.)

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Los coautores del trabajo titulado "*AMBIENT AGENTS: EMBEDDED AGENTS FOR REMOTE CONTROL AND MONITORING USING THE PANGEA PLATFORM*" con D.O.I: *10.3390/s140813955*, hacen constar que Don Gabriel Villarrubia González con DNI: *71932845-T* es el autor principal de la investigación recogida en este artículo y que conocen y dan su consentimiento para que el artículo sea utilizado para que D. Gabriel Villarrubia González presenta su tesis doctoral denominada *NEW PLATFORM FOR INTELLIGENT CONTEXT-BASED DISTRIBUTED INFORMATION FUSION* en el formato de compendio de artículos:

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(1) DEPARTAMENTO DE INFORMÁTICA Y AUTOMÁTICA, UNIVERSIDAD DE SALAMANCA, PLAZA DE LA MERCED S/N 37008 SALAMANCA, SPAIN; E-MAILS: GVG@USAL.ES (G.V.); FCOFDS@USAL.ES (J.F.P) ; CORCHADO@USAL.ES (J.M.C.)
(2) DEPARTAMENTO DE INTELIGENCIA ARTIFICIAL, UNIVERSIDAD POLITÉCNICA DE MADRID, MADRID 28660, SPAIN; E-MAILS: JBAJO@FI.UPM.ES (J.B.)

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AUTORES (P.O. DE FIRMA): SARA RODRÍGUEZ[1], JUAN F. DE PAZ[1], GABRIEL VILLARRUBIA[1], CAROLINA ZATO[1], JAVIER BAJO[2] AND JUAN M. CORCHADO[1]
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(1) DEPARTAMENTO DE INFORMÁTICA Y AUTOMÁTICA, UNIVERSIDAD DE SALAMANCA, PLAZA DE LA MERCED S/N 37008 SALAMANCA, SPAIN; E-MAILS: SRG@USAL.ES (S.G.); FCOFDS@USAL.ES (J.F.P) ; GVG@USAL.ES (G.V.); CAROL_ZATO@USAL.ES (C.Z.); CORCHADO@USAL.ES (J.M.C.)
(2) DEPARTAMENTO DE INTELIGENCIA ARTIFICIAL, UNIVERSIDAD POLITÉCNICA DE MADRID, MADRID 28660, SPAIN; E-MAILS: JBAJO@FI.UPM.ES (J.B.)

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D. ª Sara Rodríguez González *D. Juan Francisco de Paz Santana* *D. Javier Bajo Pérez*

D. Juan Manuel Corchado *D. ª Carolina Zato Domínguez*

2 Introducción.

Durante los últimos años se ha producido un fenómeno social, de tal forma que por primera vez en la historia humana, más personas viven en las ciudades que en las zonas rurales. De acuerdo a las estimaciones realizadas, esta tendencia tendrá continuidad a lo largo del tiempo. En los próximos 20 años, se espera que la población urbana crezca de 3,5 mil millones a 5,1 mil millones de personas. Esta realidad social, requiere de novedosas soluciones tecnológicas que permitan mejorar el modo de vida de las personas que habitan en las ciudades. El impacto del citado crecimiento demográfico sobre el medio ambiente debe ser reducido. Es por ello que el uso de las tecnologías "inteligentes" ha tenido un gran crecimiento en las últimas décadas, buscando mejorar la eficiencia y eficacia de los sistemas urbanos.

Una ciudad inteligente se puede definir, como la integración de la tecnología en un enfoque estratégico para lograr la sostenibilidad, el bienestar de los ciudadanos, y el desarrollo económico en un entorno urbano. Si bien hay muchos estudios piloto innovadores y desarrollos a pequeña escala, no hay ningún ejemplo en la actualidad de ciudad inteligente que apoye y mejore la calidad de vida de millones de personas. La tecnología, en una de sus múltiples ramas, tiene como objeto contribuir mediante soluciones innovadoras a encontrar una solución a los problemas a los que se enfrenta una ciudad moderna, pero actualmente todavía hay muchos retos que deben ser abordados. Si la ciudad inteligente tiene como objetivo ser un plan para el desarrollo urbano, debe superar una serie de obstáculos técnicos, financieros y políticos.

Los productos de automatización y de control de edificios, han supuesto un aumento en la calidad de vida humana mediante sistemas de regulación y la sensorizacion. En este sentido, la tele-vigilancia (o tele-detección) hace posible la obtención de información relevante que caracteriza a los usuarios y a su entorno, permitiendo ofrecer servicios personalizados en función del estado de ánimo de las personas, edad, sexo,…etc. La automatización de edificios y la construcción de sistemas de control debe tener en cuenta normas, protocolos y sistemas de distribución de datos a la hora de obtener sistemas de automatización, tales como los sistemas de seguridad, sistemas de iluminación y otros, que deben tener capacidades para interactuar e integrarse entre sí. Para que el proceso de integración sea exitoso, las infraestructuras deben incorporar gran cantidad de recursos tecnológicos como diferentes redes de datos (públicas o privadas, con cable o inalámbricas,...), características de seguridad (alarmas, control de incendios,...), seguimiento (cámaras, sensores paramétricos,...), mecanismos de automatización del hogar (sensores y actuadores), y así sucesivamente.

Dentro de este marco tecnológico, las redes de sensores se han convertido en la pieza clave que sirve de unión en todos los servicios, utilizándose en prácticamente todos los sectores de nuestra sociedad. Una de las principales características de las redes de sensores, es poder adquirir datos y actuar sobre el entorno en el que se encuentran instaladas, siendo posible construir entornos inteligentes y entornos personalizados que permitan ofrecer servicios atractivos de cara al usuario final.

A través del uso de redes de sensores, los sistemas de automatización y control de edificios, que se originaron con la tecnología de cable, han evolucionado en la era de la tecnología inalámbrica, destacando tecnologías tales como Z-Wave , ZigBee y Bluetooth entre otras. Las redes de sensores inalámbricas (WSN) se utilizan para la recopilación de la información que necesitan los sistemas inteligentes, ya sea para ciudades inteligentes, automatización de viviendas y edificios, aplicaciones industriales u hospitales.

Las WSNs contribuyen al despliegue de redes que cubren las necesidades de comunicación con un tiempo de implantación, espacio y autonomía, mínimos, sin necesidad de una estructura fija, como ocurre con las redes de comunicación cableadas. En la actualidad, coexisten varias tecnologías inalámbricas como ZigBee, Wi-Fi o Bluetooth, que permiten implantaciones más sencillas que las que ofrecen tecnologías cableadas, evitando así, la necesidad de instalaciones previas, disminuyendo los costes y los inconvenientes de la fase de instalación y puesta a punto. Sin embargo, la continua evolución que experimentan las redes inalámbricas, hace que en numerosos casos estás nuevas tecnologías sean difíciles de implantar en un entorno real. Las WSNs hacen posible la construcción de una amplia gama de aplicaciones, como las utilizadas para controlar los costes de energía, controlar datos ambientales, implementar controles de seguridad y regular el acceso en edificios, automatizando entornos industriales y domésticos. Una de las aplicaciones más interesantes que puede proveer una WSN, son los sistemas de localización en interiores (ILS). Mientras que la localización al aire libre, está técnicamente más que probada mediante tecnologías como el GPS o el futuro sistema Galileo, los sistemas ILS, necesitan aún de un mayor desarrollo, especialmente deben mejorar la precisión y disminuir el gasto en infraestructura que supone la utilización de balizas. Algunas de las aplicaciones ILS más interesantes, incluyen entre otras, la posibilidad de realizar un seguimiento (personas, bienes y animales), control de accesos, emisión de alertas en situaciones de riesgo, control de los perímetros de seguridad y optimización de recursos.

A pesar de los avances que se han producido en los últimos años, la interconexión eficiente de redes de sensores, continúa siendo un reto debido a la complejidad que supone la integración de una gran variedad de tecnologías y protocolos de comunicación existentes, cada uno de los cuales, presenta un conjunto de requisitos específicos. Además, es un reto gestionar de forma adecuada la información generada por cada uno de los sensores existentes en el entorno. La principal dificultad reside en que los datos pueden ser incompatibles por múltiples razones, destacando (i) el despliegue sobre entornos abiertos que carecen de capacidad de integración con las diferentes tecnologías de sensores (que pueden ser altamente complejas y heterogéneas); o (ii) la dificultad para combinar la información de las redes de sensores de una manera sencilla y eficiente. Por lo tanto, en la actualidad, existe una creciente necesidad de investigar acerca de plataformas versátiles abiertas capaces de integrar diferentes tecnologías, empleando técnicas de fusión de datos procedentes de fuentes heterogéneas.

En el momento de escribir este trabajo, tanto en el mundo académico cómo en el de los negocios, existen algunas arquitecturas que permiten la interconexión de redes de sensores. Sin embargo, las plataformas existentes están diseñadas para casos de estudio particulares, utilizando un conjunto de tecnologías específicas para cada despliegue, y ofreciendo un conjunto muy específico de servicios, por lo general, con una funcionalidad limitada y sin posibilidad de personalización. Por lo tanto, los sistemas actuales están limitados por la pre-instalación de una infraestructura fija, siendo los integradores los que deben de hacer frente a la decisión de adaptar sus sistemas. Además, la posibilidad de combinar la información obtenida de las redes de sensores, es una tarea difícil para los integradores, ya que carecen de herramientas adecuadas para hacerlo. Otro reto que presenta la utilización de las WSN es ser capaz de proporcionar una gestión inteligente de los servicios al usuario mediante políticas de seguridad, que puedan actuar en situaciones en las que el sistema pueda estar comprometido.

Con esta problemática en mente, en esta tesis doctoral se investiga acerca del diseño de (i) una nueva arquitectura para la integración de redes de sensores heterogéneos que puedan utilizar diferentes tecnologías, y (ii) los mecanismos para facilitar la gestión inteligente de la información de los datos proporcionados por las redes de sensores. Una arquitectura que permita la integración de sensores a través de varios protocolos de comunicación (por ejemplo Wi-Fi, ZigBee, Bluetooth, RFID, etc.) es de vital importancia para el ofrecimiento de múltiples servicios finales a la sociedad. Por este motivo, hay que investigar acerca de los modelos de gestión inteligente basados en organizaciones virtuales (OV) que ofrecen las arquitecturas multi-agente.

La arquitectura que se propone en este trabajo de tesis doctoral debe garantizar la construcción de sistemas que aborden los desafíos computacionales que existen en la actualidad, pudiendo destacar, la utilización de recursos limitados (microcontroladores sin alta capacidad computacional), topologías dinámicas e híbridas, calidad del servicio, redundancia de datos, despliegues a gran escala y seguridad e integración con otras redes tales como Internet. Hoy en día, las redes de sensores incorporan mecanismos de comunicación que facilitan la interacción con los sistemas software. Algunas redes de sensores, proporcionan software específico para administrar tanto la configuración de la red, como la información obtenida de cada sensor. Sin embargo, existe la necesidad de obtener plataformas flexibles que integren nuevas tecnologías de sensores y que sean capaces de fusionar de manera eficiente la información procedente de los sensores que forman la red.

Otro de los retos que debe abordarse, es la capacidad de adaptación dinámica de una WSN a los cambios de contexto que se producen en el entorno, y a las necesidades particulares del usuario. Las arquitecturas existentes en la actualidad, no tienen en cuenta aspectos de adaptación o de organización, ni tampoco, la posibilidad de incorporar técnicas de fusión inteligente de información.

Para diseñar una arquitectura abierta basada en una tecnología de agentes que permita la integración de diferentes fuentes de datos heterogéneas, se debe prestar atención a los diferentes protocolos de comunicación abiertos que existen en la actualidad. Existen sistemas abiertos en entornos operativos dinámicos, en los que los nuevos componentes pueden unirse de forma puntual al sistema, o componentes ya existentes en el sistema, pueden dejar de formar parte del mismo si no son necesarios. Son componentes dinámicos, que se ajustan en función de la demanda y de la necesidad computacional de la arquitectura en un momento concreto, y cuya finalidad, es la optimización de recursos. En la literatura sobre Arquitecturas Orientadas a Servicios (SOA), es posible encontrar plataformas de agentes que proporcionan herramientas para el desarrollo de sistemas distribuidos. Sin embargo, estas herramientas no resuelven el problema de la auto-adaptación dinámica de los componentes del sistema. Por esta razón, es necesario el diseño de soluciones innovadoras que permitan crear sistemas flexibles y adaptables, especialmente para el logro de mayores niveles de interacción de una manera ubicua e inteligente. Los sistemas multi-agente (MAS) se pueden clasificar como sistemas abiertos o cerrados. La principal diferencia es que un MAS cerrado se crea con una estructura fija y ofrece una funcionalidad muy particular sin posibilidad de adaptación al entorno, mientras que en un sistema de agentes de tipo abierto, los componentes del sistema pueden adherirse o abandonar el sistema de forma dinámica, pudiendo formar parte de la arquitectura en cualquier momento. Se puede resaltar que los sistemas multi-agente de tipo abierto, son una solución relativamente nueva, que obedecen al paradigma, "el cómputo es algo que ocurre por medio de la comunicación a través de y entre las entidades computacionales".

Los sistemas MAS pueden ofrecer servicios bajo demanda y, en consecuencia, en términos de entidades, los (agentes) son los responsables de informar acerca de los servicios que pueden ofrecer al resto de las entidades de la arquitectura. Cabe señalar que estas entidades pueden no haber sido diseñados de manera conjunta o incluso por el mismo equipo de desarrollo, de tal forma que puede no haber existido un diseño orientado a facilitar la integración y comunicación de los diferentes componentes del sistema.

Las entidades o agentes propuestos en este trabajo de tesis doctoral presentan un rol dinámico, formando parte de una o varias organizaciones en función de la necesidad computacional de ese instante. Por otra parte, un agente puede formar coaliciones para ofrecer una capacidad o funcionalidad determinada. Obviamente, el desarrollo de un sistema MAS de estas características es complejo, siendo necesario, analizar previamente las características de funcionamiento así como el entorno de aplicación. Dadas las características especiales de los MAS, las arquitecturas multi-agente se han explorado en los últimos años como una tendencia emergente para gestionar las redes inalámbricas de sensores. Esta nueva perspectiva puede proporcionar un modelo de gestión organizativa adecuada para gestionar los comportamientos de las redes de sensores y los servicios al usuario de una manera más eficiente.

En este sentido, los aspectos informáticos y de organización social pueden ayudar a diseñar una nueva arquitectura con capacidades avanzadas que permita interconectar y administrar WSNs heterogéneas en entornos de ciudades inteligentes.

Pese a que se han realizado distintas iniciativas para abordar esta problemática, como se muestra en el estado del arte, no se han logrado avances significativos en el desarrollo de arquitecturas para gestionar redes de sensores. En la actualidad no existe una plataforma abierta que integre de manera eficiente datos procedentes de diferentes sensores y tecnologías. Por lo tanto, no se conoce la existencia de una plataforma que facilite la comunicación e integración de los sensores existentes, que pueden ser muy diferentes entre sí, pudiendo tener cada uno de ellos capacidades y características específicas, dificultando las labores de integración. Es de vital importancia analizar los mecanismos que permitan diseñar y desarrollar una arquitectura basada en agentes que pueda ser desplegada en un entorno de supercomputación. Las organizaciones virtuales se basan en la teoría de la organización y proporcionan inteligencia a la arquitectura con la adaptación de las necesidades particulares del problema de aplicación.

El entorno de supercomputación debe garantizar la disponibilidad de los recursos necesarios en todo momento para la correcta ejecución de la arquitectura. Hay varias tecnologías y áreas que pueden ayudar en la creación de una arquitectura de este tipo. Se trata de tecnologías que están evolucionando continuamente y que además del impacto actual, se prevé que van a tener una gran importancia en los próximos años, pudiendo destacar, el cloud computing, la fusión de la información, los sistemas de detección y prevención de ataques, así como las técnicas de balanceo de carga, calidad de servicios y sistemas de alta disponibilidad.

En un entorno complejo, pueden darse situaciones en las que sea complicado determinar cuándo y cómo llevar a cabo acciones que impliquen cambios en el funcionamiento del sistema, pudiendo ser necesario modificar dinámicamente la estructura interna del sistema distribuido. En el área de la Inteligencia Artificial Distribuida (IA), específicamente en el campo de la OV de agentes, uno de los objetivos, es crear sistemas capaces de tomar decisiones de forma autónoma y flexible, cooperando con otros sistemas dentro de una organización. Los sistemas multi-agente basados en OV son una tecnología adecuada para el funcionamiento complejo y dinámico de infraestructuras de redes inteligentes, sistemas de energía o redes distribuidas.

Diferentes estudios sobre técnicas de computación social han dado lugar al paradigma del diseño de sistemas sociales. Esta perspectiva ayuda a construir herramientas socio-técnicas que tienen como objetivo final el análisis de los diferentes conjuntos de datos para la extracción de patrones o comportamientos. Las OV son un ejemplo de entorno de aplicación de este paradigma. Una OV es un sistema abierto formado por la agrupación y colaboración de entidades heterogéneas. Las tecnologías de agente, hacen posible formar OV de forma dinámica. El proceso de modelado de las diferentes organizaciones virtuales que componen una arquitectura MAS, debe incorporar regulaciones acerca de las normativas para controlar el comportamiento del agente dentro de una organización específica, pudiendo establecer normas para la regulación de entrada/salida dinámica y la formación de grupos de agentes. En la actualidad el desarrollo de los sistemas multi-agente abiertos, es un campo reciente en el paradigma de las arquitecturas MAS, siendo necesario investigar nuevos métodos para modelar OVs basadas en agentes mediante técnicas innovadoras para proporcionar nuevas capacidad de re-organización. Uno de los retos de la informática social, es un modelo de interacción con los diferentes actores que componen una arquitectura MAS, siendo los más importantes los seres humanos y las redes de sensores inalámbricas. Un aspecto importante para modelar la interacción con WSNs es la estandarización y el procesamiento de la información. Sin embargo, es necesario el diseño de nuevos modelos de gestión capaces de facilitar la integración dinámica de WSNs.

Esta tesis, presentada por el formato de compendio de publicaciones, consta de un primer capítulo *"Solicitud Presentación de Tesis"*, que engloba toda la documentación necesaria para poder presentar la tesis en este formato. A continuación, el capítulo *"Introducción"* presenta una introducción acerca del tema de estudio y la problemática a resolver.

En el capítulo *"Estado del Arte",* se presenta una revisión del estado del arte de las principales tecnologías involucradas en este trabajo de tesis doctoral, prestando especial atención a arquitecturas orientadas a la fusión de redes de sensores heterogéneas. En el capítulo *"Coherencia y relación directa entre los artículos"* se presenta un resumen con los objetivos generales y la coherencia entre las tres publicaciones presentadas. En el capítulo *"Publicaciones Originales"* se presenta la arquitectura propuesta en el marco de este trabajo de tesis doctoral. La arquitectura y los resultados obtenidos se describen a través del compendio de tres trabajos de investigación publicados en revistas indexadas en el índice ISI JCR. En el capítulo *"Resúmenes de los Artículos"* se presenta un resumen para cada uno de los artículos, prestando especial atención a los objetivos, a la propuesta realizada en cada uno de los artículos y a los resultados obtenidos.

3 Estado del Arte.

En este capítulo se presenta una revisión del estado del arte relacionado con el trabajo de tesis doctoral, prestando especial atención a las arquitecturas que permiten llevar a cabo la fusión de redes de sensores. La revisión del estado del arte permite detectar la necesidad de obtener una nueva arquitectura abierta para la fusión de información en redes de sensores heterogéneas.

Los sistemas de automatización y los sistemas de control automática han mejorado los estilos de vida de las personas y han permitido ahorrar energía y dinero con dispositivos tan simples como reguladores de luz, barómetros, sensores de movimiento o de radiación solar. En el ámbito de la salud, como puede ser el caso de pacientes crónicos, en los últimos años se han producido grandes avances en el diseño de sensores para la obtención de datos biomédicos, así como en sistemas para la monitorización remota que hace posible obtener información de los usuarios. Estos avances relacionados con redes de sensores permiten ofrecer servicios personalizados al usuario en función de sus necesidades en el hogar, trabajo o en sus propios vehículos. Los sistemas de automatización y control en edificios vienen caracterizados a través de estándares basados en diferentes protocolos, siendo posible el desarrollo de sistemas de seguridad, iluminación y otros que interactúen unos con otros y se integren entre sí [13][14][15]. Para hacer posible esta integración, las infraestructuras tienen que incorporar una gran cantidad de recursos tecnológicos como pueden ser redes de datos, sistemas de monitorización, mecanismos domóticos (sensores y actuadores), y un largo etcétera.

Dentro de este marco tecnológico, las redes de sensores han adquirido una gran importancia y se utilizan en prácticamente todos los sectores de nuestra sociedad. Su gran capacidad para la adquisición de datos hace que resulte relativamente sencillo construir entornos inteligentes; permitiendo analizar de forma detallada y flexible los procesos que se desarrollan en el entorno y los servicios que se prestan a los usuarios.

Las redes de sensores inalámbricos (WSN) se usan para capturar la información de los entornos inteligentes ya sea en entornos como construcción, ciudades inteligentes, automatización de viviendas y edificios, entornos industriales, hospitales, vehículos [61][62][17]. Existen varias tecnologías inalámbricas como 6LoWPAN [1], Dash7[2], Insteon, WiFi, ZigBee[63], WirelessHART[12], Zwave, BLE. etc. que permiten despliegues sencillos comparados con las tecnologías cableadas, disminuyendo de esta manera los costes de despliegue [2]. Los protocolos de WSNs se caracterizan por bajos consumos y también por tasas de transferencia bajas y algunos de ellos como 6LoWPAN permiten la interconexión directa a Internet sin necesidad de puertas de enlace [1][7]. La existencia de protocolos tan heterogéneos dificulta la integración de sensores ya que es necesario incorporar nuevos sistemas de comunicación entre los diferentes elementos.

Las redes de sensores inalámbricas hacen posible la construcción de una amplia gama de aplicaciones para controlar diferentes aspectos como consumo de energía, monitorización del entorno, seguridad y acceso y automatizar diferentes aspectos en entornos industriales y en el hogar. Así se pueden ver trabajos que contemplan el uso sistemas sensibles al contexto como puede ser el alumbrado inteligente [3][65], seguimiento de vehículos [3], manejo o monitorización del tráfico [5][6].

En la actualidad, existen desarrollos para crear aplicaciones que permitan integrar redes de sensores. Estos desarrollos se basan por ejemplo en el sistema operativo *TinyOS* que permite interconectar sensores y tiene como principal característica el bajo consumo.

El sistema operativo *TinyOS* se puede usar sobre sistemas como *Mica2* y su uso está muy extendido en la investigación [12]. Sobre este sistema operativo, se han desarrollado trabajos como *Maté* una máquina virtual para interpretar código en bytecodes [8]. Mediante la plataforma *Maté,* se han desarrollado trabajos que permiten crear agentes, por ejemplo el middleware *Ágila* [9] que permite crear agentes y dotarlos de la capacidad de movilidad usándose por ejemplo para el seguimiento de incendios. En el trabajo de Molla et al. [10] se pueden ver diferentes middleware que se han desarrollado y alguno de ellos que se aplican sobre *TinyOS*. Además, también se pueden encontrar simuladores para *TinyOS* como es el caso de *TOSSIM* [11] lo que facilita el desarrollo de este tipo de aplicaciones. *TinyOS* permite la comunicación remota con otros dispositivos pero no incorpora características que faciliten el desarrollo de aplicaciones distribuidas que permitan gestionar de manera sencilla los servicios proporcionados por los agentes, así como controlar y monitorizar las interacciones entre los agentes de la plataforma.

A pesar de los avances que se han realizado durante los últimos años, la interconexión de redes de sensores es un reto debido a la complejidad de interacción con las diferentes tecnologías y protocolos de comunicación existentes [20][22]. Además, el manejo de manera eficiente de la información generada, es un reto debido a la existencia de entornos que no poseen la capacidad de integrar diferentes tecnologías de sensores o simplemente debido a la complejidad de fusionar la información de los mismos. Debido a estas razones, es interesante el desarrollo de una plataforma versátil que permita la integración de diferentes sensores y que permita el manejo inteligente de la información. Aunque en la actualidad hay arquitecturas que permiten la gestión de redes de sensores tanto a nivel académico como empresarial [21][15][16], la realidad es que están orientadas a desarrollos específicos y su funcionalidad es muy limitada [26]. Por tanto, los sistemas actuales están limitados a la instalación de una determinada tecnología y por tanto hay que realizar una elección entre ajustarse a la tecnología o plataforma y adaptar sólo una de ellas en el mejor de los casos [60]. Además, es complicado combinar la información obtenida por redes de sensores heterogéneas [1][28][52]. Otro aspecto a tener en cuenta, es proporcionar a estas herramientas, mecanismos de seguridad que actúen frente ataques informáticos que puedan comprometer al sistema [56][23][28].

En los últimos años, el grupo de investigación en el marco del cual se ha desarrollado esta tesis doctoral, grupo de investigación BISITE de la Universidad de Salamanca, ha trabajado en diferentes aspectos de los anteriormente citados. En el manejo de redes de sensores BISITE tiene experiencia en el trabajo con protocolos como ZigBee en el que se ha llevado a cabo proyectos como "*El Mayor Online*". En este proyecto se sensorizaban las habitaciones de mayores mediante redes de sensores inalámbricas y se monitorizaba la actividad diaria de las personas. En sensores biométricos se han desarrollado proyectos como *"System Primary Care at Home"*, sensorización para la inserción laboral "Desarrollo del proyecto *AZTECA*: Ambientes inteligentes con tecnología accesible para el trabajo.". También se han realizado diferentes publicaciones sobre uso de redes de sensores [68][69] y sus aplicaciones para personas de avanzada edad [62][63][64][67][70]. El grupo de investigación ha participado en proyectos de la comisión europea como *"EKRUCAmI Project"* que trata de la aplicabilidad de la inteligencia ambiental en granjas. En el apartado de alumbrado inteligente, se han realizado algunos proyectos "Implantación de un proyecto piloto de gestión inteligente de alumbrado público en la localidad de la Fuente de San Esteban" y "Implantación de la red experimental de comunicaciones de soporte para el proyecto piloto de *Smart Village* en la localidad de la Fuente de San Esteban.", además en el momento de redacción, se está realizando el proyecto de la comisión europea *"Dream-Go: Enabling Demand Response for short and real-time Efficient And Market Based smart Grid Operation - An intelligent and real-time simulation approach"*, estos proyectos tratan la gestión de energía y el despliegue de infraestructuras de datos para la interconexión de elementos como la red de alumbrado. En estos aspectos se tienen diferentes publicaciones como la siguiente citada [65]. En áreas como el seguimiento de vehículos y personas se han realizado numerosos proyectos, algunos de ellos ya nombrados anteriormente aunque se han realizado otros como *"Desarrollo y despliegue del sistema de localización para el metro de Bilbao"*, *"Desarrollo de sistemas inteligentes para el control y localización en entornos sanitarios."*, *"3DMovRA: Plataforma 3D en movilidad para el guiado de personas en interiores a través de Realidad Aumentada"*,*"Higía: Plataforma Inteligente para la Gestión y Seguimiento del Personal Sanitario, Pacientes y Activos en Entornos Hospitalarios"*, en estos proyectos se desplegaban redes de sensores para localizar a usuarios en interiores. En estos temas se han realizado publicaciones como [61][64][66][67][70]. En el área de desarrollo de vehículos inteligentes se está desarrollando una silla de ruedas eléctrica adaptada a personas con diferente discapacidad que puede ser manejada mediante voz, dispositivos móviles, gestos o pensamiento mediante el uso de un caso que recoge la actividad cerebral.

En la fase de revisión del estado del arte, se han encontrados trabajos como la arquitectura MANNA que propone que se tengan en cuenta las características funcionales, físicas y manejo de las redes de sensores inalámbricas [29]. Sin embargo, esta arquitectura no tiene en cuenta ni los aspectos de adaptación y de organización, ni de fusión inteligente de la información.

Lim et al. [30][31] propone una arquitectura de red de sensores, llamada "*scalable proxy-based architecture for sensor grid (SPRING)*", para hacer frente a estos problemas de diseño [30]. Sin embargo, la arquitectura está enfocada en el diseño de redes de sensores y no en su explotación. H-WSNMS [32] usa el concepto de conjunto de comandos virtual para facilitar las tareas de gestión en aplicaciones de WSN [59] pero no tiene en cuenta aspectos de fusión de la información y la organización. MARWIS es una arquitectura para el manejo de WSNs, soporta tareas como la monitorización, reconfiguración y reprogramación. Sin embargo, no tiene en cuenta aspectos organizativos ni realiza tampoco tareas de fusión de la información. Yu et al. [33] proponen un middleware para gestionar las WSNs en tiempo real mediante el uso de un framework jerárquico [34]. En esta propuesta se tienen en cuenta aspectos organizativos pero no se consideran algoritmos de fusión de información. G-Sense [35] es una arquitectura que integra sensores móviles y estáticos para servicios de localización y aplicaciones de detección de personas pero no tiene en cuenta aspectos de organización ni de fusión de información.

Hoy en día es posible encontrar diferentes propuestas de arquitecturas para el manejo de información en WSN [13][36][37][38][39]; sin embargo, muchas de ellas se diseñan para entornos o propósitos específicos y ninguno de ellos combinan: aspectos organizativos, técnicas de fusión de información, avanzados aspectos de almacenamiento y diseños abiertos de integración. Existen diferentes tecnologías que se pueden aplicar para crear tales plataformas. Por ejemplo, Cloud computing [40][23][41], oOV [43][44][45], fusión de información [20][28][46][42][48].

Uno de los desafíos en el social computing es modelar la interacción con los diferentes actores del entorno, en este caso los humanos y las WSNs. Un aspecto importante es modelar la interacción con los estándares de WSNs y procesar la información. Los estudios actuales se orientan al paradigma de la computación social en el que los humanos y las máquinas colaboran para resolver determinados problemas [53][54]. Estos sistemas tienen un alto grado de complejidad y requieren del uso de técnicas de Inteligencia Artificial para el procesado de la información y así dotar a los sistemas de una colaboración efectiva entre humanos y máquinas [54]. Es necesario diseñar nuevos modelos capaces de proporcionar la fusión de información de manera dinámica y dar soporte a la integración de WSNs conocidas o nuevas. Las OV de agentes son especialmente apropiadas para diseñar arquitecturas abiertas así como integrar WSNs heterogéneas e implementar técnicas de fusión de información. Sin embargo, un sistema de este tipo requeriría una cantidad de recursos computaciones flexibles en función de las necesidades de ahí que sea necesario otras tecnologías como cloud computing.

Cloud computing entendido como paradigma de computación, ha ido en aumento en los últimos años; tanto es así que se ha vuelto muy común en casi cualquier campo, incluso más allá del contexto social que es tan frecuente en Internet hoy [40][58]. Las plataformas cloud se dividen en las capas [51]: plataforma como Servicio, software como servicio e infraestructura como servicio. Desde el punto de vista interno, los servicios ofrecidos poseen elasticidad, en parte por la madurez de las tecnologías que se manejan (virtualización, granjas de servidores, servicios web, portales webs, etc.).

En el apartado de arquitecturas para el manejo de información de fuentes heterogéneas se han realizado diferentes proyectos tales como *"Cloud-IO: Plataforma Cloud Computing para la Integración y Despliegue Rápido de Servicios sobre Redes Inalámbricas de Sensores."*, *"El mayor online"*, *"Arquitectura distribuida abierta con tecnología de agente para el desarrollo de entornos de inteligencia ambiental."*

El primero de los proyectos estaba orientado a localización mediante diferentes tipos de sensores, los otros dos proyectos fueron orientados a la monitorización de personas de avanzada edad.

Entre las publicaciones sobre arquitecturas de fusión de la información se tienen los trabajos como HERA [69], FUSION@ [71] o la arquitectura PANGEA para el manejo de información de sensores [74].

Las conclusiones obtenidas tras revisar el estado del arte han sido las siguientes:

- Existe una creciente necesidad de obtener arquitecturas que permitan fusionar redes de sensores de forma eficiente.
- No existe en la actualidad ninguna arquitectura que sea capaz de fusionar redes de sensores heterogéneas de forma dinámica y que permita aplicar novedosas técnicas de fusión de información.
- La incorporación de un componente social resulta novedoso y permite crear un modelo de fusión cercano al comportamiento humano.
- Existen una serie de herramientas tecnológica y paradigmas que hacen posible proponer una arquitectura abierta basada en sistemas multiagente para la fusión de información.

En los dos siguientes capítulos se presenta la propuesta realizada en este trabajo de tesis doctoral para abordar las necesidades y carencias detectadas.

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5 Coherencia y relación directa entre los artículos presentados.

En este capítulo se describe la coherencia de cada uno de los artículos que componen esta tesis doctoral. Los artículos se encuentran alineados con un trabajo de investigación bien definido y planificado orientado a la consecución de una arquitectura multi-agente con capacidades avanzadas para la interacción con sensores del entorno y la fusión de información. De esta forma el artículo *AMBIENT AGENTS: EMBEDDED AGENTS FOR REMOTE CONTROL AND MONITORING USING THE PANGEA PLATFORM* presenta el diseño de una arquitectura multi-agente para entornos dinámicos, con la propuesta de un nuevo modelo de agente embebido en dispositivos con bajas capacidades de almacenamiento y procesamiento. El artículo *MULTI-AGENT INFORMATION FUSION SYSTEM TO MANAGE DATA FROM A WSN IN A RESIDENTIAL HOME* se centra en el diseño de mecanismos de interacción con sensores que utiliza la arquitectura para comunicarse con el entorno, el sistema incorpora motores de reglas y minería de datos para analizar la información de los sensores. Finalmente el artículo *MONITORING AND DETECTION PLATFORM TO PREVENT ANOMALOUS SITUATIONS IN HOME CARE* se centra en el diseño de nuevos algoritmos y métodos de fusión de información para entornos con grandes cantidades de sensores. Los artículos presentan tres casos de estudio en los que se ha evaluado la validez de las nuevas propuestas. A continuación se presenta la motivación para llevar a cabo este trabajo y la forma en la que se ha estructurado en base a tres artículos, centrados en la indagación de tres elementos novedosos y bien diferenciados de la propuesta.

Durante las últimas décadas, las redes de sensores se han vuelto cada vez más importantes, de tal forma que hoy en día están presentes en prácticamente todos los sectores de nuestra sociedad. Su gran capacidad para adquirir datos y actuar sobre el entorno, puede facilitar la construcción de sistemas sensibles al contexto, que permitan un análisis detallado y flexible de los procesos que ocurren y los servicios que se pueden proporcionar a los usuarios.

A pesar de los avances que se han producido durante los últimos años, la interconexión de redes de sensores es un reto debido a la complejidad de interacción de las diferentes tecnologías y protocolos de comunicación existentes para la comunicación entre dispositivos, pudiendo tener estos protocolos, algún tipo de restricción funcional que dificulte su integración con otro tipo de sensores. La tarea de integración resulta demasiado complicada cuando el sistema no presenta la capacidad de adaptación a las diferentes tecnologías de sensores (altamente complejas y heterogéneas). Este hecho dificulta la extracción de información de las redes de sensores de una manera sencilla y eficiente.

En la actualidad existe una necesidad creciente, acerca de cómo investigar y desarrollar plataformas versátiles y abiertas capaces de integrar diferentes tecnologías de sensores, fusionando conjuntos de datos de fuentes heterogéneas y gestionando de manera eficiente la información para su posterior estudio.

Las redes de sensores actuales se basan en tecnologías propietarias, que hacen uso de infraestructuras y protocolos muy cerrados, resultando complejo el diseño de herramientas que permitan combinar la información obtenida por diferentes sensores. Es de vital importancia investigar acerca de plataformas que permitan la integración y el ofrecimiento de servicios a los usuarios basados en la información extraída de los datos obtenidos por los diferentes componentes del sistema.

La hipótesis de este trabajo de tesis doctoral es que es posible diseñar y desarrollar una arquitectura multi-agente abierta que permita gestionar múltiples redes de sensores heterogéneas aplicando técnicas de fusión de información de forma dinámica.

El trabajo que se presenta en esta tesis doctoral es una continuación de los resultados obtenidos en la arquitectura PANGEA ("Platform for Automatic coNstruction of orGanizations of intElligent Agents"), a cuyo diseño contribuyo el doctorando durante su etapa inicial de investigador. Los objetivos de este trabajo de tesis doctoral son: i) Obtener una arquitectura que incorpore nuevos mecanismos tecnológicos que permiten dotar a PANGEA de nuevas capacidades para obtener datos de cada uno de los sensores (localización de activos, humedad, sensores de temperatura, humo, gas…), con la novedad de que dicha adquisición se realice de forma independiente a la tecnología que usen los sensores (ZigBee, WiFi, Bluetooth, RFID, ·3G, 4G). ii) Obtener un nuevo modelo de agente especialmente diseñado para ser embebido en dispositivos con bajas capacidades de almacenamiento y procesamiento y con capacidades de integración con la arquitectura. iii) Además, la arquitectura propuesta en este trabajo de tesis doctoral podrá hacer uso de organizaciones virtuales dinámicas y autoadaptables al contexto, ofreciendo servicios eficientes y atractivos al usuario final (envío de alertas, detección de situaciones de riesgo…etc). La principal innovación en este sentido reside en el diseño de nuevos modelos de agente especializados en la fusión de información procedente de sensores heterogéneos.

El modelo de arquitectura diseñada hace uso de mecanismos que garantizan la seguridad y la integridad de los datos utilizados por los servicios que se presentan al usuario. La asignación de recursos a cada servicio es dinámica, asignándose mayor o menor número de recursos en función de la demanda en cada instante de tiempo.

La arquitectura planteada servirá como una plataforma abierta para facilitar la integración y gestión de redes de sensores, proporcionando servicios basados en la información proporcionada por las redes de sensores. Una de las principales novedades de la plataforma es su carácter abierto, lo que permite la adición de nuevas redes de sensores, pudiendo integrar diferentes tecnologías. Los sistemas abiertos se caracterizan por la heterogeneidad de sus componentes. La plataforma propuesta a lo largo de los 3 artículos que componen este trabajo de tesis, combina la tecnología de agentes junto con algoritmos de fusión de información, proporcionando una gran capacidad de adaptación a los cambios de contexto y un uso eficiente de las tecnologías de sensorización.

Esta plataforma proporcionará una herramienta capaz de adaptarse dinámicamente a la configuración de las tecnologías disponibles en un momento determinado, con el fin de suministrar a las capas superiores de la arquitectura información precisa para la personalización de servicios.

Esta tesis doctoral se presenta en el formato de "Compendio de Artículos", de tal forma que las principales características de la arquitectura multi-agente distribuida propuesta para facilitar la interconexión de redes de sensores se presentan en tres artículos bien diferenciados. Se ha planteado una arquitectura modular y ligera para dispositivos limitados computacionalmente, diseñando un mecanismo de comunicación flexible que permite la interacción entre diferentes agentes embebidos, desplegados en dispositivos de tamaño reducido. Se propone un nuevo modelo de agente embebido, como mecanismo de extensión para la plataforma PANGEA. Además, se diseña un nuevo modelo de organización virtual de agentes especializada en la fusión de información. De esta forma, los agentes inteligentes tienen en cuenta las características de las organizaciones existentes en el entorno a la hora de proporcionar servicios. El modelo de fusión de información presenta una arquitectura claramente diferenciada en 4 niveles, siendo capaz de obtener la información proporcionada por las redes de sensores (capas inferiores) para ser integrada con organizaciones virtuales de agentes (capas superiores). El filtrado de señales, minería de datos, sistemas de razonamiento basados en casos y otras técnicas de Inteligencia Artificial han sido aplicadas para la consecución exitosa de esta investigación.

6 Publicaciones originales que conforman la Tesis Doctoral.

6.1 *Monitoring and Detection Platform to Prevent Anomalous Situations in Home Care.*

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Article

Monitoring and Detection Platform to Prevent Anomalous Situations in Home Care

Gabriel Villarrubia [1], Javier Bajo [2], Juan F. De Paz [1,*] and Juan M. Corchado [1]

[1] Departamento de Informática y Automática, Universidad de Salamanca, Plaza de la Merced s/n, 37008 Salamanca, Spain; E-Mails: gvg@usal.es (G.V.); corchado@usal.es (J.M.C.)

[2] Departamento de Inteligencia Artificial, Universidad Politécnica de Madrid, Madrid 28660, Spain; E-Mail: jbajo@fi.upm.es

* Author to whom correspondence should be addressed; E-Mail: fcofds@usal.es; Tel.: +34-923-294-400.

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Abstract: Monitoring and tracking people at home usually requires high cost hardware installations, which implies they are not affordable in many situations. This study/paper proposes a monitoring and tracking system for people with medical problems. A virtual organization of agents based on the PANGEA platform, which allows the easy integration of different devices, was created for this study. In this case, a virtual organization was implemented to track and monitor patients carrying a Holter monitor. The system includes the hardware and software required to perform: ECG measurements, monitoring through accelerometers and WiFi networks. Furthermore, the use of interactive television can moderate interactivity with the user. The system makes it possible to merge the information and facilitates patient tracking efficiently with low cost.

Keywords: multi-agent system; indoor location; WIFI; home care

1. Introduction

Nowadays telemedicine and home care are becoming increasingly important in society due to advances in sensor technology [1], devices, communication networks [2] and especially as the result of an aging population in Europe [3]. It is estimated that 50% of the population in Europe will be over 60 years old in 2040, while in the USA it is estimated that one in every six citizens will be over 65 years old in

2020 [3]. In addition, people over 85 years usually require continuous monitoring [3]. For this reason, it is necessary to create systems that can appropriately monitor the users [4] and that are easily adaptable to sensor networks and hardware from different manufacturers. The high price of the components to install at home is a key problem in home care. For this reason it is necessary to develop systems that are affordable. This paper proposes an architecture based on the PANGEA platform [5]; it allows embedding agents in different hardware to facilitate and perform careful monitoring of home users.

Context aware systems use wireless sensor networks to collect information from the environment and act according to the retrieved data [6]. They have evolved and been applied in several fields such as medicine [4]. One of the key features in context aware systems is adaptability, given that different users have different needs, as highlighted in [7]. For this reason the systems must be adaptable according to the needs of the users. Some studies make use of cloud computing or multiagent systems [4,8] to manage the available distributed sensors. Virtual organization of agents can be used to achieve this adaptability, as they allow for the inclusion of new roles and for system behavior to adapt dynamically [5,9]. The BISITE research group has developed the PANGEA [5] platform, which facilitates the development of agents in light devices and the integration of different hardware.

This study proposes a system based on virtual organizations of agents that allows patient monitoring and tracking by incorporating different hardware systems. The PANGEA platform was specifically used [5] as it allows the development of virtual organizations of agents and facilitates the deployment of agents in lightweight devices. The system incorporates different virtual organizations to monitor patients at home and it includes roles to locate and monitor users, to monitor cardiac function, and to allow the user to interact with the system through a television. The location system is based on probability to determine the user's location. It is based on Received Signal Strength Indicator (RSSI) signal levels received from different WiFi routers. The accelerometer of the mobile device is used to avoid continuous fluctuations in the location system due to changes in the signal levels; this makes it possible to detect the steps taken by the user and calculate his or her location through RSSI levels. This motion information will be of special interest with the electrocardiogram, since the user will not have to manually record physical activity. Electrocardiography (ECG) incorporates the necessary hardware to send the data to the system via Bluetooth. In addition, the system incorporates a basic analysis of the ECG for sending alerts. Finally, the user can interact with the system through the television by means of a Raspberry Pi, which allows the home to be continuously connected to the Internet. The paper is structured as follows: Section 2 discusses the state of the art; Section 3 presents the proposal; Section 4 details the case study; and finally Section 5 includes the results and conclusions.

2. State of the Art

Home care systems are becoming more prevalent in society due to an increase in the population of the elderly [3]. Home care [10], elderly care [3] or telemedicine systems [7] have thus become quite common. The functionality of home care, elderly care or telemedicine systems varies according to the type work. These systems also tend to merge with sensor networks to create context aware systems [4,10–12]. In [13] we can find one of the earliest references to context aware systems; it was a location system in offices. Subsequent applications have emerged in the medical field such as [14], which allows the exchange of information among hospital workers depending on a patient's status, availability of resources or devices. Later we can find references to context aware systems based on multi-agent systems, for example, the authors in [8] propose a set of agents that interact with the different sensors in a room, and other systems such as [15] can send alerts when upon detecting an anomalous situation. Other recent studies such as [16] develop a caregiver platform to manage and fuse information gathered from multiple sensors. While the applications are diverse, the study in [4] clearly indicates that location is an important aspect to consider in this kind of system. This study [7] reviewed different works in telemedicine, and highlights the relevance of creating adaptive systems that match user needs. This property is one of the characteristics of virtual agent organizations.

Location and identification systems based on sensor networks help locate and identify items in an environment [11]. In addition, the information provided may be used to identify and analyze user behavior, and detect abnormal situations. A proper tracking system requires different technologies, as indicated in [17]. The most common technologies are Radio Frequency IDentification (RFID) [3,18], ZigBee [19,20], WiFi [21,22], Bluetooth [23], Ultra-wideband [24], *etc*., In addition to technology, there are different algorithms that can be applied such as trilateration [25], signpost, fingerprint [21]. The applied algorithm can achieve higher accuracy depending on the technology used. In this case, the required precision level was at the room level to locate a user in the area at any given time. Based on this characteristic, the technology and algorithm were selected. While ZigBee technology provides greater accuracy, its price is very high and was therefore discarded as an option, leaving active RFID and WiFi as the most viable alternatives. It also seems that Bluetooth is gaining ground once again with the appearance of ibeacon; however the 4.0 standard Bluetooth presents incompatibilities with many devices. Our research group has already developed several studies along these lines, specifically with RFID [3], WiFi [21], ZigBee [19], thus providing us ample experience in the management of these systems. As a result, we need only adapt this experience to the specific parameters of the problem. One of the problems with these systems is that RSSI signal levels vary considerably even though the user remains stationary; with the exclusive use of this system would appear to be in continuous motion even when they are sitting down. Additional information would be required to prevent this behavior; hence, accelerometers are included to create a pedometer to detect the motion of the users.

There are currently various commercial systems to detect and count steps, including FitBit, Jawbone [26], and Nike Fuelband [27], which are priced from 99€ to 139€. Given the fact that this price is approximately equivalent to the cost of a smartphone, it seems to be a high price to pay for the simple function it provides. In addition, the error rate is high for slow walkers, who are precisely the type of users that the systems target. The authors in [28] provide a rather complete analysis of the accuracy of FitBit with regard to speed. In addition to the imprecision in analyzing slow walkers, the system has also been shown to have other inaccuracies, such as detecting steps taken by the user when the user is driving. As a result, it would be preferable to have a mobile app do the work of an accelerometer at a much lower cost. These systems are based on the analysis of mobile accelerometers [27] and/or the state of the gyroscope [29], which they use to detect steps. There are several algorithms to detect steps; the most common involves establishing thresholds which, when they are exceeded, count as a step [27]. Other studies establish templates and compare the templates with the accelerometers to detect steps [30]. In the market, there are many applications that count steps, with the best known being, perhaps, the Runastic pedometer or Noom Walk. They work quite well but they may also recognize steps when the user is not walking. The accuracy of these systems is high when the user is walking slowly, as demonstrated in this work [26].

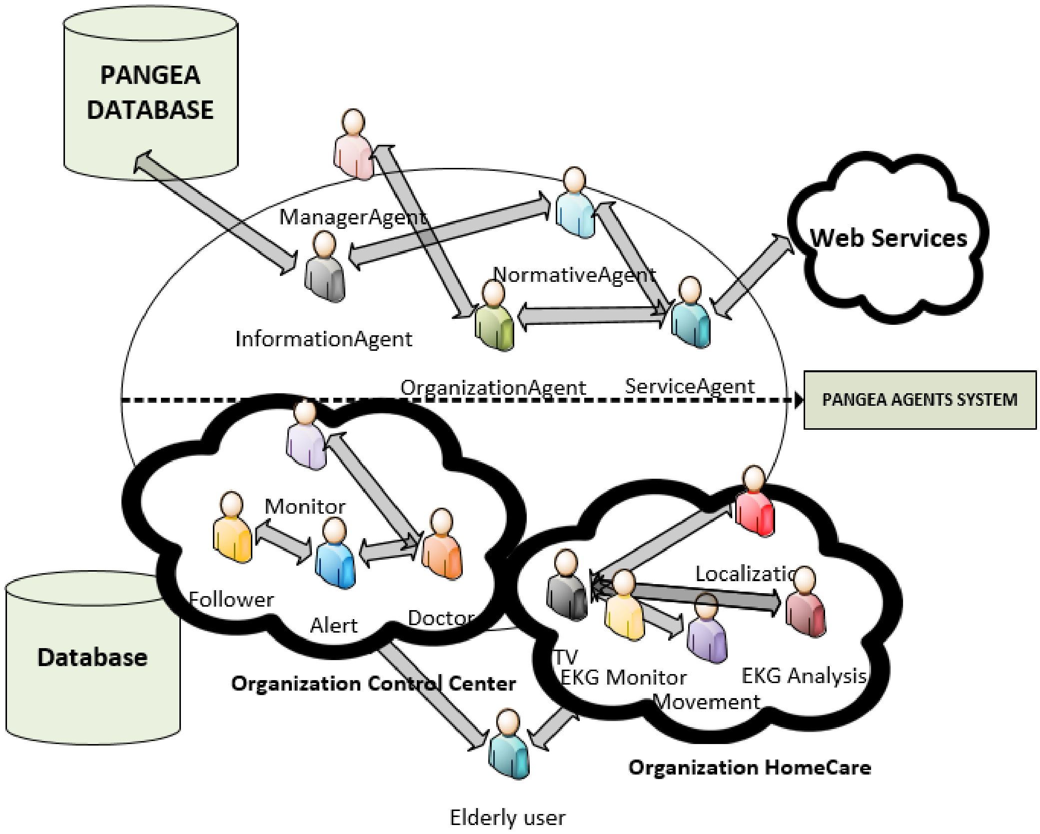
The information fusion of multiple sources may improve the results in indoor location systems [31]. The authors in [32] include information about indoor location systems using information fusion. We can also find studies that monitor daily activities according to the changes in the sensors of a mobile phone [33]. These studies usually use classifiers over the sensors to detect and classify activity; however, the number of different detected behaviors is limited. Information fusion is also applied in outdoor location systems; for example, in [34] the authors combine information gathered from GPS accelerometers and gyroscopes in order to detect trajectories. Similar, the present study could be adapted to an indoor location system using WiFi and combining the information from sensors to calculate the final position of the users. The use of cameras has been considered [35] although it would be necessary to introduce an additional algorithm to recognize people.

Currently, there are many studies on ECG that are very specialized in very different ways. Typically the majority are associated with the signal analysis of holters to detect P and T waves, and the QRS complex. Likewise, there are many studies to analyze the data of a holter and obtain the QRS complex, as shown in [2,36–39]. Some of these studies are designed to work in real time [36,40], which facilitates automatic processing at runtime—a key aspect in context aware systems. These studies are primarily based on the analysis of signals in time domain [36,40] or in the frequency domain [39], but most of them are based on the application of filters before extracting the information [36,40]. Signals are quite simple to analyze visually, but automatic processing is not always easy due to the noise and the change in the amplitude of the waves. In this regard, there are already numerous papers with many solutions. We have, therefore, simply reused some of the algorithms provided in literature and shown to have good results. The selected algorithms are fast and the results easy to interpret, as shown in both [36,40]. Once the P and T waves and the complex QRS are detected, an automatic diagnosis can be performed by using databases with different pathologies, the most common being MIT-BIH Arrhythmia, on which classifiers as SVM [41], KNN [42], decision rules [43] are applied. Given that any classifier can be applied to the database to generate a predictive model, this field was not considered very important. Some systems allow remote monitoring of users through web applications [44] and also provide further analysis on the data to detect pathologies, while others use mobile devices for real-time monitoring [45]. The main problem is that the hardware used is usually quite expensive. The cost of commercial holters such as BMS1200, or the DigiTrak XT Holter Recorder exceeds €20,000, making them far too expensive for widespread use; they also require low cost hardware to carry out these tasks. Moreover, a more effective analysis would require gathering information from the context to facilitate the doctor's work and provide details about the activities the user is engaged in.

3. Proposed System

The system proposed in this paper is based on a virtual organization of agents that monitors user information. The virtual organization of agents includes agents located in a control center and others located in the user's devices. Figure 1 shows the virtual organization of agents. The virtual organization has been created with the PANGEA platform [5]. More information about the architecture can be seen in [5]. The image shows the information associated with the system and includes only the specific platform agents, although they are not detailed in this study.

Figure 1. Virtual organization of the system.



The first organization is the control center, which includes the following roles: tracking, monitor, alert, doctor. The tracking role is responsible for tracking the users to verify that the patient is following the daily routine. This role interacts with the agent with the role of television to interact with the user. The monitor role is responsible for retrieving status information from the sensors and sending alerts to the doctor or to the user through the television using the alert role. If necessary, the monitor role can store the information for the doctor to review at a future time. The alert role receives emergency notifications from the tracking or monitoring role and sends the information to the right agent with the appropriate role. The doctor role corresponds to the doctor or a person who is responsible for monitoring the condition of the patients. During a simple monitoring, this agent simply introduces information on the treatment of patients and enters reminders that are displayed through the user's television.

In addition, the system has home organization, which includes the following roles: television, location, movement, EKG analysis. The agents are deployed on the Raspberry Pi, on the mobile device, and on the Arduino. This is the reason for using the Pangea platform, since it is possible to include lightweight agents on low performance devices. The agent that implements the location and movement roles is deployed in the mobile device; these roles are discussed in Sections 3.1 and 3.2. The agent with the monitor role is in the Arduino device, while the agent role analysis is located in the Raspberry due to the limited processing power of the Arduino device. These roles are discussed in

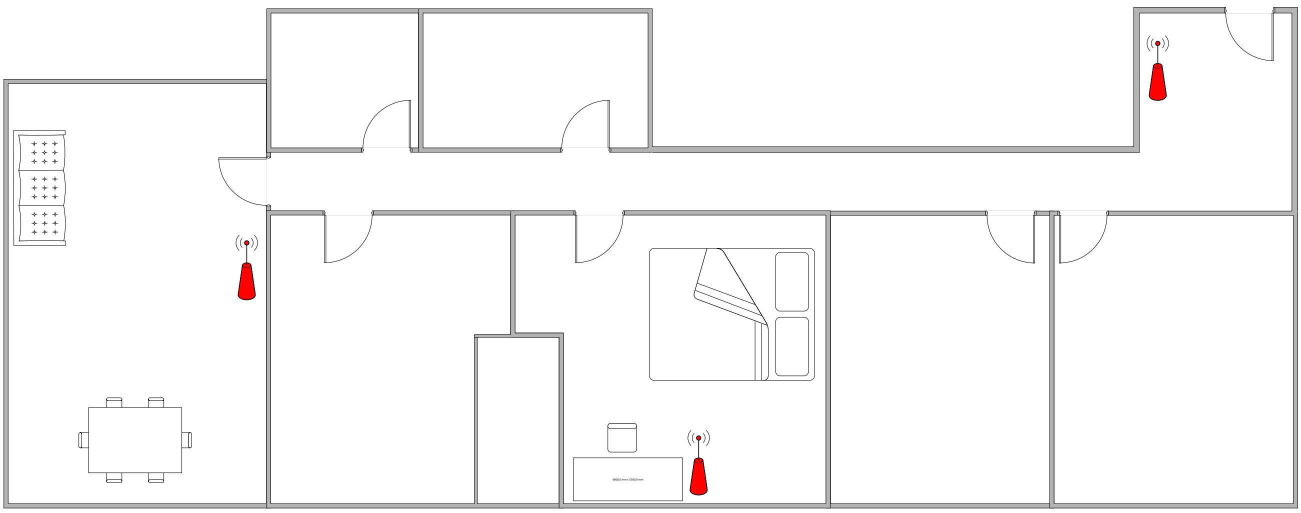
Section 3.3. Finally, the agent with the role of television is in the Raspberry, and is detailed in Section 3.4. There is an organization for each of the users.

3.1. Location System

The location role carries out the location process in a home care organization. The correct technology and location algorithm must be selected for a location system. Given the available technology, the best alternative for a low cost system is WiFi because the devices are cheap and it is possible, in many cases, to reuse the user's own devices. In addition to the technology it is also necessary to select the algorithm. In this case the alternatives were clear and they were totally dependent on the technology to be used. Technology such as trilateration is not feasible when there are many obstacles, and we want to limit the number beacons. Signpost would require installing many beacons to obtain good results. We chose to use fingerprint as the most suitable alternative to obtain adequate precision at a low cost, although it requires calibrating the environment.

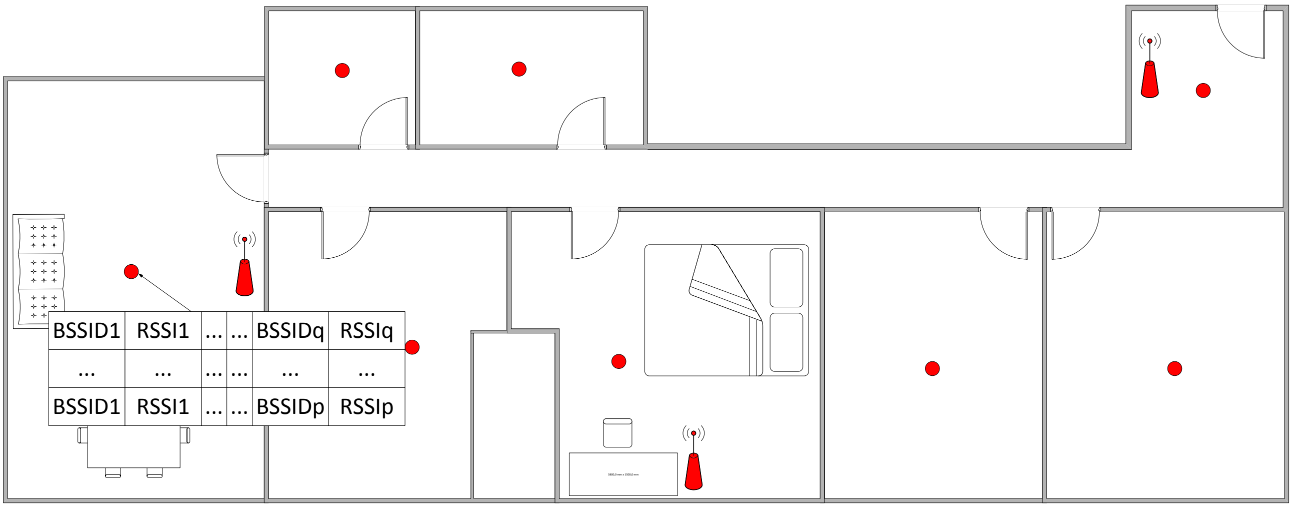
The calibration process involves taking measurements at different locations of the person's home. These measurements will then be used to calculate the location of the user. Before taking the measurements, it is necessary to place at least three access points in different areas throughout the home to determine the exact location of the user. While it would be possible to use WiFi networks from neighbors, it is not recommended because the location of the access points can vary or even turn off. In the end, the distribution of access points created for each home is similar to the distribution shown in Figure 2.

Figure 2. Distribution of the Access point in the flat.



Using this distribution, we proceeded to measure the RSSI levels in different locations. It is not necessary to know the current location of the access points and it is not necessary to enter the information of the physical obstacles. Thus several measurements are taken in for each position and each measurement contains the information of the RSSI levels for each access point, as is indicated in Figure 3. This process is repeated at different positions so the calibration process has several points/fingerprints and multiple measurements for each fingerprint.

Figure 3. Calibration Process.



The fingerprint information is represented by fi and is defined as follows:

$$f_i = \{v_{i1}, \dots, v_{ip}\} \tag{1}$$

where v_{ij} is measurement *j* in fingerprint *i* from the total number of *q* measurements. It is defined according to Equation (2):

$$v_{ij} = \{(m_1, r_{ij1}), \dots, (m_q, r_{ijq})\} \tag{2}$$

where m_k is the detected MAC *k*, and r_{ijq} is the RSSI level.

Using the information gathered from fingerprint, the system is able to scan the WiFi networks and locate the device in a given location performing probabilistic calculations. In the first step, the RSSI outliers of each MAC are removed in each fingerprint. Thus, a new fingerprint is constructed as follows:

$$v_{ij}^{'} = \{(m_c, r_{ijc}), \dots, (m_v, r_{ijv}) / Q_1 - 3 * IQR < r_{ijk} < Q_3 + 3 * IQR ? \forall_{ijk} \tag{3}$$

where Q_1 is quartile 1, Q_3 is quartile 3, $IRQ = Q_3 - Q_1$.

The values of the RSSI levels are standardized for each MAC/BSSID in a fingerprint using Equation (4):

$$r_{ijs}^{t} = \frac{r_{ijs} - \overline{r}_{i\bullet s}}{S_{r_{i\bullet s}} / \sqrt{n}} \tag{4}$$

where $\overline{r}_{ij\bullet} = \frac{1}{q}\sum_j r_{ijs}$, $S_{r_{i\bullet j}} = \sqrt{\frac{1}{n}(r_{i\bullet s} - \overline{r}_{ijs})^2}$, *q* is the number of measurements in fingerprint *i*.

In this way, each measurement is defined according to Equation (5):

$$v_{ij}^{t} = \{(m_c, r_{ijc}^{t}), \dots, (m_v, r_{ijv}^{t})\} \tag{5}$$

During the location process the system has the measurement:

$$v = \{(m_c, r_c), \dots, (m_v, r_v)\} \tag{6}$$

The standardized measurement is generated in the same way as in Equation (4). It is applied for each BSSID *s* for each fingerprint *i*:

$$r_{i,s}^{t} = \frac{r_s - \bar{r}_{i\bullet s}}{S_{r_{i\bullet s}} / \sqrt{n}} \quad (7)$$

Then, the value of $\alpha_{i,S}$ is calculated; it represents the significance level to the fingerprint i and BSSID s:

$$t_{\alpha_{is}, n-1} = r_{i,s}^{t} \quad (8)$$

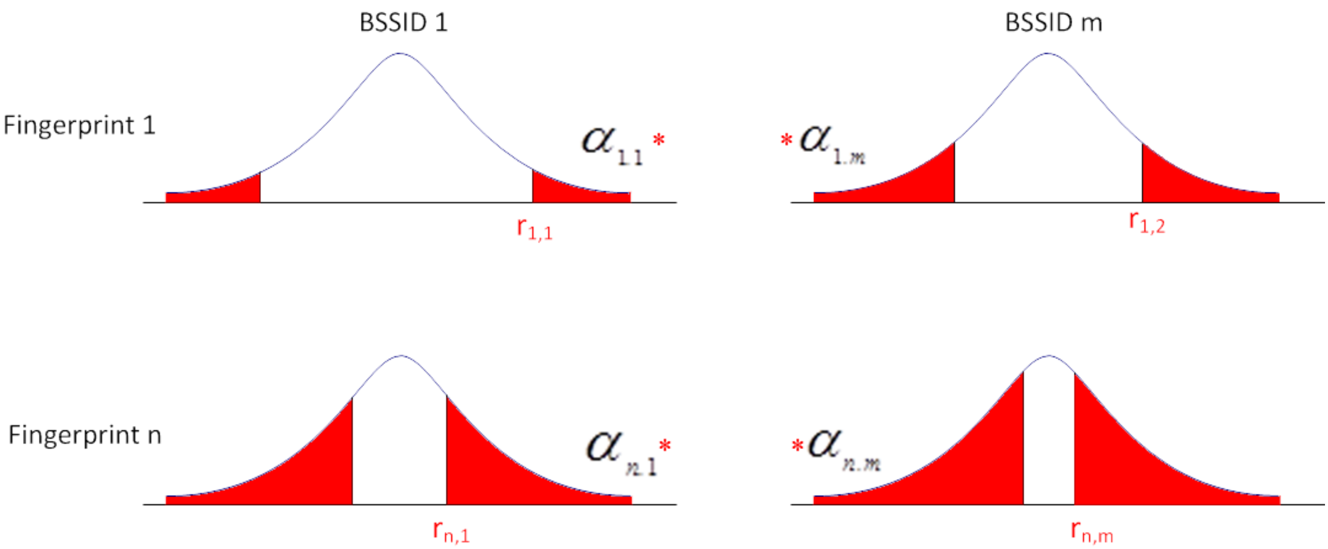
where $n - 1$ represents the freedom degree. If $n > 30$ then a normal distribution can be applied to calculate the probability. The probability of $v \in f_i$ is defined as P_{fi} :

$$P_{fi} = \frac{\prod_{s} \alpha_{i,s}}{\sum_{i} \prod_{s} \alpha_{i,s}} \quad (9)$$

To establish the associated fingerprint with the measurement v, $v \in f_i$ if P_{fi} is established as the maximum value.

The process is graphically represented in Figure 4. Each row represents the probability of a fingerprint. For each row, the probability of being in the confidence interval of each BSSID in the fingerprint is shown.

Figure 4. Process of calculating the likelihood of different fingerprints.



A time series is established to keep transitional situations from making the system unstable. The system determines that a fingerprint i has been reached when the maximum value of the probability for fingerprint i is obtained for a predetermined number of consecutive times.

Although not mentioned above, the BSSIDs that are not detected in a given fingerprint are initialized with an RSSI value 20% lower than the minimum detectable value, thus the system differentiates between missing access points and detected access point with a low intensity.

Outdoors, the system uses GPS, which means that it would not be necessary to work with the WiFi to locate the user and determine the exercise the user is engaged in at that moment. Similarly, it is necessary to use accelerometers to determine if the user is actually walking or is traveling, for example, in public transport.

3.2. Physical Activity Monitoring System

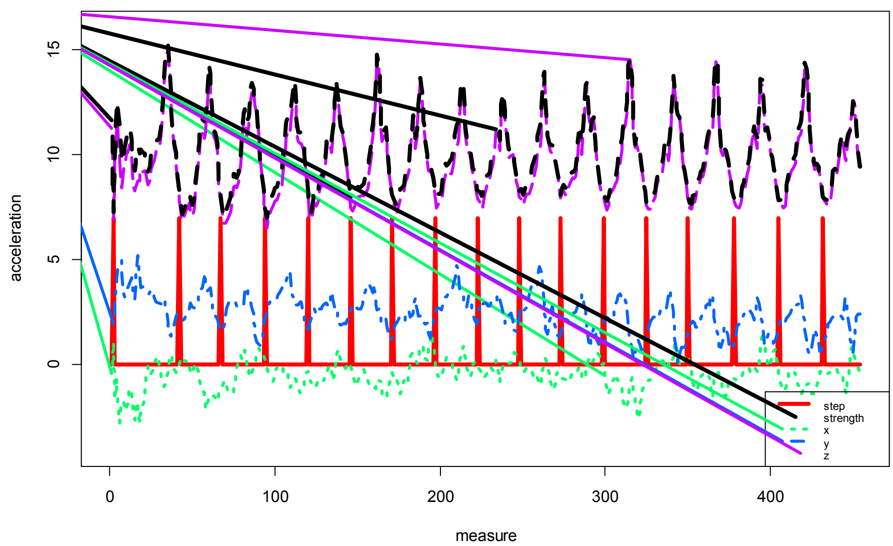
The physical activity monitoring system will be used to determine when the user is in motion or otherwise stopped. It will also serve to stabilize the position of the user and prevent false movements that can result from changes in the WiFi signal. Mobile accelerometers are used to analyze the movement of the user and detect steps. There are currently many systems that detect and count steps, including Fitbit, Nike Fuelband and even mobile applications; however, they are unreliable because they erroneously record movements other than walking as steps. For this reason the use WiFi is necessary to avoid this problem, allowing for the use of accelerometers to determine whether the user is moving and to locate the user through the WiFi. Step Detectors are based on the analysis of the values obtained by the accelerometers. These values are then used to calculate the force vector according to Equation (11). The use of the force vector to detect the steps avoids analyzing the status of the gyroscope because the values of the accelerometers are given according to the axis of the device and not with respect to the axis of the earth. Furthermore, in order to facilitate the analysis, the value of the gravity acceleration is maintained:

$$\vec{f}(x, y, z) = (x, y, z) \tag{10}$$

$$\left|\vec{f}(x, y, z)\right| = \sqrt{x^2 + y^2 + z^2} \tag{11}$$

Figure 5 shows the value of the accelerometers in the *x*, *y* and *z* axes. The figure shows the force vector information in black, while the red line represents the detected steps. The values were obtained from walking with the mobile in hand. In the results section the system was analyzed with the mobile worn in the pocket. The detection process is simple: an upper and lower threshold is marked; then, when the value of the force vector exceeds first the upper threshold and then the bottom threshold, one step is counted. The threshold values indicate the sensitivity of the system. Figure 5 shows an example of step detection.

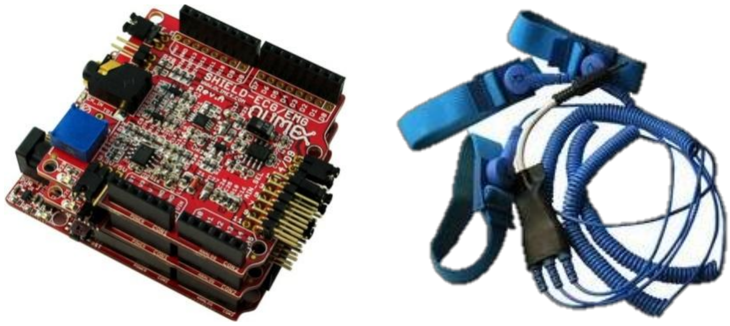
Figure 5. Variation of the accelerometers, force vector calculation and detection steps.



3.3. ECG System

The system comprises a Bluetooth Arduino Shield Arduino and Olimex SHIELD-ECG-EMG, as shown in Figure 6a. Furthermore, a few Electrodes SHIELD-ECG-EMG-PA are connected to the patient. The electrodes are shown in Figure 6b.

Figure 6. (**a**) Arduino, (**b**) electrodes.

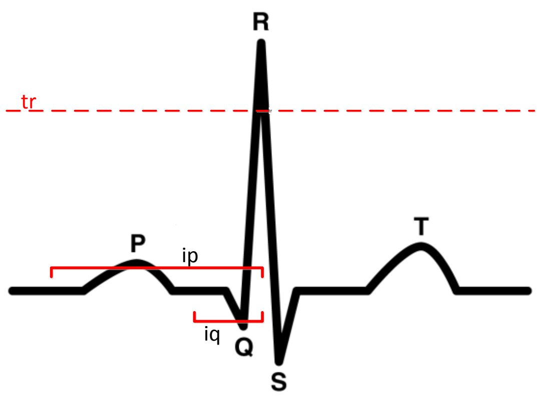


(**a**) (**b**)

The Arduino firmware executes the source code of the ECG monitor role to read the data from the ECG. We used the Arduino programming language with Mstimer2 TimerOne and the libraries provided by the manufacturer. The firmware is used to obtain the values of the attached sensors in the shield and provides the information through a bluetooth connection.

It is important to note that the hardware does not provide values in the same way as a professional ECG because it contains a lot of noise, which makes the detection of the P wave, the QRS complex and the T wave quite difficult, see Figure 7. The purpose of this module is more to monitor patients than to detect pathologies. The goal is have a low cost holter that can gather all patient information within a period of 24 h, and to then fuse this information with the values collected from the location system. This information will be useful to the doctor to discuss the patient's health status without requiring the patient to provide a detailed account of their behavior throughout the day. In any case, a basic functionality for detecting problems is included, although it is not necessarily a diagnostic system because the hardware is not considered safe for application in serious diseases. Previous studies [41] generated classifiers, such as SVM, from a trained database [46], and were able to reach an accuracy rate of near to 90%.

Figure 7. Waves P,T and complex QRS.



There are numerous studies to detect the QRS complex, as can be seen in [2,36–39]. The work done in [38] indicates that the location of the QRS complex is not an easy task due to noise and amplitude of the T wave, which may be confused in some cases with the QRS complex. Detection methods usually require dynamic management thresholds for detection of the complex when the signal is being analyzed in the time domain [36,38]. Other studies analyze the signal in the frequency domain [39], but basically all systems first filter the signal and then extract the complex QRS. The present study uses algorithms that allow extracting information in real time such as in [36,47]. The study done in [47] produced an error of 1.7% with the MIT -BIH Arrhythmia database; however, the algorithm proposed in [36] has a lower error in the different tests performed on the same database and was, consequently, selected to detect the QRS complex. Basically, the system includes four steps: (1) wavelet-based denoising with discrete wavelet transform (DWT) [40]; (2) linear highpass filtering (HPF); (3) non-linear lowpass filtering (LPF) to increase the QRS complex; and (4) decision-making based on the definition of a tr threshold according to the previous values. The threshold is used to generate decision rules to detect the complex QRS. The value of tr is defined according to the work in [36]:

$$tr = \alpha \cdot \gamma \cdot peak + (1-\alpha) \cdot tr \tag{12}$$

where α and γ are constant, and peak is the maximum local value.

As we can see, the process marked by Equation (12) does not require a lot of processing, and the highest computation time involves the application of the filters, although the process can be carried out in real time. The R value can be used to calculate Q and S by setting the search intervals the same way as in [36]. The process of finding the P and T waves is implemented according to [48], and consists of defining intervals around R. Other algorithms use classifiers such as SVM [49] to locate these waves; however, its use is discarded to avoid using black boxes in the analysis and to be able to perform the processing in real-time.

To detect anomalies, some basic rules were introduced based on the type of problem detected. These rules could be automatically generated from a case base using a J48, for example, but we prefer to rely on expert knowledge instead of an automatic generation to avoid incorrect detections associated to the database. We specifically analyzed the following: sinus tachycardia up to 150 beats, sinus arrhythmia beats (variations according to the breathing apparatus were easily observed), SA nodal blocking a pause in multiple pp intervals (sinus pause is not a pause interval, it is a multiple of *p*). When an abnormality is detected, the agent in the mobile phone sends an alert to the multi-agent platform.

The information managed information in each measurement e_i to generate the rules is shown in Table 1.

Table 1. EKG waves and times.

Wave	Time
P_i	Milliseconds from the last value P_{i-1}
Q_i	Milliseconds from the last value Q_{i-1}
R_i	Milliseconds from the last value R_{i-1}
S_i	Milliseconds from the last value S_{i-1}
T_i	Milliseconds from the last value T_{i-1}
Dpq_i	Milliseconds between the maximum value of the *P* wave and minimum value of *Q* wave.
Dqr_i	Milliseconds between the minimum value of the *Q* wave and maximum value of *R* wave.
Drs_i	Milliseconds between the maximum value of the *R* wave and minimum value of *S* wave.
Dst_i	Milliseconds between the minimum value of the *S* wave and maximum value of *T* wave.

For example, a sinus tachycardia (up to 150 beats) is triggered if the following inequality holds:

$$n60.000 / \sum_{i=k}^{k+n} R_i > 150 \tag{13}$$

k would be the initial element of the time series, and n the number of factors used to calculate the time series.

For SA nodal blocking a pause in a multiple of p-p interval, the rule would be defined as follows:

$$\frac{P_i}{P_{i-1}} > 1.5 \ \&\& \ P_i \% P_{i-1} < e \tag{14}$$

where % represents the remainder of dividing P_i and P_{i-1} and e represents the margin to determine whether the value is a multiple of two consecutives p waves.

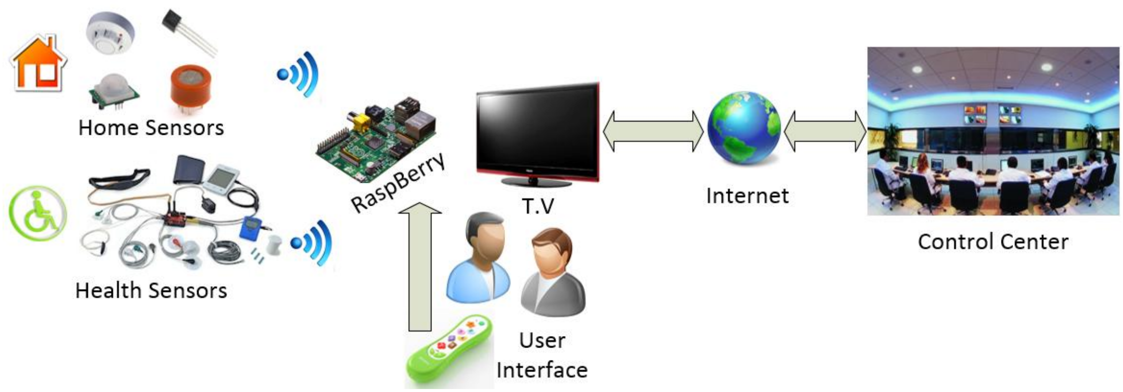
The same process would be followed with other pathologies. All rules are defined in advance but, as mentioned above, they could be generated automatically with decision rules, a SVM, Bayesian networks or any other classifier using a database with enough information about all the pathologies.

3.4. Monitoring System with Television

Nowadays most elderly people require constant attention and care, but do not have a caregiver who can permanently reside with them all day. Continuous advances in hardware design and development in recent years have caused a decrease in the manufacturing costs of sensors and other materials that can be used by researchers to design assistance systems especially oriented to the elderly population, even providing remote care services. Our system introduces a new television-based interactive model to interact with elderly people. We present an innovative solution based on a remote control device for TV that incorporates a reduced number of buttons. Interaction through television was chosen in this study because users are typically familiar with all the operations, and it is a device that can be found in most homes.

The main advantage of the proposed system compared to the existing ones in the market such as GoogleTV or AppleTV is the capacity for personalizing the services that can be offered, as well as the low cost of the proposed solution. Nowadays, existing systems focus on specialized multimedia services, renting movies, buying video games, but it is not possible to find and open, low-cost care system for the elderly people. Below, Figure 8 shows the different components of the proposed solution:

Figure 8. Interaction system based on television.



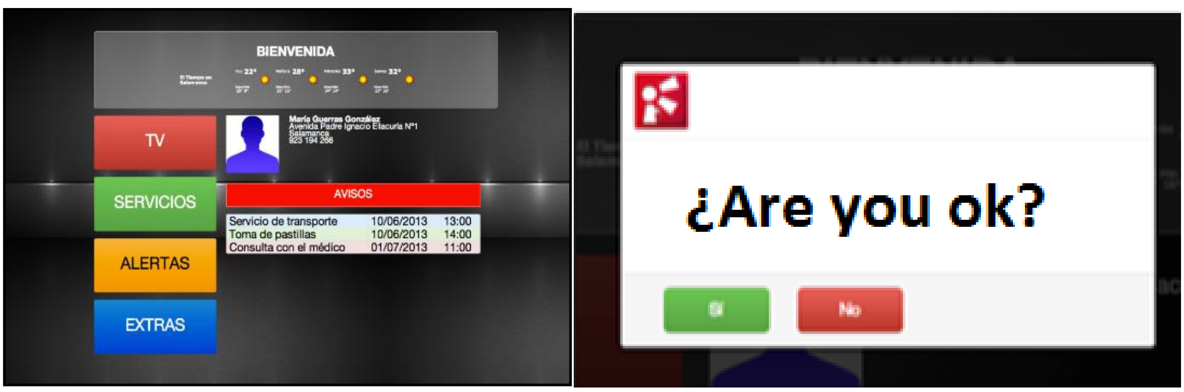
The proposed solution incorporates a low-cost computer (30$), which facilitates robustness and scalability. We propose an architecture that can be accepted and integrated with existing systems by the vast majority of people interested in home care solutions in their homes. The Raspberry mini-computer is the physical support for the architecture. One of the main advantages of the proposed architecture is its ability to embed agents in the Raspberry, enabling distributed communication and the possibility to connect remotely with the patient's home, thus obtaining context-aware information very easily. In addition, the agents will be able to obtain real-time context-aware information coming from different sensors that are connected to the Raspberry wirelessly such as gas, temperature, fire, presence sensors, or sensors which are geared to the caregiver, such as, oxygen meter, blood pressure, ECG, accelerometer … *etc*. In this case study the system incorporates accelerometers and EKG. The use of the Raspberry device allows us to easily instantiate embedded agents and connect them with the PANGEA multi-agent architecture. In our case we have embedded two agents, one of them designed to analyze data obtained from an EKG device and the TV. We have chosen Raspberry as the algorithm designed to interpret the data requires a high computational cost and the use on an Arduino device is not recommended in this case; and another agent that interacts with the elderly by means of the television. The Raspberry is also connected to Internet and can be connected to any existing TV using an HDMI cable.

The use of an agent that interacts with the user via TV allows us to issue warnings or notifications whenever necessary. For example, remind the user to take the medication, or ask if any assistance is needed when an anomalous situation is detected.

One of the advantages presented by the proposed architecture is that the information extraction algorithms that monitor the various sensors installed in the home of the elderly patient can be executed without computational restrictions. And in case of anomaly detections, a notification or alert can be automatically sent to the emergency control center. In this case, the agent with the EKG analysis role sends alerts to the control centers when it detects an anomalous situation. The doctor may send a message to the users in order to initiate interaction. Additionally, the system may provide the user with reminders, for example, to use the holter.

Figure 9 shows a screenshot of the proposed system working in the case study, where a warning message is sent to the user. This message is received by the agent with the TV role and is displayed on the TV. Even if the user is watching a movie at the moment of receiving the notification, the information is superimposed on the TV programme and made visible to the user.

Figure 9. Interaction with the user through television.



The interface agent uses a web page based on HTML5 which makes the interface easily customizable remotely, allowing the dynamic personalization of the 4 buttons to interact with the system.

The use of devices that allow embedding agents with a low cost to develop services for people, opens up a vast array of possibilities, allowing monitoring for the elderly without the high cost of entry into a residence or an assistant is present all day.

4. Case Study

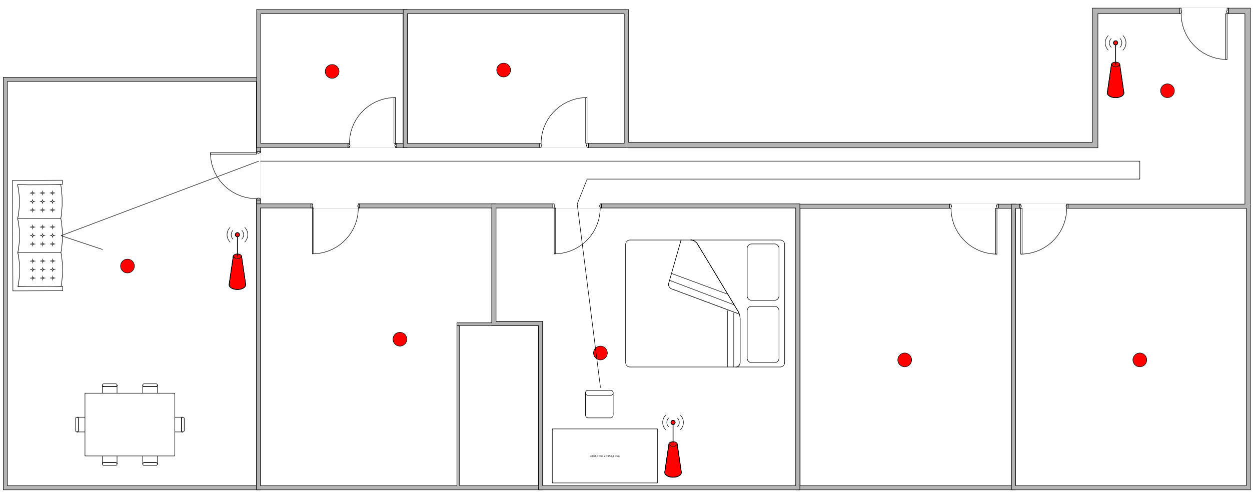
The system was tested on a person residing in an 85 m^2 flat. The necessary hardware for the tracking system, the motion detection system, ECG system, and TV system were all deployed. Each hardware element and its corresponding price are indicated in Table 2.

Table 2. Hardware.

Hardware	Quantity	Unit Price
Router TP-LINK TL-WR740N. For the location system and to connect the various elements to the data network, either through WiFi or cable.	3	15€
Any Android telephone with WiFi, GPS and an accelerometer would suffice. LG Nexus 4.	1	200€
Arduino Bluetooth	1	40€
Olimex Arduino Shield SHIELD-ECG-EMG	1	20€
Electrodes SHIELD-ECG-EMG-PA	1	8€
Raspberry PI	1	40€

TL-WR740N routers were specifically selected because they can be flashed with dd-wrt, which makes it possible to modify dBm. Dd-wrt can reduce the dBm in higher accuracy is required. Each of the routers is distributed so that the maximum possible area is covered. Figure 10 includes the floor plans for the flat in which the tests were carried out. The antennas represent the routers. As we can see, the routers are located at both ends of the floor and in the middle.

Figure 10. Path followed in the home.



The electrocardiogram has three electrodes: two placed on the user's wrists and the third one on an ankle. The electrodes in the current version are connected by wires to the Arduino, but wireless communication is also available for a much higher price. The Arduino device connects with a mobile via bluetooth; however, the user must carry the mobile device for the location and movement system to function properly and send the information from the ECG.

The ECG has not been tested on a patient with heart disease because the system is still in its testing phase. Nevertheless, the results obtained from the ECG have been validated by doctors who also consider that the use of the system would be feasible in a diagnostic application. The results were satisfactory and indicated that the *p*, *t*, and complex QRS waves could be used, although the noise is higher than a professional holter system.

5. Results and Conclusions

The system has been implemented according to the case study described in Section 4. First, we validated each of the components and then the entire system. Individual validations were performed to ensure that each component worked correctly and the results were satisfactory. The same process was applied to validate the location system, the physical activity monitoring system, the electro cardiogram, and the proper functioning of the television system.

The first system tested was the location tracking system. The first step was to calibrate the system, which consisted of taking measurements at the points indicated in picture 3. Each point corresponds to a fingerprint, and for each fingerprint 50 measurements were taken. Measurements were taken by opening and closing the door of the room in which the measurements were taken. Additionally, one of the access points was placed in the hallway to avoid signal changes associated with the opening and closing of the doors. The other doors were half open to make measurements. A LG Nexus 4 was used during the calibration process to obtain the RSSI signals. This device can scan the WiFi signal faster due to the hardware and the fact that it is an android version. The measures can be used with other devices with high precision; in this case we have used an LG Nexus in the calibration process and an HTC Sensation XL during the test. The router TP-LINK TL-WR740N was flashed with DD-WRT in order to modify transmission power to 6 dbm and provide better accuracy; the original value was 20 dbm. There is an additional router to connect the mobile phone to the WiFi; this router is not used in the location system although it could be incorporated to improve the accuracy.

The tracking system was compared with classifiers based on Bayesian networks [7], SVM [50]. The application of the time series was omitted as we considered it irrelevant for this test. These classifiers were selected because they had been used in other studies on location systems. To make a more realistic validation, a 5 × 2 cross-validation was not performed as in previous studies [51]. Instead, new measures were taken as for a new calibration. We took 50 measurements per fingerprint, each of which was classified with the constructed classifier in the first data set. The reason for not taking both sets and applying a 5 × 2 cross validation was to estimate measurements corresponding to different times. This allowed us to change the environment by opening and closing doors, modifying or moving furniture, and creating new estimates with these set of data. This process was repeated 5 times, which allowed us to statistically validate differences between systems. The differences were analyzed by Mann-Whitney. Table 3 shows the results obtained for each of the sets of validation created. The comparison between pairs of methods can be seen in Table 4. Bold values indicate that the differences are considered significant.

Table 3. Colum *ai* represents the number of elements correctly classified of *ai* training with *bi* and column *bi* the number of elements correctly classified of *bi* training with *ai*, *i* is the repetition.

Method	*a1*	*b1*	*a2*	*b2*	*a3*	*b3*	*a4*	*b4*	*a5*	*b5*	average
Proposal	386	385	378	373	387	376	379	386	379	382	381.1
Bayesian	382	378	369	374	378	379	381	375	376	368	376
SVM	353	348	357	339	368	359	359	349	356	352	354

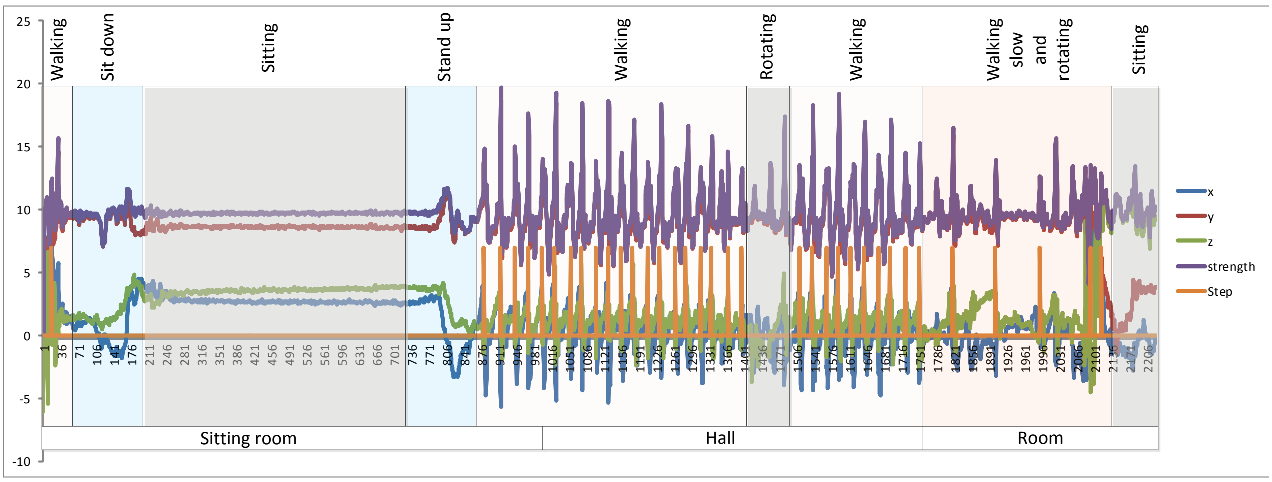
Table 4. Mann-Whitney test.

Method	Proposal	Bayesian	SVM
Proposal	1	**0.04426767**	**0.00017962**
Bayesian	**0.04426767**	1	**0.00020871**
SVM	**0.00017962**	**0.00020871**	1

The results are similar to those obtained from the Bayesian network; however, the results obtained by SVM are significantly worse. The Bayesian network must previously apply a discretization of the values and the results depend in large part on the discretization process. The validation of the GPS tracking system lacks scientific interest and is therefore not included in the paper.

To validate the physical monitoring system we proceeded to perform sequences with basic daily activities to determine whether the system was able to detect movements associated with steps. The upper and lower thresholds were fixed to 10.3 m/s^2 and 9.1 m/s^2 respectively. Figure 10 traces the user's movements, while Figure 11 shows the sequence of actions and the performance of the step detector, in which the user moves from one room to another walking down the hallway. The user began in a standing position, walked to the sofa and sat down. The user then stood up, left the room, walked to the end of the hall, turned back and entered one of the rooms. Inside the room, the user walked slowly to the back and sat on the chair. The mobile was located in the user's pocket with no particular concern as to its position. As seen in the figure, the steps marked in orange were easily detected according to the movement of the user, the frequency indicates the speed.

Figure 11. Detection steps based on different actions.



As we can see, the physical monitoring system works quite well and is able to determine the movement with high accuracy. The user is located through WiFi, so the tracking system stops updating the position after 3 s of not detecting movements; however, it is easy for the system to erroneously count steps when the user is not actually walking. For example, steps are erroneously detected when the user is preparing dinner and bends over to pick something up. Over the course of one hour, the system detects 573 steps. The number of steps detected correctly was 527, while 21 steps were lost.

Figure 12 shows the ECG at runtime. The user can monitor the values in real-time and they are interpretable as a brief training received from the staff. The ECG shows the P wave, the QRS complex, and the T waves.

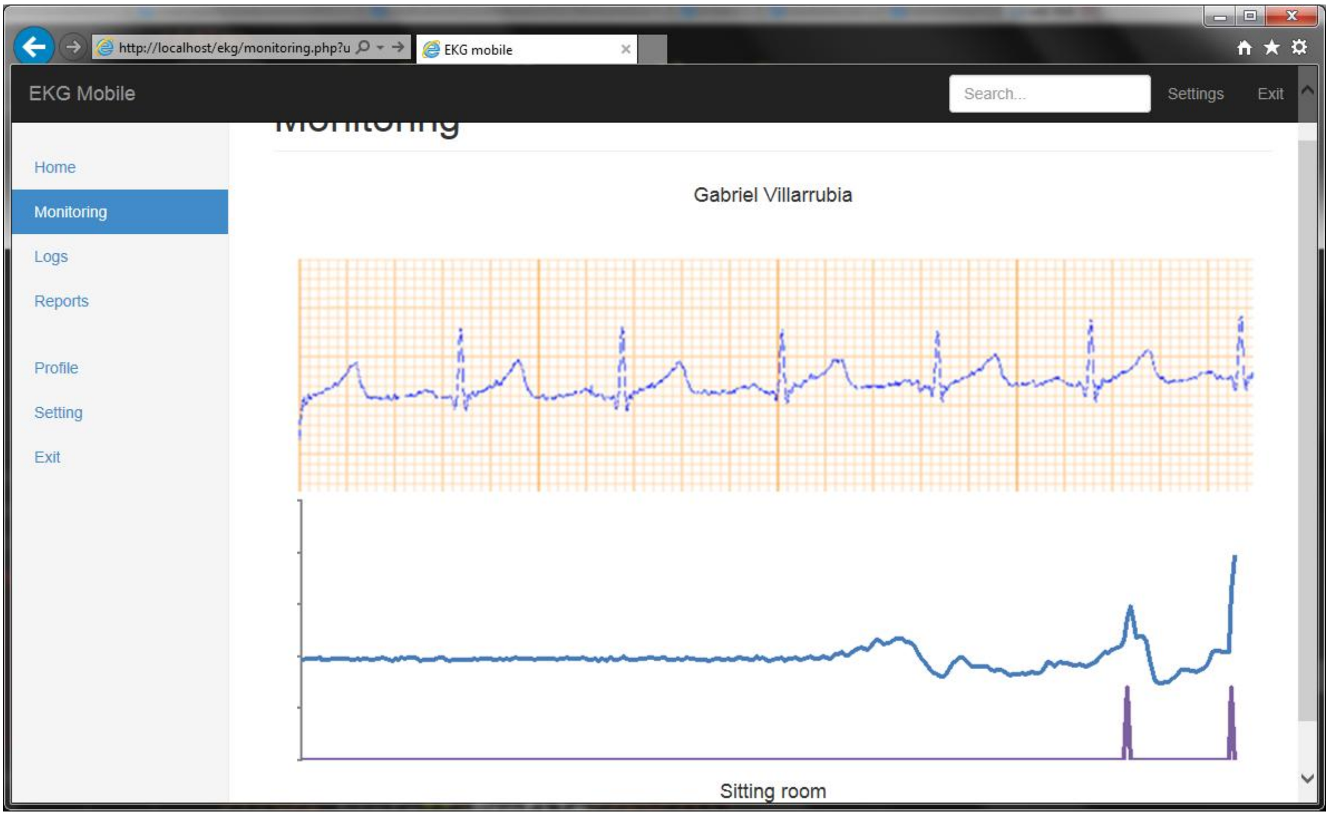
Figure 12. ECG mobile application.

The ECG system sends data to a central location where a doctor can monitor a set of patients. The element that allows connecting the health center to the patient's home is Raspberry *Pi*. When a rule is triggered, the system sends an alert to the mobile phone and to the television. Figure 9 shows an alert of the system in the TV when a rule has been triggered.

The doctor can visualize and monitor the status of the patient. When an anomaly is detected, the system sends data automatically, although the user may also send the data. Figure 13 shows the information of the ECG sent to the doctor, and includes information about the user's movements.

The system can monitor user behavior. The monitoring system functions include locating the user, monitoring physical activity, electrocardiogram; it is also able to interact with the user through the television. All hardware used is low cost, making at-home installation easily affordable. Moreover, the setup simply requires taking some measurements during 1 min in each of the rooms. The probabilistic calculation of belonging to a different fingerprint allows better performance with regard to changes of the signal level as compared to other classifiers such as decision trees. This is due to the fact that the probability is distributed between different fingerprints. Modelling the systems by means of probability allows the use of different mobile devices (with different levels of signal receiving), thus preserving the accuracy of the location system. This accuracy remains more or less constant because the probability does not change (since it would be distributed in a similar way). However, in alternative potential solutions, such as decision trees, this issue can become problematic because the signal levels play an important role in the rules that determine the final location.

Figure 13. Remote monitoring of the user status.



The tracking system and monitoring systems provide information with enough detail to determine the movement of the users. Alternatively the system could use the FitBit or another similar bracelet.

The ECG provides enough results to analyze the electro, although it produces some noise. It would be possible to use better hardware, although it would no longer be a low-cost product, which is why this alternative was rejected. Our future research will focus on improving the detection of arrhythmias systems. We will also analyze different possibilities of incorporating a new mechanism to automatically generate rules and knowledge. The current version of MIT-BIH Arrhythmia as focused on incorporating a large amount of information and functionalities that are of interest to the medical staff. The next step is to make advancements in the intelligence of the system, incorporating an expert system that can help to define rules and knowledge in order to improve the training process and to avoid potential problems with erroneous values in the database.

Finally, the Pangea architecture makes it possible to interconnect the elements of the platform very easily because it can incorporate agents in lightweight devices such as Arduinos and mobile phones. Our future work will focus on improving the automatic processing of the ECG system, although it should not be used as a diagnostic mechanism because the hardware has not been approved.

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Author Contributions

Gabriel Villarrubia and Juan F. De Paz have developed the system; they made the test and elaborate the review of the state of the art. Javier Bajo and Juan Manuel Corchado formalized the problem, the algorithms and reviewed the work. All the authors contributed in the redaction of the paper.

Conflicts of Interest

The authors declare no conflict of interest.

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6.2 *Ambient Agents: Embedded Agents for Remote Control and Monitoring Using the PANGEA Platform.*

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Article

Ambient Agents: Embedded Agents for Remote Control and Monitoring Using the PANGEA Platform

Gabriel Villarrubia [1], Juan F. De Paz [1,*], Javier Bajo [2] and Juan M. Corchado [1]

[1] Departamento de Informática y Automática, Universidad de Salamanca, Plaza de la Merced s/n, 37008 Salamanca, Spain; E-Mails: gvg@usal.es (G.V.); corchado@usal.es (J.M.C.)
[2] Departamento de Inteligencia Artificial, Universidad Politécnica de Madrid, Campus de Montegancedo s/n, Boadilla del Monte, 28600 Madrid, Spain; E-Mail: jbajo@fi.upm.es

* Author to whom correspondence should be addressed; E-Mail: fcofds@usal.es; Tel.: +34-923-294-400.

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Abstract: Ambient intelligence has advanced significantly during the last few years. The incorporation of image processing and artificial intelligence techniques have opened the possibility for such aspects as pattern recognition, thus allowing for a better adaptation of these systems. This study presents a new model of an embedded agent especially designed to be implemented in sensing devices with resource constraints. This new model of an agent is integrated within the PANGEA (Platform for the Automatic Construction of Organiztions of Intelligent Agents) platform, an organizational-based platform, defining a new sensor role in the system and aimed at providing contextual information and interacting with the environment. A case study was developed over the PANGEA platform and designed using different agents and sensors responsible for providing user support at home in the event of incidents or emergencies. The system presented in the case study incorporates agents in Arduino hardware devices with recognition modules and illuminated bands; it also incorporates IP cameras programmed for automatic tracking, which can connect remotely in the event of emergencies. The user wears a bracelet, which contains a simple vibration sensor that can receive notifications about the emergency situation.

Keywords: ambient intelligence; smart living; remote monitoring; open MAS

1. Introduction

Recent years have seen great advances in the field of ambient intelligence, which has assumed significant importance in the daily lives of individuals. Ambient intelligence tries to adapt technology to people's needs by proposing three basic concepts: ubiquitous computing; ubiquitous communication; and intelligent user interfaces [1]. In order to reach this objective, it is necessary to develop new frameworks and models to allow access to functionalities regardless of time and location restrictions. People are currently surrounded by technology that tries to increase their quality of life and facilitate daily activities. In addition, continuous advancements in mobile computing make it possible to obtain contextual information and to react physically to the context in more innovative ways [2]. These advances have led to mobile devices or sensor networks with limited processing and storage capacities that are used to design ambient intelligence environments. These devices are used within an intelligent environment in order to obtain information or to respond to the environment and, in the majority of cases, interact with the rest of the intelligent system [3].

Wireless sensor networks (WSN) provide an infrastructure capable of supporting the distributed communication needed in highly dynamic environments, increasing mobility, flexibility and efficiency, since resources can be accessed regardless of their physical location [4]. Sensor networks interconnect a large number of sensors and manage information gathered from intelligent environments. On many occasions, information management is distributed; however, it is necessary to have distributed systems sufficiently capable of managing WSN effectively, and that includes software elements containing a certain degree of intelligence that can be embedded into devices and respond both autonomously and in conjunction with the distributed system. Multi-agent systems are a very appropriate option for this type of system. There are different proposals that combine multi-agent systems and sensor networks to build intelligent environments [5–10] in ambient intelligence. However, in the field of ambient intelligence, there is currently no multi-agent architecture that functions on the concept of virtual organizations and that can provide agents capable of being embedded in devices.

Recent trends in the development of multi-agent systems to manage wireless sensor networks are based on social computing and virtual organizations. Given the special characteristics of multi-agent systems, multi-agent architectures have been explored during recent years as an emerging trend to manage wireless sensor networks [11–14]. This new perspective can provide an organizational management model appropriate to manage both internal behaviors and user services more efficiently. In this sense, social computing and organizational aspects can notably help to design new platforms with advanced capacities to interconnect and manage WSNs. In this article, we focus on the interaction with the environment, designing intelligent agents that can be embedded into hardware resource-constrained devices. This article presents the integration of the PANGEA (Platform for the Automatic Construction of Organiztions of Intelligent Agents) platform with different hardware to develop a context-aware system. An agent is embedded in an Arduino microcontroller [15]. A device without processing capacity is also integrated; for this case, we have selected an Internet Protocol (IP) camera. The deployed agents are managed through the PANGEA [16] platform, a multi-agent architecture designed on the base of a virtual organization and oriented toward the creation of ambient intelligence environments. PANGEA allows for easy integration with different hardware and several languages, due to the simplicity of the communication protocol, which is based on Internet Relay Chat (IRC). This makes it easy to find libraries in different languages or to develop specific libraries according to the IRC standard. PANGEA is a multi-agent architecture platform aimed at creating open multi-agent systems that provide various tools to create, manage and control virtual organizations. PANGEA is specifically designed to develop multi-agent systems that include organizational aspects. Two innovations presented in PANGEA are the sensor agent and the vibrator agent, which are embedded in lightweight devices that obtain context-aware information and manage actuators. The sensor agent and vibrator agent are autonomous agents embedded in an Arduino microcontroller, integrated within the PANGEA platform, which provides several advantages to manage context-aware information. In addition to the sensor agent and vibrator agent, the system also presents the camera agent, which controls the IP cameras that respond automatically to movement. The sensor agent is used to detect several kinds of alarms that are installed in a laboratory. According to the detected sounds, the agent engages a specific action in accordance with the established rules. Although the alarms are not connected to the WSNs, the sound detector created by the sensor agent can detect the sounds and respond accordingly. PANGEA allows the integration of mobile devices, facilitates a new ubiquitous communication process and provides a new mechanism to incorporate intelligent behaviors into embedded devices. These characteristics are relevant to develop intelligent environments.

The article is structured as follows: We begin with a review of the state-of-the-art of agents and multi-agent systems, with particular attention to agents that are used as embedded software. The next section describes the PANGEA platform, providing the detailed structure of the sensor agent, camera agent and vibrator agent. The architecture, as well as the sensor agent and camera agent are evaluated in a case study using an intelligent environment especially designed for indoor fire detection. The final section presents the results obtained from the case study and the conclusions that were drawn from this study.

2. Related Work

Ambient intelligence is a new paradigm that tries to adapt technology to the needs people have. The emergence of ambient intelligence involves substantial changes in the design of functional architectures, since it is necessary to provide features that enable ubiquitous computing and communication and also an intelligent interaction with users. The work of Acampora and Loia [17] highlights that ambient intelligence systems incorporate the following features: context awareness, multimodal communication and user-centered interaction. This section revises the state-of-the-art of related developments, which integrate WSNs, mainly based on multi-agent systems, focusing on the possibility of using autonomous, embedded agents, and analyzes the feasibility of a new alternative using the PANGEA platform.

Context-aware systems were first introduced by Want *et al*. [18] when they presented their Active Badge Location System, generally regarded as the first context-aware application. It is a location system for individuals in an office environment in which each person carries a badge that uses a sensor network to send signals containing information about each person's location to a centralized services area. By 2005 and through the end of the decade, several tourist guide location-aware systems emerged [19,20], which provided information about the user's location. Location information is by far the most used attribute of ambient intelligence systems. Recent years have seen considerable growth in the use of other attributes of context-aware information. One of the most precise definitions was provided by Dey and Abowd [21]. These authors refer to context as any information that can be used to characterize the situation of an entity. An entity is a person, place or object that is considered relevant to the interaction between a user and an application, including the user and the applications themselves.

Developments are currently underway to create applications that allow integrating sensor networks. These developments are based, for example, on the TinyOS operating system, which allows for the interconnection of sensors. Its main characteristic is low power consumption. The operating system can be used on systems, such as Mica2, and is widely used in research [22]. Many projects have been developed over this operating system, including Maté, which is a virtual machine that can interpret bytecodes [23]. Maté has also been used to develop other agents, such as the Agila middleware [24], which can create agents with mobility functions; it has also been used in fire tracking. A study by Mlla *et al*. [25] shows some existing middleware, some of which has been created over TinyOS. It is also possible to find simulators for TinyOS, such as TOSSIM [26], which facilitate the development of this kind of application. Although TinyOS allows remote communication with other devices, it does not incorporate characteristics to facilitate the development of distributed applications to easily manage the services provided by the agents and control and monitor the interactions among the agents in the platform.

Multi-agent architectures have been explored as an alternative to develop context-aware systems. Lim *et al*. [27] propose a project to create a context-aware home that utilizes multi-agent systems to monitor and execute appropriate actions based on the current state of the house. The multi-agent system learns and adapts the movements and actions of the occupants and makes predictions. The authors propose an architecture that includes an agent in each room that interacts with the sensors and a superagent that makes decisions and deals with risk prediction. Other authors, such as Uhm *et al*. [28], focus on the semantic aspects of the context and propose a context model that separates the upper and lower layers according to the characteristics of each class using the Web Ontology Language (OWL). The system does not provide either embedded agents or organizational aspects. Kaluza *et al*. [29] present a context-aware multi-agent system for the care of the elderly that combines sensor technologies to detect falls and other health problems, and either calls for help in the case of an emergency or issues a warning in cases that do not require immediate attention. The ambient intelligence system focuses on detecting alarm situations and does not provide embedded agents or organizational aspects. Some studies, such as the one proposed by Ning and Yang [30], present agents embedded in agents to control their functioning. Doctor *et al*. [31] use embedded agents in mobile devices and fuzzy logic to emulate certain human behaviors [32].

Some existing platforms, such as JADE (Java Agent Development Framework) [33,34] and AFME (Agent Factory Micro Edition) [35], allow the execution of agents in mobile devices, but require the use of specific libraries that are only available for certain platforms, such as Android or J2ME (Java 2 Micro Edition). JaCa-Android [35] facilitates the execution of intelligent agents in Android devices. MAPNET [36] is focused on mobility and allows the creation of mobile agents that can be executed in different platforms using the MASIF (OMG Mobile Agent System Interoperability Facility) standard [37]. As with MAPNET, UMAP (Universal Multi-Agent Platfom for .NET) [38] is based on .Net and requires Microsoft programming languages. ICARO-D project [39] provides RMI (Remote

Method Invocation) communications to distribute resources among agents. In robotics, there have been different agents embedded in robots [40], but without platform support. Purusothaman *et al*. [41] show an alternative to creating multi-agent systems in Arduino devices. The platform deployed in the Arduino devices only contains the basic functionality to be executed in these devices. This alternative allows reducing costs, although there are systems on a chip, such as Raspberry Pi [42], with higher computational capacity and a similar price; although the energy consumption is greater.

Agent-based virtual organizations can provide new capacities to create artificial societies. This area has grown during recent years with most studies focused on security [43], planning [44], role assignment [45], resource management [46], collaboration [47], *etc*. However, it is not possible to find approaches based on virtual organizations of agents and ambient intelligence, where agents can be embedded in resource-constrained devices. It is possible to find platforms especially designed to manage virtual organizations of agents, such as Janus [48], that allow the instantiation of agents in Android devices. MaDKit (Multiagent Development Kit) [49] is similar to JADE. Other platforms such as CONOISE-G [50], are founded on JADE, but provide support for virtual organizations of agents.

Previous work by the authors of this paper [51] allows the installation of embedded agents, but the proposed HERA (Hardware Embedded Reactive Agents) platform allows only the execution of reactive agents and does not provide support for virtual organizations. Moreover, the platform is based on a service-oriented architecture, which notably complicates communication with hardware devices, such as Arduino. The THOMAS (MeTHods, Techniques and Tools for Open Multi-Agent Systems) platform [31] is designed to create and manage virtual organizations of agents, but does not allow the creation of agents from embedded devices. Virtual organizations would provide artificial intelligence systems with greater dynamism, allowing services to be modified in execution time, defining interaction norms, monitoring traffic, *etc*. In addition, virtual organizations will facilitate the management of multiple WSNs by a single platform by creating different virtual organizations for each WSN.

The goal of the present study is to move one step further toward the development of an organizational-based architecture that incorporates embedded agents to store and process different types of data gathered by the system in order to improve the performance of ambient intelligence environments.

As shown in this section, ambient intelligence requires novel solutions to develop ambient intelligence environments and, more specifically, to manage context-aware information. Multi-agent systems and WSNs are essential technologies for this aim. However, it is still necessary to design effective architectures incorporating embedded agents. The next section presents the multi-agent architecture proposed in this paper, focusing on the sensor agent, which incorporates an innovative embedded agent model.

In addition to the sensor agent, this study also presents the camera agent. This agent is a common agent that is not embedded in the hardware and whose intelligent behavior is executed on the hardware devices. The new communication between these agents is established through a new protocol, which provides an added value for developing ambient intelligence environments.

3. Proposed System

The proposed system is developed over the PANGEA platform. PANGEA integrates different agents that control the operation of the devices connected to the system. In Sections 3.1 and 3.2, the platform is introduced with references to include more detail. PANGEA facilitates embedding agents in low performance devices. The agents that compose the different virtual organizations (VO) in Arduino devices are explained in Section 3.3. These agents allow the devices to recognize and treat different sounds. Finally, Section 3.4 includes information about the agent in charge of the camera.

3.1. Overview of PANGEA

With the evolution of ubiquitous and distributed systems, it is necessary to create new agent platforms that facilitate the development of open agent architectures and ambient intelligence systems [52], which must be capable of deploying their agents in any device. PANGEA [16] is an agent platform based on organizational concepts that can model and implement all kinds of open systems, encouraging the sharing of resources and facilitating the control of all nodes where the different agents are deployed.

One of the main features of PANGEA, which provides great flexibility to developed systems, is that it is geared towards VO agents [53]. A VO must be understood as an open system formed by the grouping and cooperation of heterogeneous entities and where there is a gap between the form and the function that defines its behavior [54].

The main features that a VO must support are:

- Creating organizations and sub-organizations: These organizations largely determine the communication and interaction capabilities among the agents. Moreover, each organization is determined by a structure or topology that can be altered throughout the lifecycle of the organization.
- Management of roles: Agents within the organizations are mainly characterized by the role they play, which determines their abilities, skills or services.
- Management of services: Agent skills are understood as services. Thus, providers and requester agents emulate a client-server architecture, where agents offer their services and other agents demand such services.
- Rules: One of the main reasons for the creation of the VOs was the need to emulate social systems (hence, the need for a structure). Rules are also part of social systems; in highly dynamic environments, control mechanisms that facilitate the integration of heterogeneous components must be established. This role is played by the rules within VOs.

The VOs can be considered an evolution of the multi-agent system (MAS), where new features come into play that allow systems to be more open and, thus, more flexible and adaptable. With these new features, the number of platforms available for the development of open systems is reduced, hence the need for the development of the PANGEA platform.

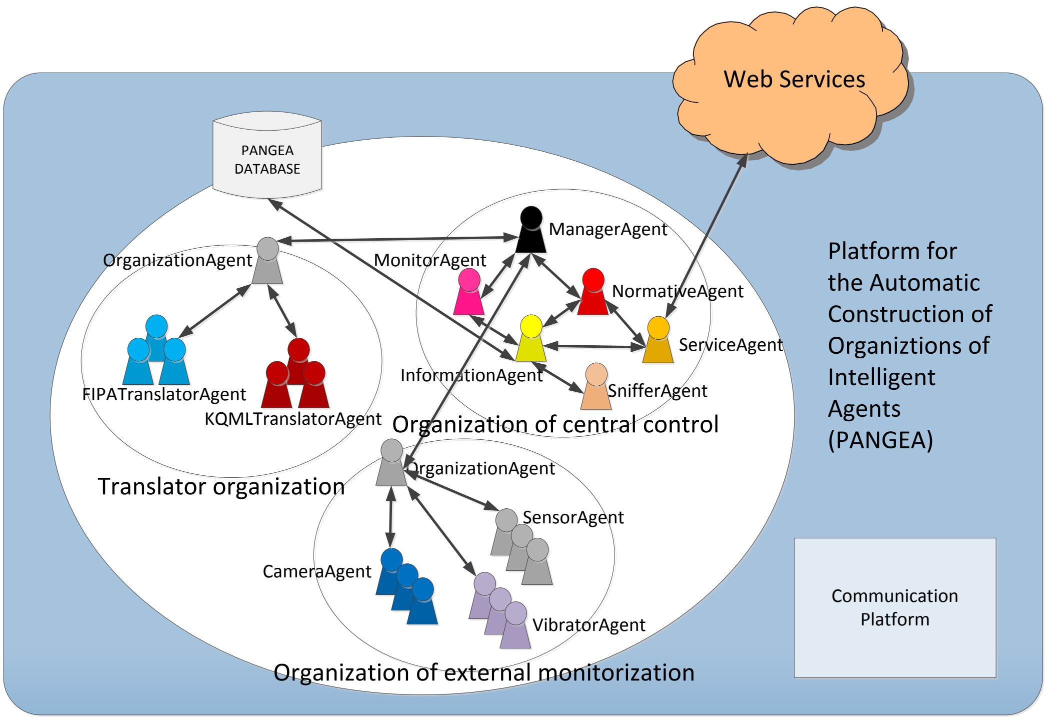
Some of the features that make PANGEA a highly recommended platform for AmI systems are: (i) the ability to include heterogeneous agents in terms of languages and runtime platforms; (ii) a robust and reliable communication mechanism; and (iii) the ease of implementation.

This platform has been used to develop many systems in fields related to AmI, such as information fusion [55] or personalization of the workspace by a proximity detection system [56]. More detailed information about the platform is already published and can be consulted in [57,58].

3.2. Integration of the Organizations in PANGEA

The PANGEA platform is a general purpose platform that can be used to implement different applications based on VOs. However, due to the fact that monitoring and control mechanisms common to all fields of study are needed, PANGEA automatically displays an organization called the Central Control Organization. As explained in detail below, all of the agents belong to this organization in order to ensure the correct operation of the platform and the life cycle of agents, the control of standards and the allocation of roles, among other factors. Moreover, specific organizations were included for this case, allowing the tasks of the described system to be carried out. Figure 1 shows the agents included in each organization.

Figure 1. Overview of the agents deployed in the PANGEA platform. FIPA, Foundation for Intelligent Physical Agents; KQML, Knowledge Query and Manipulation Language.



The organizations are:

- Translator Organization: The agents deployed in this organization are in charge of the translation and communication with agents that do not share the same Agent Communication Language (ACL) used by the PANGEA agents. PANGEA agents are implemented in Java or C++ and use the standard Internet Relay Chat (IRC) as the communication language. Currently, this organization includes agents with translation capabilities for communication languages, such as Knowledge Query and Manipulation Language (KQML) or FIPA-ACL (Foundation for Intelligent Physical Agents) [59].

- Central Control Organization: this organization includes the agents that manage and control the entire platform, which will be seen in the next section.
- Organization for External Monitoring: This organization includes those agents deployed in external monitoring devices, such as cameras, sirens, *etc*. These agents will be explained in detail in subsequent sections.

As mentioned previously, VOs should offer organizational norms, roles and the services associated with them. The agents that ensure these features in PANGEA are deployed in the Central Control Organization. Agents that are part of PANGEA can be executed on different computers, based on a decentralized scheme. A new agent may access the platform specifying the IP address of the machine on which the ManagerAgent agent is deployed. This agent is responsible for ensuring efficient and secure communication. Other agents in the system can be executed or replicated on other machines, ensuring the recovery of a possible fault in a network node.

- OrganizationManager: responsible for the actual management of organizations and suborganizations. It is responsible for verifying the entry and exit of agents and for assigning roles. To carry out these tasks, it works with the OrganizationAgent, which is a specialized version of this agent.
- InformationAgent: responsible for accessing the database containing all pertinent system information.
- ServiceAgent: responsible for recording and controlling the operation of services offered by the agents. It works as the Directory Facilitator defined in the FIPA standard.
- NormAgent: ensures compliance with all of the defined norms in the organization. This agent is responsible for ensuring that all communication complies with established restrictions and that only certain agents communicate with other specific agents. This functionality will provide security in the platform.
- Sniffer: manages the message history and filters information by controlling communication initiated by queries.
- MonitorAgent: controls the life cycle of other agents and enables the interface to display the general state of the communications, organizations and agents. This agent is responsible for starting the agents of the platform in case of failure.

The PANGEA platform is executed one time only for different WSNs; in other words, an organization that manages the elements of the WSN is created for each case study. The External Monitoring Organization was created specifically for this case study.

The main feature of the Organization for External Monitoring is to contain all of the agents who are responsible for managing and controlling the agents deployed in external devices and the agents responsible for controlling devices, in this case, the SensorAgent, CameraAgent and VibratorAgent.

An important aspect is that the platform can limit unwanted communications among different organizations. Thus, an agent from the External Monitoring Organization could not communicate with another agent from another organization unless it is enabled by a norm in the NormAgent. The agent platform is therefore unique and can be reused in different case studies. In addition, all agents, except the ManagerAgent, can be replicated in the system; therefore, if the system grows, a new agent can be deployed in another node.

3.3. Sensor Agent

The main goal of this section is to describe the functionalities of the sensor agent model that was developed and to mention its primary advantages as compared to the systems traditionally used to deploy agents. Embedded systems are designed to perform very dedicated or simple functions. Their primary use is for real-time computing applications. One of the most notable characteristics of using embedded software, with regard to other computing systems, is the low manufacturing cost, which is a result of the small size of the processor and memory in the device. There are different microcontrollers and systems on a chip currently available in the market, the most well-known microcontrollers being Arduino [60] and Propeller [61], and the most well-known systems on a chip being Beagle Board [62] and Raspberry Pi [42]. The Arduino platform was selected for the development of embedded agents in the present study, due primarily to the following advantages: it is more economical; it uses a simple multiplatform, with scalability-hardware and scalability-software.

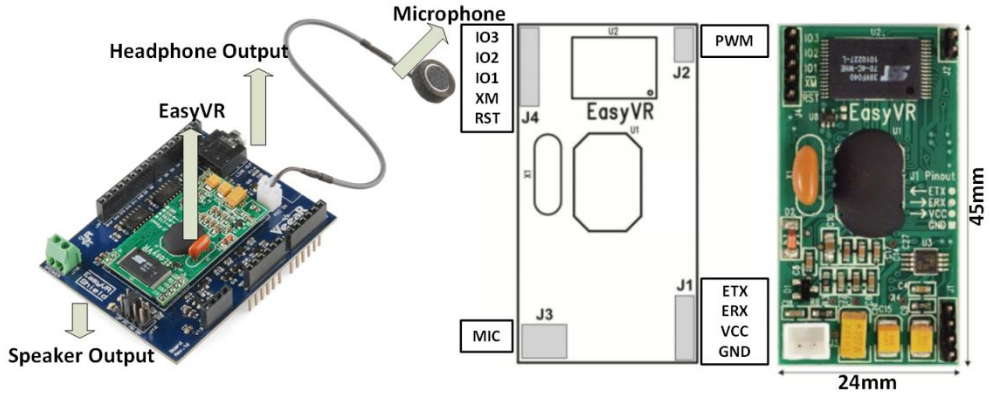
Although the aim of this work is to define a general sensor agent model that could be embedded in different devices, in order to show the effectiveness and the potential of the proposal, we have focused on the Arduino devices and some specific functionalities, all of which will be further developed in future studies. The sensor agent model presented in this paper is defined by means of a recognition model aimed at detecting sounds, an actuator system based on light control and a communication module with the PANGEA architecture. The communication is established through the IRC protocol in such a way that each of the sensor agents can communicate with the corresponding coordinator of an organizational unit of the organization. One of the advantages of the proposed sensor agent model is that each sensor agent embedded in a device has a corresponding sensor agent executed in the PANGEA platform. This way, the sensor agent in PANGEA can execute complex processing tasks that cannot be carried out by the embedded agent due to resource constraints. The sensor agent will execute a sound recognition algorithm in those cases where the embedded agent cannot classify the sound. In the following paragraphs, we define each of these components.

3.3.1. Recognition Module

The proposed sensor agent incorporates a recognition module. The processing and subsequent acoustic analysis is done with an EasyVR board [63], which provides simple connectivity with any controller through Universal Asynchronous Receiver-Transmitter (UART) [64] communication. The sounds to be recognized are stored in the internal memory, with a capacity of up to 32 sounds. It includes a microphone that allows for the continuous capture of sounds in the environment and consequently generates a response.

The minimum power supply needed to work with this module is 3.3 V, which is sufficient to work together with the Arduino Duemilanove board. Figure 2 shows a diagram of the module.

Figure 2. The voice recognition module for Arduino.

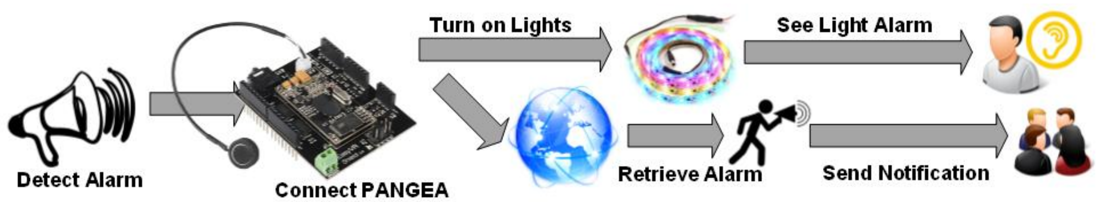


When the embedded agent cannot classify a sound, the sound is sent to the corresponding replicated sensor agent in the PANGEA architecture to execute a more precise classification algorithm. This allows the system to avoid sending data continuously, thereby sending information only when an unknown sound is detected. The replicated agent is used to carry out tasks with high processing. The agent in the Arduino device sends the information to the replicated agent with the service analysis to conduct this processing. The replicated agent implements a sound recognition algorithm that combines the Shazam algorithm [65], a very robust method to distinguish noise, with the Mel frequency cepstral coefficients (MFCC) technique [66,67]. MFCC and Shazam work in a similar way, obtaining a fingerprint of the sound; MFCC uses spectrogram peaks, while Shazam uses local maximums in the signal frequency curve.

3.3.2. Sensor Agent Functionalities

The sensor agent controls the following hardware components, which can be seen in Figure 3: Arduino Duemilanove board, EasyVR voice recognition module and a set of 100 light-emitting diodes (LEDs) of various colors.

Figure 3. The integration of Arduino and voice recognition module in PANGEA.



The speaker is measuring sounds from the environment when it detects a pattern similar to that of a siren. The microcontroller then activates and emits flickering lights using high visibility LEDs, which draw the user's attention. This is useful for the hearing-impaired, for example, who are unable to hear the sound of an alarm from a conventional acoustic device.

As shown in Figure 3, the sensor agent is connected to PANGEA by means of the IRC protocol. Thus, the organization created using PANGEA can receive and analyze the information received from the sensor agent. Based on this information, the organization can monitor the environment and define services, such as notification systems, to send alerts and notifications to users through different mechanisms. The information provided by sensor agents is used from an organizational point of view to analyze the functioning of the current organizations and to recommend possible re-organization solutions.

3.3.3. Portable Sensor (TAG), VibratorAgent

One of the advantages of using wireless sensor networks (WSN) is the ability to wirelessly interconnect multiple electronic devices in a simple and scalable way. In general, the devices connected to such networks can be considered autonomous nodes, capable of running embedded programs, with a low battery consumption level and with a very simple logic of operation. This section presents the proposed solution whose main function is to notify the user about an alarm condition through the use of the sound recognition module described in Section 3.3.1

To facilitate the portability and usability of the location device, we opted for a solution based on Arduino Nano Pro v3. It is a small sized microcontroller that the user can easily wear, since it can be placed in a bag or attached to clothes. In Figure 4, it is possible to see the actual size of the chosen device.

Figure 4. Image of the Arduino Mini Pro actual size.

As stated above, the main goal of using this hardware in our proposal is to notify disabled users who, due to physical or mobility issues, cannot observe the emergency light or sound alerts that are generated in an emergency situation, but must respond to them nevertheless. The battery of the Arduino microcontroller has a voltage of 3.7 V and a capacity of 370 mAh, ensuring the correct operation of the device during 48 h. The interconnection of the TAG with the PANGEA platform is carried out using the TCP/IP protocol and the IRC message format type defined in RFC1459 [68]. It is also necessary to use shield-type WiFly RN-171 [69], which provides wireless communication with the central server where the main agents of the PANGEA platform reside.

The agent embedded in the TAG is continuously subscribed to the Alarm and Monitor virtual organization. When any of the predefined events is triggered, the event is communicated to the user in the form of vibrations (using the vibration sensor). The event code is transformed into vibrations using an SOS in Morse code. The following section explains the algorithms used in PANGEA for sending notifications to the nodes to the network.

3.3.4. Sending Algorithms

The sensor agent executes specific algorithms to fulfill responsibilities inside the organization. It is important to take into account that the sensor agent plays a role inside the defined organization by means of the PANGEA platform. The code in Figure 5 shows how the sensor agent connects to the PANGEA platform and is executed only when the micro-controller has been initiated. Once inserted into the PANGEA platform, it joins the rest of the platform agents so that it can interact with them. After registering in the platform, the agent sends the information about the services it provides. That information is sent to the ServiceAgent, who can then provide it to other agents. The services will depend on the sensors connected to the Arduino device, and the agent deployed in the Arduino device will contain the information about the available sensors.

The sensor agent then communicates with the organization using an algorithm in charge of confirming whether there are any requests from the PANGEA-based organization. The following image in Figure 6a shows how the alarm event is recognized and then how the fire event is treated in the system. The notifications are sent to the subscribed agent in the platform, after which the notifications are received by the subscriber. The subscriber remains blocked until it receives a message, as seen in Figure 6b.

Figure 5. Simple connection agent to the PANGEA system.

```
BEGIN CONNECT
    IF NOT Client.Connected
            PRINT "Connecting"
        WHILE NOT Client.Connected
            DO
            CALL Client.Connect(IP,PORT)
            END DO
        END WHILE
            CALL Client.Write(LOGIN)
    END IF
END
```

Figure 6. Treatment Pseudocode of a fire alarm event in PANGEA. (**a**) The agent receives an event and responds to it; (**b**) The receiver remains blocked from receiving messages.

```
BEGIN EVENT_RECEIVED
    IF EVENT_RECEIVED.TYPE(SOUND_RECOGNIZED)
        PRINT "SEND ALARM"
        CALL NOTIFY_TO_SUBSCRIBER_AGENTS("SOUND ALARM RECOGNIZED")
        CALL ACTIVATE_SENSOR_LIGHT
    END IF
END
```

(**a**)

Figure 6. *Cont.*

```
BEGIN READ_FROM_PANGEA
        WHILE Client.InfoAvailable ()
                DO
                        MESSAGE:=Client.ReadMessage ()
                END DO
        CALL RESPONSE:= ProcessMessage(MESSAGE)
        END WHILE
        IF RESPONSE NOT NULL
                CALL    Client.Send(Response)
        END IF
END
```

(**b**)

Upon activating the microprocessor, the code is continuously executed.

When a known pattern is recognized, an event is initiated. In our example, the event is G1_ENCENDER_LUZ, which gives the order to turn on the bright LEDS and alert all of the agents connected to the PANGEA platform of the existing fire.

3.4. Detection and Tracking Movements by the Camera Agent

In addition to the sensor agent, another kind of sensor agent has been defined in our approach: a camera agent. The camera agent is dedicated to controlling an IP camera that tracks and detects movements. The camera is controlled by the camera agent, which is responsible for obtaining images and detecting movements. The wireless fidelity (WiFi) camera is activated remotely by an agent or automatically when the agent receives an alert through a sensor.

The processing system is very basic. The objective is to deploy an agent that manages the camera remotely; however, it must be able to interact with the camera as an embedded agent. The implementation is based on basic image processing techniques [70]. The process of motion detection and tracking consists of subtracting images and calculating the areas of the remaining objects to track specific surfaces. During the process of subtracting images, it is only necessary to consider two images captured without any movement of the camera between the two captures. The difference between the images is calculated using the red, green, blue (RGB) color channels. The image is transformed into a binary image, which takes on the value of one for a given pixel if that pixel exceeds the defined threshold for any of the channels.

Once the images have been captured, the subtraction of the images is calculated, and based on the differences, the detection of the remaining figures in the image is calculated. Using dilation and erosion algorithms [70,71], the images are then filled in order to avoid the presence of empty spaces. This is followed by the process of filling the remaining voids, applying an algorithm based on morphological reconstruction [72].

To complete the process of filling the spaces, a binary image of each of the objects is obtained. This is a simple process by which each pixel with a value of one in the binary image is considered a new object if it does not contain an adjoining pixel with a value of one that was previously tagged as a new object. This is the process followed by MATLAB for object recognition [70]. Once the objects have been located, the area of each object is calculated, and the object identified as having the largest size is tracked. A summary of the motion detection process can be seen in Figure 7

Figure 7. Movement detection.

Input: I(t), I(t-1)
Output: rectangle

$D \leftarrow I(t) - I(t-1);$

`// ` D_{CR} ` is the channcel blue, ` D_{CG} ` green, ` D_{CB} ` blue`

$binaryImage \leftarrow D_{CR} > \alpha | D_{CG} > \alpha | D_{CB} > \alpha$;
$Dmovement = D. * binaryImagen;$
$BIdilationDilateErode \leftarrow dilateErode(binaryImage);$
$BIfill \leftarrow fillImage(BIdilateErode);$
$objects \leftarrow extractObjects(BIfill);$
$areaObjects \leftarrow calculateArea(objects);$
$rectangle = boundaryRectangle(objectMaxArea(objects));$

In order to track a detected object, the objected is framed in a rectangle; the camera moves when the object exceeds the defined margins of the image that center the object in the camera. The camera moves a predetermined number of degrees, stops and captures another image to determine the position of the moving objects. It will move again if the object is found outside the central margins of the image. As the camera cannot detect the distance of the objects, it is unable to calculate the speed of movement for the object and, thus, uses this method of tracking.

3.5. Global Functioning of the System

Generally speaking, the inclusion of agents that manage sensors in the platform can be done in two ways: for the camera agent and for the sensor agent. The camera cannot be embedded with an agent, since it has not been programmed this way. Instead, the agent is installed remotely and remotely accesses the web services that have been provided to implement its behavior. The agent actually behaves as if it were deployed on the camera, and it is responsible for accessing the functionality of the camera. A remote agent will generally behave according to Figure 8.

If it is possible to embed part of the agent's behavior in the device, the services will be distributed between the embedded and the remote agent. In this case, the sequence diagram to register the agents and services is similar when there is only a remote agent. The remote agent may not be necessary if all of the services can be included in the embedded agent. Figure 9 shows the sequence of messages.

Figure 10 presents the sequence of exchanges between the PANGEA platform agents and a sensor agent when the sensor agent is registered in the platform. As can be seen in Figure 8, the sensor agent registers different services that can be used by the rest of the agents in the platform. It is represented in Message 9. More specifically, the sensor agent offers a notification service that sends information about sounds detected in the environment. The service is similar to a traditional news service subscription. An agent is registered and receives information from the detected sounds.

Figure 8. Sequence diagram describing the interaction between and remote agent and the platform during the registration process.

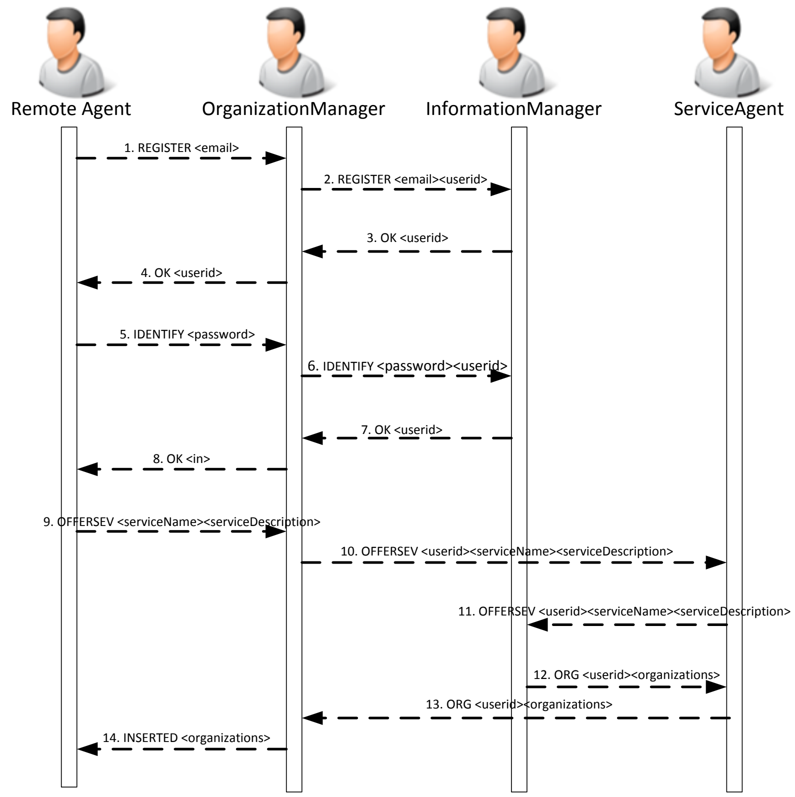


Figure 9. Sequence diagram describing the interaction among the remote agent, the embedded agent and the platform during the registration process.

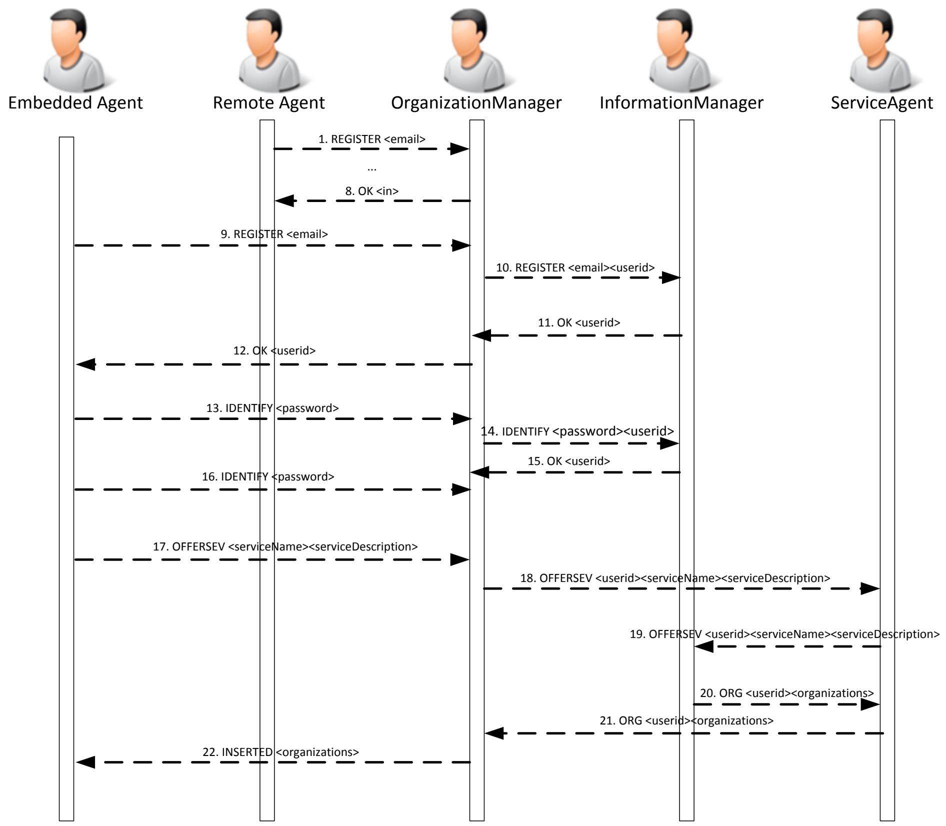


Figure 10. Sequence diagram describing the interaction between the sensor agent and the organization.

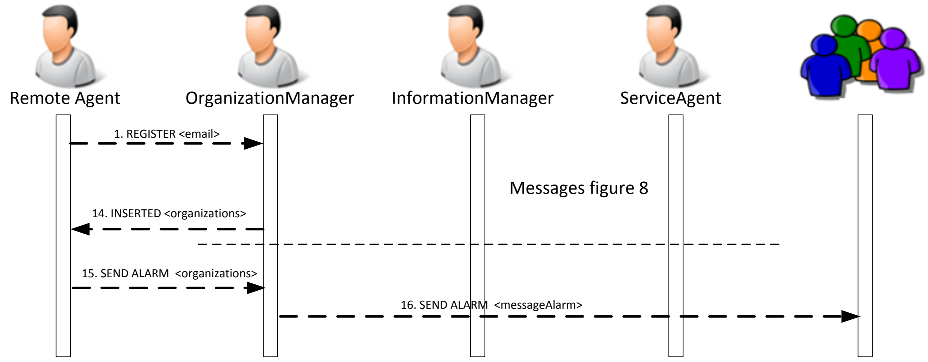
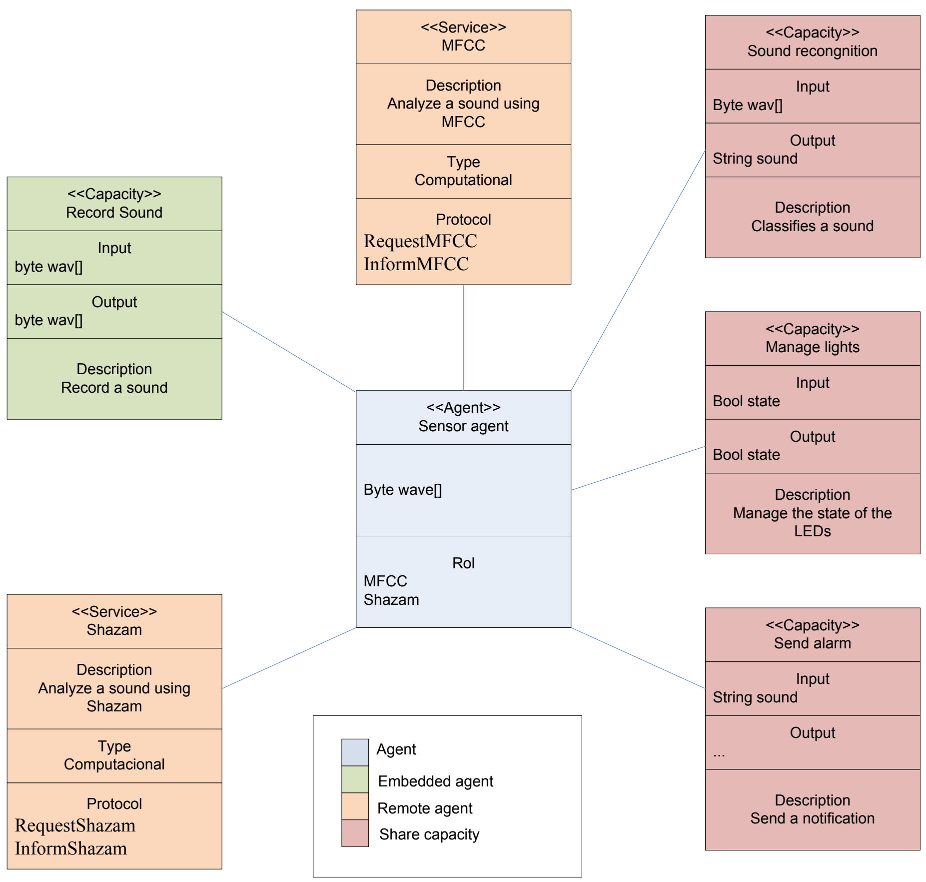


Figure 11 shows the list of capabilities and services provided by the embedded and the remote agent. Some of these skills and services are reflected in Figure 8.

Figure 11. Class diagram of the sensor agent. MFCC, Mel frequency cepstral coefficients.



The first time the sensor agent accesses the platform, a registration protocol is executed. The sensor agent is assigned a unique identifier. Then, an authentication process is executed, and the OrganizationManager agent sends a request (via Frame 6) to the information agent to validate the user data. Once the sensor agent is validated, a replicated agent is instantiated and it communicates with the OrganizationManager and the ServiceAgent agents to register the sound detection service.

The sensor agent is part of the organization; when a sound is detected, the agents subscribed to the notification service are notified.

4. Case Study: Developing an Intelligent Environment for Alarm Detection

The system was developed in a laboratory belonging to the research group. The laboratory includes different types of sensors, such as lighting, heating, IP cameras WiFi, sirens and others, all connected wirelessly through a wireless sensor network. With the exception of the IP camera, the remaining sensors are not connected to the system that was developed; this will make it possible to integrate the system into homes without needing to spend money connecting hardware, such as gas or motion detectors, to the sensor network. The sensors and the system are connected through a siren or bell. The system detects and classifies the different sounds using sound recognition modules that interpret the sounds and execute actions according to the agents that have been embedded into the devices. This allows the system to be integrated into the home without a significant increase in cost.

The following alarms were used during the case study: smoke detector, gas detector and robbery detector. The activation of these alarms affected the IP camera and the illuminated bands.

The room was equipped with an Arduino device. The Arduino is connected with a WiFi module. The agent is connected to the PANGEA platform, which is installed remotely in a mode server. The illuminated bands are connected to the Arduino board. The web camera is controlled by an agent located at the central server of the PANGEA platform, thus eliminating the need for having any equipment in the laboratory.

PANGEA will contain the agents from the Translator Organization, the Central Control Organization and the agents of the organizations belonging to the case study indicated in Section 3.1. If another case study were included, it would only be necessary to include the organizations with the agents belonging to the new case study; the Translator Organization and Central Control Organization would be shared with all of the case studies.

5. Results

In order to carry out the study, the system performance was analyzed to ensure that it correctly classified the sounds coming from the different alarms and that the alarms initiated the correct functioning of the IP camera. The PANGEA platform was installed on a PC containing an Intel Core 2 Duo P9700 processor with 2.8 GHz, connected to the network through a 100-Mbit connection. The web camera records in color with a resolution of 640×480 pixels. All agents are deployed on this computer, except the sensor agent and vibrator agent, which are located in the Arduino devices. It would be possible to run agents on other computers if so required, for example, because of either the processing or the number of suborganizations deployed to manage the WSNs.

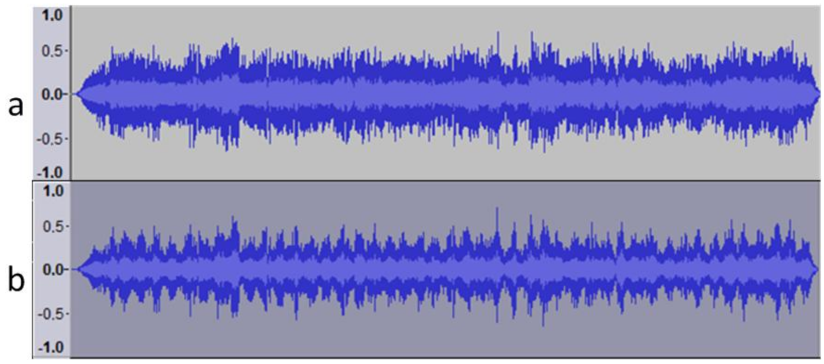
In the first test, the robbery alarm activated the camera. When the alarm was activated, the sensor agent automatically alerted the agent responsible for supervising the camera, so that it could initiate the recording and begin sending photographs. During this time, the camera detects the movements and tracks people according to the orders indicated by the camera agent.

In order to test the operation of the gas and smoke sensors, the respective sound alarm was activated in order to ensure that the system was capable of recognizing the sounds without error. The alerts were sent to email, and the camera was activated according to its configuration. As a result of the activation of the gas and smoke alarms, the illuminated bands were activated to alert the user in case of any hearing impairment. The illuminated bands are connected to the Arduino device, which is in charge of activating a sequence of colors according to the type of alarm.

In order to ensure that the system correctly detects the sound, background music was played in the room prior to activating the alarm. In this case, it was noted that sound recognition could be affected if the volume of the music were very loud or if the music were close to the microphone. In order to avoid a situation in which a loud sound could muffle the sound of the sirens and not activate the alarms, we chose to activate a warning when the volume exceeded a predefined decibel level, thus ensuring that the alarm could not be drowned out by another sound.

In order to analyze the sound recognition, the original sound of the alarm was recorded. The sound spectrum of the alarm can be seen in Figure 12a. Figure 12b takes the base sound and applies a fuzzy distortion to modify the sound frequencies. It was possible to notice the difference when the new signal was played.

Figure 12. (**a**) Original sound; (**b**) Sound obtained after applying a fuzzy filter to the original sound.

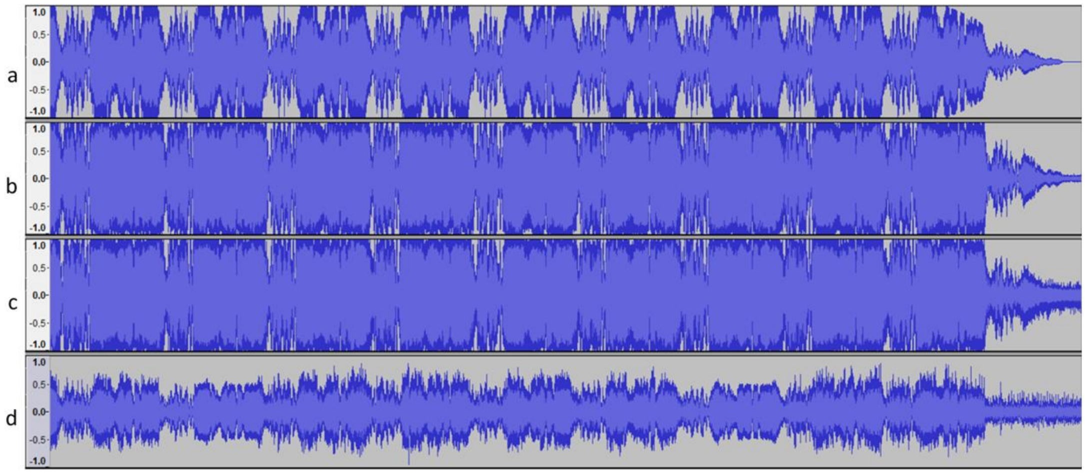


The proposed approach was evaluated using a dataset of 42 alarm sounds available at soundjax [73]. The number of sounds is higher than the number of sounds supported by EasyVR; thus, it will be necessary to send sound to the replicated sensor agent to recognize unclassified sounds. The average length for the sounds is 2.83 s, and the deviation is 2.93 s. Different alarms were selected from the dataset, and the detection was tested using the following algorithms: EasyVR, MFCC and Shazam.

The parameters settings for the MFCC algorithm were determined as indicated in [66]. The frame window was established at around 25 ms. The overlap is 50%, and the number of cepstral coefficients is 12 for each of the fingerprints. For each of the alarms, we defined several cepstral coefficient vectors that depend on the frame window and overlap. The frame window was extended to 200 ms to obtain the fingerprints. Different classifiers were used to determine the sounds [74,75], more specifically SVM, Bayes Net and J48 were used.

Different tests were executed, increasing the frame window size in increments of 25 until reaching 200 s and varying the classifiers. A 10-fold cross-validation was applied, and the best results obtained were for a 200-second frame window and the Bayes Net classifier. The set up for the EasyVR algorithm used the default parameters, while the Shazam algorithm used a landmark density of 400 per second and 600 per recognition. These values were selected due to the short length of the sounds.

Figure 13. (**a**) Original sound; (**b**) Sound with white noise; (**c**) Gaussian noise; (**d**) Original sound randomly merged with an existing alarm.



Different noises were introduced to evaluate the system: white noise, 20% of the sound; Gaussian noise with a mean of zero and a standard deviation of half the interval of maximum variation. Additionally, 42 sounds were created by merging existing sounds. Figure 13 shows the results obtained before and after the introduction of the alterations.

The sounds were played close to the Arduino device. The behavior of the sensor agent is shown in the Table 1:

Table 1. Audio recognition.

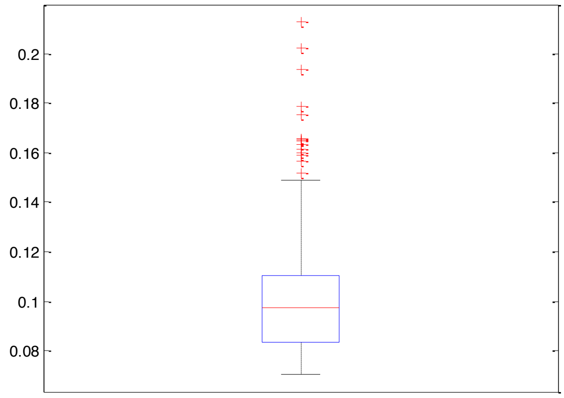
	Original			White Noise			Gaussian Noise			Mixture		
	Success	**Fail**	**Ignored**	**Success**	**Fail**	**Ignored**	**Success**	**Fail**	**Ignored**	**Success**	**Fail**	**Ignored**
EasyVR	32	0	10	25	0	17	21	0	21	2	1	39
MFCC	36	0	6	30	1	11	27	2	13	17	5	62
Shazam	42	0	0	41	0	1	38	3	1	63	21	0

The embedded and remote agents can analyze the different sound and send the alerts to the agents in the organization, thus allowing the camera agent to react to the events. Furthermore, the embedded and remote agent act in the same manner for the system, which allows the services with low processing that are carried out in the embedded agent to be separated transparently from the services with high processing that are executed in the remote agent.

In order to analyze the system performance, a study was performed on the number of images per second that the system was capable of processing. To do so, an intensive processing was performed in which a sequence of 1001 images was passed through the algorithm, and the response times were analyzed. The total time for the analysis was 98.075 s. The average execution time was 0.098075 with a deviation of 0.019300. The time distribution is shown in Figure 14.

The average size of the images was 15.7 Kb, which takes into consideration that the system processes 10.19 images per second, and the bandwidth necessary to process all of the information is 1280.65 Kb. As the bandwidth could be a bit greater for some ADLS (Asymmetric Digital Subscriber Line) connections, the system can establish the number of images processed per second.

Figure 14. Box plot with the information about the execution time during the processing.



6. Conclusions

The PANGEA platform facilitates the development of ambient intelligence systems. The platform can connect different devices, thus facilitating the integration of the information and the decisions made based on the information provided by the sensors. The architecture can carry out complex processes that cannot be done with low-processing hardware, such as Arduino, or with devices that lack processing capabilities, such as an IP camera.

One of the main novelties of the system is the incorporation of agents in Arduino devices, which permits the simple incorporation of different sensors and actuators onto the PANGEA platform.

The combination of Arduino and the voice recognition module allows the recognition of different sounds for which different responses can be programmed. This characteristic is quite relevant, since it makes it possible to incorporate different devices, such as bells and smoke, robbery and gas alarms, into the system using sound recognition. This system reduces costs, since it can incorporate any device that sounds an alarm. Due to the recognition of alarms, it is possible to initiate different actions, such as activating illuminated bands, sending vibrator movements to a user with a vibrator sensor, sending alert messages or activating an IP camera to remotely track an incident.

One of the main advantages of this system is the low cost of installation, since it is not necessary to have a computer that is turned on; low cost hardware is also used. The greatest associated cost is an Internet connection, which is necessary to supervise the environment.

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Author Contributions

Gabriel Villarrubia and Juan F. De Paz have developed the system; they made the test and elaborate the review of the state of the art. Javier Bajo and Juan Manuel Corchado formalized the problem, the algorithms and reviewed the work. All the authors contributed in the redaction of the paper.

Conflicts of Interest

The authors declare no conflict of interest.

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6.3 *Multi-Agent Information Fusion System to manage data from a WSN in a residential home.*

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Multi-Agent Information Fusion System to manage data from a WSN in a residential home

Sara Rodríguez [a,*], Juan F. De Paz [a], Gabriel Villarrubia [a], Carolina Zato [a], Javier Bajo [b], Juan M. Corchado [a]

[a] Departamento Informática y Automática, Universidad de Salamanca, Plaza de la Merced s/n, 37008 Salamanca, Spain
[b] Departamento de Inteligencia Artificial, Facultad de Informática, Universidad Politécnica de Madrid, Campus Montegancedo, Boadilla del Monte, Madrid 28660, Spain

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ABSTRACT

With the increase of intelligent systems based on Multi-Agent Systems (MAS) and the use of Wireless Sensor Networks (WSN) in context-aware scenarios, information fusion has become an essential part of this kind of systems where the information is distributed among nodes or agents. This paper presents a new MAS specially designed to manage data from WSNs, which was tested in a residential home for the elderly. The proposed MAS architecture is based on virtual organizations, and incorporates social behaviors to improve the information fusion processes. The data that the system manages and analyzes correspond to the actual data of the activities of a resident. Data is collected as the information event counts detected by the sensors in a specific time interval, typically one day. We have designed a system that improves the quality of life of dependant people, especially elderly, by fusioning data obtained by multiple sensors and information of their daily activities. The high development of systems that extract and store information make essential to improve the mechanisms to deal with the avalanche of context data. In our case, the MAS approach results appropriated because each agent can represent an autonomous entity with different capabilities and offering different services but collaborating among them. Several tests have been performed to evaluate this platform and preliminary results and the conclusions are presented in this paper.

1. Introduction

Currently, there is a growing need to find more effective ways to provide social services and medical care to the growing number of elderly people with some kind of dependency [1]. This problem has become one of the great challenges for Europe and its scientific community. Some developments such as the AAL (Ambient Assisted Living), sponsored by the IST (Information Society Technologies) under the Seventh Framework Programme of the European Union (European 7th Framework Programme), have focused on finding new ways to address this problem from a technological point of view. As mentioned in [2], Ambient Intelligence is considered “a new way to interact between people and technology, where the latter adapts to individuals and their context and contains a range of interactive devices capable of meeting the demands and requirements of the users”. Moreover, it is important to remark that the mechanisms and technologies that form an AmI system must allow their autonomous functioning without disturbing the people’s environment but making easy their daily activities.

Information fusion is understood as a process that gathers assessments from the environment. It is based on goals and combines information at a low and high level. As a result, advantages of intelligent approach as Multi-Agent Systems (MAS) within the information fusion process have been recently emerging [3–5]. Agent Technology [6] is gaining progressively more importance in the field of distributed and dynamic intelligent environments; its participation in this process fulfils the requirements and goals of the systems developed under the framework of the Ambient Intelligence and Ambient Assisted Living. These intelligent systems provide a powerful high-level tool and aim to support people in several aspects of their daily life, this support includes the prediction of different dangerous situations, detecting physical problems in people or buildings and also, provide a cognitive support. By integrating intelligent and dynamic mechanisms to learn from past experiences, the proposed architecture is able to provide users with better tools for supplying healthcare.

Wireless Sensor Networks (WSNs) are mainly used to extract information about the environment and behave consequently with an interaction on it, extending users’ capabilities and automating

* Corresponding author.
E-mail addresses: srg@usal.es (S. Rodríguez), fcofds@usal.es (J.F. De Paz), gvg@usal.es (G. Villarrubia), carol_zato@usal.es (C. Zato), jbajo@fi.upm.es (J. Bajo), corchado@usal.es (J.M. Corchado).

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daily actions [7]. One of the most important applications for WSNs is Real-Time Locating Systems (RTLS). As we previously studied in [8], although outdoor locating is well covered by systems such as the current GPS (Global Positioning System), indoor locating needs still more development, especially with respect to accuracy and low-cost and efficient infrastructures. The use of optimized locating techniques allows obtaining more accurate locations using even fewer sensors and with fewer computational requirements [9].

As presented in [10] the innovative smaller, portable and non-intrusive devices [11] are progressively more efficient when gathering context-information [12]. Thus, the new Ambient Intelligence platforms should encourage the integration of such devices in order to create open, flexible and adaptable systems. This reason lead us to said that virtual organizations of agents are an ideal option to create and develop the open and heterogeneous systems such as those normally found in the information fusion process.

The system represented in this article arises from an increasing need to research new solutions to meet the special needs of the elderly, which will result in one of the most benefit segment of population. The costs associated with these actions are no longer bearable in terms of the investments in infrastructure and human resources required for the traditional model (its survival is not guaranteed). Innovative solutions are therefore needed in order to better address the problem of aging.

More specifically, this paper presents an intelligent multi-agent system aimed at improving healthcare and assistance to elderly and dependent people in geriatric residences and at their homes. The system is based on the PANGEA multi-agent architecture (Platform for Automatic coNstruction of orGanizations of intElligents Agents) [13], which provides a high-level framework for intelligent information fusion and management. The system makes use of wireless sensor networks and a Real-Time Locating System to obtain heterogeneous data, and provide autonomous responses according to the environment status. The proposed system integrates a set of autonomous reactive and deliberative agents designed to support the carergivers' activities and to ensure that the patients are given the proper care in both the residence and their homes.

In summary, our work consists on developing a good tested system for information fusion technologies in an important real-world application scenario, covering the following issues:

- The development of a new Ambient Intelligence based multi-agent system aimed at improving the healthcare of dependent people in geriatric residences and in their own homes, focusing on information fusion techniques and extending the system proposed in [1].
- The development under the PANGEA multi-agent architecture, which provides a high-level framework for intelligent information fusion and management.
- The appropriated use of virtual organizations of agents for the overall management; and control systems for high-level sensor data management.
- To include a rule-based reasoning system to improve the accuracy of the results.

The use of virtual organizations of agents facilitate the incorporation of new information fusion techniques to the platform. Self-adaptive virtual organizations allow the dynamic incorporation of specialized agents, which provides a framework for the incorporation of new information fusion techniques. The remainder of the article is structured as follows: sections two and three review the state of the art of related projects, both national and international, as well as the various types of technology used in the study (information fusion, agents, rule-based reasoning systems, case based reasoning), in an effort to identify current deficiencies. Section four presents the proposed multiagent system, providing a general description, its infrastructure and integration within sensor networks. This section specifically describes the basic structure of the developed system, which is composed of three distinct parts: real time identification and localization service [1]; telemonitoring services; and an interface service for personnel. This article focuses on telemonitoring services that permit carrying out a study, and the observation and analysis of the users, which in this case are the elderly living either in a care home or in their own home. Finally, section five presents the results and conclusions obtained from the study.

2. State of the art

The emergence of new technologies had resulted in a number of projects that aim to improve interaction with an environment. One specific application involves improving quality of life and care of the elderly, as noted in the following specific projects:

- The CommonWell European program [14] proposes an architecture to support citizens with limited mobility or an audio or visual impairment. It focuses on the elderly but does not incorporate as many advanced adaptable or identification interfaces or location.
- The European DTV4A project proposes the use of digital television to integrate persons with limited abilities; however, the television is the only mechanism to provide the services and obtain information.
- The European Monami project [15] proposes a global framework to offer services to the elderly and disabled. It focuses on providing these services to individuals with the aim of enabling a more independent lifestyle. It does not, however, provide information for medical personnel or an alarm system.

At the national level we find the following:

- The DISCATEL project [16] aims to facilitate contact with disabled people. It offers a monitoring system especially for people with disabilities.
- The INREDIS (Interfaces for Relations between the Environment and people with disabilities) Project [17] is a CENIT project led by Technosite, which combines the concept of using personal devices with ubiquitous interoperability and characteristics to strengthen accessibility for people with special needs.
- The INCLUTEC group [18] is developing the eVia platform, which is oriented toward the analysis and development of new mechanisms to facilitate mobility such as advanced wheelchairs and specialized assistance vehicles, alternative and improved communication, manipulation and cognition. Although it can be applied to the elderly sector as a whole, this project also focuses on persons with disabilities.

Apart from the projects in development, there are a high number of projects involving wearable health devices [19–21] integrated with sensors providing continuous monitoring of person's health related issues and daily activities. There are also many systems developed to monitoring and with the recovered information, create alarms and facilitate the clinical decisions, i.e. Arezzo, DeGeL, GLARE, GLEE, HeCaSe2 compared in [22]. SHAPHIRE [23] is a system developed to provide clinical decision support for remote monitoring of patients at their homes and at the hospital to reduce the load of medical practitioners and healthcare costs. The system CAMPH, a context-aware middleware for pervasive homecare, is presented in [24]. The middleware offers several key-enabling system services that consist of P2P-based context query processing, context reasoning for activity recognition and context-aware service management. However, camera based sensors for surveillance and security in which the images of the person are taken require acceptability of the elderly which may not be possible. BehaviorScope [25] processes streams of timestamped sensor data along with prior context information to infer activities and generate appropriate notifications. In this case, the activities of interest are pre-programmed into a specification that is used by the system to interpret the incoming sensor data stream. The system interprets the activities to generate summaries and other triggered notifications that are propagated to the users. However, these projects are for very specific purposes.

There are also works centered on improving the activity patters of the elderly, looking for a better learning of the software. This is the case of the framework called DTFRA (Discovering of Temporal Features and Relation of Activities), which focus on discovering and representing the temporal features of activity patterns from sensor data. The proposed algorithm is able to discover features and relations, such as the order of the activities, their usual start times and durations by using rule mining and clustering techniques. Other related works focus on this specific activity are [26–28]. In some cases, these systems are extended with monitoring and modeling the activities of daily living [29,30].

The most complete system found in our previous research was JTH [31]. It is a prototype of wireless sensor networks, an interconnection platform and a service management platform to support large scale data interconnections and real-time activity and health state reports to related persons (e.g. doctors or nurses, elder-self, relatives) via all popular communication approaches, such as automatic voice telephone call, SMS or Email etc. This system provides 4 main functionalities, including indoor monitoring, outdoor monitoring, activity and health state decision, emergency decision and alarm.

The survey [32] about wireless sensor networks for healthcare presents some interesting systems related to the field. Nevertheless, our system is technologically far away from those taken into account. This system is more than a decision support system since it integrates other capacities such as location, monitoring and prediction of dangerous situations. Moreover, it is based on the multi-agent technology, which is highly appropriate to this end due to the need of fusioning information from heterogeneous distributed resources and autonomous entities. In this sense, the main contribution of this work is a system easily extensible that conforms a complete tool for health-care services based on WSN sensors networks. The skeleton of the system is the PANGEA platform, which provides the basic characteristics for the perfect functioning of the agents.

What we are presenting is a system that aims to improve the action of assistance in a senior home care facility. The system as a whole offers real time identification and location services [1], telemonitoring, and interface services for personnel. To this end, techniques such as information fusion, rule-based reasoning systems, WSN and MAS are used. These techniques are presented below.

2.1. Information fusion and agents

Most of the times, information fusion is a fundamental part of sensor management. Waltz in [33] define sensor management as "any system which provides automatic control of a suite of sensors or measurement devices and its. The main problem has to do with the ability to observe a dynamic scene with a set of sensors by controlling their configuration, their sequencing or their state changes, as well as the scheduling of the resources". Moreover, information obtained from multiple sensors needs to be fused because no single sensor can get all the information, and the information from different sensors may be uncertain, inaccurate, or even conflicting [34].

In our previous work [35] has been already exposed that there is a considerable variety of sensors that can observe user contexts and behaviors and multi-agent architectures that utilize data merging to improve their output and efficiency. Such is the case with Castanedo et al. [36], Pfeffer et al. [5], Liu et al. [37] or the system called HiLIFE [38].

Multiagent architectures are specially appropriated to implement the new algorithms for information fusion and to manage high level information. This adequacy of agents and multi-agent systems applied to information fusion has been deeper discussed our previous work [39]. Open MAS [40] and virtual organizations of agents [41–44,40,45], as a specialized version of MAS, are used in this paper to allow the inclusion of organizational concepts These concepts includes rules and norms [46], groups or institutions [47] and social structures [48].

From our perspective, there is already an open platform that has been created and allows any type of configuration, adaptation mechanisms, reorganization, search services, etc.

2.2. Rule-based reasoning systems

As observed in [49], the most critical step in information fusion is related to the transformation from the observed parameters, which are obtained by multiple sensors, and a decision or inference, which is calculated by fusion estimation and/or inference processes. Finally, it is also important to get an easy understandable interpretation of the observed situations and the relationships between them. In many cases, this interpretation needs not only implicit information but also explicit data that must be extracted via knowledge-based methods such as rule-based reasoning systems.

The goal in building an automated reasoning system is to create a system capable of making decisions based on the information obtained through the heterogeneous sensors.

The developed system (and the agents supporting it) uses very different techniques for base and meta-classifiers training as will be seen in Section 4. They are used in the extraction of data and the association rules from different sources of information. The system applies information fusion algorithms which combine the information gathered from each of the sensors through a case-based reasoning (CBR) mechanism [50]. But, in most cases, CBR has not been used alone, but combined with various artificial intelligence techniques. Support Vector Machine (SVM) [51] has been used with CBR in this study to perform the classification of the data obtained by sensors and automatically create the intern structure of the case base from existing data.

3. System overview

In this paper we propose a new Ambient Intelligence based multi-agent system aimed at improving the healthcare of dependent people in geriatric residences and in their own homes, focusing on information fusion techniques and extending the system proposed in [1]. The most important issue in this system is the application of information fusion algorithms [52–54] that manage data from Wireless Sensor Networks (WSN). The data collection is carried out in real-time according to the action that occurs in the environment, due to this, the agents can react accordingly in an automatic and instantaneous way. Thanks to this configuration the system enables the integration of an elevated number of WSNs with the advantage of a greater simplicity due to the reuse of available resources.

The agents in the system are implemented within the agent platform PANGEA (Platform for Automatic coNstruction of orGanizations of intElligents Agents) [55,13]. PANGEA helps the system to create agents in charge of all the functions of the system, allowing them to organize and communicate more easily and securely, regardless of how they are created, where they are located, what data to collect or what role they play within the system.

The two key concepts that come together in this system are: the use of virtual organizations of agents for the overall management; and control systems for high-level sensor data management. Furthermore, the sensors themselves will have to be managed and analyzed to extract information from them and apply them to the case study in question (healthcare and assistance to elderly and dependent people in geriatric residences).

The context information includes not only information about the environment, the people who lives in such environments is also monitorized. This information includes parameters such as location, temperature of the building, quality of the air, and heart rhythm of the patient.

A node is each element that is included in a sensor network. Each sensor node is usually formed by a microcontroller, a transceiver for radio or cable transmission, and a sensor or actuator mechanism [11]. Some nodes act as routers, allowing them to forward data that must be delivered to other nodes in the network. There are wireless technologies such as Wi-Fi, IEEE 802.15.4/ZigBee and Bluetooth that enable easier deployments than wired sensor networks [7]. At the level sensors, the basis of the WSN infrastructure of the system is made up of several ZigBee nodes. The ZigBee standard features make ZigBee an ideal supporting wireless technology for building indoor Real-Time Locating Systems. The possibility of working with low-power nodes that do not need large computational resources allows designers to reduce hardware costs when implementing the systems. In addition, these kinds of low-power nodes can reach a battery life of several years, with regards to the transmission range (transmitted power), the time resolution and the accuracy of the system. ZigBee-based Real-Time Locating Systems can use different locating techniques in order to estimate the positions of the tags in the environment. In the proposed system, each ZigBee node includes an 8-bit RISC (Atmel ATmega 1281) microcontroller with 8 KB of RAM, 4 KB of EEPROM and 128 KB of Flash memory and an IEEE 802.15.4/ZigBee transceiver (Atmel AT86RF230). These devices, called n-Core Sirius B and Sirius D are shown in Fig. 1 [56].

At higher levels (features and decision), it is possible to detect alterations in the environment and its corresponding response. For example, if a change within a node (a change of light for instance) is detected at the sensor level, the agents at a higher level can decide to send a warning message or perform an action. The actions and reactions are handled by the PANGEA platform since all the agents that formed the organizations are designed with the corresponding services and functions.

This configuration enables the capacity to manage a variety of sensors, other devices of diagnostic and different sources of information (maintenance records, monitoring and observations). The framework provides for information synchronization and high-level fusion [57].

3.1. Infrastructure

The basic infrastructure of the system proposed in this article consists of the following elements:

Wireless sensor infrastructure. This infrastructure is the foundation of the main system services. The infrastructure consists of a set of physical wireless devices on which part of the low level middleware will be executed and through which the rest of the system can access its functionalities (for example, obtaining readings from various sensors or calculating the location of the user).

Wireless devices. They form part of the wireless infrastructure hardware. A set of low consumption and small wireless devices were deployed. Each one shares a common basic architecture composed of a microcontroller, a transceptor and a set of physical interfaces for the exchange of data between the device itself and the sensors and actuators to which the device is connected. According to the application, these devices can be either battery or externally powered.

Low level middleware. A low level middleware is executed on the wireless sensor network. It is composed of different layers that permit the exchange of data between the wireless devices and the other system components. The low level middleware contains a multiagent system [1,13,58] which permits the exchange of information between the firmware included in the wireless devices, the API communication to access the functionalities, and the communication protocol.

API communication. The API (Application Programming Interface) allows the rest of the system to interact with the wireless devices in order to gather the information taken from the sensors they are connected to, and to send and receive data.

Agent-based infrastructure. This infrastructure, together with the wireless sensor infrastructure, is the other pillar of the system. It will be supported by PANGEA and will enable the transfer of tasks that require a high computational cost and that, as a result, are very difficult to implement in machines and devices, often mobiles, used by the system clients. This infrastructure is essentially composed of the agents that provide the system functionality and that can be found in a remote server. The agents execute the tasks (e.g., location). PANGEA also provides the network communication data infrastructure, which makes it possible to connect with client machines and for agents to communicate with the services they offer.

Graphical interfaces. Last, but not least important, the system includes a set of graphical interfaces that can display an

Fig. 1. n-Core Sirius devices.

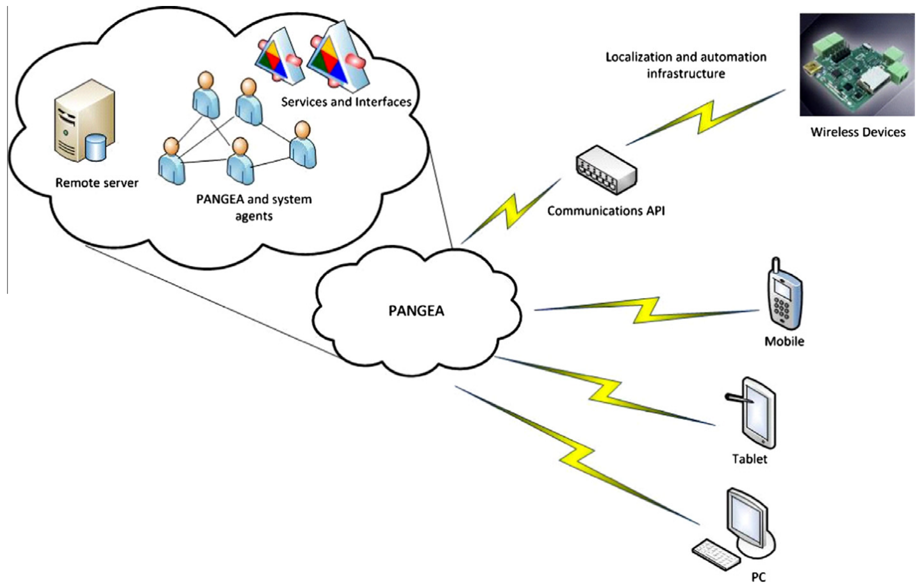

Fig. 2. System architecture.

enriched form of all the information provided by the agents based on the data they have received. This makes it possible to access all the system information and the systems themselves using practically any device that can execute a simple web browser (see Fig. 2).

All the artifacts, including sensors that make up the system have been developed and combined with PANGEA platform to obtain a system specifically oriented to manage information obtained of the environment. For the communication between agents, the IRC (Internet Relay Chat) Protocol is used in PANGEA platform [55] demonstrating its robustness. IRC is a real time internet protocol for simultaneous text messaging or conferencing. IRC provides advantages, such as ease of implementation and reliability, given that it has been widely used in online societies with good functionality. It is used mainly for agent's communication but also allows private messaging for one on one communications, and information transfers. All messages are the following format (see Fig. 3):

```
prefix command command-parameters\r\n.
```

Fig. 3. Message format.

The prefix is voluntary in some messages; the command is one of the originals from the IRC standard. For example (see Fig. 4):

```
PRIVMSG < HomeAutomationOrganization:text>
```

Fig. 4. Example of message.

All agents that are created in PANGEA extend a common basic structure that supports sending and receiving these messages. This basic agent has implemented basic methods like "initialize" or "execute" which initializes the agent with some basic information, or begin the implementation, respectively. A platform's code generating tool makes it possible to easily create an outline of an agent, with the communication code requiring few lines of code. The following lines of code are an example of this (see Fig. 5).

```
private void conect (Object sender, EventArgs e){
irc.OnJoin += new JoinEventHandler(OnQueryMessage);
irc.OnQueryMessage += new IrcEventHandler(OnQueryMessage);
irc.OnRawMessage += new IrcEventHandler(OnRawMessage):
irc.Connect(host.Text, 6667);
irc.Login(agent,Text, null);
irc.Listen()
```

Fig. 5. Agent communication code.

The architecture was initially designed to be applied within medical care environments, and defined three types of services that can be easily adapted to other types of environment:

- Real Time Identification and Location Service: system for locating elderly or dependant people and staff.
- Telemonitoring service: system with different kind of sensors that fusion the information obtaining knowledgment and alerts.
- Caregiver support system: system that allows the caregivers to set alarms and plan daily tasks and routines to take care of the elderly.

The two first services are explained below in greater detail, explaining how they are offered through the agents in the PANGEA system.

3.2. Real Time Identification and Location Service

The Real Time Identification and Locating Service can identify and know the position of the user or a particular object at any given time. As with other services, it can also use algorithms to manage alerts related to the location of the users and objects in relation to the area in which they are found, permission, etc. It does so by employing a set of location algorithms [52–54], which provides greater precision in locating persons than current location systems. These algorithms fuse the information gathered from different sensors: ZigBee, Wi-Fi, accelerometers and compasses.

The configuration used in the system is similar to the configuration of our previous and well tested system presented in [1]. It consists of a ZigBee tag mounted on a bracelet worn on the users' wrist or ankle, several ZigBee readers installed throughout protected zones, and a central workstation where all the information is processed and stored. These readers are installed all over the facilities so that the system can detect when a user is trying to enter a forbidden area according to the user's permissions profile. The ZigBee network also allows obtaining information of the environment from different sensors, such as temperature sensors, light sensors, as well as smoke and gas detectors. In addition, different locating techniques can be used as readers and tags carried by patients and medical personnel. These devices are small enough to be carried by a patient, a caregiver or even an object, and have a battery life of up to six months. The location of users is given as coordinated points obtained from the locating techniques provided by a locating engine [59]. All information obtained by means of these technologies is processed by the PANGEA agents. The system allows users to keep track of any tag in the system as well as receive distinct alerts in real-time coming from the system in any Web-based device, such as PC or a smartphone carried by doctors and nurses. Some of the different alerts include panic button alerts (when users press a panic button on their tag or in a fixed device including such a button), forbidden area alerts (when users enter a forbidden area according to their permissions), as well as low-battery alerts (if a tag in the system should be recharged).

The ZigBee infrastructure was deployed in a 600 m^2 area within a residence housing dependent people with distinct types of dementias such as Alzheimer's disease. The locating infrastructure is intended to provide the real-time position of people (i.e., patients and medical personnel) and assets (i.e., wheelchairs and lifters) with an average accuracy of 2 m within the monitored area in hallways and 0.65 m inside bedrooms, since these are the areas which contain a greater number of sensors. Fig. 6 shows one of the Web-based interfaces of the telemonitoring system in the monitored area.

In order to avoid problems produced by these algorithms, the location system's start-up procedure is modified. Instead of calculating the position of a tag based on the position of the reader, we instead calculate a map of intensities for the environment. We take the tag and calculate the RSSI levels obtained for each reader in the different areas. Using this procedure, for every point (x, y) in a plan, we obtain a set of measurements represented in:

$$m_i = (x_i, y_i, node\_id_i^1, rssi_i^1, \ldots, node\_id_i^n, rssi_i^n) \quad (1)$$

where m_i represents the measurement i, x_i, y_i represent the x-coordinates and $node\_id_i^j$, which is taken from the plans for measurement, i represents the identifier for node j for measurement i, and $rssi_i^j$ represents the RSSI value of node j from measurement i. Using $m = \bigcup m_i$ we can build a classifier based on the data from m. The classifier is incorporated into the system's LocationAgent, which is in charge of determining coordinate x according to the values from the RSSI signals obtained from the different readers. The classes are defined according to the different pairs of values (x_i, y_i).

We have applied a Bayesian network. There are various Bayesian network search mechanisms, including tabu search [60], conditional independence [61], K2 [60], HillClimber [60], TAN (Tree Argumented Naive Bayes) [62]. We have also used conditional independence, an algorithm based on the calculation of the conditional Independence test for the variables to generate a DAG that can obtain probability estimates. Assuming r pairs of different values for (x_i, y_i), the probability of measurement m belonging to class i applying classifier C is defined as follows:

$$p_i = C(m') \quad (2)$$

where m is the class with $k < r$ if

$$p_k = \mathrm{Max}(p_i) \text{ with } i = 1 \ldots r \quad (3)$$

The algorithm simply places the tag in position (x_i, y_i) with greater probability.

3.3. Telemonitoring service

The telemonitoring service can gather information from the context and respond by generating alerts and other relevant actions. To do so, it uses the contextual information taken from different sensors and from new knowledge extraction algorithms.

3.3.1. Rule-based telemonitoring

The telemonitoring service has the following objectives: (i) monitor through the use of data gathered from sensors for each participant; (ii) use the "Presence of Trace" of each person; (iii) know the different available means of monitoring (devices, professional and support personnel, resources, etc.) and the communication that exists among them, and use the assistance device to suggest certain actions to take; (iv) control and know what is

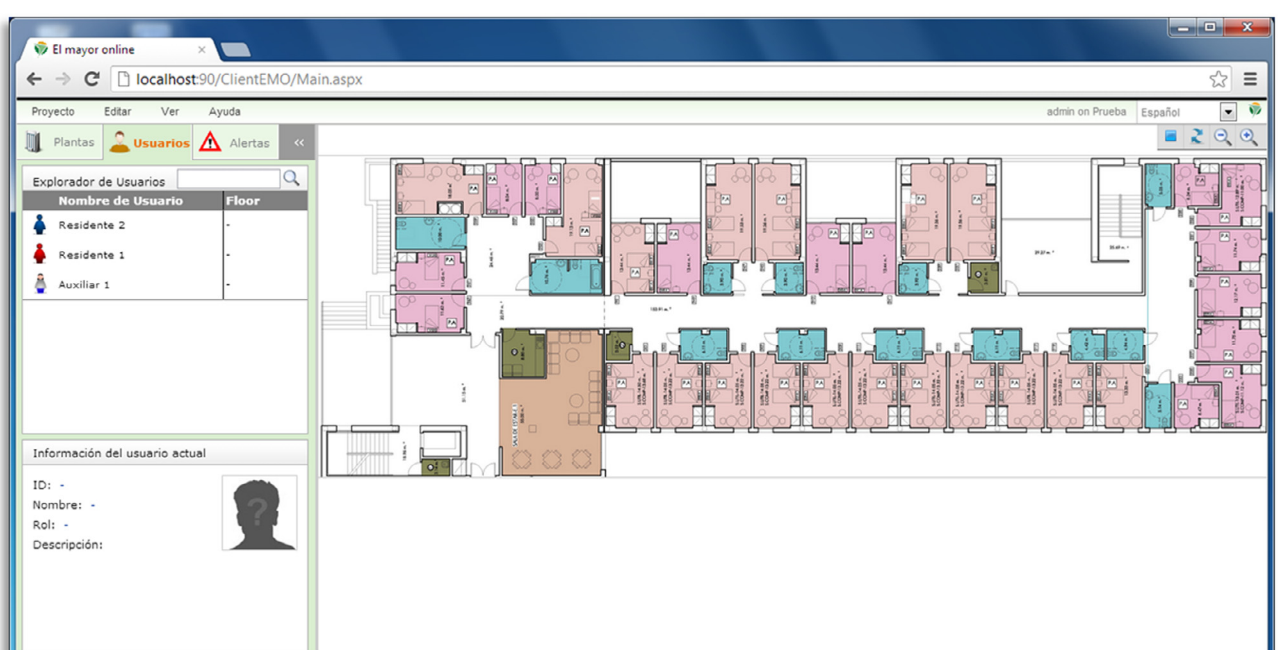

Fig. 6. Software interface of the locating system.

occurring in the global context of the residence of the person under supervision; and (v) add and personalize rules as data are expanded.

The service is offered through a remote monitoring center, a sensor network, wireless actuators deployed within the environment, and a communication network that connects all the system components.

As an example, we have a case study in which medical care is provided in a care facility and private home. This requires an infrastructure of sensors and actuators deployed both in the care facility and the home. The sensors gather information from the context, that is, from both the elderly patient and the environment itself. The information is processed and analyzed by a set of mechanisms that facilitates the decision-making process and optimizes the response of professional and support personnel. Those responsible for assisting can access specific information regarding the elderly patients: physical location in the home, medical history, high risk situations detected, etc. Similarly, after providing assistance, the data gathered from the actions taken are gathered for their subsequent analysis.

The information gathered by the infrastructure deployed in the system is fundamental for the development of a "virtual assistance services" system, which can be personalized for the home of each person. The telemonitoring infrastructure is composed of a set of Wireless ZigBee sensors [63] completely integrated within the environment. The network in the system pilot was deployed in a typical care facility bedroom (simulating the patient's home) as shown in Fig. 7. This space and the full residence were used to carry out the tests.

Fig. 7 shows a map of the deployment of sensors in living quarters. In addition to the ZigBee readers (red squares), and sensors, 4 points (blue circles) were included in the movement pattern node: one associated with the bathroom, one with the bed, one with the dining table, and the other with the front door. The zig bee readers must be located surrounding to the pattern nodes. The presence sensors are located in positions avoiding blind spots. At this point, it is important saying that here an example deployment is shown as each person will have their individualized monitored deployment system and therefore its associated rules. One advantage is that the system can adapt the system rules for each monitored person and the number and type of sensors associated. In the administration tool it is possible to select each of these monitored persons to observe the distribution of deployed sensors. And the rule system is customized through a case-based reasoning as it is explained below.

The alerts generated by the sensors are managed through a multiagent architecture that applies algorithms to manage the information and make decisions. The alarm management system is based on a behavioral module which applies the Drool production rule system, allowing the information to be processed quickly and decidedly. The architecture applies information fusion algorithms [1] which combine the information gathered from each of the sensors installed in the environment and the tracking information for each user to generate intelligent alerts through a case-based reasoning (CBR) mechanism [50]. The system includes a "daily activity planner" and a library of "rules" that generates alerts when something occurs contrary to the typical daily plan. For example: "If the subject remains in bed longer than eight hours, an alert is generated".

The detection of anomalous behaviors is done through the detection of strange movement patterns of the users. In order to detect these patterns, a series of relevance variables are established to measure a series of variables in each of the nodes in the graph that represent possible movement patterns. The values indicated in Table 1 are used for each node representing a movement pattern. The nodes for each movement pattern do not include the sample points in the map of intensities to reduce the number of values in Table 1.

The agent that detects anomalous behaviors is based on the use of predefined rules that are executed over the data from the previous table. An example of the rules can be seen in Table 1. The rules are written in a text file and they can be modified without building the source code. The Drools production rule system [64] was used to configure the rules engine. Drools is a business rule management system (known as BRMS, Business Rule Management System) with a forward chaining inference based rules engine, using an implementation oriented toward Rete algorithm objects [65]. In other words, it is a rules engine based on Java, responsible for

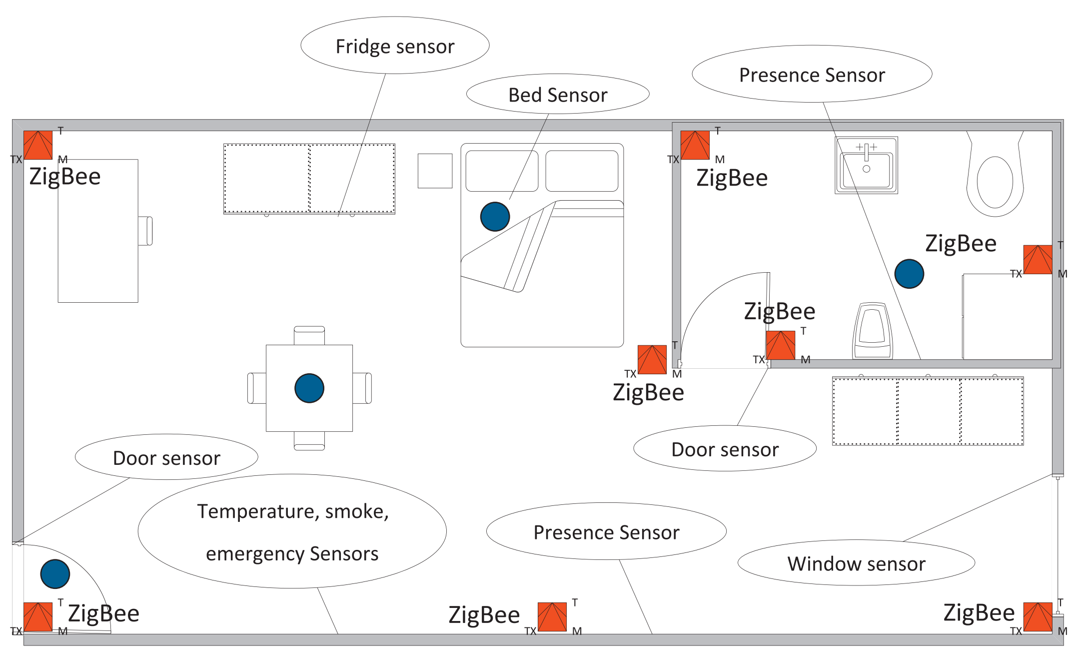

Fig. 7. Map of the deployment of sensors in the living quarters.

Table 1
Tracking data used. The variables used in Eq. (4) are represented in brackets.

Day of week (w)	1…7
Hour (h)	Seconds starting at 0:00
Node (n)	Current node
User (u)	User id
Seconds (s)	Seconds from the previous node
Previous node (p)	ID of previous node
Previous time (l)	Seconds since the node was last accessed
Number of times (t)	Number of times user has been in node since 0:00

Table 2
Sensor information. The variables used in Eq. (4) are represented in brackets.

Sensor (id)	Id sensor
Time (dt)	Date of last change
State (ds)	State of the sensor
Measurements (dm)	Number of measurements taken in the state
Alarm (da)	Alarm activated

applying business rules in our applications. This makes it possible to abstract the code and process the objects and a relatively high level with a language that is more simple and closer to natural language, separating rules from actions (see Fig. 8).

The Drool production rule system [64] is also used to manage the information provided by the sensors. The information gathered from the sensors makes it possible to know the state of the environment as well as the time instance in which the change was made and the number of measurements taken in that particular state, as shown in Table 2.

In addition to the previous rules, case based reasoning is used to generate additional rules based on J48 to detect new cases identified as anomalous. If any of the procedures detects anomalous behavior, an alarm will sound, unless a Drool rule to cancel an alarm that has been activated through J48 is detected. The ability to automatically cancel rules is to avoid launching a false positive and allow the automatic cancellation of an alarm considered to be incorrect.

The first step in defining the case-based reasoning is to establish the information according to Tables 1 and 2, as shown in (4). The variables are described in Tables 1 and 2. The case base is divided into similar groups in order to improve the prediction capability of the system.

$$c_i = (w_i, h_i, n_i, u_i, s_i, p_i, l_i, t_i, D^i) \quad D^i = \bigcup_j d_j^i \quad d_j^i = (id_j, dt_j, ds_j, dm_j, da_j) \tag{4}$$

Once the concept of case has been defined, the CBR cycle is defined for each of the following steps: retrieve, reuse, revise and retain. As new cases are received in the system, they are introduced into the reasoning cycle. A prediction is made regarding the need to generate an alarm. The complete process is described in Fig. 9.

The retrieve phase is initiated upon receipt of a new case c_{n+1}. When the new case arrives, it is associated or classified with one of the groups g_k into which the memory is divided. Once the group is determined, the J48 classifier associated with the set is recovered or created, if it did not previously exist. In order to perform the classification, the SVM [51] is applied, as part of the process indicated in Fig. 10a.

During the revise phase, the classifier retrieved in the previous phase is applied to the new case, and a prediction is obtained.

During the retain phase Fig. 10b it is determined whether the prediction made in the revise phase was satisfactory; if it was not, the prediction is updated. During the revise phase the expert confirms the prediction and during the retain phase the prediction is stored according to a results obtained. That is, the system is capable to detect new cases identified as anomalous, is capable to automatically cancel rules is to avoid launching a false positive of an alarm. In this sense, if in the revise phase the expert confirms that the alarm was a false positive is stored. If the prediction is incorrect, the new case is introduced into the system and the process of clustering and creating a classifier is carried out for each of the clusters created. The EM method is used to create the clusters since it facilitates the creation of groups without requiring the number of clusters to be previously indicated. Additionally, it works with nominal data, a process indicated. Finally, the SVM is constructed according to the new groups and the system constructs the decision tree J48 for each group.

3.4. Integration within the multiagent system

PANGEA (Platform for Automatic coNstruction of orGanizations of intElligents Agents) [13] is an agent platform to develop open multi-agent systems that can manage roles, norms, organizations and suborganizations, and facilitate the inclusion of organizational aspects. The PANGEA platform has been adapted to be applied in context-aware environments, with special attention placed on obtaining new algorithms and modules for the fusion of contextual information. This is a new perspective where social aspects are taken into account to model and manage intelligent environments. The basic agent types needed to the adequate functioning of the platform and the main characteristics of it are defined in [55].

Four specialized suborganizations have been created in the platform, all of which are managed by an OrganizationalAgent; this helps the OrganizationManager to control the correct functioning.

```
rule "Restroom alarm"
    when
        $data : Data(numberOfTimes>Configuration.getThresholdRestRoomAlarm())
    then
        ActionAlarm.sendMessageCareGiver($data);
end

rule "Sleep problem"
    when
        $data : Data($data.getNumberOfTimes()>Configuration.getThresholdWalkNight
            && $data.getNode()==new User($data.getUserId()).getIdNodeBed())
    then
        ActionAlarm.sendMessageSleepProblem($data);
end
```

Fig. 8. Example of rules.

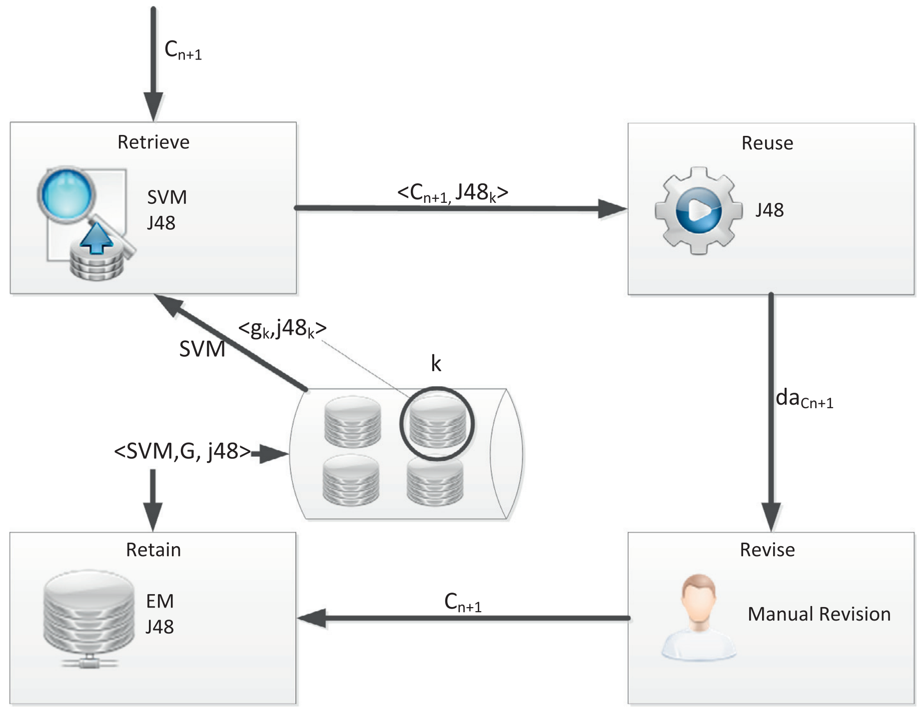

Fig. 9. CBR reasoning cycle.

```
store ← false;

// Retrieve phase
SVM ← retriveSVMFromDatabase();
g_k ← retieveMostSimilarCluster(SVM);
if ∃J48_k ∈ g_k then
    j48_k ← retrieveDecissionTree(g_k);
end
else
    j48_k ← buildDecissionTree(g_k);
end

// Reuse phase
da_{c_{n+1}} ← classifyNewInstance(j48_k, c_{n+1});
```

```
// Revise phase. Manual revision.
if misclassified(da_{c_{n+1}}) then
    c_{n+1} ← reviseNewCase(c_{n+1});
    store ← true;
end

// Retain phase
if store then
    C ← C ∪ c_{n+1};
    G ← buildClusterEM(C);
    SVM ← buildSVM(C);
    storeSVM(SVM);
    foreach g_k ∈ G do
        j48_k ← buildJ48(g_k);
        store(j48_k);
    end
end
```

Fig. 10. (a) Algorithm retrieve and reuse phase, (b) revise and retain phase.

Each suborganization is specialized according to the tasks carried out. The four suborganizations, which can be seen in Fig 5 are:

- InformationProviderOrganization: enables interaction with the user. As three different interfaces have been developed, there is an agent for each one of them.
- HomeAutomationOrganization: composed of all the agents that control the different sensors of the spaces (presence, smoke, temperature, etc.). All the information collected by them is sent to the ZigbeeSupervisorAgent. After a previous evaluation, this agent communicates the information to the InformationAgent. The InformationAgent is the interface with the database.
- LocatingOrganization: composed of all the agents that control the Zigbee sensors and tags, which allows locating the people (caregivers or patients). All the information collected by these agents is sent to the ZigbeeSupervisorAgent. This information is used by the MonitorAgent and the LocatingAgent if the user wants to track a person.
- CaregiverOrganization: each caregiver (doctor or nurse) is represented by an agent that collects information related to their respective actions. Each action has a representative collection of information that allows for knowledge extraction. This information is key for the proper operation of RulesAgent As it can, for example, create the routine for each patient. When the information provided by the caregivers and sensors falls outside the patient's routine or indicates a dangerous situation, the AlarmAgent extends the alarm throughout the system. The MonitorAgent can receive the alarm because of its communication with the SnifferAgent and shows it on the screen (see Fig. 11).

4. Results and conclusions

As indicated in the previous section, a case study was prepared in a medical care environment for the elderly. The proposed system was implemented in the "El Residencial La Vega" care facility in the city of Salamanca and was tested over a period of 8 months. The El

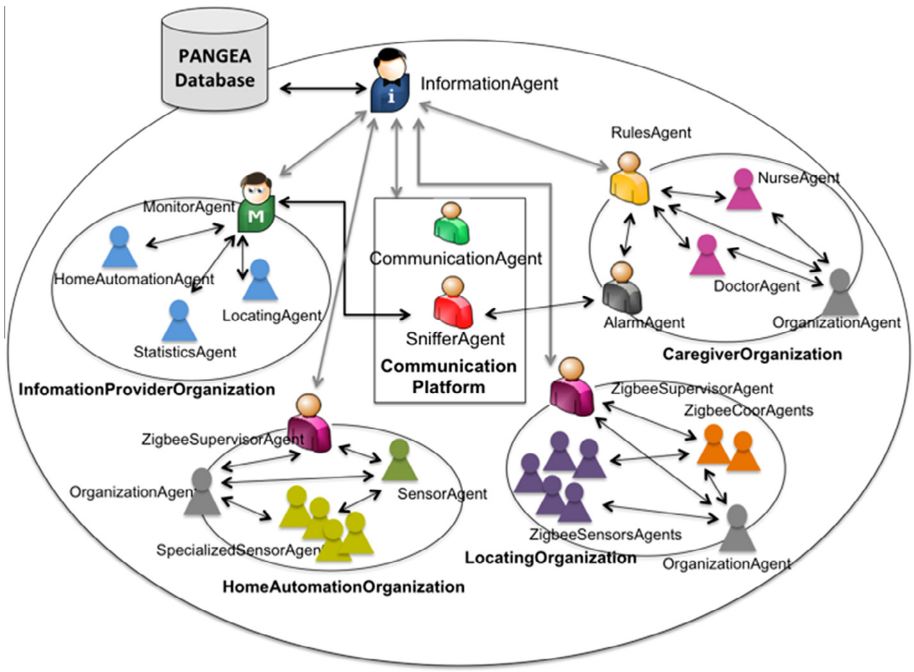

Fig. 11. Overview of the deployed agents in PANGEA.

Residencial La Vega facility has residence areas for the elderly as well as apartments similar to their patients' home. We would like to highlight the level of participation of the facility's medical personnel in implementing the prototype.

In this results section we have included some of the most relevant results obtained in the implementation of this system in the residence. Specifically, in this section, several aspects are important:

– On one hand, the possible functions of the system, showing some of the tools created (web and mobile tools) used by users of the system and results show the fusion of sensor data and information stored in the system in a distributed manner. All these functionalities are implemented with PANGEA, so we must make it clear that these features are just a sample of what could turn out to be because this platform is very easy to scale and the system can be enhance.
– On the other hand, the results of the rule system and the location algorithm used with the sensors installed in the residence are shown. In this sense, favorable results are shown in a possible evolution of the system of rules.

First, we propose to study the reasons for residence and location where they occurred (areas) taking as input data the observed data from the sensors in different areas. In short, put in any space, whether conceptual or geometric, the reasons and the situation inside the residence, integrating them in context, and interpret that situation. The residence is divided into zones (red, blue, yellow or green). Each contains a type of residents. For example, the blue area is indicated for patients with some form of dementia such as Alzheimer's and green area for seniors who can fend for themselves.

About installation, the system services were put in place for some elders, taking into account the considerations of the staff of the residence. The growing use of telemonitoring to support independent living in a residence inevitably carries out many ethical questions regarding privacy. A resident's right to confidentiality must be respected in any feature of healthcare, telemonitoring included. At the resident side, the intrusiveness of the continuing analysis of the resident in his/her own private life should be minimized as much as possible. In this sense, approval for the study was obtained from the Residencial La Vega Committee and the University of Salamanca. Moreover, all personal data were transformed previously to the storage experiment changing them for general identifiers and data encryption and secure methods were applied to ensure confidentiality of the data during transfer over the system. At the monitoring end, access to data was restricted using a hierarchical password system for the persons implied in the experiments.

As a result of the information obtained from both the telemonitoring sensors and those of the caregivers and doctors, the system agents were able to provide a system capable of interacting to control the state of the patient through a web tool.

The information obtained will permit the system to adapt dynamically to the needs of the environment and of the patient. For example, the second graph in Fig. 12 shows how a very different number of assistive actions are taken in the different areas of the residence (red, blue, yellow or green).[1] The *x*-axis represents the hours in a day and the *y*-axis the number of attendances by falls. The green area underscores the number of falls between the hours of 9 and 12 noon. If we take into account the fact that the green area is where the residents with a specific degree of dependency are located, we can adapt the number of assigned personnel to meet these needs. Additionally, the responsible personnel can use mobile devices to locate patients in real time, plan daily work tasks and respond to alarms. Personnel in the residence can access details regarding an alert and once it has been resolved, they can close the alert with a description of what occurred and the reason for it. Likewise, it is possible to consult the different alerts made in each area with respect to the time or the month they occurred, which is useful information for creating patterns. The graphical representation of this information can be done from the web page or from a mobile device. The operator can also modify the access data and view a summary of their activity. These three functions can be seen in Fig. 13.

The PANGEA multi-agent platform is used to implement the system and the information fusion process. There are several

[1] For interpretation of color in Fig. 12, the reader is referred to the web version of this article.

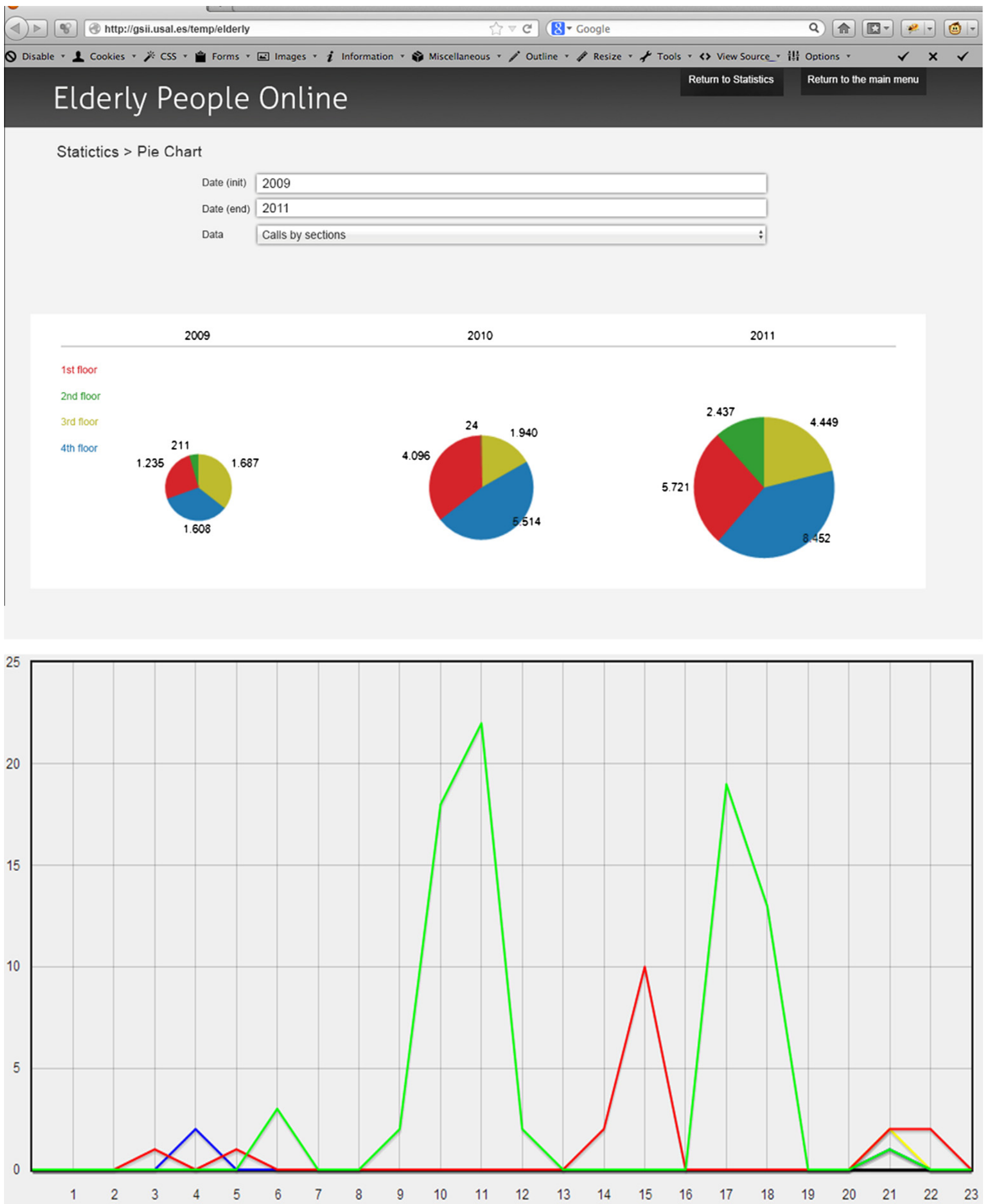

Fig. 12. Web interfaces to query statistics. Top image: Number of calls in the residence by sections. Bottom image: Graph of falls (*y* axis) per hour (*x* axis).

reasons to prefer such a platform: a multi-agent system represents an advantageous paradigm for the analysis, design and implementation of complex systems. An Information Fusion application is naturally distributed: data sources are distributed; the users use the results produced by the system are distributed, and data processing is performed in a distributed manner. PANGEA provides the infrastructure to create our multi-agent system and also to gather the data, communicate with users, and process data. If data from different sources are private or classified, PANGEA makes it possible to create different forms of access which are not available for centralized processing. Additionally, the system can be large scale in the future, and naturally deconstructed as well; this allows it to takes the most advantage of the benefits provided by the MAS (and PANGEA) approach.

To test the system's performance, we analyzed the precision in locating and detecting anomalous behaviors. The precision of the location algorithm was analyzed by comparing the mean absolute error obtained from applying the proposed procedure to the means obtained from multilateration and signpost. Besides, the Bayesian network was replaced by others classifiers in order to compare the performance. The calculation in the maps of intensities was performed by measuring the steps taken when walking through the different hallways and rooms. In each monitored area, a reference point was used to represent the area, manage the information, and therefore reduce the information that needed to be stored. In each room, a mesh was used to simulate movement patterns and obtain the surface of the room that was measured. The mean absolute error obtained is shown in Table 3.

In order to carry out the alarm detection procedure, the users' movement patterns were stored over a period of one week. During this time, the patterns were classified to include unusual behavior. The number of measurements taken is 983, following the information shown in Tables 1 and 2. A total of 173 unusual situations were identified. This information was used to create a decision tree that was subsequently used to perform the classification. The rules that were generated are similar in form to the following rule: if User = 13 and Node! = 13,001 and sensor = 13,002 and state = 1 and measurements >10 then alarm = 1.

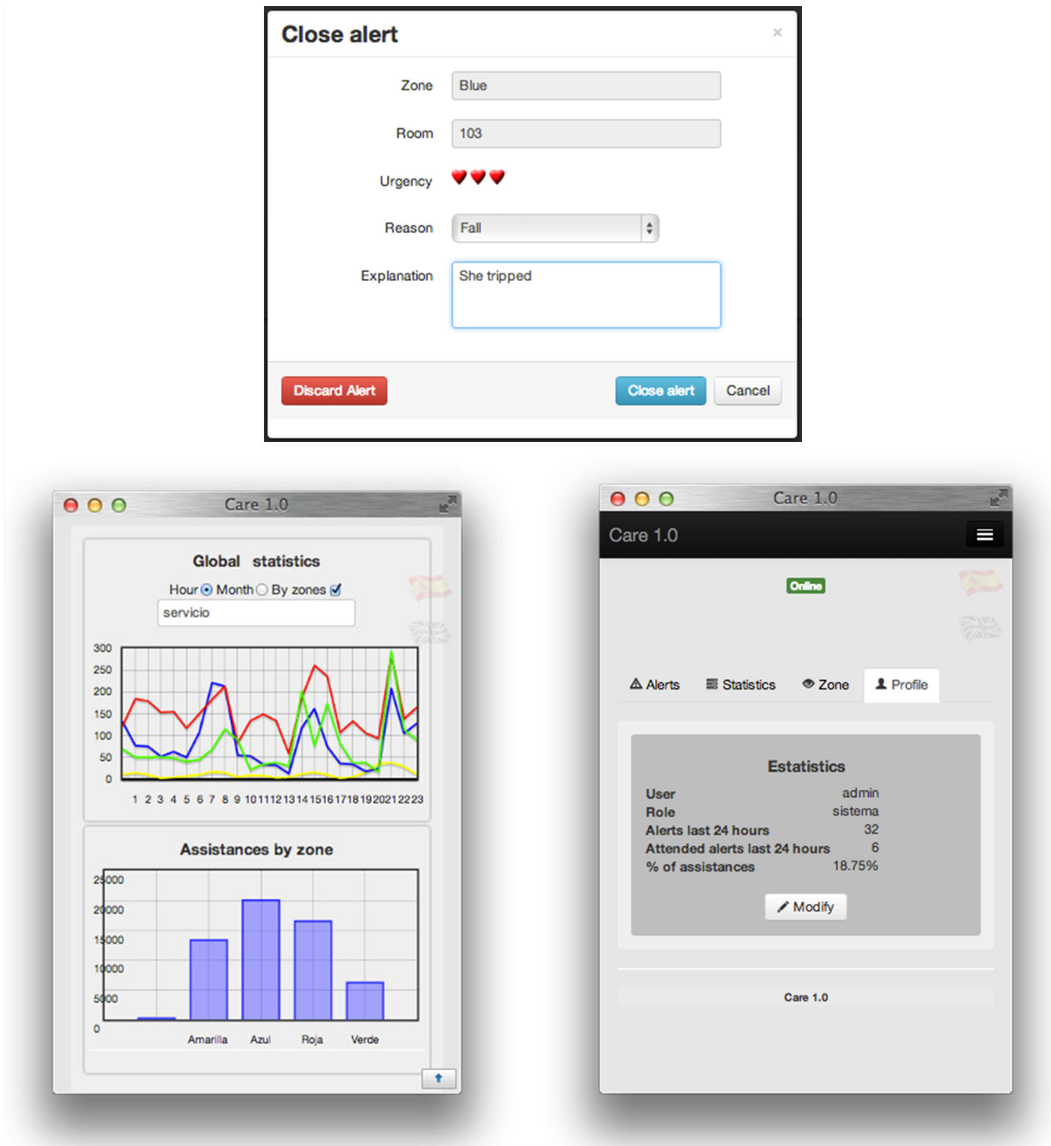

Fig. 13. System interfaces. (a) Description of an alert, (b) number of assistances by zone. Graph lines: the color of the line represents the zone, *x* axis the hour and *y* axis the number of assistances during the hour of *x* axis. Bar graph: the number of assistance during 8 months (*y* axis) for each zone (*x* axis), and (c) the information of an user. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Table 3
Error comparison between methods applying maps of intensity and algorithms without applying maps of intensities.

Model	Mean absolute error
Proposed model with Bayesian network	1.188
Proposed model with J48	1.648
Proposed model with SVM	1.789
Proposed model with IBK	1.475
Multilateration	1.981
Signpost	2.371

The rule refers to user 13, which is why the sensor identifiers and the nodes in the user's bedroom begin with 13. When 10 consecutive measurements are detected in a position different from the closest node, which is located in the refrigerator, an alarm will sound. When the rules are detected, as indicated in rule 1, where all the sensors and the user belong to the same room, they are generalized for all users so that the user ID, sensor and node information are all modified for the other users.

The system was cross validated applying the one-leave-out technique, which resulted in an average prediction rate of 93.5%. The percentage of false negatives rose to 1.2% and the remainder were false positives.

In order to analyze the evolution of the system, we began with 500 cases and introduced new cases into the system until reaching 983, as previously indicated. Fig. 14 shows the change in the number of groups in the case base, the evolution of the number of cases and the average number of rules for each group. The diagonal graphs represent the function of density for the indicated variable. For the remaining cells, file *i*, column *j*, the *x*-axis represents the variable indicated in cell *ii*, while in the *y*-axis the variable is associated with cell *jj*. The dot points represent each element; the red[2] line represents the tendency according to the represented element, the green line the regression rect. For example, in file 1, column 2 we can see the variation of the average number of rules as the

[2] For interpretation of color in Fig. 14, the reader is referred to the web version of this article.

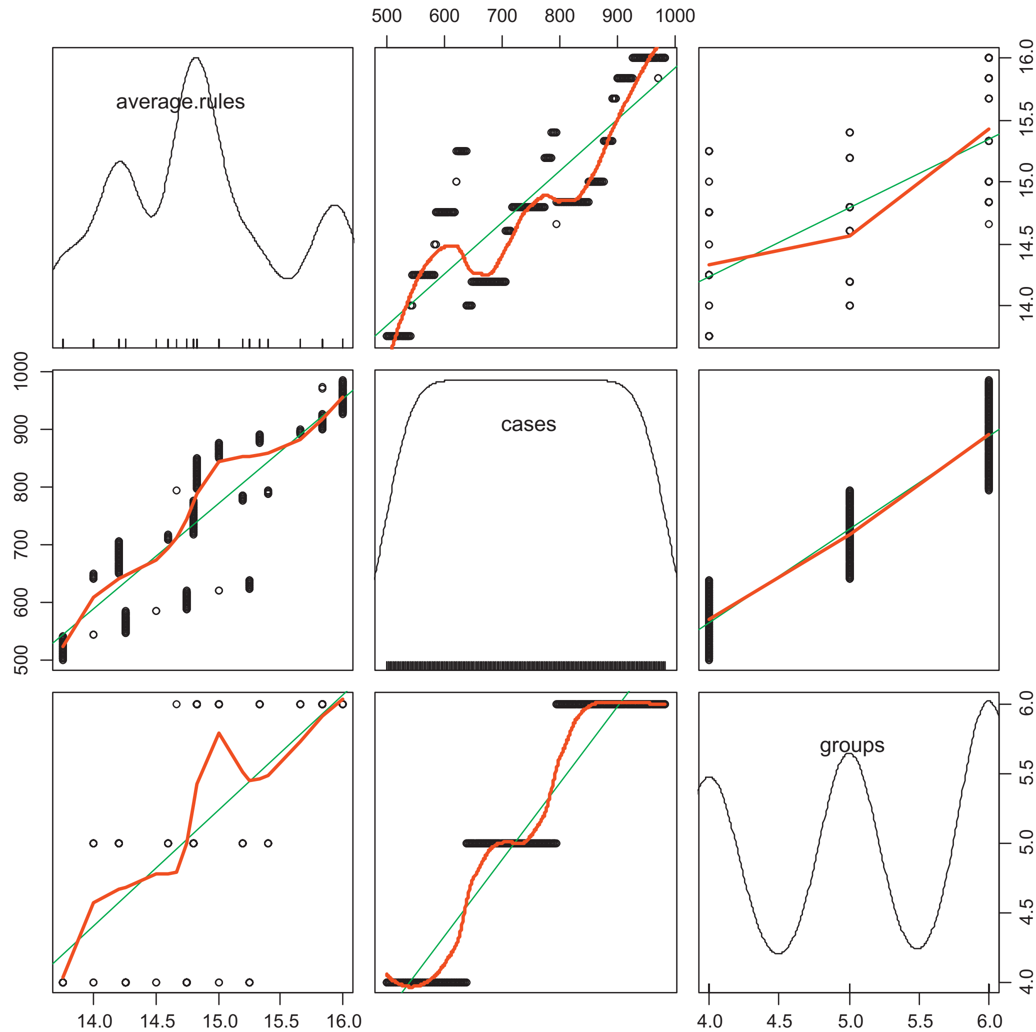

Fig. 14. Evolution of the system.

number of cases increases from 500 to 1000. We can see in the red line that the tendency increases as the number of cases also increases. However, we can see in the file 1 column 3 that the average number of rules for each group varies between 13 and 16. Similarly, the number of rules also increases, although to a lesser extent, with the number of groups, as shown in the graph shows.

As we can see in the results, the system proposed in this article exceeds the performance of the system currently used in the La Vega Residence, and improves the existing teleassistance system, providing learning and adaptation capabilities. These systems are currently very limited, as they require the elderly patients to make a conscientious and deliberate effort in their home (for example, pressing the panic button) and do not offer an automated and intelligent detection of high risk situations.

The system proposed in this article implements a significant number of the concepts used in Ambient Intelligence, in an attempt to reduce the interaction of the elderly patient as much as possible and create a much more direct communication with the professional and support staff responsible for providing assistance. The medical personnel at the residence noted the system's ease of use, as well as the support in providing patient care. The aim was to facilitate the daily activities of the elderly patients in a way that is both ubiquitous and intuitive, in addition to optimizing the assistance services and improving quality of life. The proposed system represents an advancement with regard to existing platforms, as shown in its application in the senior care facility case study. It was for this reason that the case study incorporated a set of devices that comprise sensors, id or locating elements, push button actuators and interactive elements such as screens. The study also incorporated a control center that interacts continuously with the system and a data repository, which is very useful for tracing services and the personalization of spaces and services.

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7 Resúmenes de los Artículos.

7.1 *Monitoring and Detection Platform to Prevent Anomalous Situations in Home Care.*

Resumen: Las técnicas de monitorización y seguimiento de personas en espacios cerrados, requiere generalmente de la instalación de hardware específico con unos costes de implantación elevados. La gran inversión que hay que realizar, constituye la principal desventaja a la hora de desarrollar estos sistemas. Este artículo propone la creación de una plataforma de monitorización y seguimiento de personas con problemas de salud. Particularmente se diseña una organización virtual de agentes mediante la utilización de la plataforma PANGEA, permitiendo integrar diferentes dispositivos y agentes embebidos en la plataforma de modo sencillo. En este caso, la organización virtual tiene como objetivo, ofrecer el seguimiento y la monitorización de pacientes que portan un dispositivo médico llamado holter. La plataforma está dotada de diferentes capacidades que permiten la interconectividad con diferentes agentes embebidos en dispositivos hardware tales como un electrocardiograma, acelerómetros y puntos de acceso WiFi. Además, se facilita la interacción de las personas con un conjunto de servicios 2.0 mediante la utilización del mando de la televisión. Podemos resumir, que este trabajo se centra en el diseño de las capas 1 y 2 de la arquitectura propuesta y permite la fusión de la información, facilitando el seguimiento de pacientes de forma eficiente con un bajo coste.

Los **objetivos** que se persiguen en este artículo son los siguientes:

- Diseñar un sistema basado en organizaciones virtuales de agentes que permita realizar una monitorización y seguimiento de pacientes mediante la utilización de hardware de bajo coste.

- Diseño de mecanismos de extensión para facilitar la integración de tecnologías de sensorización heterogéneas en la arquitectura PANGEA.

- Diseño de un algoritmo de localización en interiores que permita determinar la posición de un activo en un espacio cerrado, mediante la utilización de puntos de acceso de bajo coste, con el objetivo de detectar la posición de un usuario dentro del hogar.

- Desarrollo de un prototipo hardware que permita la obtención de un electro-cardiograma mediante la utilización de un Smartphone aprovechando la conectividad inalámbrica.

- Desarrollo de una arquitectura de bajo coste que permita ofrecer diferentes servicios adaptados a personas mayores mediante la utilización de su televisor.

- Evaluación de las capacidades de adquisición de información de los diferentes sensores y emisión de alertas en caso de detección de situaciones de riesgo.

Metodología: Para la consecución exitosa de este artículo, se ha llevado a cabo un proceso planificado y estructurado, y se ha realizado una ejecución basada en la obtención de prototipos evolutivos. Se ha diseñado un sistema basado en organizaciones virtuales de agentes que permite realizar una monitorización y seguimiento de los pacientes mediante el diseño de una nueva capa para la arquitectura que permite la incorporación de hardware independientemente de su fabricante. En particular, para el desarrollo del sistema, se ha utilizado la plataforma multi-agente PANGEA que permite el desarrollo de organizaciones virtuales, facilitando el desarrollo de software en dispositivos limitados computacionalmente.

El sistema desarrollado incorpora diferentes organizaciones virtuales para realizar una monitorización de pacientes en el hogar, incluyendo roles para la localización, sistema de monitorización, sistema monitorización cardiaco y sistema de interacción basado en televisión. El sistema de localización se basa en los niveles de señal RSSI que se reciben de diferentes enrutadores WiFi. Para evitar continuas fluctuaciones en el sistema de localización debido a los cambios de los niveles de señal, se introducen los acelerómetros del dispositivo móvil como fuente de información complementaria, de modo que cuando se detectan pasos se calcula la ubicación del usuario. Esta información relativa al movimiento, es de especial interés cuando se calculan los valores procedentes del electrocardiograma, de modo que el usuario no tiene que ir registrando manualmente la actividad física. Al hardware encargado de la obtención del electrocardiograma se le ha incorporado un módulo *bluetooth* que permite la lectura de los valores de forma remota, pudiendo ser utilizado con un *smartphone*.

La solución propuesta, está dotada de capacidad para el envío de alertas en situaciones de emergencia. Finalmente, para permitir la interacción del usuario con la arquitectura, se incorpora un sistema basado en una televisión mediante una Raspberry Pi, permitiendo al hogar estar continuamente conectado a Internet.

Resultados: El sistema se ha probado con una persona de edad avanzada residente en una vivienda de $85m^2$. En su vivienda se desplegó el hardware necesario para evaluar el sistema de localización, el sistema de detección de movimiento, sistema ECG y el sistema de televisión.

El sistema de localización, fue validado en dos fases, en primer lugar se realizó un calibrado que consistió en la toma 50 medidas. Para analizar el correcto funcionamiento, se tomaron 25 fingerprint y se utilizaron distintos tipos de clasificadores basados en redes bayesianas, SVM y J48. Se concluye que el sistema es es capaz de determinar la posición exacta de un usuario dentro de un espacio cerrado con una precisión de 1.5-2metros en una vivienda de $85m^2$ con la utilización de 3 puntos de acceso modelo TP-LINK TL-WR740N.

Para validar el sistema de monitorización física, se procedió a realizar secuencias asociadas a actividades cotidianas básicas y se comprobó que realmente el sistema utilizando el acelerómetro, era capaz de detectar movimientos asociados a pasos, por ejemplo, se podía detectar cuando un usuario se levantaba, iba andando a un ritmo normal o caminaba de forma acelerada. Podemos resaltar que el sistema de monitorización física funciona de forma correcta pudiendo determinar el movimiento con bastante exactitud.

El prototipo hardware construido, permite la obtención de un electro-cardiograma preciso con una relación calidad/coste razonable. Tiene la capacidad de enviar los datos a una sede central mediante un protocolo de baja latencia, para que un médico pueda tener monitorizados a un conjunto de pacientes.

El sistema de interacción con el televisor para gente adulta, tuvo una gran acogida por parte de los usuarios, su sencillez de uso y la integración de diferentes servicios, permite la monitorización para los ancianos sin el alto costo de en una residencia o un ayudante que esté presente todo el día.

Como trabajos futuros se plantea mejorar la parte de tratamiento automático del sistema ECG aunque en ningún caso se debería de usar como un mecanismo de diagnóstico ya que el hardware no está homologado.

7.2 *Ambient Agents: Embedded Agents for Remote Control and Monitoring Using the PANGEA Platform.*

Resumen: La inteligencia ambiental ha experimentado numerosos avances a lo largo de los últimos años. La incorporación de técnicas de procesamiento de imágenes y técnicas basadas en inteligencia artificial, posibilitan aspectos como el reconocimiento de patrones, permitiendo así una mejor adaptación de estos sistemas. En este artículo se presenta la arquitectura multiagente PANGEA que incorpora diferentes agentes y sensores encargados de dar soporte a usuarios en el hogar pudiendo enviar determinadas alarmas o incidencias. El sistema incorpora agentes empotrados en diferentes dispositivos hardware limitados computacionalmente, dotados con módulos de reconocimiento de sonidos, bandas luminosas, pudiendo incorporar según el caso, cámaras IPs programadas para realizar seguimientos automáticos y remotos en caso de incidencias. Una de las principales novedades de este artículo es la creación de un modelo de agente capaz de ser ejecutado como software empotrado en un microcontrolador Arduino. La utilización de los denominados artefactos inteligentes también conocidos como sistemas embebidos, están diseñados para la realización de funciones muy dedicadas o sencillas, su principal uso está destinado a aplicaciones de cómputo en tiempo real. La principal característica que presenta la utilización de software empotrado frente a otros sistemas de computación, es el bajo coste en su proceso de fabricación, debido a que el procesador y memoria presentes en el dispositivo son de un tamaño reducido. Se propone la utilización de diferentes agentes que formarán parte de la arquitectura PANGEA, una arquitectura multi-agente diseñada sobre la base de organizaciones virtuales, orientada a la creación de entornos inteligentes. Los agentes embebidos de forma autónoma, pueden ejecutarse en dispositivos limitados computacionalmente, pudiendo obtener información del entorno y en consecuencia emitir respuestas inteligentes.

Los **objetivos** que se persiguen en este artículo son los siguientes:

- Obtener el diseño e implementación de un modelo de agente para la plataforma PANGEA que pueda ser ejecutado de forma autónoma y embebida en microcontroladores limitados computacionalmente.

- Diseñar una arquitectura multi-agente basada en organizaciones virtuales que permita el envío de alertas en situaciones de riesgo a los diferentes dispositivos que pueden conectarse a la arquitectura.
- Diseño e implementación de un sistema de comunicación flexible, escalable que permita la interconexión de los diferentes dispositivos hardware que componen la arquitectura.
- Validación del sistema mediante un caso de estudio que permita detectar una alarma sonora y generar una respuesta inteligente.

Metodología: Se siguió un método basado en la obtención de un prototipo inicial, que ha sido mejorado progresivamente. Se estableció un plan de trabajo y se desplegó el sistema en un laboratorio del grupo de investigación BISITE de la Universidad de Salamanca. En el laboratorio se disponía de diferentes tipos de sensores para llevar a cabo el estudio, como sensores de luminosidad, detección de presencia por calor, cámaras IP, sirenas y otros tipos de sensores, interconectados mediante una red de sensores inalámbrica. La conexión de los sensores a la arquitectura se realiza a través de una red inalámbrica y de agentes especializados. La arquitectura detecta y clasifica los diferentes sonidos que puede haber en el entorno a partir de un módulo de reconocimiento de sonido, que es capaz de interpretar los sonidos y ejecutar acciones predefinidas. De este modo, el sistema se puede desplegar en los hogares de forma sencilla y sin necesidad de un gasto elevado. El entorno de prueba establecido para el caso de estudió, se basa en un dispositivo *Arduino* según lo indicado en la *sección 3.1 del artículo*. El agente embebido en el dispositivo, se encuentra conectado a la plataforma PANGEA instalada en un servidor de modo remoto. Las bandas luminosas utilizadas para interaccionar con el usuario en el prototipo se encontraban conectadas al dispositivo de forma física. La cámara web utilizada para monitorizar a los usuarios, estaba controlada por un agente situado en el módulo central de la plataforma PANGEA de modo que no fue necesario tener equipos en el laboratorio especialmente dedicados a la gestión de cámaras. Para llevar a cabo las pruebas, se analizó el funcionamiento del sistema propuesto, para determinar que clasificaba correctamente los sonidos procedentes de las diferentes alarmas y que dichas alarmas provocaban el correcto funcionamiento de la cámara IP. La plataforma PANGEA fue configurada en un PC con procesador Intel Core 2 Duo P9700 a 2,8GHz, conectado a la red mediante una conexión a 100MBits. La cámara web instalada puede recopilar imágenes a color con una resolución de 640x480 pixeles.

Resultados: La extensión propuesta para la arquitectura PANGEA permite interconectar dispositivos heterogéneos con independencia del fabricante, facilitando así la integración de la información y una posterior toma de decisiones a partir de los datos proporcionados por los sensores. La arquitectura permite realizar procesamiento complejo que de otra forma no es posible de realizar en hardware con capacidad de procesamiento limitado como un microcontrolador de tipo arduino o algún otro dispositivo que carezca de capacidad de procesamiento como una cámara IP. Una de las principales hitos conseguidos, es la incorporación a la arquitectura de agentes embebidos en dispositivos arduino, permitiendo de este modo la incorporación sencilla de diferentes sensores y actuadores a la plataforma PANGEA. El agente embebido en el microcontrolador arduino, junto con el módulo de reconocimiento por voz, permite reconocer diferentes sonidos a partir de los cuales se pueden tomar decisiones sobre los diferentes comportamientos a ejecutar por el sistema. Esta característica es de relevancia, ya que posibilita la incorporación al sistema de dispositivos como timbres, alarmas de humo, robo, gas mediante el reconocimiento de los sonidos. La propuesta tiene como objetivo reducir costes, haciendo posible incorporar cualquier dispositivo que emita sonidos de alarma. Como resultado del reconocimiento de alarmas, fue posible reproducir diferentes acciones como activación de bandas luminosas, envío de mensajes de alerta o activación de una cámara IP para realizar un seguimiento de la incidencia de modo remoto. Una de las principales ventajas del sistema es el bajo coste de instalación ya que no es necesario tener ni un ordenador encendido y el gasto en hardware es reducido. El coste más elevado está asociado a la conexión a Internet que es necesaria para realizar la monitorización del entorno.

7.3 *Multi-Agent Information Fusion System to manage data from a WSN in a residential home.*

Multi-Agent Information Fusion System to manage data from a WSN in a residential home.

Resumen: Recientemente se ha incrementado la utilización de sistemas inteligentes basados en Sistemas Multi-Agente (MAS) y el uso de redes de sensores inalámbricos (WSN) en escenarios u entornos sensibles al contexto. La fusión de información se ha convertido en una parte esencial de este tipo de sistemas en los que la información se distribuye entre nodos o agentes. En este trabajo, se presenta un nuevo sistema multi-agente con el objetivo de gestionar datos procedentes de diferentes sensores. La arquitectura MAS propuesta en este artículo, se basa en organizaciones virtuales, incorporando comportamientos sociales para mejorar los procesos de fusión de información. La arquitectura resultante de este trabajo, se validó en una residencia de ancianos. Los datos que el sistema gestiona y analiza corresponden a los datos reales de las actividades de un residente. Los datos se recogen como parte de eventos de información detectada por los sensores que forman parte de la arquitectura en un intervalo de tiempo específico, típicamente un día. Este sistema pretende mejorar la calidad de vida de las personas dependientes, especialmente ancianos, fusionando los datos obtenidos por múltiples sensores y la información de sus actividades diarias. El desarrollo de sistemas que permiten la extracción y el almacenamiento de la información, hace imprescindible la mejora de los mecanismos para hacer frente a la avalancha de datos provenientes del contexto.

Los **objetivos** que se persiguen en este artículo son los siguientes:

- Diseño de una arquitectura multi-agente especializada en fusión de información, que permita el cuidado y la atención de personas adultas en residencias geriátricas.
- Creación de un Sistema para la localización de personas mayores dependientes en un espacio cerrado.
- Implementación de un sistema de tele-monitorización remota mediante la utilización de sensores de bajo coste.
- Sistema de apoyo al cuidado que permita la planificación de tareas pudiendo establecer la emisión de alertas en situaciones de riesgo.

Metodología: Los trabajos a realizar, se planificaron siguiendo una metodología de trabajo colaborativa entre todos los miembros del equipo. Los agentes del sistema se han implementado mediante la plataforma PANGEA ("Platform for orGanizations of intElligents Agents"). Se ha diseñado una estructura de organizaciones virtuales de agentes de tipo jerárquico en la que cada agente pertenece a una organización virtual cumpliendo un determinado rol y ofreciendo al resto de agentes de la arquitectura, un conjunto de funcionalidades que puedan ser solicitadas en cualquier momento y de forma distribuida. La infraestructura hardware se basa en la utilización de dispositivos inalámbricos, cuya característica principal es el bajo consumo y el coste reducido de fabricación. Los datos proporcionados por los diferentes sensores incluyen información acerca de la ubicación del usuario dentro de su residencia habitual, la temperatura de la habitación, calidad de aire y ritmo cardiaco del paciente. Además, se han incorporado diferentes sensores que permiten recuperar información y analizar patrones de comportamiento del paciente en su hogar, pudiendo destacar, sensor de puerta, humo, apertura del frigorífico, presencia y sensor de apertura de ventana. Los datos recopilados por los diferentes sensores permiten conocer el estado del entorno, pudiendo emitir alertas en caso de que algo ocurra fuera del plan previsto.

Resultados: El sistema propuesto se evaluó en el centro de atención de personas mayores "Residencial La Vega" en la ciudad de Salamanca, y se puso a prueba durante un período de 8 meses. Con la participación de los servicios médicos del centro, el sistema se puso en marcha para 3 residentes. Como resultado de la información obtenida por la plataforma de sensorización y localización en interiores, los cuidadores así como el personal médico, son capaces de conocer el estado del paciente con precisión en cualquier momento del día y remotamente, ya que se desplegó el sistema en una plataforma web. La información obtenida por los diferentes sensores, permite al equipo humano que trabaja en la residencia adaptarse a las necesidades del paciente. El personal responsable de la atención de los mayores puede utilizar dispositivos móviles para la localización de los pacientes en tiempo real, pudiendo planificar las tareas de trabajo diarias y responder a las alarmas. De los diferentes clasificadores que se aplicaron al sistema de localización en interiores, se comparó el error obtenido con diferentes clasificadores, obteniendo el mejor resultado con una red Bayesiana. Para la detección de patrones anómalos, la información de los sensores fue almacenada durante 7 días. El número de medidas totales que se recopiló fue de 983, clasificando como situaciones "no normales" 173. La tasa de acierto promedia fue de un

93,5%. El personal médico de la residencia destacó la facilidad de uso del sistema, así como el apoyo en la prestación de atención al paciente.

El sistema contribuye a la optimización de los servicios de asistencia y mejora de la calidad de vida de los residentes.

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Departamento de Informática y Automática

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AUTOR

Gabriel Villarrubia González

DIRECTORES

Dr. D. Juan Francisco De Paz Santana

Dr. D. Javier Bajo Pérez