ADCAIJ: Advances in Distributed Computing and Artificial Intelligence Journal
Regular Issue, Vol. 8 N. 2 (2019), 73-85
eISSN: 2255-2863
DOI: http://dx.doi.org/10.14201/ADCAIJ2019827385

IoT based intelligent irrigation support system for smart farming applications

Neha Kailash Nawandar and Vishal Satpute

Visvesvaraya National Institute of technology Nagpur
nehanawandar@gmail.com, vrsatpute@ece.vnit.ac.in

KEYWORD

IoT; smart farming; DCT; neural network; automatic irrigation

ABSTRACT

India is an agricultural country with an ample amount of arable land that produces wide variety of crops. Growing population and urbanization puts up challenges: more and quality yield in limited area, effective utilization of water resources, inculcating technology with traditional mechanisms, to be faced. A crop irrigation management system with sensor data fetch, transfer and operate functionalities is proposed to meet the expectations. The system comprises of: sensing, data processing and actuator sections, with a network of ambient temperature and humidity at a height and, soil moisture sensor placed at the root zone of the subject. The sensor generated data is compressed and then sent to an FTP server for processing. At the server, a 2-layer Neural Network with 4-Inputs, plant growth, temperature, humidity and soil moisture is used for decision making that controls water supply, fertilizer spray, etc. and a plant is used as the test object. Results show that there is tolerable error in the reconstructed data and 62.5% and 67.5% compression is achieved for ambient temperature, humidity and soil moisture respectively. The decisions are only 2% erroneous when done using Neural Networks using this data. Thus, due to its good data handling, decision making capabilities for precise water usage, being portable and user-friendly, this system proves beneficial in home gardens, greenhouses.

1. Introduction

Food; One of the fundamental needs and the most sensitive issue being faced today, can be the perfect definition for it. Agriculture, dairy farms, poultry farms are the main sources where food comes from, out of which agriculture is most important when it comes to food production in India (Abrol, 2000), (Gupta and Deshpande, 2004). India is mainly an agricultural country and 60% (Binswanger and Khandker, 1995) depend upon farming for their livelihood. It is estimated that the population of India will surpass 1.69 billion by the year 2050 (Coale and Hoover, 2015), and the current food availability is not sufficient to feed the whole population. It is thus required to improve the food yield and reduce the crop loss taking place in the farms. To solve this, it has become essential to merge the developing technologies with agriculture and to come up with smart techniques that will reduce loss with proper food management for catering various needs. Crop loss is also faced due to improper irrigation techniques used in farms, which can be overcome by using correct methodologies. Another problem faced is of not using the total available arable land for producing crops. These issues need to be tackled to meet up the actual food expectations.

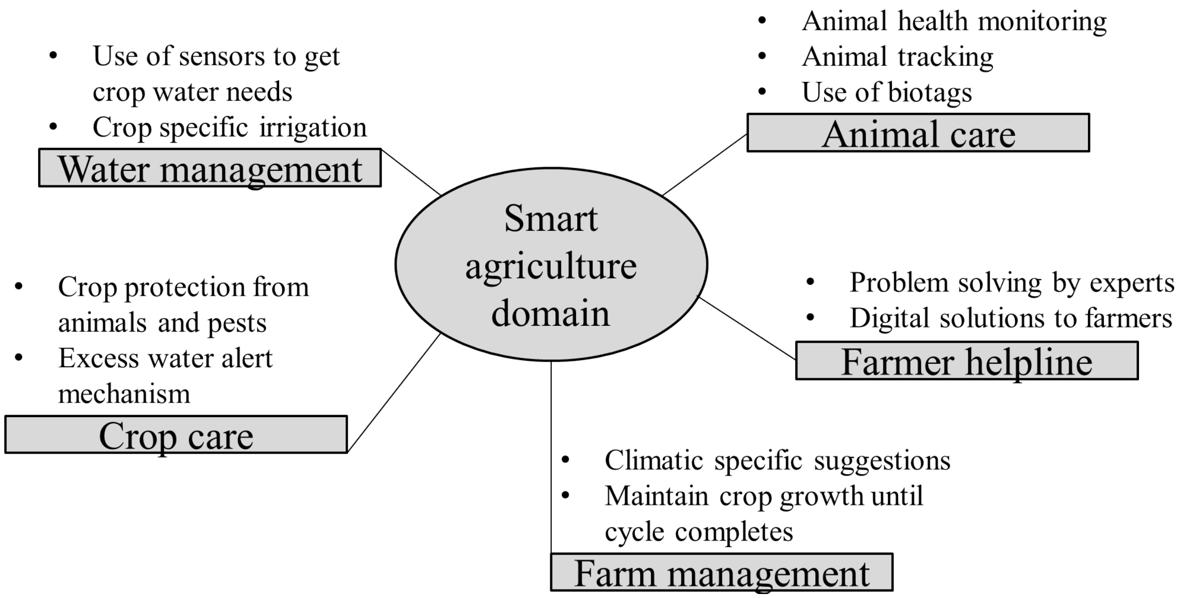


Figure 1: Application domain of smart agriculture.

Many of the farmers in India are not well educated that keeps them away from using the limited water resources efficiently which in turn restricts the crop growth and the final yield is not as per the expectations. They are also refrained from using the technological advancements. It is also needed to come up with solutions that can solve issues like, improved yield with limited and minimum water resources i.e. water management, protection of crops from damage, a system to manage whole farm, etc. With the movement of Digital India concept, there is a tremendous growth in digital information storage, retrieval and communication. This technological movement should be incorporated to the ground level problems faced by the country currently.

Internet of Things (IoT) (Xia *et al.*, 2012) has come up which incorporates multiple aspects that targets making human life more comfortable. One such domain where it could be effective is agriculture. With the improvements in wireless telephony, internet and various government initiatives, these technologies have now started reaching the farmers. In developed countries, farmers are much more technologically educated and with the proper use of the latest technological advancements, their crop yield is huge. Even though we have information available about the farm technical parameters, it is still not easy for farmers to access and use them. Thus it is essential to have simple and less expensive techniques by which the necessary help can be provided to the farmers. With the evolution of IoT it is possible to rectify these problems and reach to the end user with proper information and deliver better results.

Smart farming is a well-established subject in itself with broad areas of work like: water management (Gutierrez *et al.*, 2014), crop care (Mahlein *et al.*, 2012), animal tracking (Floyd, 2015), care and management (Wang *et al.*, 2010), farm management systems (Kaloxylos *et al.*, 2012), helplines, etc. as shown in Figure 1. There are unending advantages of putting technology with the farmers' experience, such as, improved crop quality and yield, water savings by its efficient utilization via proper irrigation mechanisms, high quality dairy products, good quality leather. All of this is achieved but, along with the generation of huge data at the back end, that needs to be taken care of.

Data is has size worth Exabytes, Zetabytes, etc., and the how's, where's, what's related with it is not easy as it seems to be. Companies today (McAfee *et al.*, 2012), (Davenport and Dyché, 2013) are coming up with sections dedicated to handle this huge amount of generated data, technically termed as Big Data (Manyika *et al.*, 2011). It has thus become a major aspect today to think about handling this huge data, without losing any of it. Data generated in case of smart farming techniques is mainly obtained via the sensors, Radio Frequency IDentification (RFID) (Juels, 2006) tags, bio-chips implanted in the fields, in the animal farms or the animal body.

Various sensors like, temperature, humidity, soil moisture, soil pH, wind speed, etc. are incorporated when smart irrigation techniques are used in the fields. Some of these sensors almost work 24×7 that generate farm parameters, which is further used to perform actions like turning On/Off a motor, water pump, etc. if required. This huge generated data might be redundant and thus sending it in original form will unnecessarily consume high bandwidth and more processing power. Hence arises the need to smartly handle the data, send only that of importance and process them.

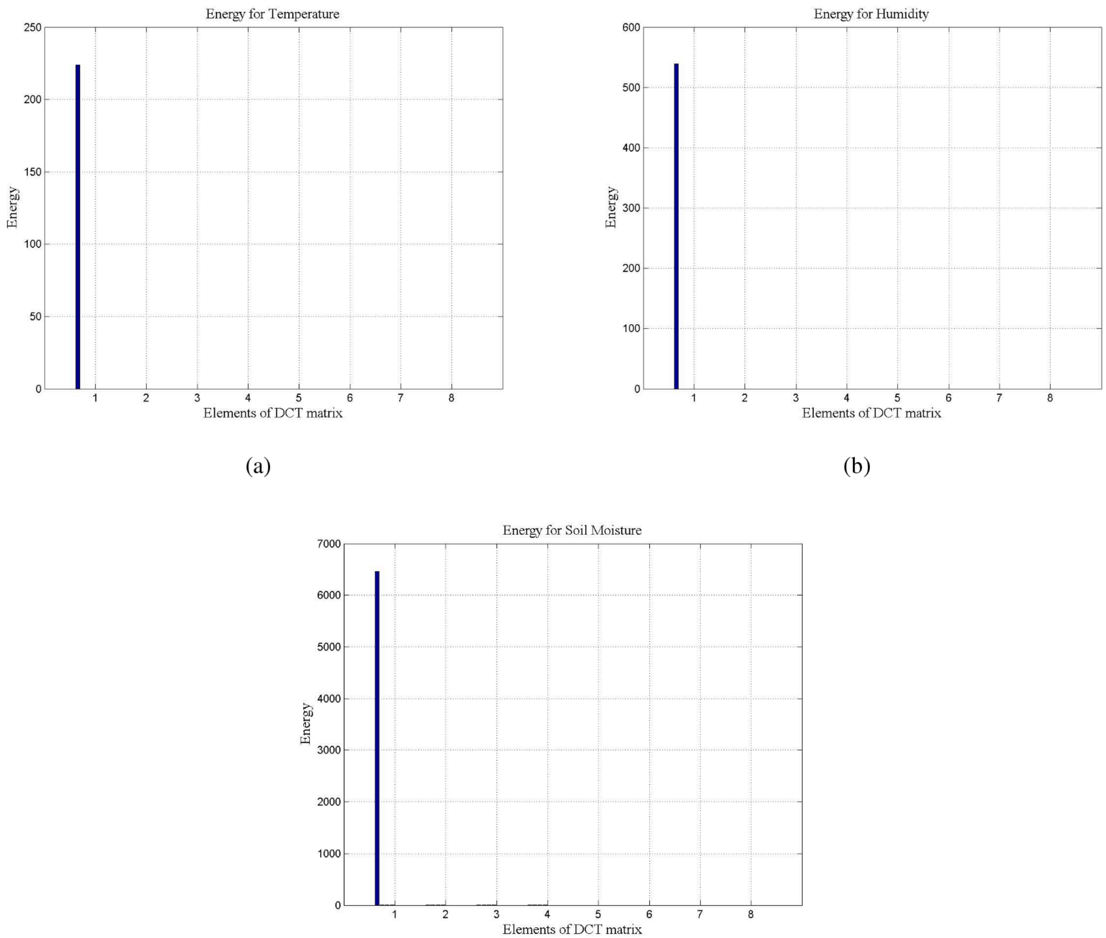
Handling the redundancy in the sensor data introduces the space for compression to fit in. So, using compressed data for communication is a better option than sending the big sized data. Compression technique can be made better and power efficient to be used on portable devices. Best available solutions for data compression include using discrete cosine transform (DCT) (Ahmed *et al.*, 1974) and discrete wavelet transform (DWT) (Madanayake *et al.*, 2015). DCT is preferred over DWT due to its energy compaction property (Roy *et al.*, 2012), information packing ability (Kaur and Kaur, 2012) and requirement of lesser computational resources.

The work proposed in this paper mainly focuses on utilizing the concept of IoT in Smart Farming application domain to improve the way things work in the home gardens, backyard vegetation, green houses, farms, etc. It also aims at compressing the data fetched by sensors and then sending this data for processing at the server end. It starts with short description about broad areas and work related to smart agriculture, the reason for choosing DCT, as described in Section 2, followed by the proposed work in Section 3. The experimental setup and results for the proposed work are given in Section 4, and the paper is concluded in Section 5. Finally references have been mentioned in the end.

2. Related work

The smart farming domain is spread over various applications with some broad areas as shown in Figure 1. Research in this field is being carried out heavily and contribution of research groups that address some of these issues have been mentioned in this section. One of the major concerns with today's agricultural scenario is water availability for crop growth which gives rise to development of intelligent irrigation mechanisms. In (Muñoz-Carpena and Dukes, 2005) the authors mention various methods of soil moisture testing, water conservation and irrigation technology, differentiation between the direct and indirect ways of soil water status determination. This is helpful at the initial stages for soil preparation to know its suitability for different crops. An intelligent irrigation system is proposed by Gao *et al.* in (Gao *et al.*, 2013) that uses WSN, fuzzy control and monitoring center where, the nodes work on solar energy and collect soil and crop growth information for different time periods.

Parameswaran *et al.* in (Parameswaran and Sivaprasath, 2016) have presented a smart drip irrigation system that takes input from various sensors for sensing the soil requirements, alerts the controller and updates status to the server which leads to better productivity. Another automated irrigation system that optimizes and effectively uses water has been discussed by authors in (Gutierrez *et al.*, 2014). It has a WSN of sensors implanted in the fields that works on solar, does data inspection and irrigation scheduling via a web page. Dursun *et al.* in (Dursun and Ozden, 2011) describe an application of WSN for cost effective, real time monitoring and data acquisition of soil water content. Work presented by Harun *et al.* in (Harun *et al.*, 2015) describe WSN as an alternate and effective method for optimum utilization of farm resources and accurate decision making. A smart phone based automated irrigation system is proposed by Gutierrez *et al.* in (Gutierrez Jaguey *et al.*, 2015), where the phone captures, processes soil images and estimates water content optically.



(c)

Figure 2: Distribution of energy in frequency domain for: (a) T_a^s, (b) H_a^s and (c) M_s^s

Another parameter that affects the crop post growth is intrusion of animals and attacks by insects and as a solution to this, Milind *et al.* in (Milind and Bhaskar), have proposed an adaptive irrigation and an insect avoidance system for improved yields. A method for early detection of sugar beet diseases has been proposed by Rumpf *et al.* in (Rumpf *et al.*,) that is based on support vector machines and spectral vegetation indices. In (Simeon *et al.*, 2013) authors present development and performance evaluation of an automatic frequency variant electronic pest controller. It aims for design of a device that emits ultrasonic sounds of varied frequencies and can affect auditory senses of insects and repel them thus preventing crop damage. Related work has been presented in (Rupanagudi *et al.*, 2015) that detects borer insects in tomatoes, (Awate *et al.*, 2015) wherein color, texture and neural network (NN) based fruit disease detection is given and (Sankaran *et al.*, 2010) which gives a review on methods for detecting plant diseases.

It is also very important that proper information reaches the farmers for them to know about the weather conditions, the measures that need to be taken, etc. Such a mobile information system is proposed by Alemu *et al.* in (Alemu and Negash, 2015). Abdullah *et al.* in (Abdullah *et al.*, 2016) have proposed a smart agriculture system that can analyze an agricultural environment, deal with agricultural challenges like temperature, humidity, etc. and a similar intelligent farming system with sensor and control blocks is presented in (Putjaika *et al.*, 2016). A functional architecture of farm management system is also presented in (Kaloxylos *et al.*, 2012) and, (Kaloxylos *et al.*, 2013) presents an overall vision for future internet services to revolutionize farming sector.

Much more work in this domain, apart from that discussed in this section, has been carried out by various research groups, giving rise to new research areas with wide scope and opportunities. Huge amount of data is generated by the sensors and removing redundancy is a must. Sending such redundant data consumes huge bandwidth and is not essential, thus creating compression requirement in smart farming. One of the most important properties of DCT, the energy compaction (Roy *et al.*, 2012) property states that, in the frequency domain, the first few coefficients at the top left corner consist of the maximum energy, whereas it is equally spread in the spatial domain. It can also pack most important information in very few number of coefficients (Kaur and Kaur, 2012) and takes less computational resources to transform the data.

The energy distribution is computed after finding energy associated with every coefficient for various data sets (temperature, humidity and soil moisture data sets have been taken here). Figure 2 shows the average energy associated with the coefficients, where the x-axis represents the 64 elements of 8×8 matrix obtained after DCT operation on T_a^s, H_a^s, M_s^s: ambient temperature, humidity and soil moisture, while y-axis shows energy associated with the coefficients. From here, it can be inferred that, moving towards high frequency components implies moving towards low energy or less important coefficients.

The proposed work uses energy compaction property of DCT where, only the most important DCT alphabets are accurately computed, while the least important ones are computed approximately. Keeping in consideration these issues, the sensitivity of the smart agriculture field and the requirements today, a DCT algorithm, an NN based decision making algorithm and IoT based system has been proposed in the next section.

3. Proposed irrigation system

The work presented in this paper aims at proposing a handy and user friendly automatic irrigation system. As many people are moving towards growing veggies at home, the system finds its application in organic farming, vertical gardening, backyard vegetation, etc. It collaborates with the latest IoT technology and intelligent sensors for sensing the needs of the planted veggies. A broad architecture of the proposed system and its segments is given by Figure 3. The system deals with environmental parameters and the soil water content for decision making regarding irrigating the plants, and comprises of sections given below:

- Sensing segment: It uses the sensors to fetch the required data and compress them for further processing. It is achieved using the sensing and compression portion of Figure 3.
- Processing segment: It does all the data processing on the data given by the sensing block and does the decision making for irrigation.
- Actuator segment: It takes action as per the command given by the processing segment. It controls the motor relay and sends alerts to the user as seen in actuator and alerts part of Figure 3.

3.1. System illustration

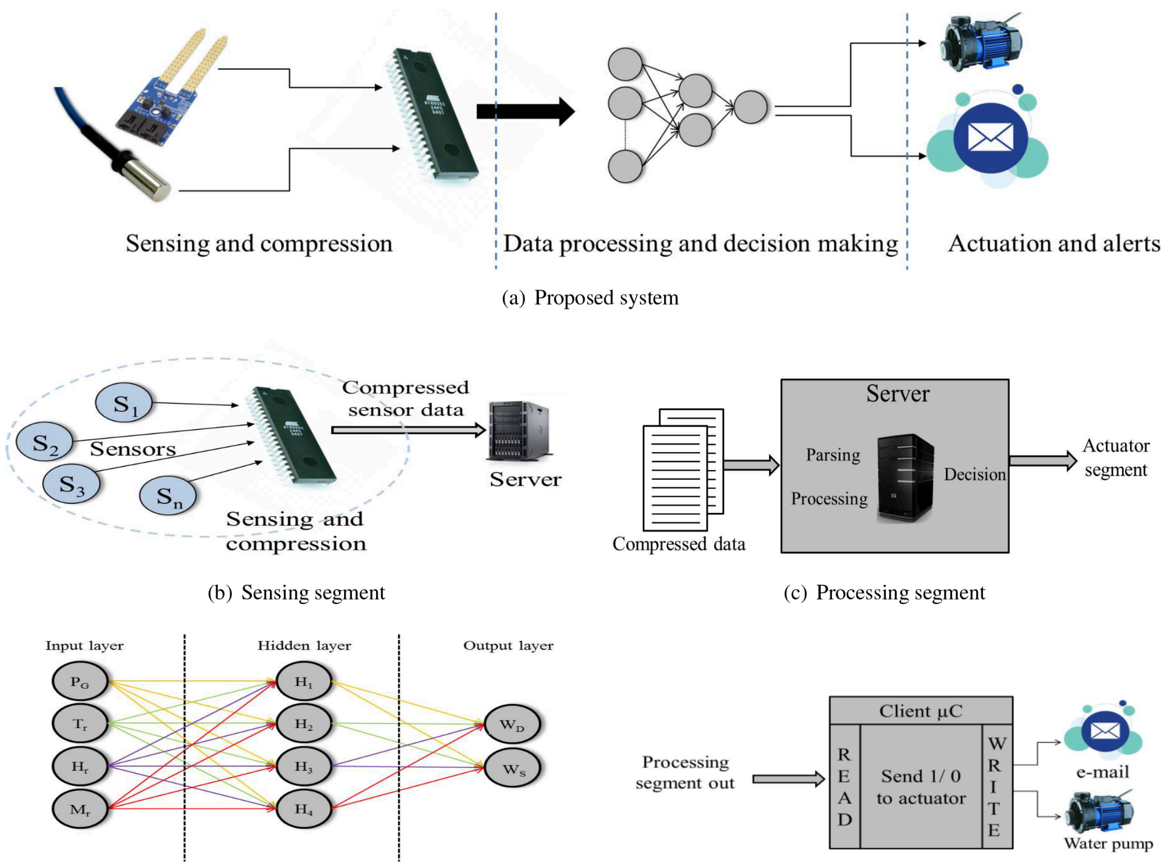
The proposed system consists of the following components:

- Sensors: Used for getting the physical data and providing them for further processing. Temperature and humidity (Wang and Chi, 2016) and soil water content sensors (Feuer, 1995) are used in the work.
- Controller: It is the core component of the sensing segment that control the sensors, reads data from them, keeps the data backup on a server for processing and decision making.
- Processing and data backup: The sensor data is stored on the server and the data processing and decision making is done here. It sends an alert to the user and the decision to the actuator unit.
- Actuators: These take output from the processing segment, control the water pumps for irrigation and send mail alerts about the status to the user for manual operation if required.

3.2. Sensing segment

It consists of the sensors, a controller board for managing the sensors and a sensor data compression module. In this work the sensors used for crop *C* are, a temperature and humidity sensor for getting the ambient conditions and, a soil moisture sensor. This segment senses the data, compresses this data and stores it on a FTP server. Figure 3(b) gives its architecture and the functionality is given by Algorithm 2. Here, a novelty is instigated by incorporating a data compression module which uses the Algorithm 1 to compress the data.

The necessity of sensor data compression: The sensors implanted in the plants create heavy and redundant data, which consumes enormous memory and more bandwidth for transmission. It is thus advantageous to first compress the data and thereafter upload the compressed data to the server. Also the sensor data in this case is not confidential and so there is a scope for managable minor error after reconstruction. This is achieved using Algorithm 1, where the input angles: $\pi/16$, $2\pi/16$ and $4\pi/16$ respectively yield a, b and d DCT coefficients. It is benefited as it uses fixed 3 iterations and parallely performs them to overcome data dependency (Meher *et al.*, 2009) problem with conventional CORDIC, thus performing it faster with only few computational steps. The obtained coefficients are used to compress the sensor data with another approximation introduced at this stage that involves computing only 16 most significant elements instead of all 64 elements for an 8×8 data block. The compressed data is then uploaded to an FTP server where it is reconstructed using the same algorithm and is used for further processing and decision making.



(a) Proposed system

(b) Sensing segment

(c) Processing segment

(d) 2-layer NN

(e) Actuator segment

Figure 3: Proposed system and its components.

Algorithm 1 Sensor data compression pseudo-code

Inputs: mπ/16 m$\rightarrow$ 0, 1, . . ., 4, iter: i$\rightarrow$0, i$\rightarrow$1, i$\rightarrow$2, sf$\rightarrow$0.6
Outputs: a, b, . . ., g
Begin
for count = 1, 2, 4 **do**
  if count == 1 **then**
    $\{\sigma_0, \sigma_1, \sigma_2\}$ = 1
    a = f(R_{11})
  else if count == 2 **then**
    $\{\sigma_0, \sigma_1\}$ = 1, σ_2 = 0
    Evaluate b = R_{11}
  else if count == 4 **then**
    σ_0 =1, $\{\sigma_1, \sigma_2\}$ = 0
    Evaluate d = f(R_{11}, R_{21})
  end if
  R_{11} = (1-$\sigma_1\sigma_2 2^{-j-k}$-$\sigma_0\sigma_2 2^{-i-k}\sigma_0\sigma_1 2^{-i-j}$)*0.5sf
  R_{21} = ($\sigma_2 2^{-k}$+$\sigma_1 2^{-j}$-$\sigma_0\sigma_2 2^{-i-k}$-$\sigma_0\sigma_1 2^{-i-j}$)*0.5sf
end for
return a, b, d
End

Algorithm 2 Sensing segment pseudo-code

Inputs: $\{S_1{:}S_n\} \rightarrow$ sensors
Outputs: $\{T_a^c, H_a^c, M_s^c\} \rightarrow$ compressed sensor data
Begin
do Algorithm 1
if $\{S_1{:}S_n\}$ **then**
  fetch sensor data
  for val(data): 0:64, type(data): 0:3 **do**
    get compressed data
  end for
  send data to server
  val–
else
  send data to server
end if
End

3.3. Processing segment

Its functionality is implemented at the server end which uses the compressed data and reconstructs it after parsing is done as seen from Figure 3(c). The working of processing segment is given by Algorithm 3, that takes the compressed data and reconstructs it for further processing and decision making. This is done using cron scheduling (Keller, 1999) at the server end which uses the previously trained NN shown in Figure 3(d) to generate a proper output. This generates an e-mail and sends it to the user and also sends it to the actuator unit, thus allowing both automatic and manual handling of the irrigation unit.

Algorithm 3 Processing unit

Input: $\{T_a^c, H_a^c, M_s^c\}$
Output: $DE\{on : off\} \rightarrow$ decision
Begin
do Algorithm 1
schedule cron job
if routine#1(out) **then**
    parse T_c, H_c, M_c
    for size(data): 0:64, type(data): 0:3 **do**
        reconstruct data
    end for
else
    Check for routine#1
end if
NN routine
Generate output
return $DE\{on : off\}$
End

Algorithm 4 Actuator unit pseudo-code

Input: DE
loop
    read DE
    schedule cron job
    send mail notification: smtp
    alert to client controller
end loop

3.4. Actuator segment

Algorithm 4 depicts the working and Figure 3(e) shows the block diagram of this unit. The decision taken by the processing segment is sent here so as to control the irrigation supply to the crops and send mail alerts to the user regarding current status. Mail notification is sent to the user using SMTP and the slave controller also receives the decision and acts accordingly. The simulation results for the sensor data compression module, the reconstructed output data, decision using neural network and related parameters have been mentioned in the next section.

Table 1: Stagewise nomenclature for sensor dataset

Category & Data	Fetched	Compr.	Reconst.	Mean	Var.	Max. error
Ambient temperature	T_a^s	T_a^c	T_a^r	T_μ	T_{σ^2}	$T_{e_{max}}$
Ambient humidity	H_a^s	H_a^c	H_a^r	H_μ	H_{σ^2}	$H_{e_{max}}$
Soil moisture	M_s^s	M_s^c	M_s^r	M_μ	M_{σ^2}	$M_{e_{max}}$

4. Results and Discussions

The proposed work deals with: (i) sensor data compression and (ii) NN based decision and this section presents results for the same. The nomenclature used for data in various stages is given in Table 1. A potted plant C yields T, H and S that are acquired using the sensors and are compressed using Algorithms 2 and 1. Results for a sample data is shown in Figure 4, which is for a small data block. A comparison and some parameters as mentioned in Table 1 are given in Table 2 and Figure 5.

Decision is either {1:motor on, 0:motor off} for the drip and sprinkler supply and is taken by the neural network. T_t, H_t, M_t: temperature, humidity and soil moisture thresholds are not directly decided, instead they vary depending upon {T, H, M} combinations and the NN. For this work, a NN shown in Figure 3(d) is trained and used for decision making. A combination of 4, 4 and 2 neurons at the input, hidden and output layers respectively, i.e. total 30 learnable parameters occur. A parameter plant growth *PG*[0: initial stage, 1: germination stage] is the fourth input, *WD* (0,1): drip, *WS* (0,1): sprinkler are the outputs i.e. type of irrigation required. The network is trained, validated and tested using a dataset, until minimum Mean Square Error (MSE) and maximum Regression (R) is obtained. Weights and biases for the network are obtained after training which gives required outputs for any input combination. The NN is trained using Bayesian Regularization algorithm and the MSE and R is given in Table 3.

Table 2: Sensed data vs reconstructed data

Ambient Temperature		Ambient Humidity		Soil Moisture	
T_a^s	T_a^r	H_a^s	H_a^r	M_s^s	M_s^r
24	24	37	39	834	828
26	26	38	41	814	834
28	28	39	43	832	841
29	30	40	43	837	844
31	31	41	43	834	843
32	32	42	42	833	841
33	33	43	42	834	842
34	34	44	41	836	843
24	24	45	40	835	829
26	26	46	41	838	831
28	28	47	43	871	834
29	30	48	44	832	834
31	31	49	43	852	833
32	32	40	41	846	831
34	33	37	40	845	830
34	34	38	40	841	830
24	24	39	41	839	827
26	26	40	43	823	825
28	28	41	43	819	822
30	30	42	43	819	820

Table 4 shows the actual output and the results obtained using the network, where the NN out fails for only a single input combination. Similarly, NN based decision making done for a big dataset gives an acceptable error of 2% in the output. The output is then notified to the user via e-mail so that he is updated about the latest status, and is also sent to the client μC that invokes an action for *WD* and/or *WS*. It works on the decision taken by the NN which helps in taking irrigation related actions. It also supports the user by providing a manual way of control via an e-mail notification. Thus it is valid to say that the proposed system for automatic irrigation works on the principle of IoT, without any human intervention.

$$\begin{bmatrix} 834 & 835 & 839 & 811 & 801 & 799 & 799 & 798 \\ 814 & 838 & 823 & 826 & 802 & 800 & 793 & 768 \\ 832 & 871 & 819 & 809 & 796 & 797 & 796 & 793 \\ 837 & 832 & 819 & 810 & 799 & 802 & 794 & 794 \\ 834 & 852 & 816 & 805 & 799 & 796 & 796 & 793 \\ 833 & 846 & 815 & 804 & 797 & 797 & 795 & 789 \\ 834 & 845 & 814 & 803 & 797 & 795 & 791 & 787 \\ 836 & 841 & 811 & 803 & 797 & 802 & 809 & 789 \end{bmatrix} \Rightarrow \begin{bmatrix} 6481 & 132 & 34 & 6 \\ 8 & 3 & -20 & -12 \\ 0 & -6 & -11 & -1 \\ -2 & -2 & -3 & -5 \end{bmatrix} \Rightarrow \begin{bmatrix} 828 & 829 & 827 & 819 & 807 & 797 & 791 & 790 \\ 834 & 831 & 825 & 816 & 805 & 797 & 792 & 790 \\ 841 & 834 & 822 & 811 & 802 & 796 & 793 & 791 \\ 844 & 834 & 820 & 808 & 799 & 795 & 793 & 792 \\ 843 & 833 & 819 & 806 & 797 & 794 & 793 & 793 \\ 841 & 831 & 807 & 804 & 797 & 794 & 794 & 793 \\ 842 & 830 & 814 & 803 & 798 & 796 & 795 & 793 \\ 843 & 830 & 803 & 802 & 799 & 798 & 796 & 792 \end{bmatrix}$$

(a) (b) (c)

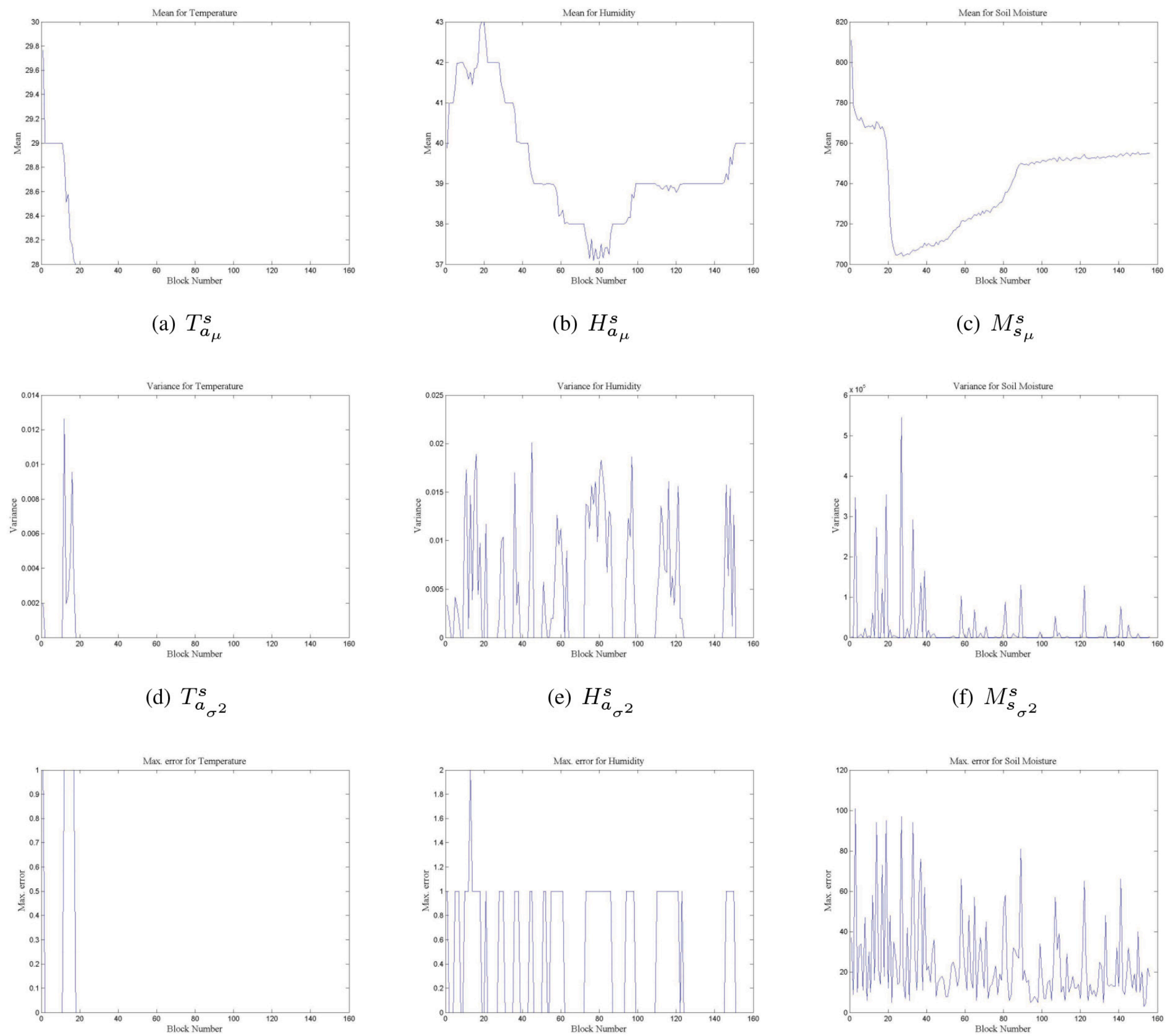
Figure 4: Sample data: (a) Sensed, (b) Compressed and (c) Reconstructed.

Table 3: MSE and R

Parameter	Training	Validation	Testing
MSE	0.0075	0	0.008
R	0.984	1	0.981

Table 4: Required vs NN outputs

Inputs				Outputs			
P_G	T	H	SM	Actual		Obtained	
				W_D	W_S	W_D	W_S
0	20	20	300	0	0	0	0
0	24	37	390	0	0	0	0
1	27	34	485	0	0	0	1
1	27	37	620	0	0	0	0
1	32	27	320	0	1	0	1
1	39	20	555	0	1	0	1
0	40	29	170	1	0	1	0
0	27	38	250	1	0	1	0
1	21	40	155	1	0	1	0
1	27	37	350	1	0	1	0
1	27	36	150	1	1	1	1
1	39	20	250	1	1	1	1



(a) $T^s_{a_\mu}$ (b) $H^s_{a_\mu}$ (c) $M^s_{s_\mu}$

(d) $T^s_{a_{\sigma^2}}$ (e) $H^s_{a_{\sigma^2}}$ (f) $M^s_{s_{\sigma^2}}$

(g) $T^s_{a_{e_{max}}}$ (h) $H^s_{a_{e_{max}}}$ (i) $M^s_{s_{e_{max}}}$

Figure 5: Mean (μ), Variance (σ²) and Maximum error (e_{max}) for T^s_a, H^s_a, M^s_s.

5. Conclusion

This paper presents an irrigation management system with sensor data fetching and compression, compressed data transfer, data processing, decision making and action invoke capabilities. A network of sensors implanted for the plants and three basic blocks form the whole system, compress the sensed data, send it to the FTP server which reconstructs it back into original form. A 2-layer Neural Network that utilizes the 4 inputs is used here for decision making. The actions comprise of notifying the user and, turning On/Off water motors for drip and sprinkler irrigation. The proposed system monitors the test object 24×7 and it is capable to monitor a farm for its water and other requirements. It has compression and decision making capabilities which makes it useful for home gardens, greenhouses, etc. It is also cost effective and works on batteries thus making it suitable for remote areas and useful in places with water scarcity for proper water management.

6. Acknowledgements

The work presented in this paper has been supported by Visvesvaraya PhD scheme, Ministry of Electronics and Information Technology (MeitY), Government of India.

7. References

Abdullah, A., Al Enazi, S., and Damaj, I., 2016. AgriSys: A smart and ubiquitous controlled-environment agriculture system. In *Big Data and Smart City (ICBDSC), 2016 3rd MEC International Conference on*, pp. 1-6. IEEE.

Abrol, I., 2000. Agriculture in India. *Centre for Advancement of Sustainable Agriculture, Retrieved from http:// www. google. co. in/url*.

Ahmed, N., Natarajan, T., and Rao, K. R., 1974. Discrete cosine transform. *Computers, IEEE Transactions on*, 100(1):90-93.

Alemu, D. and Negash, S., 2015. Mobile information system for small-scale rural farmers. In *Technological Innovation in ICT for Agriculture and Rural Development (TIAR), 2015 IEEE*, pp. 79-83. IEEE.

Awate, A., Deshmankar, D., Amrutkar, G., Bagul, U., and Sonavane, S., 2015. Fruit disease detection using color, texture analysis and ANN. In *Green Computing and Internet of Things (ICGCIoT), 2015 International Conference on*, pp. 970-975. IEEE.

Binswanger, H. P. and Khandker, S. R., 1995. The impact of formal finance on the rural economy of India. *The Journal of Development Studies*, 32(2):234-262.

Coale, A. J. and Hoover, E. M., 2015. *Population growth and economic development*. Princeton University Press. Davenport, T. H. and Dyché, J., 2013. Big data in big companies. *International Institute for Analytics*, p. 3.

Dursun, M. and Ozden, S., 2011. A wireless application of drip irrigation automation supported by soil moisture sensors. *Scientific Research and Essays*, 6(7):1573-1582.

Feuer, L., 1995. Soil moisture sensor. US Patent 5,445,178.

Floyd, R. E., 2015. RFID in Animal-Tracking Applications. *Potentials, IEEE*, 34(5):32-33.

Gao, L., Zhang, M., and Chen, G., 2013. An Intelligent irrigation system based on wireless sensor network and fuzzy control. *Journal of Networks*, 8(5):1080-1087.

Gupta, S. and Deshpande, R., 2004. Water for India in 2050: first-order assessment of available options. *Current science*, 86(9):1216-1224.

Gutierrez, J., Villa-Medina, J. F., Nieto-Garibay, A., and Porta-Gándara, M. Á., 2014. Automated irrigation system using a wireless sensor network and GPRS module. *Instrumentation and Measurement, IEEE Transactions on*, 63(1):166-176.

Gutierrez Jaguey, J., Villa-Medina, J. F., Lopez-Guzman, A., and Porta-Gandara, M. A., 2015. Smartphone Irrigation Sensor. *Sensors Journal, IEEE*, 15(9):5122-5127.

Harun, A. N., Kassim, M. R. M., Mat, I., and Ramli, S. S., 2015. Precision irrigation using Wireless Sensor Network. In *Smart Sensors and Application (ICSSA), 2015 International Conference on*, pp. 71-75. IEEE.

Juels, A., 2006. RFID security and privacy: A research survey. *IEEE journal on selected areas in communications*, 24(2):381-394.

Kaloxylos, A., Eigenmann, R., Teye, F., Politopoulou, Z., Wolfert, S., Shrank, C., Dillinger, M., Lampropoulou, I., Antoniou, E., Pesonen, L. et al., 2012. Farm management systems and the Future Internet era. *Computers and electronics in agriculture*, 89:130-144.

Kaloxylos, A., Wolfert, J., Verwaart, T., Terol, C. M., Brewster, C., Robbemond, R., and Sundmaker, H., 2013. The use of Future Internet Technologies in the agriculture and Food sectors: Integrating the Supply Chain. *Procedia Technology*, 8:51-60.

Kaur, A. and Kaur, J., 2012. comparison of DCT and DWT of Image Compression Techniques. *International Journal of Engineering Research and Development*, 1(4):49-52.

Keller, M. S., 1999. Take command: cron: Job scheduler. *Linux Journal*, 1999(65es):15.

Madanayake, A., Cintra, R. J., Dimitrov, V., Bayer, F., Wahid, K. A., Kulasekera, S., Edirisuriya, A., Potluri, U., Madishetty, S., and Rajapaksha, N., 2015. Low-Power VLSI Architectures for DCT/DWT: Precision vs Approximation for HD Video, Biomedical, and Smart Antenna Applications. *IEEE Circuits and Systems Magazine*, 15(1):25-47. ISSN 1531-636X. doi:10.1109/MCAS.2014.2385553.

Mahlein, A.-K., Oerke, E.-C., Steiner, U., and Dehne, H.-W., 2012. Recent advances in sensing plant diseases for precision crop protection. *European Journal of Plant Pathology*, 133(1):197-209.

Manyika, J., Chui, M., Brown, B., Bughin, J., Dobbs, R., Roxburgh, C., and Byers, A. H., 2011. Big data: The next frontier for innovation, competition, and productivity.

McAfee, A., Brynjolfsson, E., Davenport, T. H., Patil, D., and Barton, D., 2012. Big data. *The management revolution. Harvard Bus Rev*, 90(10):61-67.

Meher, P. K., Valls, J., Juang, T.-B., Sridharan, K., and Maharatna, K., 2009. 50 years of CORDIC: Algorithms, architectures, and applications. *IEEE Transactions on Circuits and Systems I: Regular Papers*, 56(9):1893-1907.

Milind, P. K. and Bhaskar, P. Microcontroller Based Adaptive Irrigation System Using WSN for Variety Crops and Development of Insect Avoidance System for Better Yield. *IJRET: International Journal of Research in Engineering and Technology eISSN*, pp. 2319-1163.

Muñoz-Carpena, R. and Dukes, M. D., 2005. Automatic irrigation based on soil moisture for vegetable crops. *ABE356*.

Parameswaran, G. and Sivaprasath, K., 2016. Arduino Based Smart Drip Irrigation System Using Internet of Things. *International Journal of Engineering Science*, 5518.

Putjaika, N., Phusae, S., Chen-Im, A., Phunchongharn, P., and Akkarajitsakul, K., 2016. A control system in an intelligent farming by using arduino technology. In *Student Project Conference (ICT-ISPC), 2016 Fifth ICT International*, pp. 53-56. IEEE.

Roy, A. B., Dey, D., Mohanty, B., and Banerjee, D., 2012. Comparison of FFT, DCT, DWT, WHT compression techniques on electrocardiogram and photoplethysmography signals. In *IJCA Special Issue on International Conference on Computing, Communication and Sensor Network CCSN*, pp. 6-11.

Rumpf, T., Mahlein, A., Steiner, U., Oerke, E., and Dehne, H. Early detection and classification of plant diseases with support vector machines based on hyperspectral reflectance. *Computers and Electronics in Agriculture*, 74(1):9.

Rupanagudi, S. R., Ranjani, B., Nagaraj, P., Bhat, V. G., and Thippeswamy, G., 2015. A novel cloud computing based smart farming system for early detection of borer insects in tomatoes. In *Communication, Information & Computing Technology (ICCICT), 2015 International Conference on*, pp. 1-6. IEEE.

Sankaran, S., Mishra, A., Ehsani, R., and Davis, C., 2010. A review of advanced techniques for detecting plant diseases. *Computers and Electronics in Agriculture*, 72(1):1-13.

Simeon, M. I., Mohammed, A. S., and Adebayo, S. E., 2013. Development and preliminary testing of an electronic pest repeller with automatic frequency variation. *Development*, 2(1).

Wang, Y. and Chi, Z., 2016. System of wireless temperature and humidity monitoring based on arduino uno platform. In *Instrumentation & Measurement, Computer, Communication and Control (IMCCC), 2016 Sixth International Conference on*, pp. 770-773. IEEE.

Wang, Z., Fu, Z., Chen, W., and Hu, J., 2010. A RFID-based traceability system for cattle breeding in China. In *Computer Application and System Modeling (ICCASM), 2010 International Conference on*, volume 2, pp. V2-567. IEEE.

Xia, F., Yang, L. T., Wang, L., and Vinel, A., 2012. Internet of things. *International Journal of Communication Systems*, 25(9):1101.