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A Novel Algorithm Based on LoRa Technology for Open-Field and Protected Agriculture Smart Irrigation System

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***Abstract*— A novel algorithm for smart irrigation system adaptable for both open-field and protected agriculture based on LoRa technology is proposed in this paper. The algorithm suits a networked architecture, in which a central controller is communicating with distributed units of sensors and actuators. Communication within the system units use LoRa devices, where a LoRa is an IoT based technology providing low-power and long-range radio connectivity. Within an agricultural farm, the system can be configured such that it can suit the control of environmental conditions applicable for either an open-field and/or a protected (e.g. greenhouse) agricultures. A database has been developed and designed to comply with the system architecture. The collected data is analyzed and used by the system for automatically adjusting itself to an optimal or semi-optimal performance. At the central control, the user interface offer system monitoring capability, statistics, as well as report generation.**

Keywords—smart irrigation, IoT, LoRa technology, smart monitoring, soil sensor, greenhouse, and climate conditions.

I. INTRODUCTION

Obtaining a good crop yield requires careful surveillance for the crop in line with following a set of common sense observations to ensure fruitful results. A number of continuously changing and effective factors are related and important to consider. Such factors may include; temperature, humidity, the soil condition, wind and the stage of development of the crop. Among the set of factors, the irrigation is one of the most important to get right.

In addition to the worldwide challenge of water scarcity and seasonal shortage, farming nowadays is facing additional challenges affecting both quantity and quality [1], which makes it necessary to keep up with technology to make better product. Crops can either grow in open-field farms or as a protected agriculture [2]. A protected field is an indoor agriculture that is commonly referred to as a greenhouse. In both cases, adopting technologies may help in getting more control over the growing conditions, including the irrigation water, and hence achieving better yields and more profit.

A broad measure of performance for modern irrigation systems is their ability to minimize water consumption, while maximizing crop productivity. This performance measure is in fact critical and may require compromise between the two factors (i.e. water supply and gross crop production). An optimal point is normally hard to determine due to effects of many static and dynamic parameters such as field train and climate conditions.

Many irrigation systems have been developed and used to achieve water savings with various crops. In [3], for instance, a system utilizing thermal imaging to monitor an irrigation schedule is proposed. While in [4], a preplanned irrigation schedule based on water optimization is adopted. Wireless Sensor Networks (WSN) architecture was implemented in another system to achieve the effectiveness of water management [5].

In general, irrigation systems, which are proposed in literature, and designed to automate the irrigation process, are mostly composed of three main components: (i) environmental sensors; (ii) the control unit as a decision-maker; and (iii) the actuator component [6]. The advancement of the Internet of Things (IoT) has highly facilitated its implementation in various industries and sectors including smart agriculture and smart irrigation. Systems in these fields intend to utilize water efficiently, in terms of place, time, and amount [7]. Further, such systems may also optimize labor costs as well as the consumption of electricity.

With respect to IoT related technologies, a long range, low-power IoT communications is offered by adopting LoRa, which is a radio modulation technology licensed by Semtech Corporation [8]. LoRa represents the physical layer of the wireless modulation and it is designed specifically to provide long-range connectivity operating at the industrial, scientific and medical (ISM) radio bands of 433 MHz, 868 MHz, and 915 MHz [9].

A LoRa Wide Area Network (LoRaWAN) can be a suitable technology to use in various applications including smart irrigation systems, where it is possible to cover 20 km in rural area and around 8 km in urban areas. Further advantage of a LoRa device is the possibility of long term operation with up to ten years on battery because of low power consumption. More features can also be emphasized in a smart irrigation system utilizing LoRa technology are water-saving, and lower costs of maintenance and deployment. Therefore, a novel algorithm for smart irrigation system based on LoRa technology is proposed in this paper. An experimental prototype of the system, adopting the proposed algorithm, is also developed intending to make use of the features offered by adopting the LoRa technology to suit both indoor and outdoor agriculture (i.e. open-fields and greenhouse).

The next section of this paper introduces an overview of the system for which the algorithm is proposed. In section III, the system database is described. Section IV, explains the proposed algorithm in terms of principle of operation, formulas and their main assumptions. A short description of the system hardware implementation is outlined in section V. Section VI, however, presents results and calculations with a case study for a possible scenario of algorithm implementation using a set of different sensor readings. Some concluding remarks about the paper are mentioned in section VII.

II. OVERVIEW OF THE PROPOSED SYSTEM

The layout of our system for which the algorithm is proposed, is illustrated in the block diagram of Fig. 1.

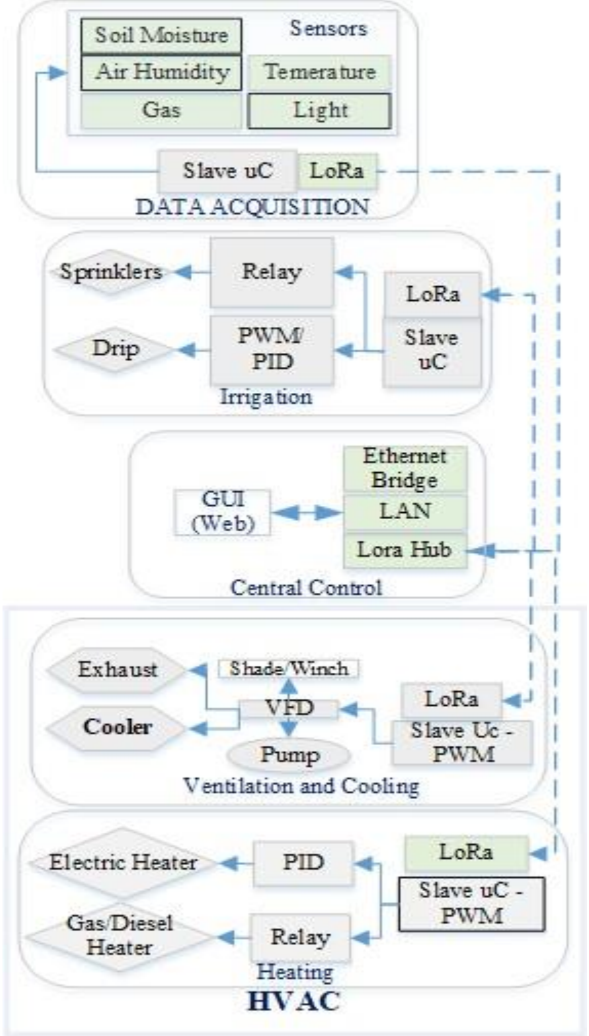

Fig. 1. Overview of the smart irrigation system based on LoRa technology.

The system is mainly composed of four major units:

- *Data Acquisition Unit:* In this unit, a microcontroller is interfaced with necessary sensors (e.g. temperature, humidity, soil moisture, etc.). The collected data will be prepared in the suitable format and sent via the LoRa device to the central control unit. The number and types of sensors will necessarily vary depending on the type of farming.
- *Central Control Unit:* In this unit, the collected data from remote sensors are processed and analyzed. The unit is mainly equipped with a LoRa hub, a master controller, and a user interface.
- *Irrigation Unit:* In this unit, two irrigation methods are assumed and hence interfaced to the LoRa and microcontroller devices. Irrigation using sprinklers and drip irrigation systems can be both controlled. Certain crop type related factors will decide on which irrigation method is used at a certain time.
- *Heating, Ventilation, and Air Conditioning* (*HVAC*) *Unit*: There are two sub-units attached to HVAC, namely; heating unit, and ventilation and cooling unit. The LoRa and microcontroller devices in the ventilation and cooling unit are interfaced to four types of actuators (Fans, Exhausts, Water Pump, and Shade Winch), while the LoRa and microcontroller devices in the heating unit are responsible for activation and deactivation of heating units. This unit is applicable for protected farms.

III. DATABASE DESIGN

In addition to the algorithm that will be presented in the next section, a database has been developed. The structure of this database is shown in Fig. 2. It is composed of 14 tables representing the hierarchy of the data within a generalized farming system. Tables are named based on their intended purpose and functionality with their names having the prefix *iot*. Following is a definition of the tables comprising the database.

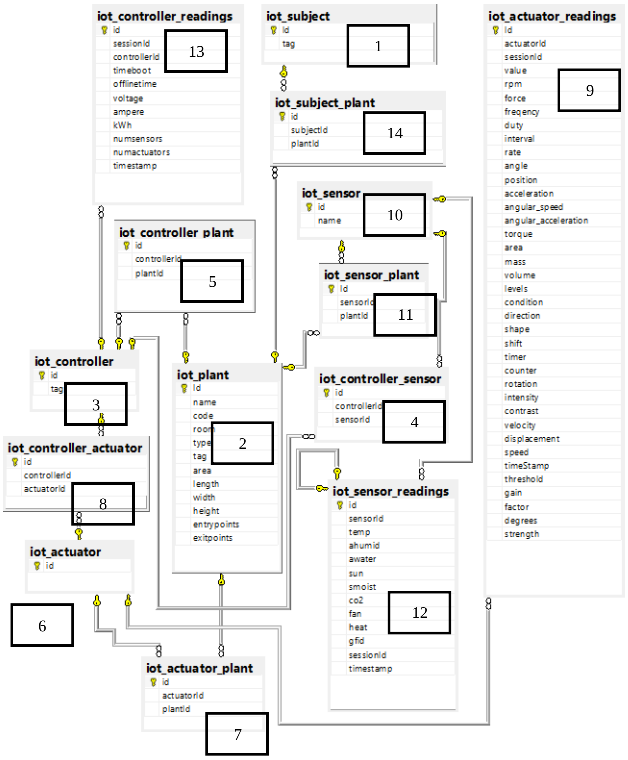

Fig. 2. The database structure.

1) *iot_subject*: Each subject is a farming related process, e.g. Irrigation, Poultry, and Fish.

2) *iot_plant*: Each subject has multiple process plants (e.g. Irrigation subject has one or more plants called as Field 1, Field 2, etc.)
3) *iot_controller*: A controller is an identity that has a set of sensors.
4) *iot_controller_sensors*: A controller has a set of related sensors identified by this table.
5) *iot_controller_plant:* This table is used to identify controllers according to the process plant in which they are installed.
6) *iot_actuator*: This table has identities of actuators.
7) *iot_actuator_plant*: This table identifies the link to those actuators which are operating in a plant as a standalone device.
8) *iot_controller_actuator*: This table has identities of those actuators which are operating through a controller.
9) *iot_actuator_readings*: This table has readings on actuators.
10) *iot_sensor*: Identities of sensors used in the system are available in this table.
11) *iot_sensor_plant*: This table identifies the link to those sensors which are operating in a plant as standalone devices.
12) *iot_sensor_readings*: This table is used to save sensors readings.
13) *iot_controller_readings*: In this table, a controller can save its own dedicated readings. Readings may include power consumptions or deduced parameters from multiple sensors or algorithms.
14) *iot_subject_plant:* This table assigns the plant to the system's subject under process.

IV. THE PROPOSED ALGORITHM

A. *Principle of System Operation*

For a given crop, there are number of parameters that need to be controlled. These targeted parameters have to be maintained within certain allowable limits (threshold range) through a supervised real-time feedback (e.g. PID - Proportional Integral Derivative). The values to control may vary among crops and even from time to time for a certain crop [10]. The system is assumed to save a set of reference information about different crops for comparison and hence assessing periodic sensor readings.

At the central control, sensor readings are continuously received from data acquisition units. Processing of these readings will result in the central control issuing proper commands, which are mostly either to activate or deactivate relevant actuators to reach the desired optimal set point. The status of all actuators (activated/deactivated) are saved in a record together with a time stamp. These records of sensor readings are utilized to help in system monitoring, system optimization, preparing statistical data, and generating performance reports.

B. *Rule for Deriving Logical Values for a Data Sample*

In Table I, the sensor data sample (*x_val*) is assigned with a binary value in reference to a threshold range (th). The rule states that, if the data sample value is above the threshold range, it is replaced with a logical "1", and if the value is within or below the threshold range, it is replaced with a logical "0". Note that threshold range can vary depending on crop type and climate conditions.

TABLE I. RULE FOR REPLACEMENT OF (*x_val*) WITH LOGICAL VALUES

Label for Sensor Threshold	**Threshold Range (th)**	**Assignment Rule**		
		If (x_val > max(th))	If (x_val < min(th))	If(x_val ≥ min(th) && x_val ≤ max(th))
ah_th	28-30	1	0	0
t_th	25-27	1	0	0
sm_th	15-20	1	0	0
co2_th	30-35	1	0	0
s_th	45-50	1	0	0

In Table II, examples of value assignments based on the rule of Table I is illustrated, where a sample (x_val) corresponding to a sensor reading (e.g. air humidity sensor (ah)) is replaced with a logical "1" because it is less than the threshold (ah_th).

TABLE II. EXAMPLE OF REPLACEMENT OF SENSOR SAMPLE *(*x_val*)* WITH A LOGICAL VALUE

Threshold Designation	**ah_th**	**t_th**	**sm_th**	**co2_th**	**s_th**
Threshold (th[n])	28-30	25-27	15-17	30-32	45-47
Sample Value (x_val)	27	28	16	40	47
(x_val > max(th[n]) = ?	no	*yes*	no	*yes*	no
Logic Assignment	0	1	0	1	0

C. *Demarcation of Samples*

The algorithm assumes that the threshold range (th), is an array of size *n*, consisting of real numbers within a threshold range. For example, in case of *ah_th* the threshold is set as (28-30). This means that ah_th = {28, 29, 30} with minimum value represented at th[0] = min(th[n]), and maximum value represented by th[2] = max (th[n]). Divergence from minimum and maximum values are named as "*below threshold*" and "*above threshold*", respectively. The "*distance"* of *x_val* (sample) from minimum and maximum is represented with *d_min* and *d_max respectively*. This assumptions leads to two distinct conditions to deal with.

D. *Dealing with "Below Threshold" Values*

For a sample value below the minimum of threshold, the following condition is true: *(x_val < min (th[n]))*

In response to analyzing any sensor data value, it is expected to have relevant actuators to be activated/deactivated (triggered) in order to normalize the parameters of the crop. To illustrate this part, consider the air humidity parameter, with the threshold range *ah_th* = {28, 29, 30}. If (x_val = ah = 20), then the distance

$$d\_min = \lceil th[0] - x\_val \rceil, \qquad (1)$$

Therefore $d\_min = \lceil 28 - 20 \rceil$ = 8. The value d_*min* = *8* will be used for the strategy of actuators operation.

In the algorithm, actuators' operation is divided into four states (namely; "00", "01", "10", and "11"). The state "00" is *off* state, "01" refers to the *low*, "10" is the *medium*, and "11" is *high*. Based on this consideration, there will be three level settings. The heater used for temperature control in protected fields, for example, will be operating at highest when the state is “11”, and lowest at “01” setting. The power consumption [watt/h] for the heater will be divided into three levels accordingly. If a (90 watts) heater is used, then it will operate at three equally divided levels (i.e. 30 watts each). In autonomous mode for the system to reach the set point within the threshold, the actuator states will be auto set according to the distance of current sample deviation from the threshold range.

For further illustration, lets recall the sensor reading (*x_val =ah = 20*), which has *d_min = 8*. State switching interval is obtained by dividing *d_min* by three fixed levels (i.e. 8/3 = 2.6). The value 2.6 is called an “*interval”*, and it relates to 3 states of actuator operation, and three trigger points. The “*trigger point*” is the value at which the state of the actuator shifts to another level.

In Table III, the actuators’ states are derived along with the interval range during which the level stays the same. The algorithm has a function ah *(p, h, f)*, where the air humidity is considered effected by the operation of the water pump (*p*), the heater (*h*), and the fan (*f*). While below the threshold, air humidity can be increased by pumping more water, while keeping other actuators off. The state of the pump operation (i.e. High, Med., and Low) can be changed according to the required level. The calculated intervals are stored in an array called sub_interval array si[ ] = si[0], si[1], si[2].

TABLE III. ACTUATORS’ OPERATION LEVELS BASED ON THREE SUB-LEVELS INTERVAL RANGE BELOW THRESHOLD

sub_interval si [3]	**Actuators’ Operation Levels**								
	Pump		**Le-vel**	**Heater**		**Le-vel**	**Fan**		**Level**
20.001-22.666	1	1	High	0	0	Off	0	0	Off
22.666-25.332	1	0	Med	0	0	Off	0	0	Off
25.332-27.999	0	1	Low	0	0	Off	0	0	Off

If *x_val* is equal to one of the values in the threshold range, the “*distance*’ is always 0.

E. Dealing with “Above Threshold” Values

As the sample value is found to be above the maximum of threshold, the condition is denoted by:

$$(x\_val > max(th[n]))$$

We consider an extension to our case study about the air humidity parameter in which the threshold is set as ah_th = [28, 29, and 30]. Assume now an “above threshold value” is received from air humidity sensor (say x_*val = 36*), then the distance *d_max* is calculated based on the formula;

$$d\_\max = x\_val - \lceil th[n] \rceil \tag{2}$$

therefore $d\_\max = 36 - \lceil 30 \rceil$ = 6.

The states of actuators’ operation corresponding to (*x_val = ah = 36*), with a distance above the threshold d_max = 6, are illustrated in Table IV. The interval for state switching of the concerned actuators (i.e. pump, heater, and fan) is similarly obtained by dividing the *d_max* by the fixed operation levels (i.e. 6/3 = 2). The interval considered, therefore has 3 trigger points at increment of 2.

TABLE IV. ACTUATORS’ OPERATION LEVELS BASED ON THREE SUB-LEVELS INTERVAL RANGE ABOVE THRESHOLD

sub_interval si [3]_	**Actuators’ Operation Levels**								
	Pump		**Le-vel**	**Heater**		**Level**	**Fan**		**Level**
36-34	0	0	Off	1	1	High	1	1	High
34-32	0	0	Off	1	0	Med	1	0	Med
32-30.001	0	0	Off	0	1	Low	0	1	Low

We emphasize our previous note, that if (*x_val*) is equal to one of the values in the threshold range, the “distance’ is always 0.

It's worth mentioning that a main objective for the control strategy in the system is to maintain the climate conditions, such as air temperature, at their threshold range. This objective is achievable and easier to attain when considering protected architecture.

V. SYSTEM IMPLEMENTATION

An experimental prototype of the system, whose overview was presented in Section II is implemented using suitable hardware components.

The microcontroller units used are built with Arduino Uno. The LoRa devices are of type E32-TTL-100 SX1278 LoRA Module, the LoRa hub is LG01 LoRa Open W IoT Gateway, and number of sensors and actuators are used too. Fig. 3 is showing the main hardware devices used in the prototype implementation.

Fig. 3. The hardware system implementation.

VI. RESULTS AND CALCULATIONS

A. Gathering and Analysis of Sensors’ Readings

In addition to controlling the irrigation system intelligently, the application of the algorithm can be implemented for continuous and effective monitoring. The analyzed data can offer statistics and may be utilized for optimizing the system performance in terms of power consumption and in adjusting, and hence offering the most suitable climate parameters for various crops. In Table V, sensor readings from five sensors (namely; air humidity, temperature, soil moisture, co_2 gas, and sun) for a period of 11 minutes, are considered. The distances of each sample from the closest boundary to threshold range is calculated. Distance calculations for readings from the five sensors are plotted in the graph of Fig. 4. Based on the value of the distance, the algorithm calculates an interval value to asses about how far the climate conditions are from their normalized values in the threshold range (set point). According to this interval, the operation level for concerned actuators is applied. These calculated levels of actuators operation are also illustrated in in Table VI.

In Table VI, the actuator has to work harder in case of level 3, while lowest in case of level 1. An actuator is off in case of 0 level. We can replace duplicate levels with a single level that is required at current distance of combined samples from each sensors (e.g. 3-3 or 3-3-3 can be replaced with 3). Whereas, level with 2-3 indication shows the option for the controller to select either of the two operation levels of the actuator to attain the required set point.

TABLE V. DISTANCE OF SAMPLES FROM THRESHOLD

Time stamp	Distance d_x				
	d_ah	**d_t**	**d_sm**	**d_co2**	**d_s**
1:00	8.00	4.00	4.00	4.00	4.00
1:01	7.00	3.00	3.00	3.00	3.00
1:02	5.00	2.00	2.00	2.00	2.00
1:03	2.00	1.00	1.00	1.00	1.00
1:04	0.00	0.00	0.00	0.00	0.00
1:05	0.00	0.00	0.00	0.00	0.00
1:06	0.00	0.00	0.00	0.00	0.00
1:07	1.00	1.00	1.00	1.00	1.00
1:08	3.00	2.00	2.00	2.00	2.00
1:09	4.00	3.00	3.00	3.00	3.00
1:10	5.00	3.00	4.00	3.00	3.00
1:11	2.00	0.00	0.00	0.00	0.00

TABLE VI. LEVELS OF OPERATION FOR THE ACTUATORS

Time stamp	Actuator Operation Level				
	f_lvl	**e_lvl**	**p_lvl**	**h_lvl**	**s_lvl**
1:00	3-3	3-3	3-3	3-3	3
1:01	3-3	3-3	3-3	3-3	3
1:02	2-2	2-2	2-2	2-2	2
1:03	1-1	1-1	1-1	1-1	1
1:04	0	0	0	0	0
1:05	0	0	0	0	0
1:06	0	0	0	0	0
1:07	2-3	1-1-1	0	1-3	0
1:08	2-2	2-2-2	0	2-2	0
1:09	1-3	3-3-3	0	1-3	0
1:10	1-3	3-3-3	0	1-3	0
1:11	2	0	0	2	0

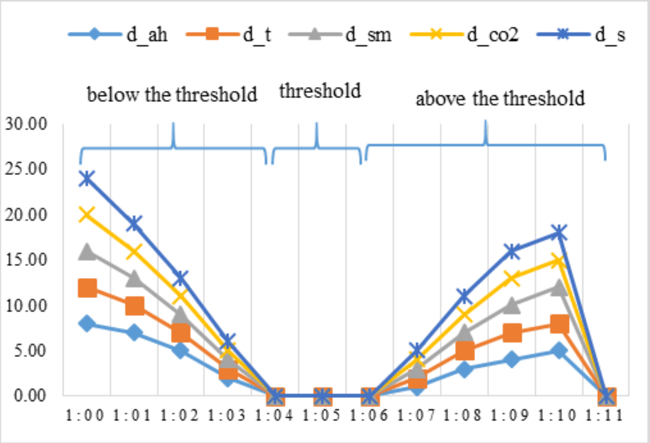

Fig. 4. Sensor readings distance from threshold.

B. Calculation of the Power consumption

Considering now both Tables V, and IV, where the relevant actuators used in the system for climate parameters' control are fan, water pump, air exhaust, heater, and shade winch. Their factory power ratings are (90, 750, 90, 5000, and 80 watts) respectively. Based on the level of operation shown in Table IV, the power consumption measured in Kw/min is calculated and illustrated in Fig. 5. Higher power consumption for the level 3, while minimum for level 1. The power consumption [KW/min] is obtained using the estimation:

$$P = \lceil (\text{rated\_kwh})/\text{level})/60 \rceil \qquad (3)$$

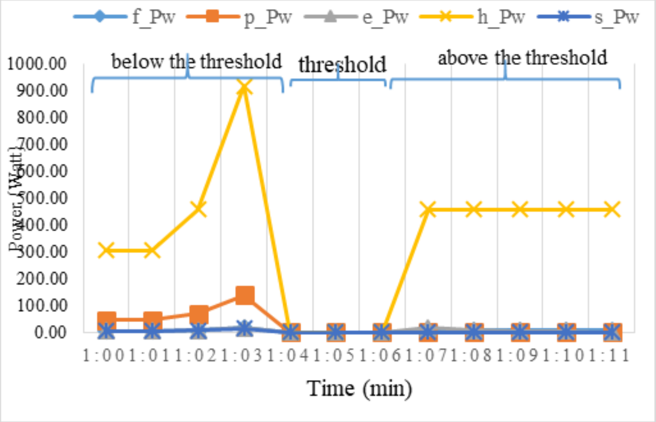

Fig. 5. Power consumption of system actuators.

In fact these analyzed data can be offered for users to monitor the system status, and for designers to study the behavior of the system and for making decisions leading to better system performance. Further, these data analysis and calculations can be fed back to the system to allow for automatic adjustments. All the parameters used in the proposed algorithm are defined in Table VII.

TABLE VII. NOMENCLATURE

Abbrev.	Meaning
x_val	Sensor Value
th	Threshold
ah	Air humidity value
sm	Soil moisture value
co_2	Carbon dioxide value
s	Sun Light value
ah_th	Air Humidity Threshold Range
t_th	Temperature Threshold Range
sm_th	Soil Moisture Threshold Range
co2_th	Carbon dioxide Threshold Range
s_th	Sun Light Threshold Range
f	Fan status
e	Exhaust status
p	Pump status
h	Heat Source status
sh	Shade status

VII. CONCLUSION

A novel algorithm for smart irrigation system based on LoRa technology is proposed in this paper. An experimental prototype of the system, adopting the proposed algorithm, is also developed with a main objective of making use of the features offered by considering the LoRa technology. The proposed algorithm and its relevant system can be implemented in both indoor and outdoor agriculture farming (i.e. open-fields and greenhouse). A database is designed to accommodate the big amount of data that is expected to be gathered from the set of distributed sensors in various farms. Local units within a farm (open-field and/or greenhouse) communicate with a central control by continuously sending sensor readings via the LoRa device, while receiving response about their actuator control.

Since we are working with big data, improvement to resource utilization becomes vital. We observed that data storage consumption in the system database can be reduced if data points for the time duration for which sensors readings (*x_val*) stays within the threshold range, is discarded as it will not be needed in actuators' control.

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