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Design of a Greenhouse Monitoring System Based on GSM Technologies

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Abstract. *Nowadays, internet and mobile technologies are developing and being used in everyday life. Systems based on mobile technologies and IoT (Internet of Things) are being popular in every area of life and science. Innovative IoT applications are helping to increase the quality, quantity, sustainability and cost effectiveness of agricultural production.*

In this study; a system which monitors temperature, relative humidity and PAR (Photosynthetically Active Radiation) and warns the farmer via SMS if any of these atmospherical parameters is beyond the pre-defined limits, in order to prevent damages to the plants, was developed. A software and hardware was developed which interprets data from sensors and transmits data into GSM terminal. Data have been collected with a computer that is connected to the system via USB. Later, these data have been used to identify data loss via GSM connection. A website has been used to monitor actual values and save data in an online database.

Experiments was held firstly in a laboratory for 6 months during development period and then in a greenhouse between 21 February and 25 February, 2015. Temperature, relative humidity and PAR values were uploaded to a remote server via GPRS and analyzed on the computer. Between these dates; temperature values outside the pre-defined limits occurred 3 times and relative humidity values outside the pre-defined limits occurred 10 times. The developed system sent 70 SMS messages which informs the farmer that temperature is low for 2100 minutes total and 129 SMS messages which informs that the relative humidity is high for 3908 minutes total. Total SMS loss was identified as 0.5%.

At the end of the experiments, differences was observed between data saved on the computer and data on the remote server. These differences were 150 repeating records, 25 missing record and 1 wrong record on the remote server. It is believed that these errors occurs because of the EMI

(Electromagnetic Interference) from GSM terminal and atmospheric charges.

In conclusion, greenhouse monitoring systems such as developed in this study are seem to be successful. When designing systems to be used in greenhouses, a faraday cage which blocks the EMI and an earth connection should be used to protect the system from atmospheric charges.

Keywords. *Greenhouse management, internet of things, precision agriculture.*

Introduction

In plant production, controlled environment is mainly used in greenhouses. *Esmay ve Dixon*

In order to provide an optimal environment for plants, variables such as temperature and humidity inside the greenhouse should be known (Akgül et al., 2006). In intensive greenhouse production, power cuts or malfunctioning of greenhouse appliances may occur and effects greenhouse climate suddenly. This situation causes rapid spread of plant diseases and frost. It is necessary to prevent these unwanted conditions in terms of intensive processing and production of greenhouses.

Nowadays, continuous measurement of many physical parameter is needed in technological greenhouses. Systems are developed to measure and record temperature, humidity, wind speed and direction, light intensity, soil moisture. Firstly, mechanical and electro-mechanical devices were used. When these systems are used, instant remote monitoring is not possible and unwanted conditions are learnt lately. With the recent developments in technology, number of the applications which makes remote monitoring and controlling possible are increasing. In these applications, different communication protocols such as RS-485, CAN, Bluetooth, GPRS are used depending on distance, installing costs, data rates (Guofang et al., 2010).

Greenhouse Monitoring and Controlling Technologies

Electronic control systems to manage greenhouse environment are developed. These systems measure physical parameters with electronic sensors, record and control appliances of greenhouse in an algorithm. Some of these parameters and increase/decrease methods are given in Table 1.

Table 1. Some parameters and increase/decrease methods

Parameter	Measuring Device	Unit	Controlled Appliance
Temperature	Thermometer	°C	Heaters, Fan/pad cooling
Humidity	Hygrometer	% RH	Fogger, Ventilation
Light (PAR)	PAR Sensor	$\mu mol/m^2s$	Lighting, Sun screen
Air speed	Anemometer	m/s	Ventilation, Fan
CO_2	CO_2 Sensor	ppm	CO_2 injection, Ventilation

In recent years; electronic measuring, recording and reporting devices via SMS and Internet are developed. These devices are used in a wide range of applications and provide control and early intervention for users.

Mobile Communication Technologies

Nowadays, GSM has widespread use. GSM uses radio frequencies to communicate. Voice and data transmission is made by these radio frequencies.

When GSM network first installed, only voice calls were made with developed first generation (1G) mobile phones. In 2000, second generation (2G) networks developed as a replacement and and provided 14.4 kbps digital voice transfer rate and Short Message Service (SMS). This expanded over time to include data communications, first by circuit-switched transport, then by packet data transport via GPRS (General Packet Radio Services) and EDGE (Enhanced Data rates for GSM Evolution or EGPRS).

Short Message Service (SMS)

Short Message Service is a text messaging service component of phone, Web, or mobile communication systems. It uses standardized communications protocols to allow fixed line or mobile phone devices to exchange short text messages.

By June 2015, according to reports, there are 72 million mobile subscribers in Turkey. In year 2014, 124 billion SMS was sent (Figure 1).

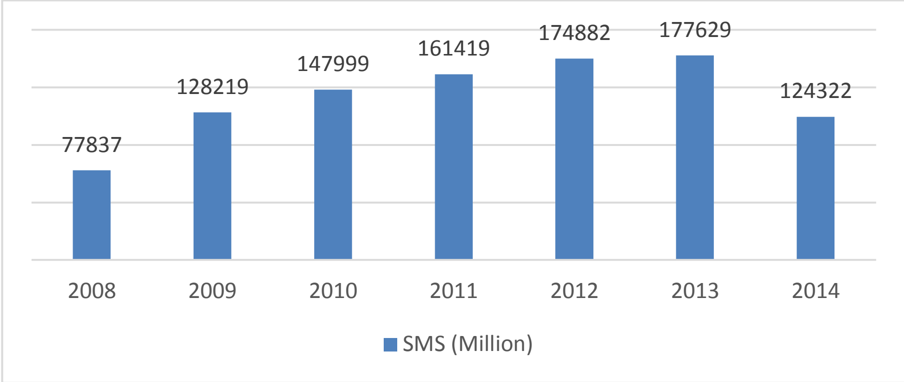

Figure 1. Number of SMS Messages by Year in Turkey

Background

In this study, parameters such as temperature, humidity, soil temperature, water temperature, PAR (Photosynthetically Active Radiation) are measured, mains electricity is detected. Used sensors are shown in Table 2.

Table 2. Parameters and sensors

Parameter	Sensor
Air temperature and humidity	DHT22
Soil temperature	DS18B20 waterproof
Water temperature	DS18B20 waterproof
PAR	SQ-110
Soil wetness	SEN-13322
Mains electricity	Arduino UNO analog inputs

Air Temperature and Humidity Sensor

A sensor named *DHT22* which is produced by *Aosong Electronics* is used to measure air temperature and humidity (Figure 2). This sensor is known for its low price and single-pin data transmit. It uses a DS18B20 to measure the temperature and a capacitive sensor to measure humidity. The sensor is placed in a sensor shield in order to keep away from direct sunlight and rain (Figure 3). The sensor's technical data is given in Table 3.

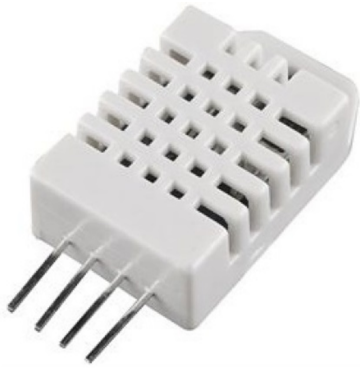

Figure 2. DHT22 air temperature and humidity sensor

Figure 3. Sensor shield

Table 3. DHT22 technical data

Working voltage	3.3 – 6 V DC	
Sensing element	Temperature: DS18B20	Humidity: Capacitive
Measurement range	Temperature: -40 - +80 °C	Humidity: 0%RH – 100%RH
Accuracy	Temperature: ±0.5 °C	Humidity: 2%RH
Resolution	Temperature: 0.1 °C	Humidity: 0.1%RH

Soil and Water Temperature Sensors

In order to measure soil and water temperature in greenhouses, a well-known, single-pin digital sensor *DS18B20* is used (Figure 4). In the study, waterproof versions of this sensor is used. A waterproof DS18B20 is shown in Figure 5.

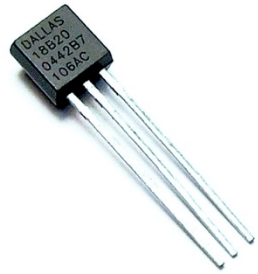

Figure 4. DHT22 air temperature and humidity sensor

Figure 5. Sensor shield

Because of these sensors use Dallas' OneWire® protocol, single wire is enough to communicate both sensors. Technical data of DS18B20 is given in Table 4.

Table 4. Technical data of DS18B20

Working voltage	3.0 – 5.5 V DC
Measurement range	-55 – +125 °C
Accuracy	±0.5 °C
Resolution	0.0625 °C

PAR Sensor

PAR sensor which is used in this study is a sensor developed by *Apogee Instruments, SQ-110* (Figure 6). This sensor is calibrated to sunlight and only receptive for photosynthetic wave length. This sensor is mounted on the sensor shield in order to prevent any shades or other effects. Technical data is given in Table 5.

Figure 6. SQ-110 Quantum PAR sensor

Table 5. Technical data of SQ-110

Working voltage	None
Output voltage	0,2 mV / µmol m^{-2} s-^{1}
Measurement range	0 – 4000 µmol/m^{2}s
Working conditions	-40 - +70 °C 0% - 100%RH

Soil Wetness Detector

A soil wetness detector which is named *SEN-13322* by *Sparkfun* is used to detect if soil is wet or not (Figure 7). This sensor is not calibrated to sense soil moisture. This sensor outputs HIGH for soil moisture being higher then set value and LOW for lower then set value.

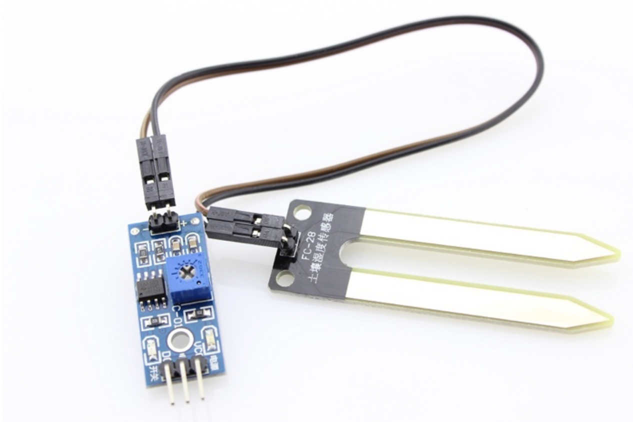

Figure 7. SEN-13322 soil wetness detector

GSM Module

A GSM module is used in the developed system in order to connect to the Internet via GPRS and send emergency SMS messages. In this study, *SIM900* by *SIMCOM* is used (Figure 8). Technical data about the module is given in Table 6.

Figure 8. SIM900 GSM module

Table 6. SIM900 technical data

Frequency band	850 / 900 / 1800 / 1900 MHz
Dimensions	24 x 24 x 3 mm
Weight	3.4 g
Supply voltage range	3.2 – 4.8 V
Current	Sleep: 1.5 mA Stand-by: 22 mA Burst: 191 mA
Serial communication	UART @ 9600 BAUD 8-n-1 AT command set

SIM900 GSM Module is controlled via AT Command Set which is a specific command language originally developed by Dennis Hayes. The command set consists of a series of short text strings which can be combined to produce commands for operations such as dialing, hanging up, and changing the parameters of the connection. Some of these commands are given in Table 7.

Table 7. Some AT commands

AT Command	Function
ATD	Dial a number
ATA	Answer incoming call
ATH	Hang up current call
AT+CMGS	Send SMS message
AT+CMGL	List received SMS messages
AT+CMGR	Read SMS message
AT+CMGD	Delete SMS message
AT+CSQ	Signal quality
AT+CBC	Battery situation
AT+COPS	Carrier name

Power Management

Average total power consumption of the system is shown in table 8.

Table 8. Average power consumption of system components

Component	Average power consumption (mA)
Main board (Arduino Uno)	160
LCD Display	56
GSM Module	22
Air Temperature / Humidity Sensor	1
Soil and Water Temperature Sensors	2
Soil Wetness Sensor	4
PAR Sensor	0
TOTAL	**245**

A 12 Volt adapter is used to supply energy to the system and charge a 6 Volt battery. When electricity goes off, system is supplied by the battery and system sends a message to warn the user. A battery charger controller and battery saver circuit is design during the development.

Enclosure

Developed system is placed in a 226 x 166 x 60 mm plastic enclosure during experiments. The enclosure is shown in Figure 9, Figure 10 and Figure 11.

Figure 9. System enclosure front view

Figure 10. Bottom view of the enclosure

Figure 11. Top view of the enclosure

Method

Electronic Design

A block diagram of developed system is shown in Figure 12. A photo of enclosure interior is shown in Figure 13.

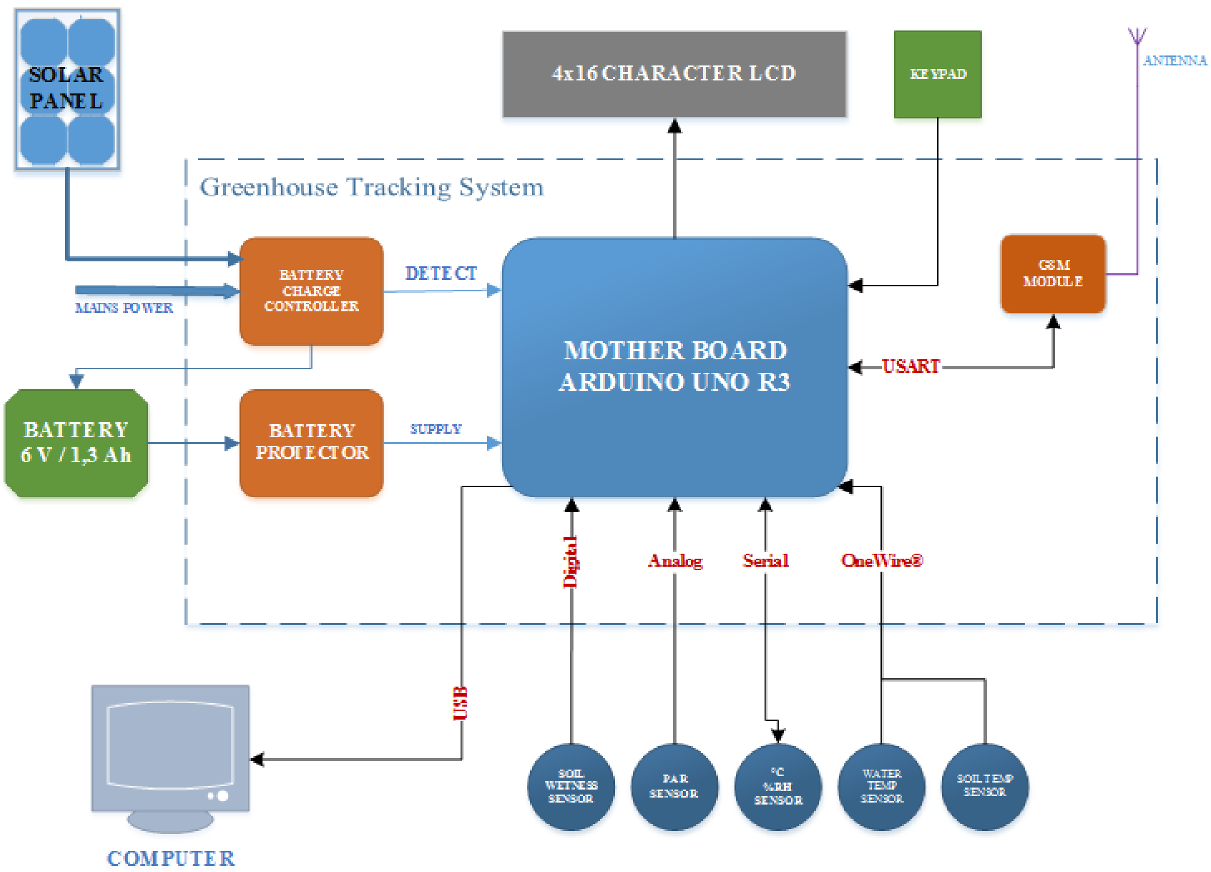

Figure 12. Block diagram of developed system

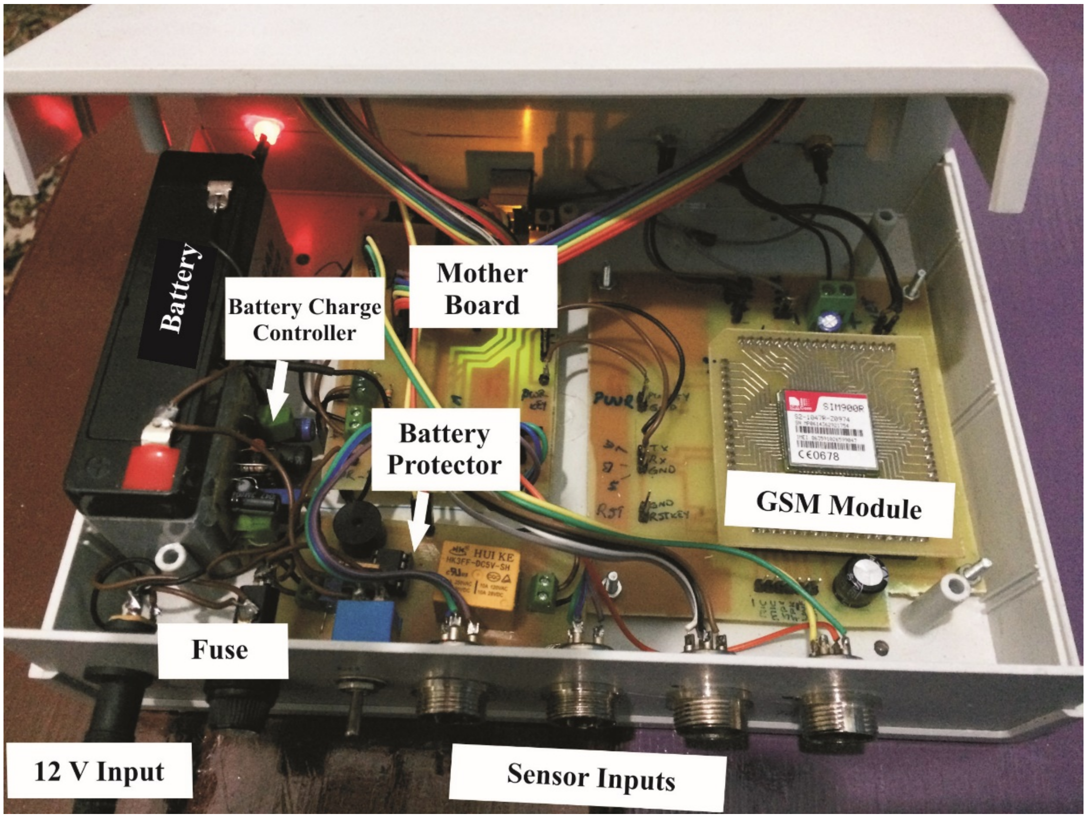

Figure 13. Interior of developed system

System connects to a php program running on a remote server via GPRS connection and data is saved in a database.

Computer Software

System is connected to a computer which records instant data and SMS sending times in order to compare online database records with cable connected records (Figure 14).

Figure 14. Computer software

Website and Online Application

A website *http://www.gokturkseyhan.net/seratakip* and a php script is used to store data in SQL database (Figure 15).

Figure 15. Website

Field Experiments

Once system was completed, firstly experiments was made in laboratory and then in a greenhouse (Figure 16). Preset values for air temperature, humidity, soil temperature, water temperature and PAR are given in Table 9. System is adjusted to send data every 5 minutes. Once the phone number for alerts is set, experiments started.

Figure 16. Greenhouse setup

Table 9. Adjusted minimum and maximums

Parameter	Minimum	Maximum
Air Temperature	0 °C	-
Humidity	20 %	80 %
Soil Temperature	0 °C	25 °C
Water Temperature	2 °C	30 °C
PAR	-	1000 µmol / m^2s
Power Cut	Warning ON	
Water Cut	Warning ON	

Analysis of records

After the field experiments, online records and computer records were compared. With this comparison; repeated, missing and wrong records were found. Comparison methods are described below.

$$Expected\ records\ count = {Experiment\ duration}/{Recording\ interval} \quad (1)$$

$$Expected\ records\ count = {5\ days * 24 \frac{hours}{day} * 60 \frac{minutes}{hour}}/{5\ minutes} = 1440 \quad (2)$$

Wrong records

If a record on the computer is not equal to its online version, this record is a “wrong record”. A wrong record is shown in Figure 17.

$$Wrong\ records\ (\%) = {Wrong\ records\ (count)}/{Expected\ records\ count} \quad (3)$$

tarih	havaSicakligi	havaNemi	toprakSicakligi	suSicakligi	par	id
2015-02-24 10:09:22	0	0	0	0	0	13204

Figure 17. A wrong record

Missing records

If a record on the computer is not found in online records, this record is a “missing record”. A missing record from 09:55 can be seen in Figure 18.

$$Missing\ record\ (\%) = {Missing\ records\ count}/{Expected\ records\ count} \quad (4)$$

tarih	havaSicakligi	havaNemi	toprakSicakligi	suSicakligi	par	id
2015-02-25 09:50:20	7.1	99.9	21.62	22.19	110	13487
2015-02-25 10:00:55	7.1	99.9	21.62	22.25	145	13488

Figure 18. A missing record

Repeated records

If the duration between two consecutive records is less than interval (5 mins) and equals to each other, this records are "repeated records". A repeated record can be seen in Figure 19. Observed records count must be used instead of expected record count to calculate the percentage of repeated records.

$$Repeated\ record\ (\%) = {Repeated\ records\ count}/{Observed\ records\ count} \tag{5}$$

tarih	havaSicakligi	havaNemi	toprakSicakligi	suSicakligi	par	id
2015-02-21 03:06:57	-4.2	82.4	19.12	20.75	0	12218
2015-02-21 03:07:00	-4.2	82.4	19.12	20.75	0	12219

Figure 19. Repeated records

Correct records

Correct records count can be calculated with two equalizations. First one;

$$Correct\ records = Observed\ records - Repeated\ records + Missing\ records - Wrong\ records \tag{6}$$

Second one;

$$Correct\ records = Expected\ records - Missing\ records - Wrong\ records \tag{7}$$

Results

Experiments was held between February 21, 2015 and February 25, 2015. Within this duration, 1565 rows of data were recorded on remote server (Table 10).

Table 10. Recorded data count and percentage

Observed records	Repeated records	Expected records	Correct records	Missing records	Wrong records
1565	150	**1440**	1414	25	1
100 %	0.95 %	**100 %**	98 %	1.74 %	0.06 %

During the experiment, maximum and minimum air temperature measured as 17 °C and -6.1 °C. Air temperature chart is shown in Figure 20.

Blue horizontal line indicates adjusted minimum value. In this study, minimum value was chosen as 0 °C. System sent SMS messages when air temperature was lower than 0 °C and kept sending with 30 minutes interval until temperature was higher than 0 °C. During trial period, temperature was lower than 0 °C for 3 times and totally 2100 minutes long. System sent 70 messages for "Low Temperature" alert. All messages were delivered.

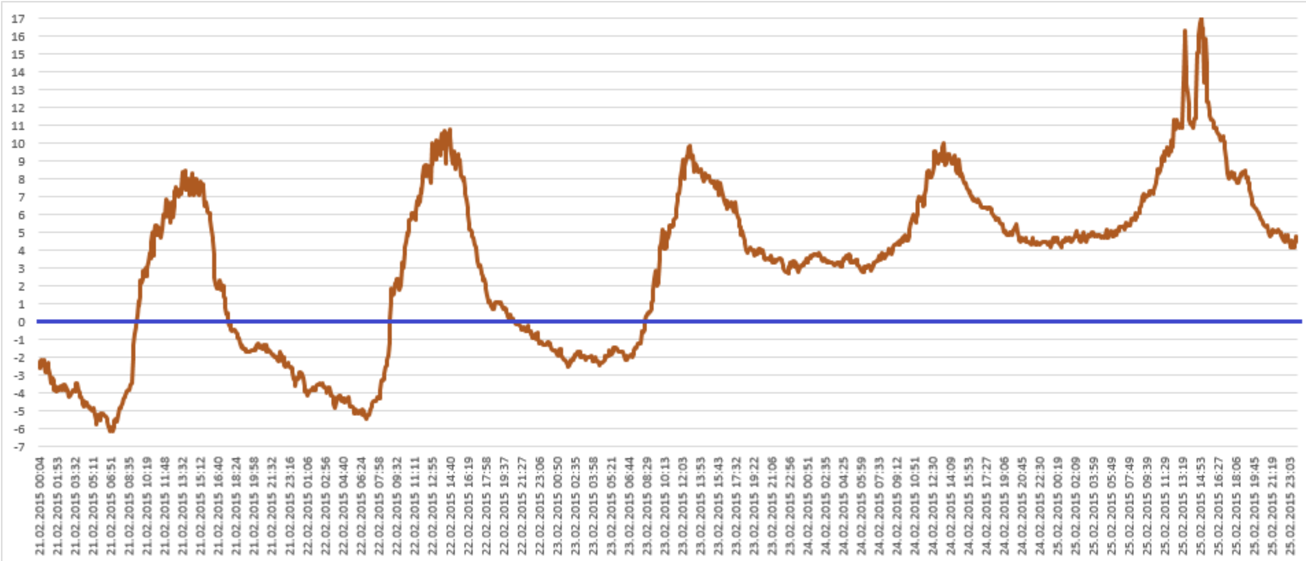

Figure 20. Air temperature chart

The other parameter was relative humidity and it was measured maximum 100 %, minimum 25.8 %. Fourth day of the trial was rainy (Figure 21).

In this study, minimum and maximum values for relative humidity were set as 20 % and 80 %. Relative humidity was higher than maximum value for 10 times and 3908 minutes long. System sent 130 messages that contains “High humidity” alert. 1 message was not delivered.

During trials, neither power nor water cut happened. But these conditions were made artificially 3 times for each. System sent 3 messages for power cut and 3 messages for water cut. All messages delivered.

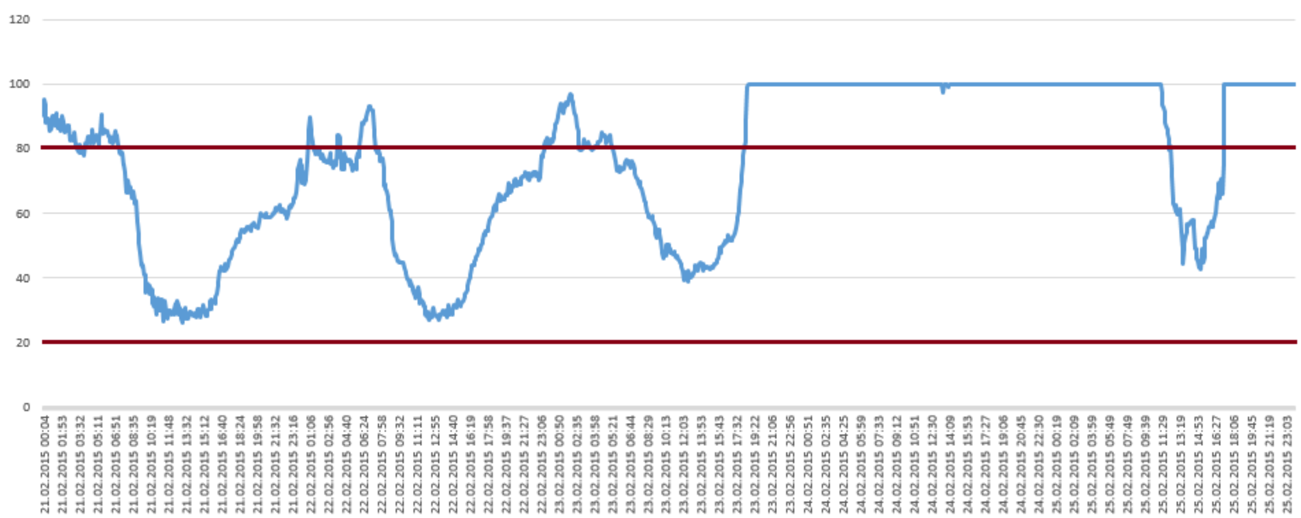

Figure 21. Relative humidity chart

Conclusion and Discussion

During field experiments, some problems occurred. Some wrong records were recorded because of the EMI of power source. Salt deposition on the probes of soil wetness sensor and thus inaccurate measurements were observed.

Total SMS loss was identified as 0.5 %. This amount of SMS loss is acceptable according to Tseng et al.(2006).

Missing records on the remote server were not consecutive and were negligible (1.8 %).

Suggestions

The enclosure of the system has to be water, dust and UV resistant. Also a Faraday cage around the system can be helpful to block EMI from power source and weather according to Rafique et al.(2012).

Soil wetness sensor is insufficient to use in a system like this. A more practical probe should use AC measuring current and use corrosion resistant probes. It should be calibrated for soil moisture.

Since data are recorded on a remote server, mobile phone applications are easy to develop and helps real-time monitoring.

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