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A Long-range Context-aware Platform Design For Rural Monitoring With IoT In Precision Agriculture

D. Taşkın, S. Yazar

Deniz Taşkın
Department of Computer Engineering
Trakya University, Turkey
Ahmet Karadeniz Yerleşkesi, Edirne, 22030, Turkey
deniztaskin@trakya.edu.tr

Selçuk YAZAR*
Department of Computer Engineering
Trakya University, Turkey
Ahmet Karadeniz Yerleşkesi, Edirne, 22030, Turkey
*Corresponding author: selcukyazar@trakya.edu.tr

Abstract

The Internet of Things (IoT) applications has been developing greatly in recent years to solve communication problems, especially in rural areas. Within the IoT, the context-awareness paradigm, especially in precision agricultural practices, has come to a state of the planning of production time. As smart cities approach, the smart environment approach also increases its place in IoT applications and has dominated research in recent years in literature. In this study, soil and environmental information were collected in 17 km diameter in rural area with developed Long Range (LoRa) based context-aware platform. With the developed sensor and actuator control unit, soil moisture at 5 cm and 30 cm depth and soil surface temperature information were collected and the communication performance was investigated. During the study, the performance measurements of the developed Serial Peripheral Interface (SPI) enabled Long Range Wide Area Network (LoRaWAN) gateway were also performed.

Keywords: Internet of things, context-awareness, LoRa, precision agriculture, rural monitoring.

1 Introduction

IoT is a network of physical devices that are connected to the Internet and are able to talk to each other. Some predictions are there will be over 25 billion devices connected to the Internet by 2020. There are many types of wireless technologies to connect these devices to the Internet, such as Short-range wireless, Cellular, and Low Power Wide Area Network (LPWAN) communication. LPWAN is designed for sending small data packages over long distances, operation on a battery. There are several

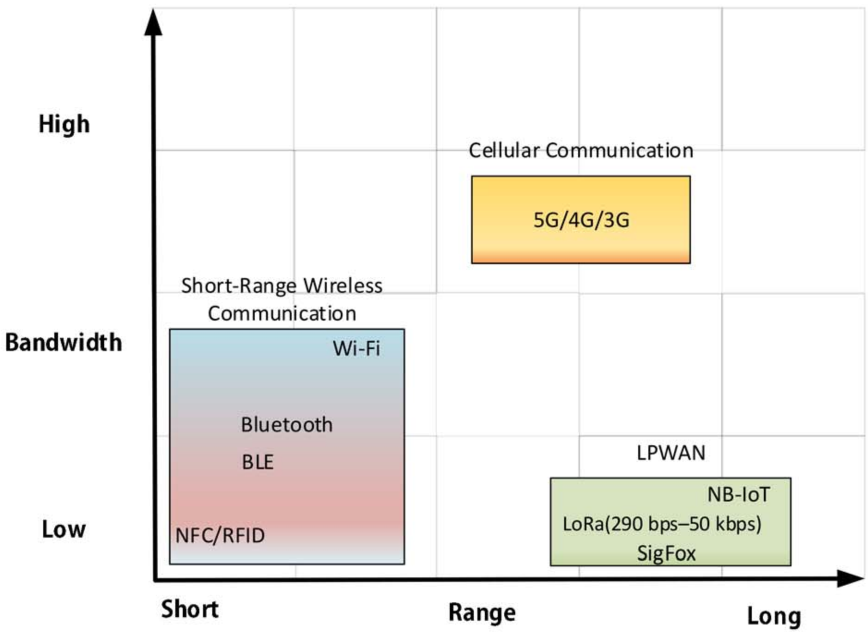

Figure 1: IoT wireless connectivity technologies.

competing technologies in the LPWAN space such as Narrowband IoT, SigFox and LoRa. Range and bandwidth relations of wireless technologies shown in Figure 1.

An important field of study where IoT promises plenty of potentials in agricultural engineering applications. Distributed sensors and actuators have increasing importance in such applications. In these applications, sensors are used as in-situ or proximal detection devices directly next to agricultural lands. Naturally, however, the size and geographical location of these areas accommodate difficulties for sensor and actuator communication. Besides, energy-efficient components, long battery life, and long-distance communication requirements are important for the reliability of agricultural sensors. In most cases, cellular communication is not always healthy due to rural coverage problems. Cellular communication may not be considered the best solution in this regard. Soil and environment in which the sensors work in agricultural applications contain properties that often do not change characteristics. In this case, the data rate requirements of the information, which is transmitted are quite low. These features are not suitable for cellular communication costs. In general, considering low power consumption and long distances, LPWAN communication is a necessity in agricultural applications.

In 2012, LoRa technology developed by Semtech is based on Chirp Spread Spectrum (CSS) modulation. Any Media Access Control (MAC) layer can be used in LoRa. However, the MAC currently proposed is LoRaWAN, which works on the simple star topology principle. Since LoRa works in this topology, data transmission can cover long distances. The gateway used in LoRa communication, which is directly connected to the nodes in the field, is connected to a network backbone structure in the background. The gateway devices are generally capable of providing instantaneous communication of up to 50 nodes. The LoRa modulation technique enables communication around the world at regional ISM frequencies of 430, 433, 868 and 915 MHz. The node devices are divided into three classes according to the use of the MAC layer. These classes and specifications are shown in Table 1.

Table 1: LoRa classes and properties.

Class A (Baseline)	**Class B (Beacon)**	**Class C (Continuous)**
Battery powered sensors or actuators	Battery powered actuators	Mains powered
Most energy efficient	Energy efficient	-
Must be supported by all devices		Continually listen
Downlink after TX	Latency controlled downlink	No Latency for Downlink
EU 868 **EU 434**	**US 915**	**AS 430**

LoRa modulation has six orthogonal spreading factors (SF) ranging from SF7 to SF12. In this way, data can be transmitted in more than one spreading frequency at the same time in the same frequency channel. LoRaWAN gateways could also communicate operating eight different channels at the same time.

Through the MAC used, LoRa/LoRaWAN provides bidirectional communication, end-to-end security and mobility requirements as required by IoT. In LoRaWAN, the data rate ranges vary from 0.3 to 50 kb / s per channel. The general characteristics of LoRa and other LPWAN protocols are shown in Table 2.

Table 2: LoRa and similar LPWAN features.

LPWAN Technologies	LoRa/LoRaWAN	SigFox	NB-IoT
Modulation	CSS	BPSK	QPSK
Frequency	Unlicensed ISM bands (868 MHz in Europe, 915 MHz in North America, and 433 MHz in Asia)	Unlicensed ISM bands (868 MHz in Europe, 915 MHz in North America, and 433 MHz in Asia)	Licensed LTE frequency bands
Max. Data Rate	50 kbps	100 kbps	200 kbps
Max. Payload Length	243 bytes	12 bytes/8 bytes	1600 bytes
Builtin Security	Yes	No	Yes
Standards	LoRa Alliance	Sigfox-based	3GPP
Low Cost	Yes	Yes	Moderate
Low Power Requirements	Yes	Yes	Moderate
Topology	Star-of-Stars Topology	One-Hop Star Topology	Star Topology

Today, there is a wide range of IoT applications using LoRa technology. These can be listed as Energy, Agriculture, Health and Smart city studies. The studies in the field of energy are mostly seen as Smart Grid applications [13]. There are several kinds of research on the use of LoRa in monitoring and directing electricity consumption according to needs. In energy management applications, LoRa wireless communication is a feasible method in such downlink networks to provide remote monitoring and control of devices [24]. Compared to other wireless communication technologies such as Bluetooth, ZigBee, and Wi-Fi, LoRa technology has advantages in terms of low cost and low energy consumption [5, 23]. Together with LoRa, 5G networks can be easily combined in a hybrid structure [17, 25].

Typical IoT applications are also widespread for remote management of medical services in rural areas. LoRa is often preferred in these applications. Within the Ubiquitous Healthcare concept, the instant status of patients can be monitored remotely by using Wireless Body Area Network (WBAN) [7]. In European countries, studies are being carried out, especially to monitor elderly people, Parkinson's patients and people with mental problems [2, 27].

Today Smart city applications are conceivably the most researched area for IoT [1]. Instant monitoring is important to improve the quality of providing services to people in cities. Many commercial applications are still in practice and new ones are constantly being developed. In these studies, subjects such as remote reading of meters, municipal services, public transportation, and waste management are very important where LoRa frequently finds a place. Research opportunities for IoT applications that can be used in smart city scenarios are discussed in [26]. In this study, weaknesses and possible risks are discussed. Surveys about smart city applications and technologies have also been applied.

One of the first examples of smart city applications is the European public lighting project [9]. Similarly, there are studies conducted in the simulation environment for lighting. On the other hand, there are smart campus applications that can be evaluated within smart city applications. The best-known example of smart city applications is the RIGERS project in Bologna, Naville and Saragosa in Italy [18]. In this project, temperature, humidity, lighting, CO2 values of public buildings and some residences were collected through sensors for a year. Currently, the project has reached completion. The data were also collected in the star topology using LoRa and 3G networks [32].

In this study, especially we want to usage area of LoRa applications using in precision agriculture and agricultural engineering practices. Precision agriculture can be defined as a set comprises of the proper agricultural activities and taking advantage of machinery, information technologies to optimize crop by considering variability and difficulties within agricultural systems. With the increasing population in the world, making agricultural production more efficient has become a necessity. It is important to monitor agricultural activities and make decisions based on the data collected. Most researchers and engineers around the world develop numerous monitoring and decision methods with different methods and architectures, taking into account the various crop and yield information. All these studies are transforming the agricultural industry. Technological advances such as wireless networks, ubiquitous computation have changed the classical approach of agricultural applications in particular. These developments have led to the emergence of precision agricultural practices [4, 6, 21]. Some of the precision agriculture practices are automatic irrigation systems [20, 22], fertilization applications [15], pest control [14, 19] and crop, harvest monitoring [16].

The key feature in IoT applications is context-awareness. There is a wide range of applications within the concept of context-awareness. All the IoT-based studies that we have just mentioned can be considered in this feature. Developing strategies related to this concept first came up in 2016 [3]. In this study, they developed an approach for collecting the data obtained in areas close to each other. In general, agricultural applications are based on transmitting data of a commercially produced sensor and actuator components with a particular topology. Commercial sensor types are numerous and frequently used. This sensor data is collected at specific centers with the help of a base station. The collected data provide linear information as a function of time. In the context-awareness approach, there is more to collecting and storing data. Mainly automatic irrigation systems and fertilization systems are sample context-aware application examples. Related automated solutions used in precision agriculture applications often include big-data analysis and artificial intelligence applications. In this study, an alternative application model for sensor and Infrastructure layers is introduced in context-awareness. The IaaS (Infrastructure as service) layer has been transferred to the localized LoRa Gateway in particular directions.

2 Implementation of the sensor layer.

In this work, we developed a sensor and actuator controller unit (SACU) in the sensor layer with a microprocessor to measure the conditions of the soil and the environment. SACU measures the temperature and humidity of the soil and air in the area where it is located. In SACU design, it is provided to turn on and off devices such as the water pump by using an optional relay.

The SACUs we use in the field are class A and are only responsible for transmitting data. On the other hand, the units that also include an actuator operate in class B. We did not use any C class SACU in the field because of power consumption increases in this case. The design of the platform is shown in Figure 2.

We used Espressive ESP32 open-source microcontroller to use peripheral devices on SACU [28]. ESP32 is a powerful component for IoT applications in the field with low cost and low power support. It has built-in Bluetooth and Wi-Fi support. There are 36 GPIOs on the ESP32 and 14 of these ports have Analog to Digital converters. In this study, the temperature and humidity values of the environment are measured by DHT22 temperature and humidity sensor on SACU. With SACU, the SEN0193 capacitive soil moisture sensor is used to measure soil moisture at a depth of 5cm and 30cm. The soil moisture sensor is analog. It operates in a range of $3.3 \sim 3.5$ V and performs real-time humidity measurement. The probe that will measure at 30 cm is sealed with Plexi after the connection is made to prevent it from being affected by moisture conditions in the soil. MLX90614 non-contact thermometer sensor is used to measure soil surface temperature in SACUs. This sensor can also measure the ambient temperature if desired.

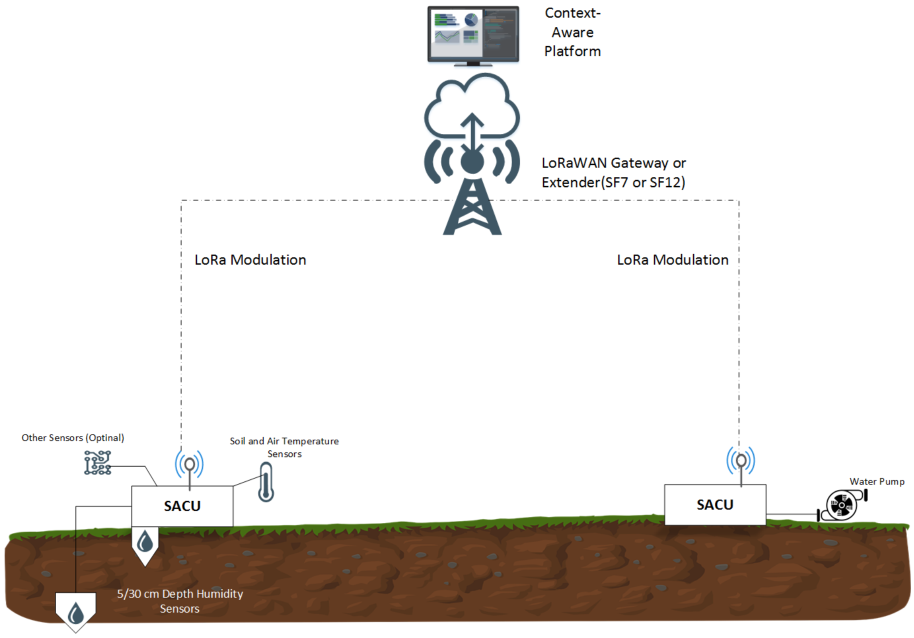

Figure 2: The workflow of the platform that we designed.

Heat diffusion in the soil depends on the mineralogical composition of the soil and physical constituents such as water content. Soil temperature should be between 16-18 ° C to plant the seed, especially in vegetable production. In the studies, heat exchange and diffusion do not show any difference at depths higher than 20 cm [12]. In this study, we measured soil surface temperature with SACU. The depth where most vegetable and grain seeds are planted is 5 cm. In this study, we used an approximation for 5cm depth by measuring soil surface temperature [11]. When the soil reaches the appropriate temperature, planting provides an increase in yield close to 10% [10].

In addition, the moisture content in the soil is an important component to be measured. Typically, the amount of moisture in the soil determines the time for irrigation. We used a moisture sensor in SACU, which has a capacitive feature that is resistant against corrosion. Thus, it can be used under the ground for long periods. The measuring unit also measures the moisture value of the soil at a depth of 30 cm with the help of a probe. We have designed for the study SACU is used on the surface of the soil. In this way, LoRa communication is provided to be more robust. In addition, the damage was prevented by agricultural machinery, for being the definite location on the soil. The design components (a,b) and sensor example(c) of SACU are shown in Figure 3.

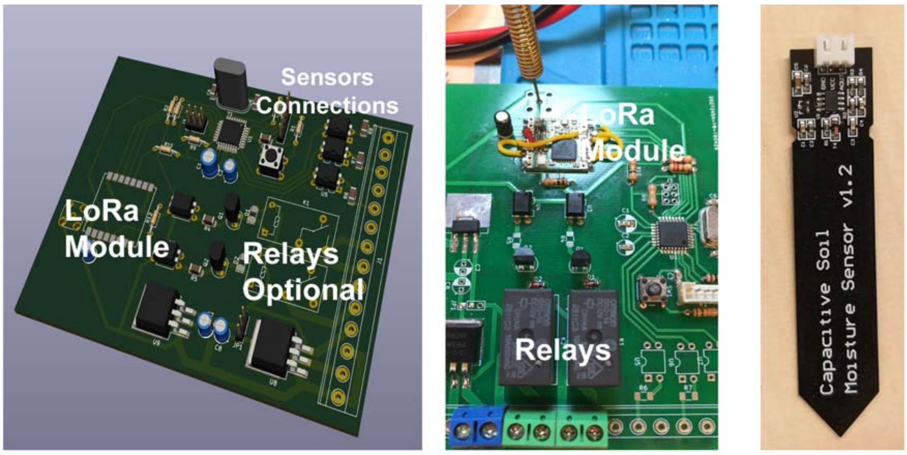

Figure 3: (a) Base SACU and (b) optional relay twin and (c) capacitive soil moisture sensor.

During the study, we used the RFM95 Lora transceiver module on both SACUs and gateways. It uses Semtech technology on these radios but has some improved features. The RFM95 module is an ultra-long distance spread spectrum transmission and interference immunity device while minimizing current consumption. Hope RF's patented LoRa modulation technique provides accuracy over -148 dBm with low-cost materials [30].

There are five environmental contents in the data packages transmitted by SACUs. These are moisture content at 5cm and 30cm depth, soil surface temperature, ambient temperature, and ambient humidity, respectively. The total PHY data packet size is in 5 bytes.

3 Implementation of the infrastructure layer

An important part of LoRa communication is gateways. Together with the LoRaWAN layer, these devices enable data in the field to be carried over the network. The gateway we have developed in this study has an optional LoraWAN layer. First, we used the Gl.6416 OpenWrt enabled device with 64MB of memory with a Qualcomm Atheros 9331 processor in the gateway prototype [31]. We used five GPIO ports on the device to connect the RMPF95 module. The OpenWRT Linux distribution we use for the gateway we developed supports the LoRa libraries. SPI connection can also be supported on the prototype of the gateway device. We used this protocol to communicate and program with the LoRa module in the device we developed. The software developed for the gateway has two features. Optionally, TheThings Network communication infrastructure can be used. However, completely independent of this, network communication is also possible. There is only one RFM95 radio in the prototype device, but there are two radios in the gateway device where we design the PCB. The purpose of the two radios is to allow these gateway devices to collect data from the field and also send data to the field devices for operation. It is also possible to use the second radio to extend the LoRa coverage range in the field. The gateway devices we use to extend the coverage area only communicate long-distance LoRa and do not have a MAC layer. The gateways, which we plan to work as a coverage extender, contain two radio modules with different A and B classes, spreading factors and communication frequencies. Typically, during operation, gateway devices are located at points that are not restricted in terms of electrical supply or are supported by a powerful battery supply. Irrigation devices can be activated from platform software with relays that we use optionally in sensor control units in the field. In the construction of the context-aware network, these options are tailored to the requirements of the application in the field.

The data received on both types of gateways can communicate with the MQTT protocol or REST-full service directly thanks to the developed firmware software. In this study, we preferred bish-bosh MQTT client which can be used in OpenWRT distribution [29]. The gateway prototype(a) and PCB design(b) we designed is shown in Figure 4.

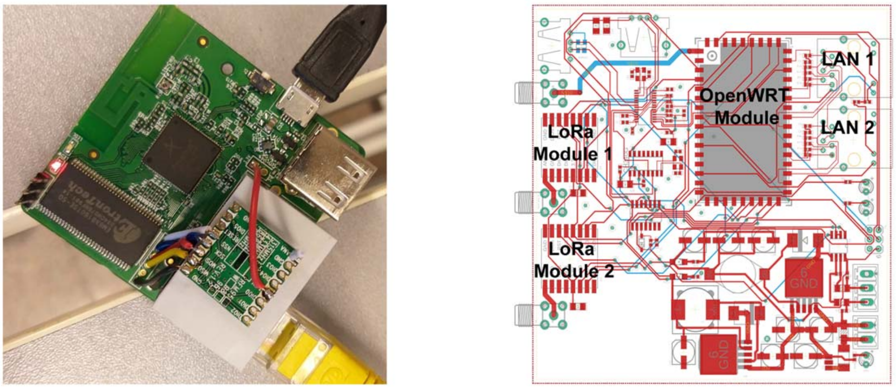

Figure 4: (a) Prototype LoRaWAN gateway and (b) produced PCB Gateway.

4 Results

In this study, we first tried the SACUs and prototype gateway. In these tests, the devices communicated successfully from a distance of 780 m, although they were out of Line-in-sight. We measured dBm, SNR and data loss values during communication between devices. Our results are shown in Table 3.

Table 3: Results of the Prototype gateway device and SACU performance for different spreading factors at 868.3 MHz.

SF	RSSI (dBm)	SNR	Loss (%)
SF7	-116,3	-5.8	1,2
SF12	-119,3	-7,4	3,6

After our prototype gateway trials, we tested the PCB gateway device, which we had built. During this test, according to the results of the previous experiment, we increased the antenna strength in the prototype gateway and made a signal enhancement with the improvements we made in the firmware software installed in SACU. In our tests outside the province of Edirne/Turkey (41° 44' N - 26° 38' E), gateway and SACUS communicated successfully with each other at a distance of 8.52 km. The dBm, SNR, and data loss values obtained during tests are shown in Table 4.

Table 4: Results of the PCB gateway device and SACU performance for different spreading factors at 868.3 MHz in rural.

SF	RSSI (dBm)	SNR	Loss (%)
SF7	-105,4	-6.1	1,8
SF12	-120,1	-8,4	4,4

We had produced a total of five SACUs for this study. We also performed performance measurements while transferring the data obtained from 5 SACUs that we placed on the field for testing with the gateway. To carry out these tests, we placed SACU units at a distance of 7 and 8 km from the territory where we will measure. As a performance criterion, we measured how much data from field devices is transferred to the platform software we developed over the network. We compared the data we collected for 24 days from the log records stored on the gateway device. We found that the rate of loss here was 2.6%. The distances of our measurements in rural are shown in Figure 5.

In our study, we had the opportunity to compare the measured values with a similar study. In the study we compared, there are communication values obtained by burying LoRa devices in the soil. We have compared the results obtained in terms of communication distance and efficiency, even though there is a difference in application. The comparison results are shown in Table 5.

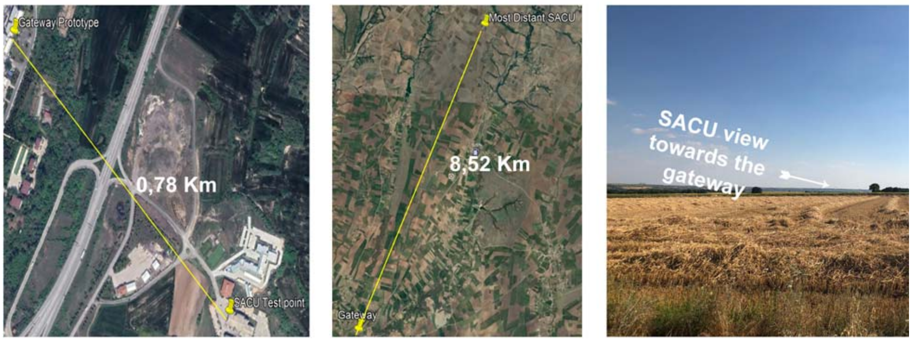

Figure 5: Prototype gateway (a) and PCG gateway (b) communication ranges during the study. Most distant SACU view with line-in-sight 8,52 km away (c).

Table 5: The comparisons of the previous study with test results (SF7)

	Distance	**RSSI for Depth (0 - 10 cm)**	**SNR for Depth (0-10cm)**
Grunwald et al. [8]	40 m / 350 m	-81,2 / -87,5 dBm	9,1 / 8,8
Our Proposal	780 m / 8520 m	-116 dBm	5,8 / 6,1

Since the SACUs we used in the field were standing on the soil surface, we healthily took 5cm and 30cm measurements. All the soil moisture and temperature values we collected in the field were shown on the web interface via Ordinary Kriging and Inverse Distance Weighting (IDW) interpolation methods. Here, instead of showing users the values with a line or bar graphs, we aimed to show the possible values on the terrain in a way to make predictions. These interpolation methods are based on the principle of estimating non-value points using known data obtained in the field. Both methods were adopted to provide alternative viewpoints for agricultural scientists using the software we developed. We used IDW for soil moisture values and Ordinary Kriging for temperature values. The awareness views from the data we obtained are shown in Figure 6.

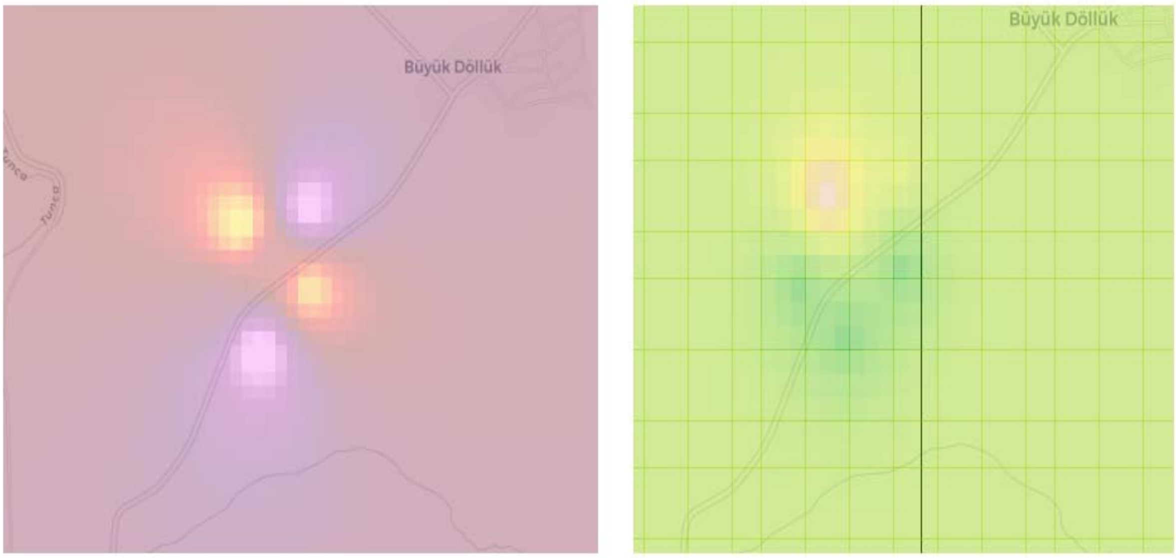

Figure 6: Sample awareness views for soil moisture (a) and soil temperatures (b) with using IDW and Ordinary Kriging interpolation methods in order.

5 Conclusions

Today, one of the areas where the Internet of Things is frequently used is agricultural practices. In general, IoT applications collect the data produced at a central point and present it to the users. Nevertheless, the data produced should be transformed into information and used more effectively in decision support systems. The context-awareness approach puts that environmental data collection is required not only in decision support systems but also in business intelligence applications. Our study is aimed at knowing the instant state of the components of the producers to make the food production process more efficient rather than automating the processes such as irrigation and fertilization according to the threshold of specific values only in the cultivated areas. In this respect, it is an essential effort to present the processes such as irrigation, fertilization, and pest control to the producers with analytical methods and data produced in the field. In the near future, if it is predicted that the use of robots in agriculture will now become commonplace, it is clear that the use of analyzed information instead of raw data in machine communication will provide a very compelling solution in the field of food production.

The areas we hope to improve in this study can be said that the antenna power of the SACUs and the gateway device play a more productive role in decision-making. Increasing the power of communication will allow more areas to be monitored and the momentary status of these fields in terms of agricultural production will be known. In the gateway device, we have developed, it is important for certain processes to be realized automatically, thanks to modeled methods, without human intervention in the management center, and to intervene on the spot immediately. This approach will also minimize crop losses.

With the prolongation of the time we collect data during this study, we plan to improve it for using the Recurrent Neural Network (RNN) approach instead of the interpolation methods we use. It will be an important effort to develop a stronger platform by establishing context-awareness and artificial intelligence relationships with the RNN approach.

Author contributions

The authors contributed equally to this work.

Conflict of interest

The authors declare no conflict of interest.

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