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Research Paper

Low-cost Edge Computing devices and novel user interfaces for monitoring pivot irrigation systems based on Internet of Things and LoRaWAN technologies

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The increase in irrigated crop areas, especially in countries such as Spain and Italy, has led to an increase in technological solutions for monitoring the irrigation. Furthermore, the centre pivot irrigation systems used in these crops have facilitated the daily work of farmers in recent years, however, the monitoring of these systems and the reporting of problems in their operation has become a key aspect during the growing season. For this reason, different monitoring solutions have been proposed from the area of Precision Agriculture and Information and Communication Technologies (ICTs). Nevertheless, it is necessary that these solutions take into account the digital divide their potential users may suffer and be low-cost solutions in order to be attractive to the end-users. This paper presents several low-cost solutions using novel user interfaces and wireless communication technologies for the monitoring of this type of irrigation systems. This paper presents the results obtained after the deployment of the proposed systems on a real environment and the main conclusions drawn after their use in irrigated maize crops.

1. Introduction

According to a Eurostat study (Augère-Granier, 2016) South European countries, and in particular Spain and Italy, are the nations with the most irrigated agricultural areas with farmers investing in more efficient irrigation systems such as centre pivot irrigation systems. These systems can be automated (Rusu & Simionescu, 2016) and facilitate the farmers'

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Nomenclature

3D	Three-dimensional
3G	Third generation
4G	Fourth generation
AMR	Automatic meter reading
API	Application programming interface
AT	Attention
ICTs	Information and communication technologies
IoT	Internet of things
IPAs	Intelligent personal assistants
GPRS	General packet radio service
GPS	Global positioning system
gRPC	g remote procedure calls
HTTP	Hypertext transfer protocol
LED	Light-emitting diode
LoRa	Long range
LoRaWAN	Long range wide area network
LPWANs	Low power wide area networks
LTE	Long-term evolution
MAE	Mean absolute error
NB-IoT	Narrowband-internet of things
OCR	Optical character recognition
PWA	Progressive web application
REST	Representational state transfer
RSSI	Receiver signal strength indicator
SMA	Sub miniature version A
SNR	Signal to noise ratio
TTN	The things network
UART	Universal asynchronous receiver transmitter
UDP	User datagram protocol
Wi-Fi	Wireless-fidelity
YOLO	You only look once

daily work whilst ensuring a high degree of irrigation uniformity in the fields. Nevertheless, these systems are not infallible, and errors occur during operation. Among the issues that can occur in these irrigation systems is their ceasing to operate due to lack of water pressure or electrical outages. These situations can be a problem for farmers with a restrictive irrigation timetable since they may miss their available irrigation slot. Another common problem that can occur is the pivot's path becoming obstructed for some reason. This can cause a security stop of the pivot, halting its operation for several hours.

Consequently, studies have proposed several solutions for monitoring pivot irrigation systems and notifying farmers when a problem occurs. Most of the solutions require GPRS communication in order to operate which involves a good operator coverage in the area where the crop is located. As a result, new low power wide area networks (LPWANs) have emerged that can provide long communication range and low power consumption.

Moreover, current irrigation monitoring systems do not take into account those from older generations who may suffer the effects of the digital divide due to their age (as well as due to other factors). According to a report (European Comission, 2017) European Union has a ratio of ‘young to old farmers’ of 0.18, indicating a farming community with an older age profile. In countries such as Portugal, Spain this ratio can be even worst with a ratio <0.1. For these reasons, monitoring tools should have friendly interfaces that users with little ICT knowledge can easily use. In this work we propose to use novel user interfaces such as chat bots (used in social networks like Telegram) and voice assistants to interact with the proposed monitoring systems in a friendly way for this population.

The present work reviews irrigation systems automation, the communication techniques developed in these systems and several low-cost monitoring systems for pivot irrigation are presented. The proposed systems use GPS localisation (Matilla et al., 2020), LoRaWAN communication and Edge computing technologies for monitoring several variables related to pivot operation (position and direction) and others regarding water consumption and pressure. Furthermore, the proposed systems employed new user interfaces such as voice assistants and chat bots in order to make easier the access to people who suffer the digital divide effects.

All the systems have been deployed in two different fields with centre pivot irrigation systems to evaluate their efficiency. The results obtained are illustrated and explained to evaluate the advantages and drawbacks of the proposed systems.

1.1. *Background*

The monitoring of pivot irrigation involves different technologies and aspects. In this section the current systems and works are presented.

1.1.1. *Crop irrigation systems*

Three different irrigation systems are mainly used in farming (Persons & Morris, 2019):

1. Gravity: the crop area is flooded, and gravity distributes the water over the crop with furrows.
2. Micro-irrigation: also called localised irrigation, low volume irrigation or drip irrigation. These systems irrigate the field with little water spread over the farming plants.
3. Sprinkler systems: pressure is used to spray water through nozzles across fields to form a spray pattern creating artificial precipitation. Several subtypes exist:
    (a) Centre pivot sprinklers: they are fixed to a metallic frame with wheels that rotates over a fixed central point able to irrigate circle areas.
    (b) Linear move tower sprinklers: they move themselves in straight line and they irrigated a rectangular area.
    (c) Wheel-move irrigation systems, also known as wheel line, side roll, or lateral roll system. This is a mechanical irrigation system which can be moved from one part of the field to another and it consist of an engine and a lateral pipe equipped with several sprinklers and wheels.
    (d) Fixed set sprinklers: they are permanently connected to a pipe located over or under the ground to distribute the irrigation uniformly.

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Table 1 – Several of the current pivot centre monitoring solutions based on GPS in the market.

Solution	Mobile application	Voice Assistant interface	Communication Technology	Cost[a]
AgSense (Valmont)	Yes	No	GPRS	High
FieldNet (Pivot Watch)	Yes	No	GPRS	Low
Raindancer	Yes	No	GPRS	Medium
RainLoc (Otech)	Yes	No	GPRS	Medium

[a] Low (350–700 US $) Medium (700–1400 US $) High (>1500 US $).

This work focusses on the use of sensors to monitor the running of subtype (3). This is sprinkler systems such as linear or centre pivots. Several works have been already presented by other authors such as (Abioye et al., 2020) and (Capraro et al., 2018). Furthermore, commercials solutions have been launched on the market such as AgSense from Valmont company (Valley Irrigation, 2020) and FieldNET from Lindsay (Lindsay, 2020) among others (Rainloc, 2021; Raindancer, 2021).

These solutions allow to monitor the pivots and different variables such as the position of the pivot, water pressure or the irrigation rate. In the variable rate irrigation (VRI) (Mendes et al., 2019), the amount of irrigation in each section is controlled using the GPS and varying the speed of the pivot's movement.

However, these types of solutions are, in general, very expensive for farmers and in some cases, they can present issues due to the low or ineffective signals in the field. These solutions can also be difficult to use for those farmers that suffers the effect of digital divide. The following Table 1 shows the main features of current available GPS based solutions in the market as well as our system features.

1.1.2. *Communication technologies*

The irrigation systems and the presented solutions need a communication technology to transmit the collected data. Table 2 shows the most important wireless communication technologies used to transmit data obtained from pivot sensors during operation.

- Wi-Fi: it is possible to establish a Wi-Fi link from the pivot to a router which provides the Internet connection. This technology is useful when the crop is close to the router zone and the sensors have access to an electrical network. Its main disadvantage is high-power consumption and the low availability of this communication technology near to crops.
- GPRS/3G/LTE: This network system is the most commonly used in commercial solutions. It is possible to provide connectivity to the pivot sensors via a network card and a GPRS module. However, it also has some disadvantages; the high-power consumption in these modules is something to take into account when designing a system. Many crop fields do not have neighbouring energy supply and/or they may not have a good quality network coverage. Another important factor is the cost of every network card needed for the proper deployment of the system. Moreover, many of these systems still use SMS to notify users and this could increase the final cost.
- LPWANs: Low Power Wide Area Networks are specialised networks for long-range communication and low power consumption. These characteristics made them the perfect solution for devices and sensors placed in crop areas that are located far from the village or town and therefore, it is not possible to provide energy supply. The systems transmit the information via the Internet and the communication can be bidirectional. The main disadvantage is that these technologies need a specific network range in the area of deployment. There are several types of LPWANs such as LoRaWAN with an open standard and an infrastructure that can be installed by the farmer him/herself. On the other side, alternatives such as Sigfox or Narrow Band Internet of Things (NB-IoT) used the infrastructure of other network companies. Consequently, they offer a more limited solution than LoRaWAN technology.

1.1.3. *Edge computing and Automatic Meter Reading*

According to Khan et al. (2019), the Edge Computing paradigm is a new concept in the computing ecosystem. This paradigm brings the services and computing power of the Cloud closer to the device located on the “edge” and is characterised by fast application response times and high computational performance.

There are many applications such as surveillance, virtual reality, traffic monitoring or applications that require the implementation of computationally expensive machine learning algorithms which need a fast response time and therefore high computing capacity. Unfortunately, in many cases, the distant cloud facilities will not be able to satisfy these ultra-low latency requirements.

To solve the problem of high bandwidth requirements, other paradigms have emerged, such as Fog Computing (Yousefpour et al., 2019), which aims to fill the gap between Internet of Things (IoT) devices and the cloud by enabling computing, storage, networking and data management in the vicinity of the IoT devices. Both the concept of Fog Computing and Edge Computing shift computing and storage to the edge of the network and close to the end nodes, but they are often confused. For the Open Fog Consortium (IEEE Communications Society, 2018; Open Fog Consortium, 2017) the distinction between Fog Computing and Edge Computing resides in the hierarchical

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Table 2 – Communication technologies for crop irrigation monitoring.

Technology	Range	Power Consumption	Yearly cost	Own Infrastructure
Wi-Fi	2–4 km	High	Low	Yes
GPRS/3G/4G	Coverage[a]	High	High	No
LoraWAN	15 km	Low	Low	Yes
NB-IoT	Coverage[a]	Low	Medium	No
SigFox	Coverage[a]	Low	Medium	No

[a] The coverage depends on the service operator in a specific area.

factor of Fog Computing and the various services it offers such as networking, computing, storage, control and acceleration away from the Cloud, while Edge Computing is more limited concept related to offering computing capacity on the edge.

The literature defines the “edge” of Edge Computing as the local network where the IoT sensors and devices are located, such as a Wi-Fi wireless local area network. But this edge could be a device employing other communications such as LoRaWAN or NB-IoT.

Therefore, the main advantages of using this paradigm in the design of architectures and software solutions (Baktir et al., 2017) for this work are (1) the position change of move the computation needed to run machine learning algorithms to on the edge, (2) the reduction of the network traffic and dependence on a good connection and (3) the improvement of privacy by avoiding the transmission of sensitive data (such as photos or videos) to the Cloud.

This allows the deployment of solutions in isolated environments such as irrigated crops and avoiding the transmission of big amounts of data to the Cloud, performing the required computations on the edge and sending only the minimum data needed.

This paradigm is the most suitable for the area of Automatic Meter Reading (AMR) (Khalifa et al., 2011). This area focuses on the automation of electricity, gas or water meters offering many advantages including the possibility of automatic reporting and avoiding the need for staff in charge of visit each meter to obtain current values. In addition, this automation enables notifying the user if the pattern in the consumption abruptly changes.

Regarding to how automation is done, this can be performed on the measuring device itself or on an external device that is attached to a conventional measuring device. Depending on the meter, these devices could have an external communication interface such as a pulse emitter, however the oldest ones only have digital counters together with needle counters. The last ones can be automated by employing of computer vision techniques. Recent studies such as (Laroca et al., 2019; Vo et al., 2020) have exploited the capability of machine learning techniques such as Optical Character Recognition (OCR) along with advanced deep learning models such as YOLO (Salomon et al., 2020) to build devices that attach to conventional meters and can read their signals (Fig. 1). This can be costly if the device which use these techniques is expensive and it may not be cost-effective to apply such a device to an old meter.

However, the recent advances in the field of quantisation of machine learning models (David et al., 2020) have allowed these models to be integrated into hardware with very limited computational capabilities in terms of memory and computational capacity. This makes it possible to include machine learning models which can recognize the characters of a meter in very low-cost electronic devices such as ESP32-CAM (Ai-Thinker Co., Shenzhen, China) (AI Thinker, 2020).

In this work we propose a solution employing a low-cost Edge Computing device which uses machine learning models and LoRaWAN communication for monitoring the current water consumption of each crop.

1.1.4. *Chat bots and voice assistants as user interfaces*

According to the European Commission (European Commission, 2017), many of the farmers who will use these systems for irrigation monitoring are very likely to be relatively old, where the digital divide due to age (in addition to other factors) may become a problem when interacting with software applications.

To overcome this digital divide, new user interfaces such as voice assistants or chat bots which are used in instant messaging applications such as WhatsApp or Telegram are being proposed.

In the case of chat bots, the user can interact with the messaging application by exchanging a series of commands in a chat conversation with a bot. This allows the user to get the requested information about the system or to be notified by the chat bot if certain conditions are met. Work such as that of (Sisyanto et al., 2017) proposes its use for monitoring different crops, in this case a hydroponics system.

Voice Assistants or Intelligent Personal Assistants (IPAs), are a software which employs a verbal or multimedia communication interface to the user and uses several techniques such as natural language processing, dialogue systems and speech synthesis. The interaction with the user is similar to that of chat bots, but in this case only voice is required. This is a point that significantly facilitates interaction with people who have had very little contact with ICTs, since with a simple keyword the user can start a conversation with the assistant and it will guide him to provide him with the information he needs. Works such as that of (Taib et al., 2020) propose this type of system for monitoring the temperature and humidity conditions of an indoor garden.

In this work we propose to explore these novel communication interfaces integrated in low-cost systems, aiming to improve the accessibility of irrigation monitoring systems to farmers who may suffer from the effects of the digital divide.

2. Material and methods

This section presents a series of systems based on low-cost IoT devices that employ the Edge Computing paradigm and new communication technologies and user interfaces such as

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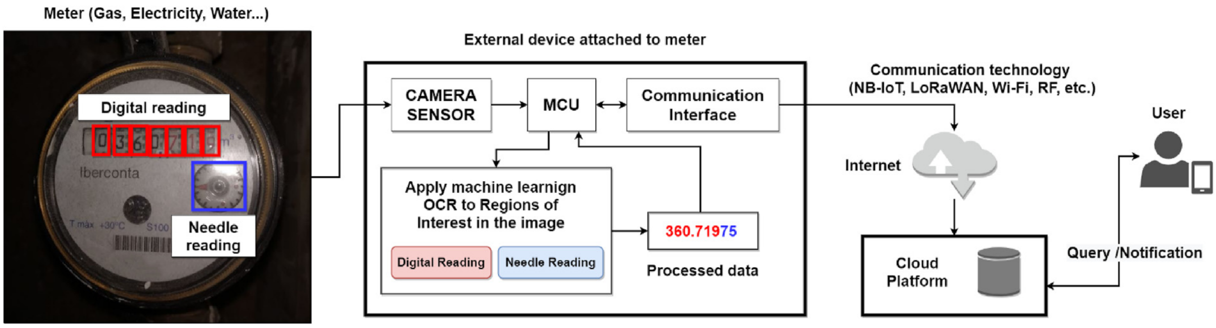

Fig. 1 – Automatic Meter Reading process by OCR device

chat bots or voice assistants. These systems are aimed to monitor several variables in the irrigation system such as the water consumption in the crop, the control panel of the centre pivot and finally the position of the pivot. The following sections describe each of them.

2.1. Centre pivot monitoring based on a LoRaWAN sensor and a Telegram Bot

This system consists of a Telegram Bot, a LoRaWAN sensor and cloud services for monitoring the irrigation of a central pivot. The objective of this conversational bot is, on one hand, to report to the farmer on demand the state of the pivot and on the other to notify the farmer in case of a change in its operation, such as an unexpected stop.

2.1.1. System architecture

Figure 2 shows a schematic diagram of the system architecture and the communication between each of its components.

The first component of the system (A of Fig. 2) is a sensor LoRaWAN responsible for monitoring the status of the pivot, this will be described in detail in the next section. This sensor communicates with The Things Network (TTN) (Things Network, 2020) platform, a LoRaWAN platform (B of Fig. 2) with a collaborative approach: the TTN gateways deployed by the users of this platform are shared with the rest of the users and the applications deployed on this platform can use any gateway registered on it. This allows the LoRaWAN infrastructure to grow collaboratively among all the users being this coverage increasing all over the world. However, there are open source alternatives to this platform such as ChirpStack (ChirpStack, 2020) for a totally proprietary deployment. Therefore, the status of the pivot is transmitted by the sensor through the gateways near it. These gateways have the task of relaying received messages to TTN via UDP or gRPC communication. Once the message arrives in TTN it is linked to a device registered in this platform which is associated with an application. In this application, it is then possible to register different integrations which facilitate the communication of this platform with external systems. Two of these integrations are: (1) the storage integration, which allows the storage of messages received which can be consulted through a REST API, and (2) the HTTP Integration, which is a service that supports establishing a webhook that makes a POST request to an established endpoint every time a new message arrives from a LoRaWAN sensor.

Another component of the system is a Telegram Bot developed using its programming API and deployed in the Heroku Cloud (Heroku, 2020). In this conversational bot, two endpoints have been established to receive the transmitted message data from (1) the HTTP integration of TTN and (2) to receive the messages from Telegram sent by users to the bot (C of Fig. 2). At the same time, this bot communicates with TTN Storage integration service to retrieve the last pivot

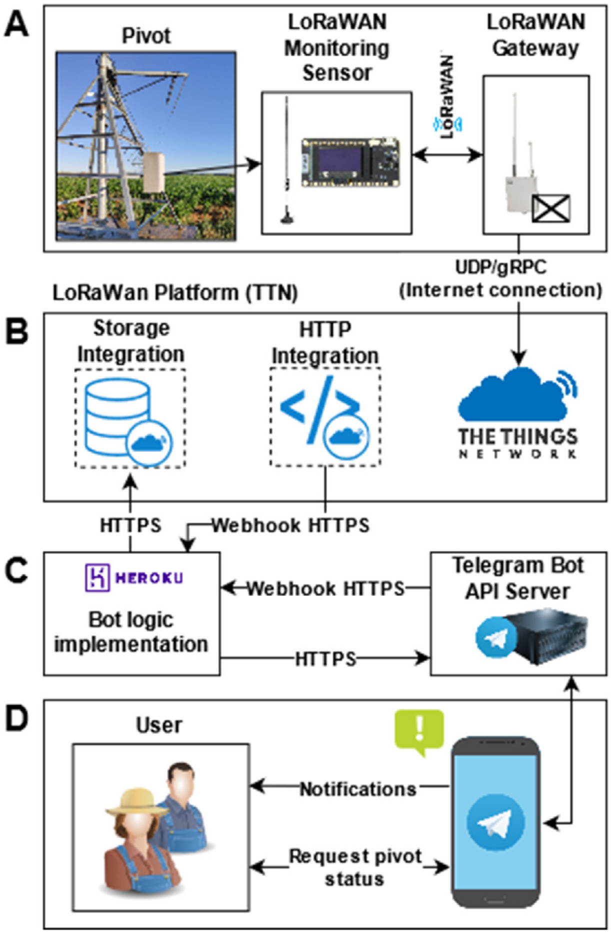

Fig. 2 – Telegram Bot system architecture.

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status when it is requested by the user. Finally, Fig. 2 (D) shows how users can communicate with the Telegram Bot by simply looking for it in the application and establishing a conversation with it. It is possible to request the current status of the pivot through a predefined message and then the bot will query the last available information and will only answer to those authorized users. It will also notify through a message the relevant changes in the operation of the pivot. The pivot implementation is totally stateless which is suitable for a free Heroku cloud plan as it can turn this bot off after 24 h of inactivity. If later the activity was resumed, a new fresh instance of the bot would be started by Heroku and would continue its normal operation since the persistence of information is available at TTN Storage integration.

2.1.2. *Control panel LoRaWAN Monitoring Sensor*

For the monitoring of the pivot status, a prototype LoRaWAN sensor has been designed to check the status of the current electronics installed in the pivot control panel. The pivot employed in the system implementation has been an Otech ST127-ep3 (2010) (OTECH S.A.S., Puyoô, France) (Otech et al., 2020; Riegos del Duero, 2010) with a control panel that allows to identify through LED indicators the pivot's movement to the right or left direction and to identify the moving/stop states through the pressure and safety LED indicators. In order not to interfere with the currently installed electronics, the status of the panel's LEDs has been monitored using an optocoupler (al-zard dst-1r8p-p, icstation.com, Shenzen, China). This completely isolates the electronics from the pivot with the electronics installed for monitoring. This optocoupler will provide 3.3 V digital outputs indicating the status of each of the LEDs (24 V) without interfering with their operation. For the implementation of the LoRaWAN sensor, a development board based on the ESP32 microcontroller and the LoRa Semtech SX1276 module has been used, specifically (TTGO LoRa32 V2.0, Lilygo, Shenzhen Xin Yuan Electronic Technology Co., Shenzhen, China). A diagram of the connections and installation of the prototype is shown in Fig. 3.

The operation of the sensor is straightforward, using the digital outputs of the optocoupler to obtain the current status of the central pivot based on its LED indicators. On the control panel of the pivot used (Fig. 3 left) it is possible to find the indicators: Right Movement, Left Movement, Safety and Pressure, which are monitored with the LoRaWAN sensor. The antenna is located on the outside of the control panel and connected to the module via an SMA connector.

The non-intrusive aspect of this approach allows this same system to be installed in other models of pivot control panel where information of the operation of the pivot is provided to the user by means of LED indicators.

2.2. *PWA for monitoring crops via GPS sensors based on LoRaWAN or GPRS communication*

This system uses both GPS sensors employing LPWAN or GPRS connectivity in the same system which allows to register both the crops and the GPS devices attached to the pivots and therefore to notify of their activity in real time. This system, unlike earlier systems, is completely nonintrusive and can be installed in any pivot independently of its hardware.

2.2.1. *System architecture*

Figure 4 shows a diagram of the proposed system architecture. The system is based on the use of two types of GPS sensors: the first ones are based on LoRaWAN communication and the second ones on GPRS communication.

In the case of LoRaWAN sensors the messages are sent as in the previous system, via TTN's HTTP integration. Regarding GPRS-based GPS sensors, the Traccar platform (Traccar, 2020) has been used. This open-source platform is designed to integrate different compatible GPS trackers and supports a multitude of protocols of the different device brands available on the market. Also, this platform allows forwarding the measurements of the devices registered on it to other platforms. With these two subsystems, it is possible to receive the information from the GPS sensors in the platform developed in this work called MiFincapp.

This platform is made up of different elements, the main ones being: (1) a set of cloud functions that act as endpoints to receive measurements from Traccar and TTN via HTTP requests, (2) a Firestore real-time database where the platform information is stored, (3) a Progressive Web App (PWA) with which users can register their crops, pivots, and deployed devices and thus monitor the movement of the pivots and (4) a Google Action which enables user to query this information employing uniquely voice conversation with different devices such as speakers, smart TV, smart displays or any other device which implements Google Assistant.

2.3. *Edge Computing device for monitoring water consumption at the hydrant of the crop*

This section presents a system for monitoring the hydrants located in each of the parcels. These hydrants are used by irrigation communities to control the water consumed on each crop. In the case where the equipment is modern, these hydrants have pulse meters that can be used to read and capture the information as they do in the work of Chazarra-Zapata et al. (2020).

However, older hydrants may not have automatic metering and must be checked periodically and many of them are also not accessible to crop owners. Farmers often include their own meters to check the water consumption of their own crops, although they usually use meters that do not have any kind of connectivity and must be checked periodically on the farm.

The proposed prototype is based on a low-cost device based on the ESP32-CAM microcontroller which is equipped with a camera capable of taking pictures of the existing water meter and processing the image to obtain the current measurement.

The process of obtaining the current measurement from the image is performed on the device itself without the need for connection to a cloud service that performs this procedure. This allows sending the measurement information already

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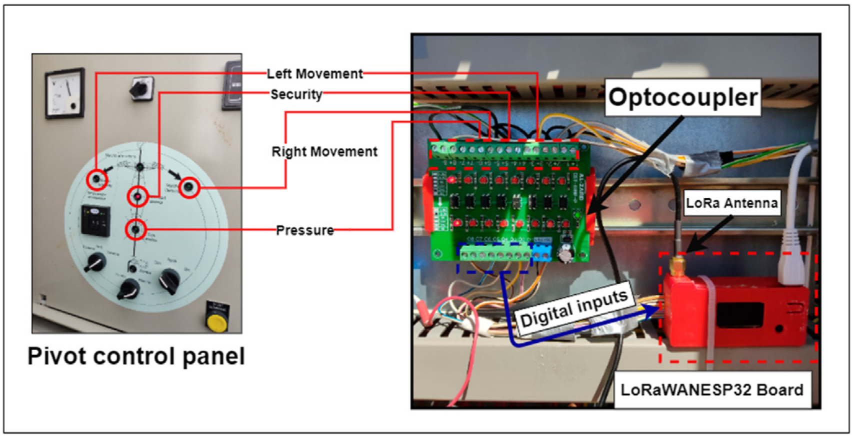

Fig. 3 – LoRaWAN monitoring sensor.

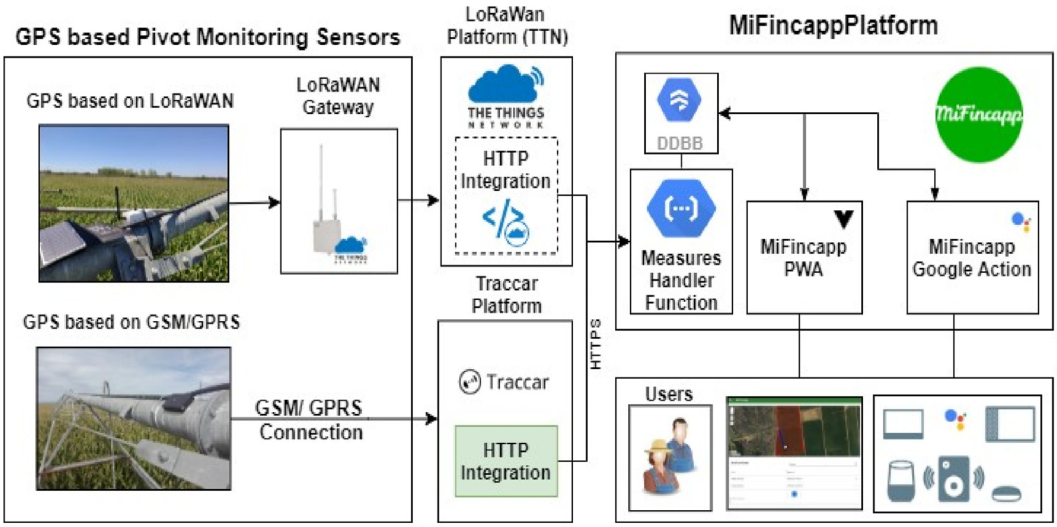

Fig. 4 – System Architecture of the PWA for monitoring crops via GPS sensors based on LoRaWAN or GPRS communication.

processed at the edge with communication technologies such as LoRaWAN to the MiFincapp platform, as was the case with previous LoRaWAN GPS devices.

2.3.1. *Automatic water meter reading prototype*

A diagram of the prototype sensor with its main parts is shown in the upper right s of Fig. 5. In addition, the diagram shows the placement of this sensor in a 3D box that would be applied on the water meter and the communication of the device with the Mifincapp platform.

The prototype has been developed from different functional modules: (1) ESP32-CAM and (2) RAK811 LoRaWAN module (Shenzhen RAKwireless Technology Co., Shenzhen, China) (RAK Wireless, 2020). The ESP32 Cam part of the prototype is based on the work of Josef Muller (Müller, 2020) but we have replace the communication interface enabling a LoRAWAN communication and we also have modified the machine learning model employed for processing images from digital dials.

Communication between the RAK811 module and the ESP32CAM microcontroller is performed via UART and AT commands. In addition, the ESP32-CAM can be powered by a battery-powered charging module attached to a small solar panel, if no access to electricity is available. The LoRaWAN antenna of the prototype should be placed in a suitable location avoiding obstacles with the gateway to obtain the best possible coverage.

Regarding the meter reading process, the ESP32-CAM microcontroller takes a picture of the water meter and extracts a series of bounding boxes previously configured for that meter. These bounding boxes are processed by machine learning classifier that provides the values for each image, obtaining the actual meter data. This data is then sent periodically through LoRaWAN communication to the TTN platform, where it is redirected to the MiFincapp platform, as was the case with the GPS sensor measurements. Finally, on the platform, this measurement is processed and becomes available to users.

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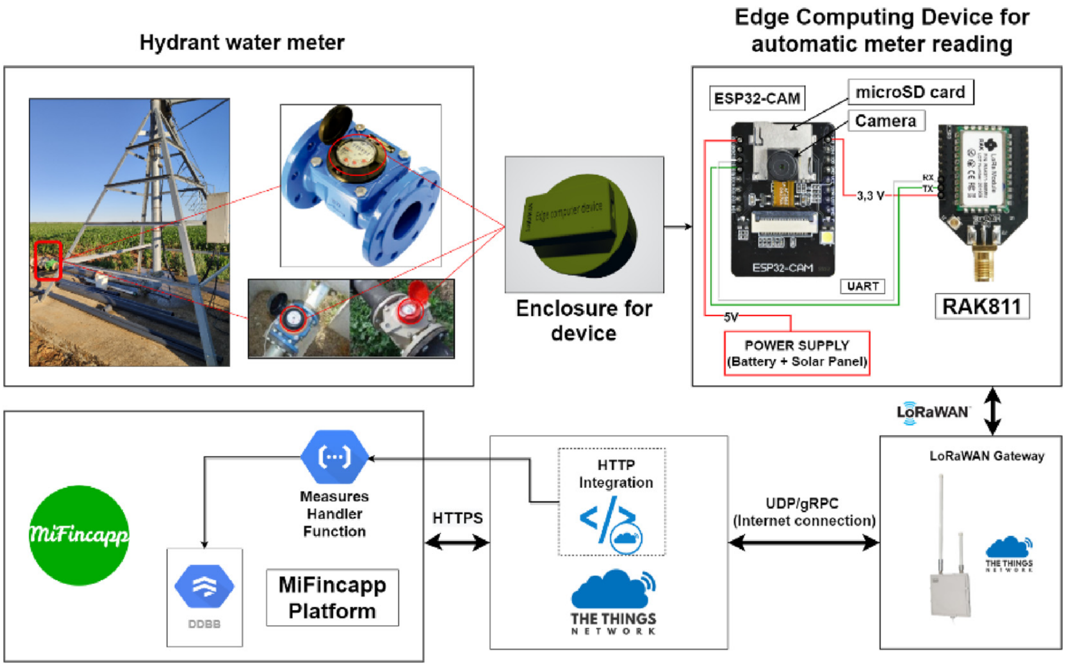

Fig. 5 – Schematic diagram of the proposed Edge Computing device for water metering.

3. Calculation

3.1. *Case study description*

All three previous systems (described in subsections 2.1, 2.2, 2.3) were deployed in two real maize fields equipped with irrigation by central pivot each of them. These maize fields are located in the municipality of Pobladura de Pelayo García, León, Spain.

The Edge Computing device for monitoring water consumption and the Telegram bot monitoring system were deployed in order to monitor a control panel in the pivot irrigation system of field #1.

Two different kind of GPS trackers were deployed in both fields (#1 and #2). The implementation of these two types of GPS sensors (Fig. 6 left) is described below:

1. GPS sensor based on GPRS communication: it uses a commercial GPS tracker called TKStar-915 (TKStar Technology Co., ShenZhen, China), which is compatible with the Traccar platform.
2. GPS sensor based on LoRaWAN communication: it uses two different sensors.
   (a) A prototype based on the TTGO T-Beam development board with an external GPS antenna (Lilygo, Shenzhen Xin Yuan Electronic Technology Co., Shenzhen, China).
   (b) A commercial device called RAK 7200 (Shenzhen RAKwireless Technology Co., Shenzhen, China).

The devices have been registered in the TTN, the Traccar, and the MiFincapp platforms. Also, the sensors have been properly associated with the maize fields as shown in Fig. 6 (right). The different systems are used to validate the monitoring of crop irrigation systems.

4. Results

This section shows the results after the deployment of the three proposed systems implemented in the specified field lands.

4.1. *Results of centre pivot monitoring system based on LoRaWAN sensor and Telegram bot*

The centre pivot control panel was monitored for a month. The monitoring system was active during all the irrigation campaign allowing the farmer to supervise the operation of the pivot.

The Telegram bot solution provided messages to the farmers notifying when the pivot was started, when the pivot status has changed and when the user requested status and information of the pivot. The interactions between the bot and the users are illustrated in Fig. 7.

The left side of the Fig. 7 illustrates the messages that the pivot system sent when it is initialised. The message shows the time and the LED status. There were four different LEDs lights that were associated with different information about the pivot; the LEDs showed if the pivot was off (all LEDs off),

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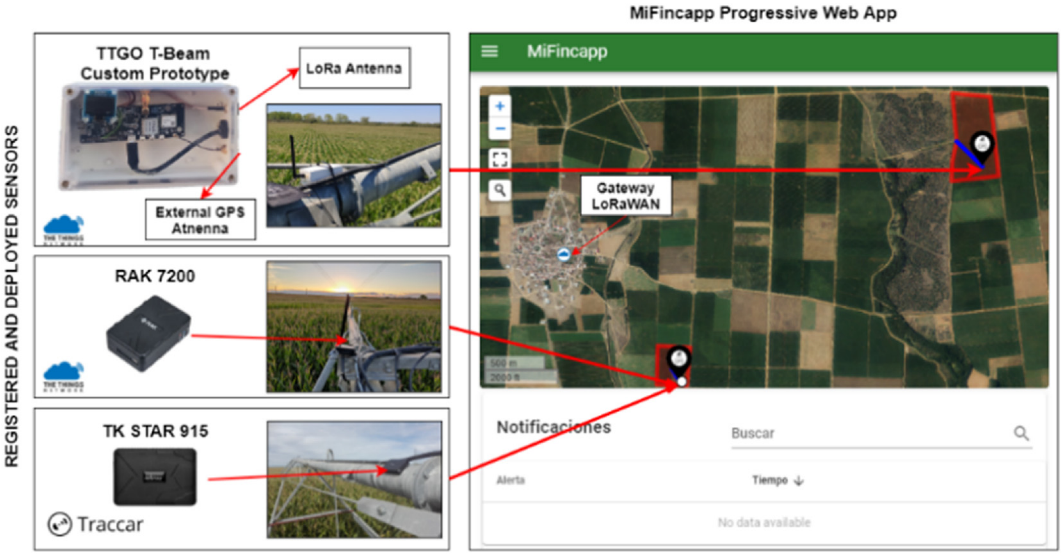
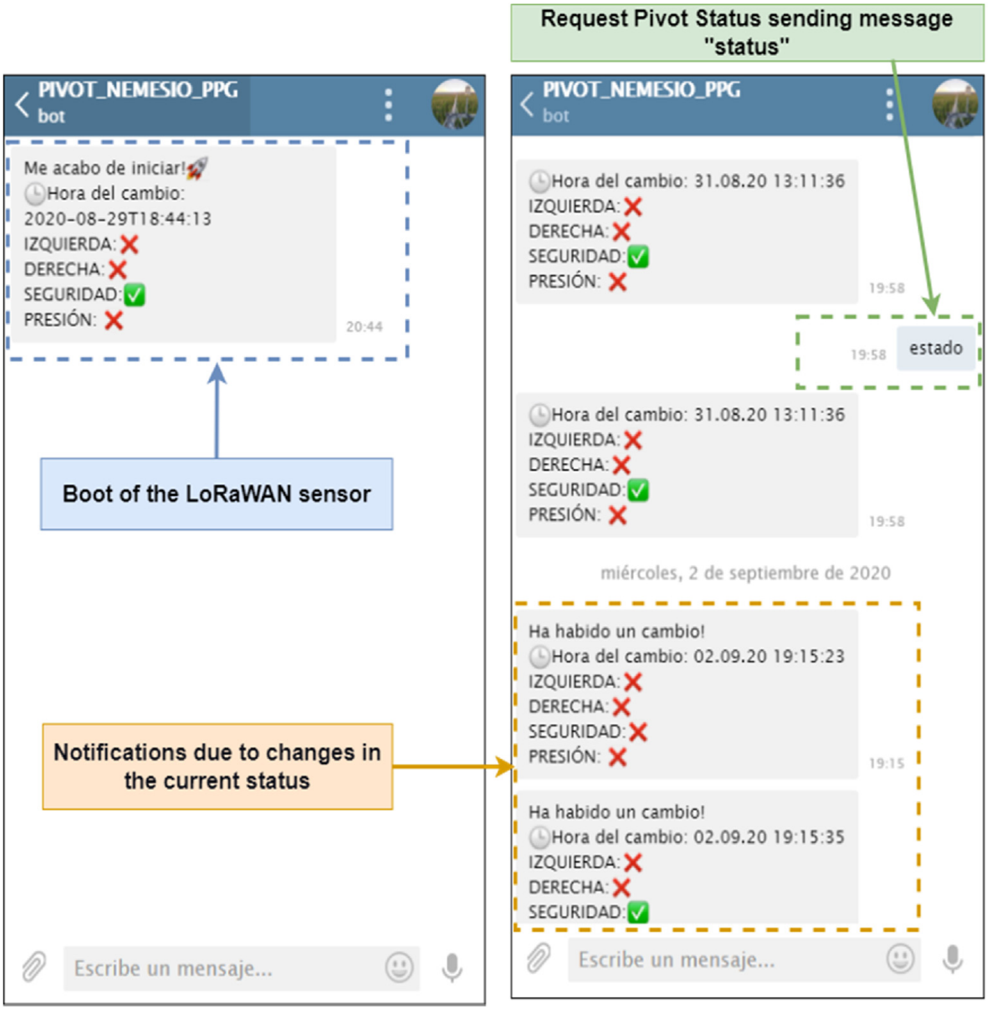


Fig. 6 – Sensors deployed on the MiFincapp platform in the maize fields of Pobladura de Pelayo García, León, Spain.


Request Pivot Status sending message "status"

PIVOT_NEMESIO_PPG
bot

Me acabo de iniciar!🚀
🕓Hora del cambio:
2020-08-29T18:44:13
IZQUIERDA:❌
DERECHA:❌
SEGURIDAD:✅
PRESIÓN: ❌
20:44

Boot of the LoRaWAN sensor

Notifications due to changes in the current status

Escribe un mensaje...

PIVOT_NEMESIO_PPG
bot

🕓Hora del cambio: 31.08.20 13:11:36
IZQUIERDA:❌
DERECHA:❌
SEGURIDAD:✅
PRESIÓN: ❌
19:58

19:58 estado

🕓Hora del cambio: 31.08.20 13:11:36
IZQUIERDA:❌
DERECHA:❌
SEGURIDAD:✅
PRESIÓN: ❌
19:58

miércoles, 2 de septiembre de 2020

Ha habido un cambio!
🕓Hora del cambio: 02.09.20 19:15:23
IZQUIERDA:❌
DERECHA:❌
SEGURIDAD:❌
PRESIÓN: ❌
19:15

Ha habido un cambio!
🕓Hora del cambio: 02.09.20 19:15:35
IZQUIERDA:❌
DERECHA:❌
SEGURIDAD:✅

Escribe un mensaje...

Fig. 7 – Messages received from the Telegram Bot installed on the centre pivot.

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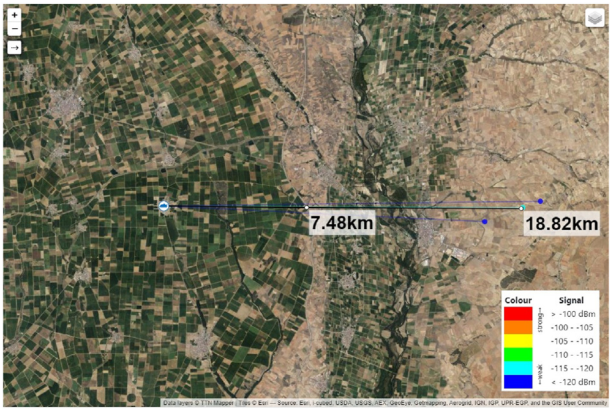

Fig. 8 – LoRaWAN test coverage at near crops.

stopped (safety LED on), moving (left or right LEDs), and if water pressure was available (LED on when the pivot is irrigating). The upper right-hand side shows a change of status message. Afterwards, the user introduces the word "status" to request the last status of the pivot. The massage includes some icons to easily read the LEDs' information.

4.2. *Results of the system based on a PWA for monitoring crops via GPS sensors employing LoRaWAN or GPRS communication*

4.2.1. *LoRaWAN coverage results*

Figures 8 and 9 showed how the sensor could maintain normal operation at distances of 3.5 km and probably distances up to 10 km if there is sufficient line of sight with the sensor. It can be seen that the deployed infrastructure and LoRaWAN sensors was sufficient to receive the GPS measurements. It is interesting to mention that one of the packages was received through a LoRaWAN gateway placed 80.1 km away from the TTGO-T-Beam sensor (Fig. 9).

The transmission power employed was the maximum allowed for Europe, 25 mW (14 dBm). Taking this into account, several coverage tests have been performed with the TTN Mapper tool (Sealy, 2018).

The quality of the transmission signal of the LoRaWAN sensors during the irrigation was evaluated. The measurements received from the two RAK 7200 and TTGO T-Beam sensors in land #1 located at 1.29 km have been analysed (Fig. 10). Table 2 describes the total amount of packets received by each of the sensors during the test together with the lost packets and the packet loss percentage.

The lost packets shown in the Table 3 were calculated from the frame counter field of each message. In Table 3 the mean SNR (Signal to Noise Ratio) is obtained by calculating the mean of this value that is sent with each of the received packets. Similarly, the mean RSSI (Receiver Signal Strength Indicator) is calculated by obtaining the mean. All sensors show a high packet loss percentage in field #1. However, in Fig. 11 it was possible to appreciate the results obtained after 24 h in field #2 located at 3.5 km from the gateway.

Similarly, the measurements received by the TTGO T-Beam sensor in field #2 at 3.5 km are shown in the Fig. 11. The summary of received packets from the TTGO-T-Beam sensor is presented on Table 3, showing how in this case packet loss was only 1% despite the fact that field#2 was farther away from the gateway.

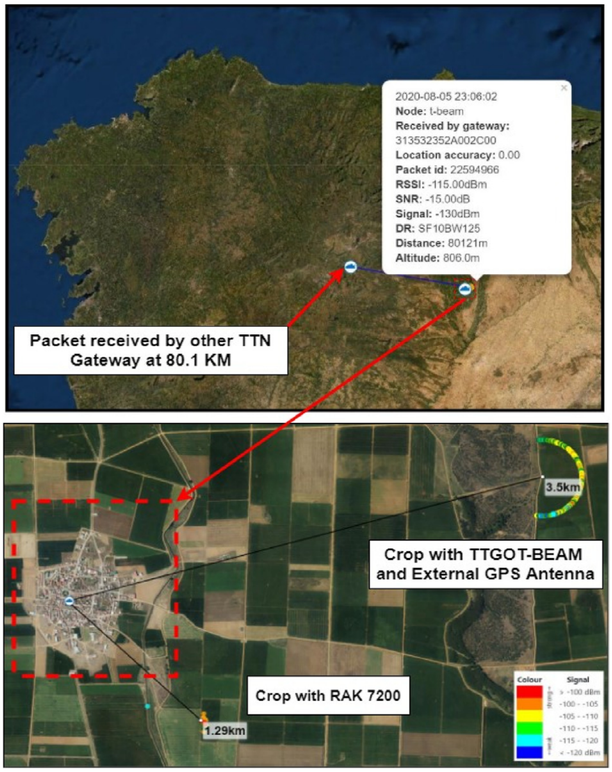
2020-08-05 23:06:02
Node: t-beam
Received by gateway: 313532352A002C00
Location accuracy: 0.00
Packet id: 22594966
RSSI: -115.00dBm
SNR: -15.00dB
Signal: -130dBm
DR: SF10BW125
Distance: 80121m
Altitude: 806.0m

Fig. 9 – LoRaWAN coverage and measures received by deployed sensors.

4.2.2. *GPS sensor position error results*

To make a fair evaluation regarding the position error by each GPS sensor, all the sensors were placed in the same pivot position for 24 h. The results of the sensors are shown in Table 4.

Figure 12 also illustrates a density plot of the measured absolute error for each sensor. It is important to mention that in the case of the TTGO-T-Beam LoRaWAN sensor, it had an external antenna that has allowed better accuracy than the RAK 7200 in the tests performed in the crop.

4.2.3. *Voice assistant user interface*

After the deployment of the sensors in MiFincapp, users were able to access the status of their pivots from the PWA while they could do it through a Google Action from Google Assistant. Figure 13 shows the graphical interface on a smart display (bottom side) and on a smartphone (upper side) after invoking the Google Action with "Talk to My Crop". This shows how after just a simple conversation the user can retrieve relevant information about the state of their crop.

This interface was well received by farmers since it was possible to obtain the current status of the pivot in the crop. There was no need to navigate through an application to find the specific pivot or sensor, thus facilitating easy access to farmers.

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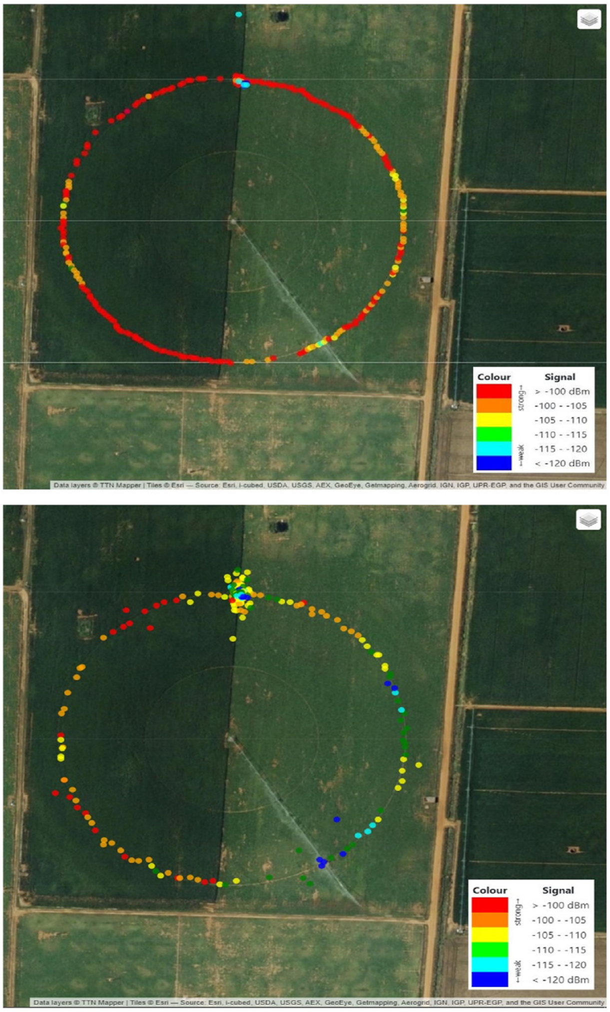

Fig. 10 – Received packets from TTGO-T-Beam (upper side) and RAK 7200 (bottom side) on the field #1.

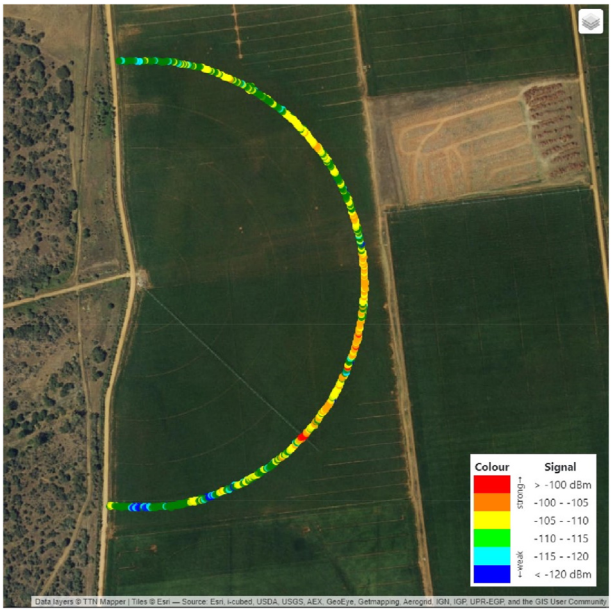

Fig. 11 – Received packets from TTGO-T-Beam on the field #2.

Table 4 – GPS absolute error results.

Sensor	#Measurements	MAE (m)	Standard deviation
TTGO-T-Beam	1046	2.94	1.16
TKSTAR 915	691	3.38	1.18
RAK 7200	554	4.06	2.78

4.3. *Results of AI in the edge for water consumption monitoring*

This section shows the results of the machine learning model built for the water meter reading process and the user interface developed to display the data through the MiFincapp PWA.

4.3.1. *Machine learning for Automatic Meter Reading*

This section describes the dataset used to build the machine learning model included in the prototype and the results obtained after evaluation of this model.

For the preparation of the dataset, from the starting point was the Water Meter Number Dataset used in the work by Yang et al. (2019) and added images taken at one of the hydrants at the farms. In this case, only values for numerical meters were considered, not dial (i.e. analogue) meters.

The AutoKeras framework from the work of Jin, Song, and Hu (2019) was used to build the model. This is an efficient neural architecture search system used in this case to find a neural network architecture that provides the best results. There are other frameworks in this area, such as Keras Tuner (O'Malley et al., 2019). A training scheme was used to build the model, reserving 64% for training 16% for validation and 20% for test, all of them randomly selected.

Once the model was generated, it was converted to the format supported by tensor-flow for microcontrollers (David et al., 2020), in this conversion process, some optimisations were applied to reduce size in order for it to be used in microcontrollers. For example, one of these optimizations is quantisation, i.e., usually neural network models trained with the Keras framework or TensorFlow (Abadi et al., 2015; Chollet, 2015) store their parameters as 32 bit floating point

Table 3 – Packet loss results.

Sensor	Field	Mean SNR	Mean RSSI	Sent packets	Lost packets	Packet Loss %
RAK 7200	#1	6.1	−106.6	118	29	24%
TTGO-T-Beam	#1	9.1	−97.8	224	45	20%
TTGO-T-Beam	#2	5.7	−110.3	1429	15	1%

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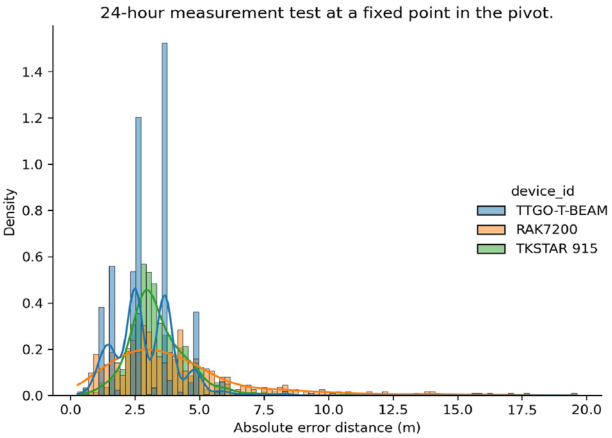


Fig. 12 – Density plot of distance errors from the three sensors.

numbers, allowing high precision operations to be performed using this type of data during training. Quantisation makes it possible to reduce the precision of these numbers so that they are adjusted to 8-bit integers, implying a 4 times reduction in the size of the final model with respect to the model produced initially. This reduction may be coupled with a reduction in the final accuracy of the model, but in many cases the decrease in accuracy is not significant. These limitations were taken into account during the search and training of the model due to the memory restrictions of the ESP32-CAM hardware.

The same scheme proposed by Yang et al. (2019) was followed, so that there are a total of 20 output classes: ten labels for each of the digits (ranging from 0 to 9) and 10 for the transitions between each of the digits (labels ranging from 10 to 19). Table 5 shows a summary of the results obtained in the two models obtained, one in its normal version and the other in the microcontroller version. Likewise, and to visualise more effectively the efficiency of these models with each of the classes, their confusion matrixes are shown in Fig. 14. Both, Table 5 and Fig. 14, were obtained with test subset of the dataset that has not been used during the training of the model.

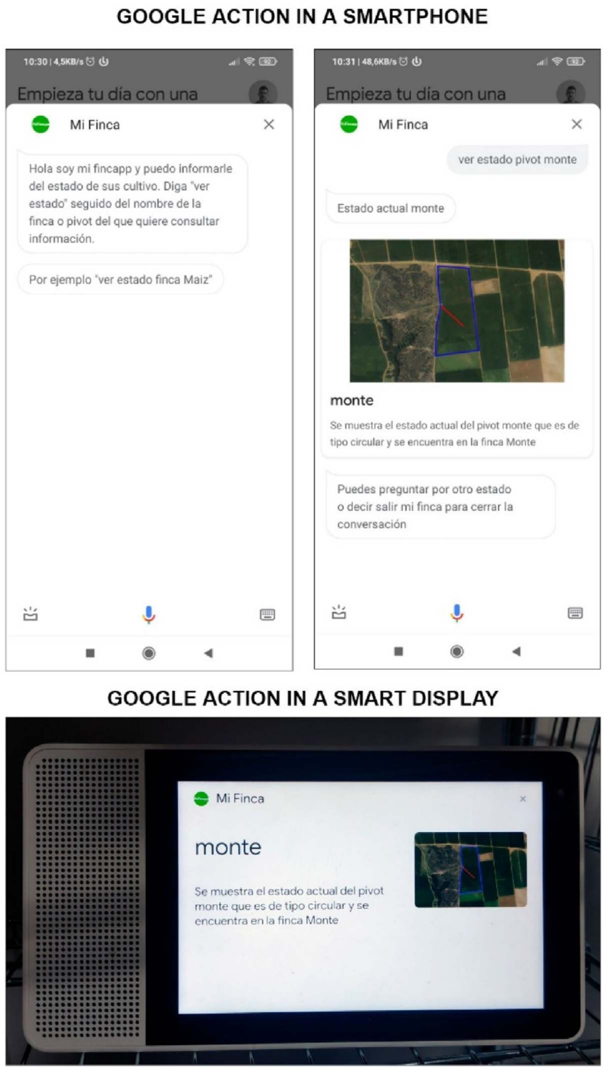
Finally, this model was used in the device to calculate each of the values of the image taken, forming as a whole the value of the water meter reading. This value is transmitted using LoRaWAN communication to the MiFincapp platform. Figure 15 shows the interface of the device in the MiFincapp PWA. It shows the last value taken from the meter and a graph with the water consumptions grouped by months or weeks in that crop.

5. Discussion

This section discusses the results of each of the systems presented in the previous section.

5.1. *Discussion of centre pivot monitoring system based on LoRaWAN sensor and Telegram bot results*

The Telegram bot solution has been demonstrated to be a useful solution for monitoring the pivot status. It is extremely useful for users since they are commonly used to use instant message apps. The farmer can easily determine pivot status by sending one message to the bot which answered with a new message showing the more relevant pivot information. All the messages can be modified, and other information could be shown such as a picture of the pivot status.


GOOGLE ACTION IN A SMARTPHONE

Hola soy mi fincapp y puedo informarle del estado de sus cultivo. Diga "ver estado" seguido del nombre de la finca o pivot del que quiere consultar información.

Por ejemplo "ver estado finca Maiz"

ver estado pivot monte

Estado actual monte

monte

Se muestra el estado actual del pivot monte que es de tipo circular y se encuentra en la finca Monte

Puedes preguntar por otro estado o decir salir mi finca para cerrar la conversación

GOOGLE ACTION IN A SMART DISPLAY

monte

Se muestra el estado actual del pivot monte que es de tipo circular y se encuentra en la finca Monte

Fig. 13 – Google Action on a smartphone and on a smart display.

5.2. *Discussion of PWA for monitoring crops via GPS sensors based on LoRaWAN or GPRS communication results*

The Progressive Web App (PWA), designed for the solution, is an alternative interface and management platform in which farmers can easily introduce the sensors used for the monitoring of the irrigation process. The PWA follows the last interface design principles, so, its use is very intuitive, and the learning curve is shorter than in other similar apps. Additionally, the PWA can be used for monitoring the irrigation process.

Moreover, as explained the PWA used LoRaWAN and GPS technologies. As shown in Section 4 some experiments were

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Table 5 – Model results.

Class	Model's Results				Microcontroller model's results			
	Precision	Recall	f1-score	Support	Precision	Recall	f1-score	Support
0	0.96	0.88	0.92	83	0.96	0.88	0.92	83
1	0.93	0.95	0.94	110	0.93	0.95	0.94	110
2	0.97	0.95	0.96	114	0.97	0.95	0.96	114
3	0.92	0.92	0.92	101	0.92	0.92	0.92	101
4	0.98	0.92	0.95	106	0.98	0.92	0.95	106
5	0.89	0.91	0.90	94	0.89	0.90	0.89	94
6	0.75	0.93	0.83	88	0.75	0.93	0.83	88
7	0.94	0.96	0.95	53	0.94	0.96	0.95	53
8	0.97	0.86	0.91	71	0.95	0.86	0.90	71
9	0.75	0.90	0.82	73	0.76	0.90	0.82	73
10	0.80	0.44	0.57	18	0.80	0.44	0.57	18
11	0.75	0.27	0.40	11	0.75	0.27	0.40	11
12	1.00	0.73	0.84	11	1.00	0.73	0.84	11
13	0.62	0.62	0.62	13	0.62	0.62	0.62	13
14	0.58	0.88	0.70	8	0.58	0.88	0.70	8
15	0.78	0.78	0.78	9	0.78	0.78	0.78	9
16	0.78	0.54	0.64	13	0.78	0.54	0.64	13
17	0.57	0.57	0.57	7	0.57	0.57	0.57	7
18	0.40	0.20	0.27	10	0.40	0.20	0.27	10
19	0.36	0.57	0.44	7	0.36	0.57	0.44	7
Accuracy			0.88	1000			0.88	1000
Macro average	0.79	0.74	0.75	1000	0.79	0.74	0.75	1000
Weighted average	0.89	0.88	0.88	1000	0.89	0.88	0.88	1000

performed. Regarding the LoRaWAN, both sensors located on field #1 showed a high packet loss percentage (Table 3).

Although both sensors were close to the data gateway, high packet loss could be due to factors such as a poor line of sight (in this case the farm was closer but with more obstacles in the line of sight) or other factors such as a high SNR can negatively influence the transmission. However, in Fig. 11 it is possible to appreciate that the results obtained after 24 h on field #2 are much better (the packet loss was only 1%), despite this land being located at 3.5 km from the gateway. This information is also shown in Table 3.

Therefore, it is quite clear that package loss can vary in different environments and how it could have a negative impact on these types of systems. Regarding the GPS position accuracy, as shown in Fig. 12, the GPRS sensor (TKSTAR915) presented a similar error to the TTGO-T-Beam sensor. However, sensor RAK 7200 has had an error with a very large deviation, making it unsuitable for pivot monitoring. At this point the use of an external GPS antenna seems to be a decisive factor.

Google Action, developed as a novel alternative interface to the PWA, was well received by senior users of the application, highlighting the simplicity of obtaining the necessary information with just a few voice commands. More intensive research work is needed in this regard to compare the two interfaces.

5.3. *Discussion of AI in the edge for water consumption monitoring results*

After deployment of the prototype, it has been possible to evaluate the viability of the system in a real environment. The results obtained after training present an accuracy similar to that of the AMR field, however with the added difficulty of deploying a model limited in size and computational capacity.

Regarding the efficiency of the borrowed models, it was observed that despite the added restrictions in the transformation of the microcontroller model, there is no excessive decrease in the accuracy of the models. The normal model obtains an accuracy of 0.881 and the model for microcontrollers obtains an accuracy of 0.88. This small difference is also observed in Table 5 and Fig. 14 in classes 5, 8, and 9. The efficiency of the model was quite high given the characteristics of the problem and the limitations of working with neural networks on Edge devices.

It is important to note that in the confusion matrixes there are much fewer examples of the classes that establish the transitions between numbers as explained in Yang et al. (2019). At the time of deploying the model, when one of these transitional classes is detected, its value is updated with the previous value, taking advantage of this domain since the counter always increases.

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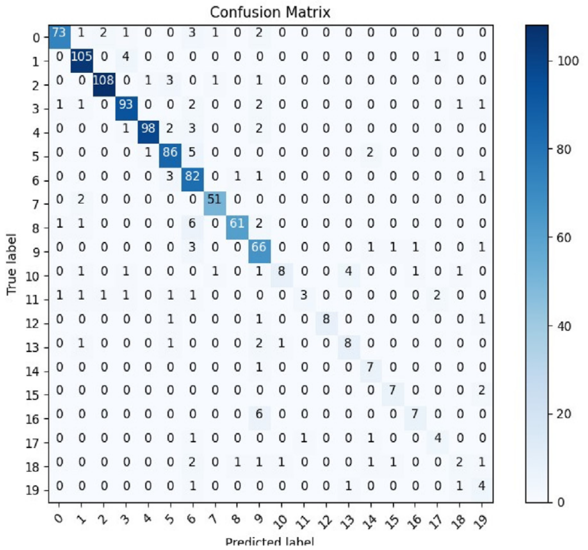
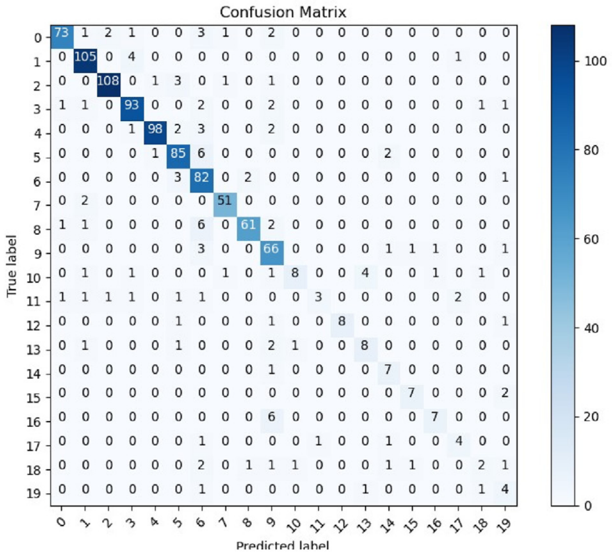


	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
0	73	1	2	1	0	0	3	1	0	2	0	0	0	0	0	0	0	0	0	0
1	0	105	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
2	0	0	108	0	1	3	0	1	0	1	0	0	0	0	0	0	0	0	0	0
3	1	1	0	93	0	0	2	0	0	2	0	0	0	0	0	0	0	0	1	1
4	0	0	0	1	98	2	3	0	0	2	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	1	86	5	0	0	0	0	0	0	0	2	0	0	0	0	0
6	0	0	0	0	0	3	82	0	1	1	0	0	0	0	0	0	0	0	0	1
7	0	2	0	0	0	0	0	51	0	0	0	0	0	0	0	0	0	0	0	0
8	1	1	0	0	0	0	6	0	61	2	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	3	0	0	66	0	0	0	0	1	1	1	0	0	1
10	0	1	0	1	0	0	0	1	0	1	8	0	0	4	0	0	1	0	1	0
11	1	1	1	1	0	1	1	0	0	0	0	3	0	0	0	0	0	2	0	0
12	0	0	0	0	0	1	0	0	0	1	0	0	8	0	0	0	0	0	0	1
13	0	1	0	0	0	1	0	0	0	2	1	0	0	8	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0	0	1	0	0	0	0	7	0	0	0	0	0
15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7	0	0	0	2
16	0	0	0	0	0	0	0	0	0	6	0	0	0	0	0	0	7	0	0	0
17	0	0	0	0	0	0	1	0	0	0	0	1	0	0	1	0	0	4	0	0
18	0	0	0	0	0	0	2	0	1	1	1	0	0	0	1	1	0	0	2	1
19	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	1	4

(a) Model confusion matrix



	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
0	73	1	2	1	0	0	3	1	0	2	0	0	0	0	0	0	0	0	0	0
1	0	105	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
2	0	0	108	0	1	3	0	1	0	1	0	0	0	0	0	0	0	0	0	0
3	1	1	0	93	0	0	2	0	0	2	0	0	0	0	0	0	0	0	1	1
4	0	0	0	1	98	2	3	0	0	2	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	1	85	6	0	0	0	0	0	0	0	2	0	0	0	0	0
6	0	0	0	0	0	3	82	0	2	0	0	0	0	0	0	0	0	0	0	1
7	0	2	0	0	0	0	0	51	0	0	0	0	0	0	0	0	0	0	0	0
8	1	1	0	0	0	0	6	0	61	2	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	3	0	0	66	0	0	0	0	1	1	1	0	0	1
10	0	1	0	1	0	0	0	1	0	1	8	0	0	4	0	0	1	0	1	0
11	1	1	1	1	0	1	1	0	0	0	0	3	0	0	0	0	0	2	0	0
12	0	0	0	0	0	1	0	0	0	1	0	0	8	0	0	0	0	0	0	1
13	0	1	0	0	0	1	0	0	0	2	1	0	0	8	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0	0	1	0	0	0	0	7	0	0	0	0	0
15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7	0	0	0	2
16	0	0	0	0	0	0	0	0	0	6	0	0	0	0	0	0	7	0	0	0
17	0	0	0	0	0	0	1	0	0	0	0	1	0	0	1	0	0	4	0	0
18	0	0	0	0	0	0	2	0	1	1	1	0	0	0	1	1	0	0	2	1
19	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	1	4

(b) Microcontroller model confusion matrix

Fig. 14 – Confusion matrices.

6. Conclusions and future works

Once the results were analysed and explained it was clear that it is possible to monitor the operation of central pivot irrigation systems using low-cost sensors linked to rising communication technologies like LoRaWAN. This is the main contribution of the study, a low-cost and easy use system that allows farmers to monitor their fields without making a large investment. To address the digital divide which suffer farmers can suffer (due to factors such as age, and economic, social or cultural circumstances), the Telegram bot system and the Google Assistant action in MiFincapp were two attractive ways for farmers to obtain information about their crops. The Telegram bot system developed for the prototype did not exceed US$ 40. Another positive point of this alternative is that the Cloud services used for the prototype have been used in their free to use version. However, the use of the paid version would not represent a significant cost increase. As mentioned before, the interface is intuitive as the farmers found during the tests of this work. Also, the response of the bot can be modified following the guidelines used by the farmer. An interesting option to develop in the future is to include controlling operations over the pivot, employing downlink messages. This future line would imply establishing a LoRaWAN class C device due to the control operation would not depend on uplink messages.

With regards to the Google Assistant action, this conversational agent is a perfect shortcut on the MyFincapp platform to directly access specific information, without the need for technical knowledge and making this technology more accessible.

The PWA has shown how it is possible to effectively monitor the operation of pivots using GPS and LoRaWAN technologies. If we take into account the LoRaWAN sensors, it has been shown that its effectiveness can vary depending on the crop; the packet loss could affect the operation of the system. On the other hand, the GPRS sensor laid its effectiveness in the availability of coverage; even so, LoRaWAN sensors have not to field coverage problems for crops at 3.5 km away from the deployed gateway. Nevertheless, packet loss requires more deep analysis to evaluate its operation in more remote areas.

Another remaining issue about the operation of the PWA is the error derived from the GPS measurements. Both TTGOT-Beam and TKSTAR915 sensors had a mean absolute error of approximately 3 m, a measure much lower than the one obtained for the RAK 7200 sensor. Nonetheless, this error could be enough to monitor the position of the centre pivot, but it makes it difficult to easily detect when the pivot stops. As a result, the system needs more time to detect the using only the measurements from the GPS sensor. A future line of research in which initial information provided by the farmer about the location of the pivot is used and its centre is used along with the use of filters for the GPS's measurements could improve stop detection and pivot status information.

Regarding to the water meter on the edge, the proposed system is able to process the image of the meter on the edge and transmit only the processed data. This is a low-cost solution since the sum of the cost of an ESP32-CAM and the RAK811 module are no more than $30. This could enable to create a custom solution with a very little cost. However, this solution is only suitable for older equipment where the cost of change the current equipment could be quite high. Despite this, the proposed Edge Computing device shows a particular case which could be applied in other domains and shows the potential of this paradigm.

As future work within the different systems, we plan to improve the voice assistant system to include more functionality and to conduct a usability study compared to the PWA of the MiFincapp platform. However, regarding the water meter prototype, we first wanted to improve our accuracy model results but would like to try other low-cost devices that allow larger models to be deployed such as YoLo and neural network architectures with larger backbones. In addition, our aim is to generate a dataset related to dial meters and generate a model that accurately obtains the measurements and

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MiFincapp

Dispositivo: ContadorAgua

Medida anual 51.690,000m3

Semana: 15-8-2020 21-8-2020

Tipo
Semanal

Fig. 15 – Water meter UI MiFincapp

publish openly since to the best of our knowledge there is no open dataset related to this type of dial meters.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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