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Building a Text Messaging-Based System to Support Low-Cost Automation in Household Agriculture

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Abstract

Home garden crops, small-scale agricultural systems for local food production, are becoming an integral part of the food supply chain in a number of developing countries and peri-urban areas of some developed regions. In this work, we propose a low-cost, monitoring and irrigation system which can be applied in household and local community gardens. The basic architecture consists of a sensing/actuation station based on commercial off-the-shelf hardware and a mobile application for the interaction with remote users. A key aspect of the system is the use of legacy text-messaging service as a mechanism to support alert and control operations for monitoring and irrigation. This feature enables widely available and highly-reliable connections between the cropland station and remote users without the need for new network infrastructure. We implemented a functional prototype of the system to check its effectivity in a small open-field area for tomatoes cultivation. The results show that water usage can be substantially improved if using both the actual information collected from the system and public tools for decision support in agriculture. We conclude that the proposed solution has a good prospect as an input for the design of more automated decision-strategies to be used in plant cultivation of a similar kind and/or of a larger scale.

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***Abstract*—Home garden crops, small-scale agricultural systems for local food production, are becoming an integral part of the food supply chain in a number of developing countries and peri-urban areas of some developed regions. In this work, we propose a low-cost, monitoring and irrigation system which can be applied in household and local community gardens. The basic architecture consists of a sensing/actuation station based on commercial off-the-shelf hardware and a mobile application for the interaction with remote users. A key aspect of the system is the use of legacy text-messaging service as a mechanism to support alert and control operations for monitoring and irrigation. This feature enables widely available and highly-reliable connections between the cropland station and remote users without the need for new network infrastructure. We implemented a functional prototype of the system to check its effectivity in a small open-field area for tomatoes cultivation. The results show that water usage can be substantially improved if using both the actual information collected from the system and public tools for decision support in agriculture. We conclude that the proposed solution has a good prospect as an input for the design of more automated decision-strategies to be used in plant cultivation of a similar kind and/or of a larger scale.**

***Index Terms*—Android, Arduino, CLIMWAT, CropWAT, home garden, monitoring, GSM, IoT, Smart irrigation.**

I. Introduction

In recent years, the academic and industrial interest to apply the Internet of Things (IoT) paradigm and related communication technologies to the agricultural sector has grown considerably [1]–[4]. The relevant literature in such a direction includes efforts that range from highly-automated solutions for precision agriculture [5] to very simple monitoring systems to be used in individual gardening [6]. The expected benefits from this kind of systems are typically based on the provision of a better agricultural management supported by an innovative use of information and communication technologies (ICT) [1]. The final goal is, in essence, to positively influence the efficiency of the overall agricultural sector and thus to contribute to their profit and/or sustainability.

In spite of that, the case of small-scale agriculture, more precisely related to household and local communities, is one of the sub-sectors in agriculture with relatively low adoption of such ICT technologies [4]. The abrupt technological disruption that indeed characterises precision agriculture and other activities in this sector is not the reality in household gardens, most probably due to the lower entrepreneurial/profit interest involved. However, household crops and other small-scale non-professional crop gardens are an integral part of the food supply chain in a large number of developing countries, as well as in several peri-urban areas of more developed regions [7]. Therefore, they represent an important economic activity with clear potential to be positively impacted by IoT-based technological approaches. In effect, although numerous existing works in the related literature can be applied to small-scale croplands of such a kind, most of these systems target larger and more complex scenarios that does not necessarily match well with the needs of simpler and cost-effective solutions for household and community crops.

In this work, we propose a low-cost monitoring and irrigation system which can be applied in small-scale agricultural activities such as household and local community crops. The system consists of a sensing/actuation node based on commercial-off-the-shelf hardware (i.e., microcontroller, sensors/actuators and shields) and a simple text messaging-based Android mobile application for the interaction with remote users. A key aspect of the proposed system is the support of alert and control operations for monitoring and irrigation using the legacy text messaging service of Global System for Mobile Communication (GSM) cellular networks, i.e. the short-message-service (SMS). This technology enables widely available and highly-reliable connections between remote users and the cropland station, without the need for new network infrastructure. We tested the effectivity of the system in a small open-field area for tomatoes cultivation and we showed that the system can be effectively used to improve water usage using both the actual information collected from the system and public tools for decision support in agriculture, particularly, CropWat 8.0 [8] and CLIMWAT 2.0 [9]. In future work, we plan to use the basic building-blocks of this system as an input for the design of more automated decision strategies using text messaging-based operations, as well as to test it in larger and different conditions for plant cultivation.

II. Related Work

The use of SMS to support IoT-based systems applied to agriculture has been considered in previous literature [10]–[14]. In the early years of IoT, for example, the authors in [10] proposed an SMS-based alert system to inform remote

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users if the value measured by a given sensor (e.g., soil moisture, temperature, humidity) in a greenhouse, exceeds a certain threshold. This system also allowed to communicate by SMS to a central server in order to store the data collected from the sensors in a database. In the same line of work, the authors in [12] considered SMS as part of an early warning notification system that complement a more complete solution using a wireless sensor network (WSN) and a central SQL server, in facility agriculture. More recently, and in an alike manner, the authors in [11] proposed a system that uses SMS as a redundant (or backup) notification mechanism that complements an Internet-based text message exchange for precision agriculture. Other works in the literature have proposed systems with similar ideas, also in different but related fields (e.g, home automation or smart cities), often motivated by the common needs to provide early warning and event-triggered functionalities to remote users.

The case of the control of the irrigation system (or the control of another relevant process in agriculture) commanded by SMS, is a less common or less documented approach in the literature. The works in [13], [14] discussed SMS-based irrigation notification and control system for precision agriculture, but without offering a text message-based service to control the irrigation. The authors in [15], instead, were able to control the irrigation system remotely via SMS but without providing a special user interface for that purpose.

In this work, we aim to provide a simple text messaging-based system able to do both: (i) receive sensor-based notifications about the state of important variables of crops production, (ii) remotely control the activation/deactivation of the irrigation system using text messages. These functionalities are shown to the user via a mobile application so as to improve both user experience and the adoption of the system.

III. System Description

This section provides details about the design of the monitoring and irrigation system proposed for household crops. It also presents the complementary decision-making tools used to support the calculation of crop water needs.

A. System Architecture

Figure 1 illustrates the general architecture of the system. It consists of two main components: (i) a remote mobile terminal with a text message-based application, and (ii) a cropland station for monitoring and irrigation purposes. The mobile node

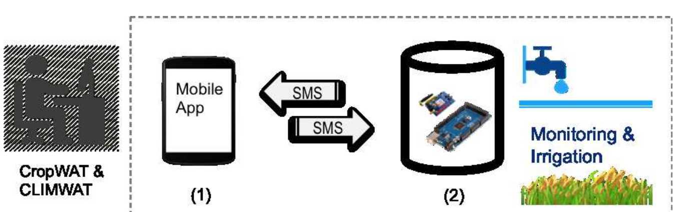

Fig. 1. The general architecture showing: (1) the remote user, and (2) the cropland station. It also illustrates the external tools for decision making.

Fig. 2. A view of the main hardware used for the cropland station.

can receive/send notifications to/from the cropland station via text messages (SMS); while the cropland station can processes these messages and take actions regarding monitoring and irrigation. The cropland station can stores the data collected from the sensors, and send event alarms by SMS to the remote users, e.g., if exceeding a given threshold value. The remote users can take decisions based on the notifications received from the cropland station, as well as based on external decision support tools for agriculture management; in this case, the software CropWat 8.0 and CLIMWAT 2.0.

B. FAO Software Tools

CropWat and CLIMWAT are two computer programs used in agriculture and provided by the Food and Agriculture Organization of the United Nations (FAO). CropWat has been used since decades [16], mainly as a tool for calculating crop water requirements, irrigation supply and irrigation scheduling. CLIMWAT has appeared later [17], as a complementary database for CropWat providing agroclimatic information (e.g., about soil, climate and crop) from over 5.000 stations distributed around the world [9]. These two decision-support tools are adopted in settings of different complexity, i.e., ranging from traditional to precision agriculture methods.

C. Cropland Station

The cropland station corresponds to the node responsible for the automated monitoring and irrigation processes. It is essentially a single station notifying and being controlled by a remote user. The technical design aspects are mostly based on an Arduino board (MEGA 2560), a set of commercial off-the-shelf electrochemical/electromechanical sensors and actuators, and a GSM/GPRS module compatible with Arduino (SIM900). It also considers a micro SD card module to store measured sensors values, and a real-time clock module (DS3221) with a CR2032 battery. The basic sensors

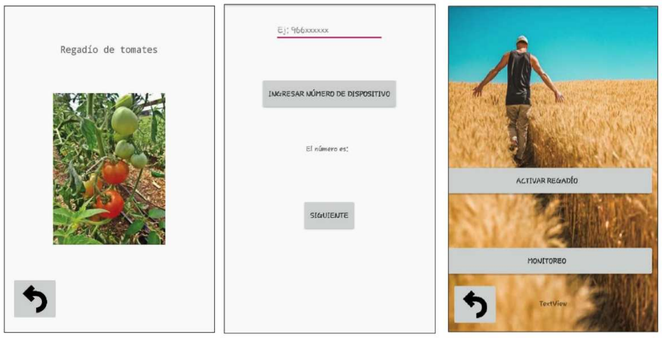

Fig. 3. Mobile application mockup showing: (left) presentation page, (center) remote user configuration, and (right) monitoring/irrigation setup page.

chosen for the implementation were: temperature/humidity (DHT22), rain (YL-83), soil moisture (FC-28) and ambient light (TEMT6000). The actuation part consisted of a plastic 220v AC solenoid valve of $1/2$” size, a water flow sensor meter (YF-S201) and 12v DC relay. These components were used in a conventional way, i.e., following connections and configurations suggested in their datasheets. Their acquisition was relatively inexpensive and easy to found in the local market, having an overall estimated cost of fewer than ~ 100 USD at the moment of the implementation. Fig. 2 shows a general view of the main hardware elements composing the station.

D. Remote User

The remote users correspond to the cropland stakeholders, i.e. the users actually interested in acquire the system. We assume they have (or are willing to have) an Android-based mobile phone with a text messaging-based application installed, which was specially developed to exchange SMS with the cropland station. This application can receive pre-configured notifications or alarms about the crop status from the monitoring station, and send command messages to control the irrigation system, e.g., to activate/deactivate the passage of the water to the crop. A representative view of the graphical interface designed for this mobile application is in Fig. 3.

IV. Preliminary Results & Discussion

This section reports some preliminary results and evidence of the implementation of the testbed in a private home garden. It also provides some remarks and discussion in this respect.

A. Tesbed Setup

Fig. 4 shows a schematic layout of the crop area being monitored as well as some representative pictures of the installation at the actual location. The testbed area is a small piece of land of 0.7mx3.0m=2.1m^2 destined for the cultivation of tomatoes. The cropland station was mounted near to this area using a regular black plastic case (so as to protect it from rain and other environmental factors). The sensing, actuating and communication hardware were wired to the main controller inside of this plastic case. The sensors were configured in the main controller board so as to measure their respective variables, i.e., soil moisture, temperature, humidity, rain and ambient light; and then stored in the SD card for further processing. The actuation part in contact with the irrigation system, i.e., the water flow meter and the solenoid valve, were fixed to the existing water pipes as shown in Fig. 4.

B. Water needs calculations using CropWat & CLIMWAT

Fig. 5 shows screenshots of both CropWat and CLIMWAT as evidence of the process of determining the irrigation requirements of the cropland area. First, we used CLIMWAT, so as to select in the database, the closer agro-climatic station to the city of San Fernando, in Chile, where the cropland was situated. This location, as well as its associated statistical data, were used as an input for CropWat and thus for the specific water need calculations. The results led us to an estimate of $18,573$ L/m (on a daily basis) for the period of the year under evaluation. Other general parameters, relevant for this calculation were the irrigation method and the crop type; in this case, furrow and tomatoes, respectively. More specific parameters, such as evapotranspiration and crop coefficient were also considered in the software tools configurations.

C. Remote-controlled irrigation using text messages

We tested a simple case of remote control and notification in order to demonstrate the basic principles of the system, i.e., the text messaging-based interaction between the cropland station and remote users. We sent messages via the mobile application so as to set the maximum irrigation needs for the tomato crop area based on the data provided by CropWat and CLIMWAT. The cropland station received these messages and then extracted and set the corresponding maximum amount of water to irrigate during a day. The actuation part was able to estimate the actual amount of water delivered (using the flow meter), to then activate/deactivate the solenoid valve according to the water needs configurations. In a similar manner, the cropland station was tested as a notification/alert system, so

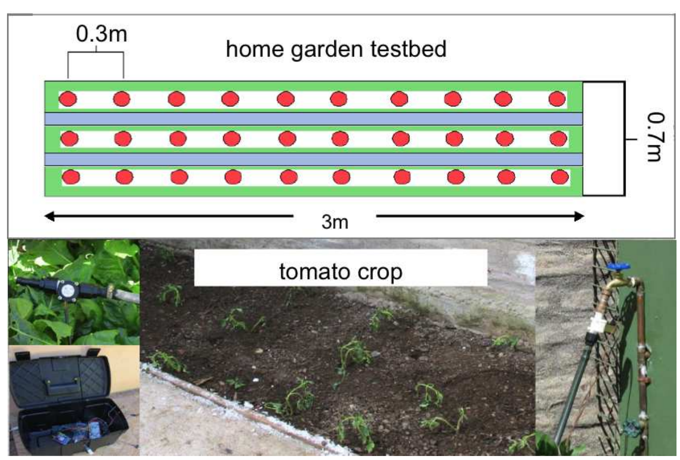

Fig. 4. Testbed setup: (top) schematic layout of the crop area; (bottom-center) tomato crop area; (bottom-left) black case with hardware mounted and water flow meter in operation; (bottom-right) solenoid valve in operation.

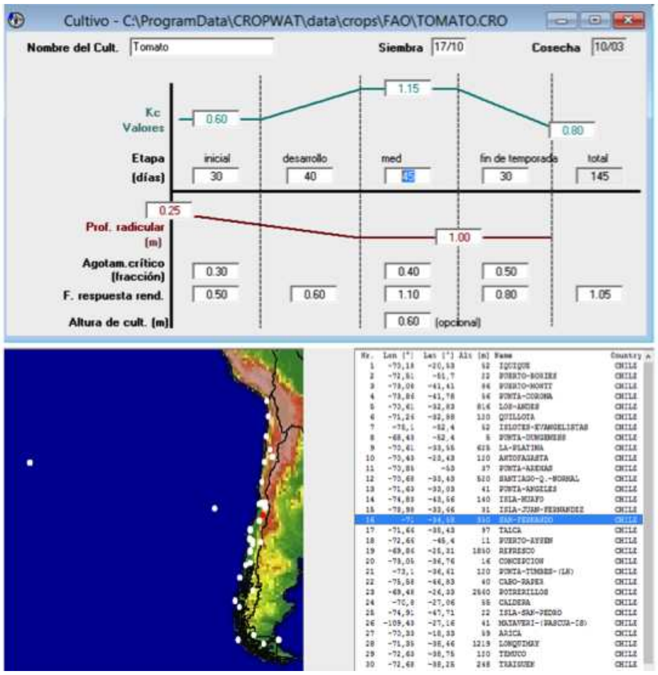

Fig. 5. Two screenshots of the FAO software tools being used: (bottom) selection of the closest CLIMWAT station to our cropland in San Fernando, (top) CropWat calculations of water needs using CLIMWAT predictions.

	Fecha y Hora	Caudal	Volumen	SensorTemp	SensorHume	Lluvia	Sensor de Tierra
	03-11-2018 17:28	0.000	0.000	21.70	65.20	No lluvia	Tierra seca
	03-11-2018 17:28	0.000	0.000	21.70	65.20	No lluvia	Tierra seca
	03-11-2018 17:28	0.000	0.000	21.70	65.20	No lluvia	Tierra seca
	03-11-2018 17:28	0.000	0.000	21.70	65.20	No lluvia	Tierra seca
	03-11-2018 17:28	0.000	0.000	21.70	65.20	No lluvia	Tierra seca
water flow	03-11-2018 17:28	0.000	0.000	21.70	65.20	No lluvia	Tierra seca
transition	03-11-2018 17:28	0.985	0.016	21.70	65.20	No lluvia	Tierra seca
	03-11-2018 17:28	11.392	0.206	21.60	65.00	No lluvia	Tierra seca
	03-11-2018 17:28	8.720	0.352	21.70	65.20	No lluvia	Tierra seca
	03-11-2018 17:28	12.658	0.563	21.70	65.20	No lluvia	Tierra seca
	03-11-2018 17:28	11.533	0.755	21.70	65.20	No lluvia	Tierra seca
	03-11-2018 17:28	12.518	0.963	21.70	65.20	No lluvia	Tierra seca

Fig. 6. (Left) Evidence of the flow meter and volume measurements. (Right) Evidence of some sensors data collection. (Left and highlighted) The transition from no-water flow to flowing water in the water pipe.

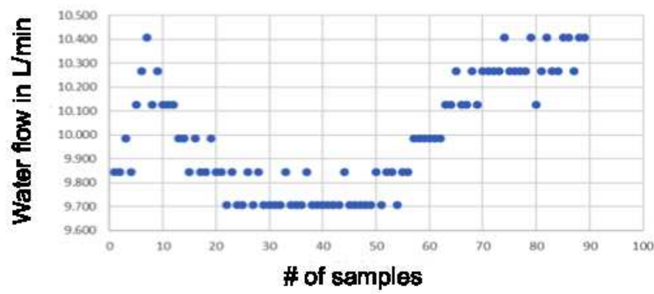

Fig. 7. Example of sensors data analysis for water flow in L/min.

far, only to inform that the irrigation needs have been satisfied. Similar operations could have been tested using the other parameters under monitoring, however, these extensions are for now beyond the exploratory nature of this work.

D. Discussion

The testbed setup, the basic calculation of water needs as well as the remote alert and control operations, create the preliminary framework for the following results and discussions.

1) Data Collection: The $18,573$ L/m of water needs above estimated were contrasted with the $26,629$ L/m declared by the stakeholder. This latter value was obtained empirically in a real tomato crop using conventional furrow irrigation. The $\sim 30\%$ difference between these two quantities is, in fact, the potential benefit of using CropWat and CLIMWAT for the estimation. The amount of water irrigated was deducted from the water flow meter, which provides an estimation in L/m based on the number of *pulses* detected per minute. We calibrated this estimation based on the actual volume of water delivered (measured without sensors). Fig. 6 shows evidence of these variables, as well as for some of the sensors data collected.

2) Data Analysis: The data collected from sensors and stored in the SD card has the potential to be used in further data analysis processes, e.g., looking to improve the water need estimations, as well as other characteristics of crop production and management. The data can be analysed graphically, for example, as shown in Fig. 7, to perform operations such as identification of patterns, anomalies detection, or others tasks of similar nature or purpose.

In this work, we are interested in enabling the management and visualization capabilities for the analysis of a large number of cropland stations, particularly by leveraging in a crowdsourcing framework proposed in a previous work [18]. This platform allows us to effectively organize sensors data (e.g., temperature, soil humidity) in geographical square regions of arbitrary size, and present them efficiently on a web-based platform. The integration of such a platform with the software/hardware solution presented in this work does not require much intervention since the basic principles of data collection are similar to those presented in the cropland station and the mobile application. In particular, sensor data can be sent through the Internet to a central server which store, summarized, and visualize the data based on the actual needs of the stakeholders.

3) Some remarks about cost: An important consideration for household crops stakeholders is cost. The existent solutions able to provide automated capabilities of monitoring and irrigation are typically prohibitive for low-income local communities or individual farmers. The proposed solution in this work is of low cost, when compared with traditional technologies, and even lower and simpler than other possible solution using similar hardware. In effect, the system here presented is the result of a design process discarding other two similar solutions of higher cost. In particular, two prototype versions using Rasberry Pi and Arduino UNO boards, where they were at least $\sim 30\%$ and $\sim 40\%$, respectively, higher in cost than the final system; even if achieving equivalent capabilities.

In any case, the system here proposed may have a disadvantage related to the fee cost of sending or receiving SMS several times during the day. This is, that at some locations, the overall cost of the SMS service could be higher than having a permanent Internet connection; especially in areas where free Wi-Fi access is available. Still, the proposal compensates in terms of the benefits of GSM cellular networks, which provide enough good levels of reliability and availability without the need for new (or private) infrastructure. Therefore, the proposal could even be competitive with recent IoT-based solutions using low-power wide-area networks (LPWAN) (e.g., based on LoRa, Sigfox or NB-IoT), since not yet available in every rural area where the GSM coverage exists, and thus where a higher density of cropland stations may exist.

V. Conclusions

This work reports the experience of design and implementing a monitoring/irrigation solution for a small crop area based on off-the-shelf hardware and a mobile application for remote operations. We provided an architecture based on the exchange of SMS between a cropland station and a mobile remote user. We supported the decision making process about irrigation with well-known tools in agriculture (CropWat and CLIMWAT). We implemented a testbed of the system (with a total cost of fewer than ~ 100 USD) in a private home garden used for tomatoes cultivation. We collected data from sensors and configured an alert function able to inform remote users via SMS if a relevant event has occurred; in this case, if a certain amount of water has been irrigated. We also tested the SMS mechanism to control irrigation from a remote location. We observed that both the remote operation mechanisms, and the external decision support tools perform well as a combined approach to reduce water consumption. In this work, we obtained a reduction of $\sim 30\%$ (on daily basis) when compared with traditional (manual) irrigation methods. We conclude, that the overall proposal has a good prospect to be used as valuable input for the design of more automated irrigation strategies (e.g., irrigation scheduling) targeting both, plant cultivation of similar or different kind, as well as larger cropland areas. In future work, we aim to provide a complementary management system able to visualize several of these monitoring/irrigation stations so as to provide a general view of the performance, and thus improve the decision-making processes involved.

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