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Original
Long-Range Low-Power Electronic System for Drip Irrigation in Precision Agriculture / Barezzi, Mattia; Pettiti, Francesca; Nari, Luca; Gisolo, Davide; Canone, Davide; Demarchi, Danilo; Garlando, Umberto. - ELETTRONICO. - (2023), pp. 167-171. (Intervento presentato al convegno 2023 IEEE Conference on AgriFood Electronics (CAFE) tenutosi a Torino (Italy) nel 25-27 September 2023) [10.1109/CAFE58535.2023.10291511].

Availability:
This version is available at: 11583/2985341 since: 2024-01-26T12:39:44Z

Publisher:
IEEE

Published
DOI:10.1109/CAFE58535.2023.10291511

Long-Range Low-Power Electronic System for Drip Irrigation in Precision Agriculture

Mattia Barezzi*, Francesca Pettiti†, Luca Nari†, Davide Gisolo‡, Davide Canone‡, Danilo Demarchi*
and Umberto Garlando*
*Department of Electronics and Telecommunications, Politecnico di Torino, Torino, Italy
†Fruit growing division, Fondazione AGRION, Manta (CN), Italy
‡Interuniversity Department of Regional and Urban Studies and Planning, Politecnico di Torino, Torino, Italy

Email: umberto.garlando@polito.it

Abstract—**Nowadays, food security is threatened by population growth, wars, climate change, and desertification due to human activities. Precision agriculture is a novel concept to minimize the usage of natural resources in the agriculture field, mitigating the anthropological effects. This is possible by adopting electronic systems to measure plants' requirements and to make optimal decisions on the crop, avoiding wastefulness. One critical aspect of agriculture is the handling of potable water: an essential resource for all living entities. This paper proposes a long-range, low-power electronic system for drip irrigation in orchards, especially Actinidia and apple trees, to control the distributed water to the cultivars. In this way, the irrigation cycle depends on the plants' needs, saving water and energy resources. The node communicates using LoRa radiofrequency protocol, and it can be used in rural areas where no internet connection is present.**

Index Terms—**Precision Agriculture, Precision Orchard Management, Wireless Systems**

I. INTRODUCTION

Food insecurity and malnutrition were reported as caused by conflicts, climate extremes, desertification [1], economic shocks, and growing inequalities in the world. FAO estimates around 2.3 billion people in the world were moderately or severely food insecure in 2021, and 11.7 percent of the global population faced food insecurity at severe levels [2].

Furthermore, it is increased awareness to find the optimal usage of resources (water, soil, fertilizer) for the agrifood context to mitigate the anthropological effects in the agriculture field. In particular, the demand for potable water is rising not only due to increasing water needs from agriculture but also from industry and energy sectors. This should be added to the effects of decades of misuse, poor management, and over-extraction of groundwater: the storage water is wasted or used inefficiently.

For this reason, United Nations (UN) set up two specific goals in the Sustainable Development Goals (SDG), especially number six, related to water management: increasing water-use efficiency across all sectors (SDG 6.4) and protecting and restoring water-related ecosystems, including mountains, forests, wetlands, rivers, aquifers, and lakes (SDG 6.6) as illustrated in [3].

Precision Orchard Management (POM) is a novel trend in the precision agriculture area to improve the usage of resources, such as water, soil, fertilizers, and energy in orchards. In particular, proximal systems are promising technologies where low-cost low-power smart devices are stably installed on the field to satisfy a precise soil-plant equilibrium need.

For example, it is fundamental to determine the right timing to perform an irrigation cycle. Some methods are available to compute in real-time the water needs of a plant: the first technique is to extract the information by the evapotranspiration metric method [4], a mathematical computation where the water balance is computed. Another way is to evaluate the plant water needs by measuring the stem impedance, as illustrated in [5] and [6]. Finally, the last solution is the measurement of the soil-water retention curve [7] to set up irrigation thresholds.

In particular, the last technique is the most diffused nowadays: it requires the measurement of two soil quantities: the volumetric water content and the matric potential. The former is the ratio of the volume of water per unit volume of soil. It is typically expressed as a percentage ratio of m^3/m^3. The latter is the potential energy of water per unit volume with respect to pure water in reference conditions. It is typically expressed in kPa, and practically, it quantifies the work that the roots carry out to extract water from the soil, winning osmosis, gravity, mechanical pressures, and capillary action.

These data could be measured and interpolated nonlinearly to obtain the so-called soil-water retention curve. This curve describes the soil type and, considering the water needs of the selected cultivar, it can help to determine the matric potential thresholds that trigger irrigation. In [8], thresholds for apple and Actinidia orchards were found using measured data, van Genuchten soil-water retention curves [9] and simulations with Hydrus 1D hydrological model. In particular, for apple orchard sites, an activation threshold of −60 kPa at 20 cm of soil depth and a deactivation threshold of −50 kPa at both 20 cm and 40 cm of depth were found. Instead, the Actinidia orchard was characterized by an activation threshold of −25 kPa and a deactivation threshold of −18 kPa, both at 20 cm of soil depth. Moreover, it is possible to design an Automatic System (AS) to irrigate orchards on demand considering only soil matric potential measures and the aforementioned thresholds.

II. PROPOSED DESIGN

The realization of the complete micro-irrigation system for orchards requires the design of an electronic system for sensing matric potential data and an electronic system for controlling the electrovalve connected to the dripper, a typical irrigation system for apple and Actinidia cultivars.

The former electronic system (called WappSen) in charge of reading the sensors is described in [10]. This board is able to sense data of a matric potential sensor (TEROS21, METER Group, Inc., Pullman, WA, USA) for a maximum of three connected sensors per node. In this way, it is possible to know the matric potential at three specific depths. Sampled data are packed and sent via LoRa (Long Range) with the desired periodicity.

LoRa is a well-established long-range low-power protocol that works on unlicensed sub-GHz band [11] and is able to cover 10 to 15 km in rural environments, drawing a few tens of mW. Typically LoRa works on a LoRaWAN (Long Range Wide Area Network), a popular MAC (Media Access Control) protocol for wide area networks. This concept is based on the star network topology, where end devices (also called nodes or motes) transmit data to a gateway. The end devices are the vertexes of the star, where instead, the gateway is the central point of the star.

The latter board (called WappAct) is in charge of engaging and disengaging the bistable solenoid valve connected to the dripper on the field. In this way, the AS can physically actuate its decisions on the experimental fields.

Moreover, WappAct hardware considerations to minimize consumptions and maximize the functionalities on the field, the designed WappAct downlink and uplink commands needed to perform tasks required by the AS, and the irrigation cycle to water the orchards are presented in II-A, II-B, and II-C, respectively.

A. Hardware

WappAct is designed as a shield for a LoRa-enabled development board NUCLEO-WL55JC1 (STMicroelectronics, Geneva, Switzerland), and it turns on or off the bistable solenoid of the electrovalve based on the received command through LoRa. The system guarantees a long lifetime, and it is autonomous and compatible with harsh environments: the node is supplied by batteries that retain their capacities as much as possible in a wide range of temperatures (−20 to 50 °C). This is a typical range for outdoor environments. The node (Fig. 1) works using one AA-size 3.6 V LiSOCl2 (lithium thionyl chloride) battery and one 1604-size 9 V ZnMnO2 (alkaline) battery. The former powers the so-called processing section, including the NUCLEO-WL55JC1 board, and the latter supplies the H-bridge, the component that physically engages/disengages the solenoid in the electrovalve. This element is a tiny electronic component named DRV8210 (Texas Instruments, Dallas, Texas, USA), and it guarantees a very low quiescent current (around 300 nA with a supply voltage equal to 9 V). The system is low-cost: a Bill Of Material (BOM) equal to 81.3€ was found, including a PCB prototype production, electronic components and a LoRa development board. It can be integrated with existing irrigation systems: WappAct is shut in an IP65 (Ingress Protection 65) box and takes control of the dripper in place of commercial irrigation control systems. It can be directly connected to the solenoid if the present one is a 9 VDC latch type. If it is not the case, it is possible to change the solenoid, avoiding the need to modify the irrigation system already in place. The system works in LoRa class-A [12]: this mode allows minimum consumption from a communication point of view, maintaining a reasonable reactivity of the system to the actuation commands. Since the node is not always listening for incoming commands, a periodic status message is sent, opening a receive window for commands. The duty cycle of the operation can be modified at run-time to match the responsiveness needs keeping the power consumption under control.

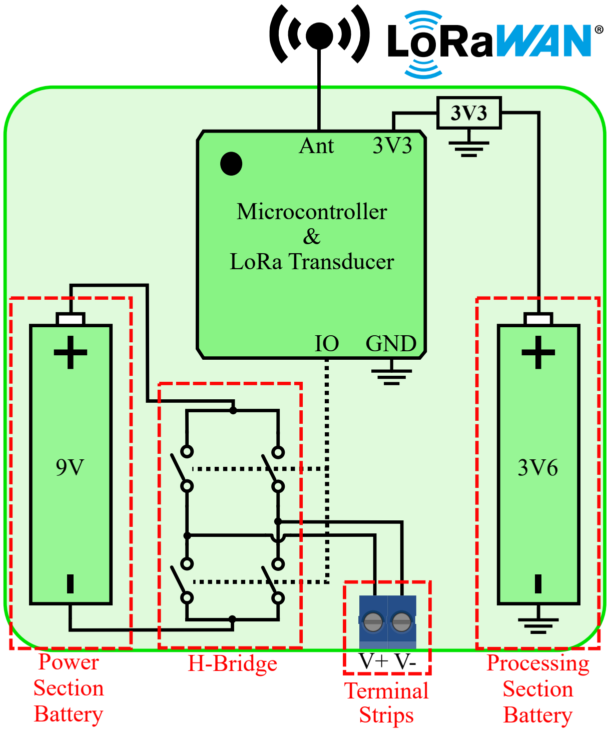

Fig. 1. A general overview of WappAct end node.

B. Firmware

WappAct is programmed to receive the following downlink commands:

- *Changing_LoRa_Periodicity*: it changes the periodicity of LoRa uplink packets. The accepted value range is limited from 10 to 5400 s: the lower bound is intrinsically connected to the class-A LoRa protocol and the upper bound avoids that an erroneous downlink command could set the periodicity to a too high value, losing precious information about the actual irrigation state;
- *Start_Irrigation*: it engages the bistable solenoid inside the electrovalve allowing the flow of water for a custom value (timeout value) expressed in seconds. After

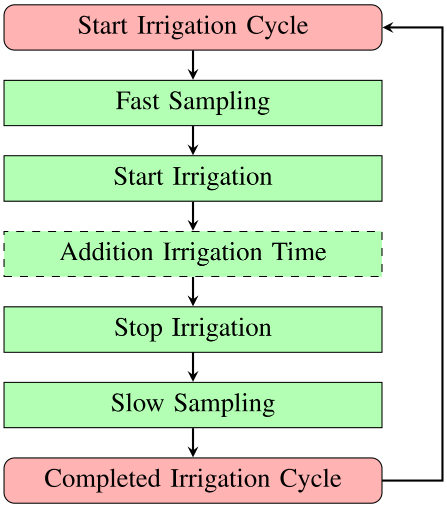

Fig. 2. Step sequence of an irrigation cycle.

this time, automatically, the system will disengage the solenoid preventing the water flow;

- *Stop_Irrigation*: it closes the electrovalve, stopping the water flow. Timeout timer is stopped and reset in such a way as to be ready for the next irrigation cycle;
- *Add_Time_Irrigation*: it adds time to the remaining timeout value. In this way, it is possible to increase the irrigation time depending on updated soil moisture data during the irrigation cycle.

WappAct is also programmed to send periodically uplink packets containing:

- *Status* byte: it provides information about the system and an acknowledgment of received downlink commands;
- *Water_Is_Flowing* byte: this boolean data informs whether the node has the electrovalve opened ('1') or closed ('0');
- *Remaining_Time* 2 bytes: it is appended to the uplink packet only if the electrovalve is opened. It provides the remaining timeout value (in seconds) of irrigation.

C. Irrigation Cycle

The irrigation cycle is planned to consume as less as possible avoiding unnecessary wake-up of electronic systems. In Fig. 2 are described the steps of a single irrigation cycle: when the irrigation threshold is overcome, an irrigation cycle starts. The first step is to reduce the periodicity of uplink packets in such a way as to have a greater reactivity to the actual data received by WappSen end nodes. A good range of LoRa periodicity is 1 to 5 min. After this, it is possible to start irrigation, using the downlink *Start_Irrigation* command, setting up a default opening time (1 h) and allowing water to flow in the dripper. When the remaining irrigation time is a few minutes (10 to 15 min) and the soil is still not watered adequately, it is necessary to add irrigation time using the downlink *Add_Time_Irrigation* command. At some point, matric potential overcomes the cultivar needs depending on the deactivation threshold: it is necessary to stop the irrigation by sending a downlink *Stop_Irrigation* command to stop the water flow. Before completing the irrigation cycle, it is fundamental to reconfigure a slower periodicity, setting up a duty cycle of 30 to 60 min in such a way as to reduce energy consumption when no irrigation is needed.

III. PERFORMANCE ANALYSIS

One fundamental pillar for a low-power electronic system for drip irrigation in orchards is the reduction of consumption. It is possible to demonstrate quantitatively the efficiency of WappAct, measuring the current consumption in the main phases of the system. In this way, it is possible to estimate the lifetime of WappAct.

For this reason, it has been performed a testbench employing a DMM7510 (Keithley Instruments, Cleveland, Ohio, USA), a digital sampling multimeter to measure current consumption in a test irrigation cycle in the laboratory. Fig. 3 shows the measured current consumption for both the processing section, supplied by 3.6 V LiSOCl2 battery, and the power section, supplied by 9 V ZnMnO2 alkaline battery.

Tested WappAct end node has been supplied and connected to a test electrovalve with a bistable solenoid 9–20 V model S392T (Bermad, Inc., California, USA). The current consumptions of the processing section and power section are measured separately since they are two independent power domains in WappAct.

Starting from the processing section measurement, a LoRa class-A sequence with a LoRa packet periodicity equal to 30 s starts with an uplink packet broadcasted to gateways. After 5 s, the first RX slot is opened: a downlink command to start irrigation was sent (*Start_Irrigation* downlink command with 45 s of opening time). Consequently, in the power section, it is possible to see a peak current consumption to engage the solenoid driven by DRV8210 H-bridge. After LoRa periodicity (30 s), a new uplink packet is sent in such a way as to allow the generation of a new receive slot to control the irrigation and to provide updated information about irrigation status (contained data in the uplink packet as described in Section II-B). In this situation, no new downlink

TABLE I
THEORETICAL AND EXPERIMENTAL WAPPACT CURRENT CONSUMPTION MEASUREMENTS.

Processing Section		
State	***Worst-case Curr.***	***Measured Aver. Curr.***
Low-power Mode[a]	4.0 µA	2.6 µA
State	***Worst-case Curr.***	***Measured Peak Curr.***
TX	45.5 mA	40.4 mA
RX1	8.9 mA	6.1 mA
RX2	8.9 mA	6.4 mA
Power Section		
State	***Worst-case Curr.***	***Measured Aver. Curr.***
Low-power Mode	≈300.0 nA	317.0 nA
State	***Worst-case Curr.***	***Measured Peak Curr.***
EV_ON / EV_OFF	1.5 A	1.2 A

[a] NUCLEO-WL55JC1 in STOP2 mode with RTC enabled.

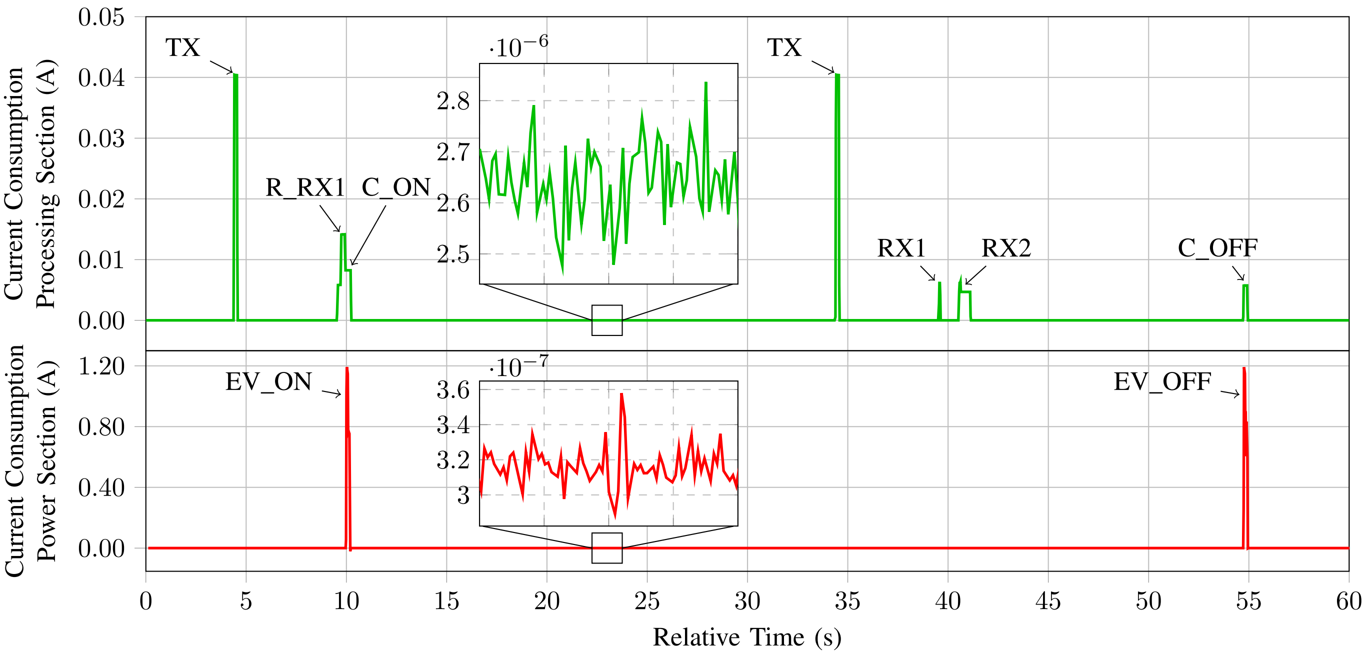

Fig. 3. Current consumption profiles measured during the test irrigation cycle.

commands are sent, so the system comes back to low-power mode. Finally, after 45 s, the associated timer to the irrigation is expired, so WappAct wakes up and disengages the solenoid stopping the water flow. It is not necessary to test fast and slow sampling because they do not change the current profile but only the periodicity of LoRa packets.

In Table I, the average current consumption in low-power mode and measured peak current during each run-time phase for both processing and power sections are highlighted. Results showed measured low-power mode average currents equal to 2.6 µA and 317.0 nA, respectively, for processing and power sections. Measurements showed peak currents equal to 40.4 mA, 6.1 mA, and 6.4 mA, respectively, in TX, RX1, and RX2 LoRa phases. A preliminary simulation of the batteries' lifetime was computed using measured current consumptions during the test irrigation cycle. A practical worst-case scenario in drip irrigation systems for Actinidia and apple orchards could be considered as follows: three months where one irrigation cycle is performed per day and two months where an irrigation cycle is performed once every four days. This simulation set up slow sampling equal to 60 min and fast sampling equal to 3 min. The experimental energy consumption in run-time was computed by integrating sensed current (linear interpolation) multiplied by the nominal voltage over time for each phase (TX, R_RX1, etc.) and adding energy consumption in low-power mode using measured average current consumption for both power and processing sections. The power section (EV_ON + EV_OFF) resulted in 840.8 µW h. Considering the high peak current (greater than 1 A) involved, a real capacity for an industrial 1604-size 9 V alkaline battery could be 40 mA h, a strong reduction with respect to the nominal value. These considerations lead to a maximum of 428 irrigation cycles: this value in real scenarios could be lower due to temperature variations and non-optimal discharge conditions. Considering 100 irrigation cycles per year, a realistic value could be 2–3 working years for the power stage. Processing section power is computed considering the sequence described in Fig. 2 without the addition of irrigation time. For this simulation, a LiSOCl2 battery (nominal capacity 9360 mW h) having 2700 mW h of real energy capacity at 0 °C was considered. A theoretical battery lifetime equal to 14.4 years was found. This value is heavily affected by several factors, such as LoRa data rate, the choice of LoRa periodicity for both fast sampling and slow sampling, the number of irrigation cycles per year, and the auto-discharge battery contribution. In a practical scenario, a realistic figure could be 3–4 years.

IV. CONCLUSION

This paper presented the design of an electronic system called WappAct able to control an electrovalve for drip irrigation in orchards. The designed node is low-power and, moreover, is able to work for several years in harsh environments in a rural context. This node is wireless and long-range, employing LoRa radiofrequency communication protocol, ranging several km. WappAct, presented in this paper, and WappSen are the elements composing an architecture to realize a micro-irrigation system for orchards directly on the field. The purpose is to contribute to water management, reducing irrigation waste in orchards.

ACKNOWLEDGMENTS

This work is funded by "PSR 2014-2020, Regione Piemonte, Operazione 16.1.1 Project: WAPPFRUIT" - CUP: J66B20006390002.

This article was funded under the National Recovery and Resilience Plan (NRRP), Mission 4 - Component 2 - Investment 3.1 - Call for tender No. n. 3264 of 28/12/2021 of Italian Ministry of Research funded by the European Union – NextGenerationEU - Project code: IR0000027, Concession Decree No. 128 of 21/06/2022 adopted by the Italian Ministry of Research, CUP: B33C22000710006, Project title: iEN-TRANCE. This manuscript reflects only the authors' views and opinions, neither the European Union nor the European Commission can be considered responsible for them.

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