



**HAL**  
open science

## A low cost sensor to improve surface irrigation management

Paul Vandôme, Simon Moinard, Guilhem Brunel, Bruno Tisseyre, Crystele Leauthaud, Gilles Belaud

► **To cite this version:**

Paul Vandôme, Simon Moinard, Guilhem Brunel, Bruno Tisseyre, Crystele Leauthaud, et al.. A low cost sensor to improve surface irrigation management. *Precision Agriculture*, 2024, 25, pp.3072-3085. 10.1007/s11119-024-10190-5 . hal-04775496

**HAL Id: hal-04775496**

**<https://hal.science/hal-04775496v1>**

Submitted on 14 Nov 2024

**HAL** is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

[Click here to view linked References](#)

# A low cost sensor to improve surface irrigation management

P.Vandôme<sup>1</sup>, S.Moinard<sup>2</sup>, G.Brunel<sup>2</sup>, B.Tisseyre<sup>2</sup>, C.Leauthaud<sup>1</sup>, G.Belaud<sup>1</sup>.

<sup>1</sup>*G-EAU, Univ. Montpellier, AgroParisTech, BRGM, Cirad, IRD, INRAE, Institut Agro, 361 rue J.F Breton, 34196 Montpellier, France*

<sup>2</sup>*ITAP, Univ Montpellier, INRAE, Institut Agro, 2 Place Pierre Viala, 34060 Montpellier, France*

Corresponding author: [paul.vandome@gmail.com](mailto:paul.vandome@gmail.com)

ORCID: 0000-0003-3096-9341

## Abstract

This study presents the development and the evaluation of a low-cost sensor-based system to optimize the management of surface irrigation at the field level. During a surface irrigation event, water flows according to the slope of the field and it is difficult and time-consuming to predict the optimal time when inflow should be stopped. In such systems, measurement tools are uncommon and those existing are far too complex and expensive to be used as decision support tools on small farms. This article presents the development of an Open Source system, based on low-cost technologies, Internet of Things and LoRaWAN network, that allows: (i) detection of water at the sensor location in the field, (ii) sending an alert by phone to the user and (iii) remote control of surface irrigation gates. The metrological characteristics of the system and its suitability were tested in real conditions during one irrigation season of hay fields in the Mediterranean region. The results highlighted the reliability of the low-cost sensor system for detecting water and transmitting information remotely, with a 100% success rate. Remote control of irrigation gates was successful in 89% of trials carried out in the field, and adjustments resulted in a 100% success rate. The savings in labour time for the farmer and in irrigation water volumes made possible by the use of this system, as well as the inevitable trade-offs between accessibility, reliability and robustness of new technologies for agriculture, are finally discussed.

**Keywords:** Low cost sensor, Agricultural water management, Internet of Things (IoT), Surface irrigation

1 **Statements and Declarations**

2  
3 **Acknowledgements**

4 This paper is part of the first author's PhD project, funded by the CIRAD and the  
5 Occitanie Region (France). The work was carried out as part of HubIS project (EU's  
6 PRIMA programme 2019, grant ANR-19-P026-0006-02). We are grateful to the Domaine  
7 du Merle, and notably F.Charron, for participating in the project.  
8  
9

10  
11  
12 **Conflict of interest**

13 The authors declare that they have no conflict of interest.  
14  
15

16  
17 **Introduction**

18  
19 Surface irrigation consists in applying water directly on the soil surface and using gravity  
20 for its distribution within the field. This traditional practice is the most widely represented  
21 irrigation method in the world, but also the most controversial as it is often considered to  
22 have the poorest performance (Pereira and Gonçalves, 2018). Indeed, surface irrigation is  
23 often difficult to manage, labour intensive and involves the application of large volumes  
24 of water. The labour constraint generally leads to an increase in the surface area of  
25 irrigation units, resulting in a reduction in optimal efficiency (Zerihun et al., 2005). In  
26 addition, the lack of feedback information for surface water flow management leads to  
27 sub-optimal irrigation times (Clemmens, 1998). Given the volumes of water involved,  
28 technological solutions have been developed, based on supervision and control systems  
29 (Koech et al., 2014), but which remain inaccessible for agricultural production with low  
30 added value. In a context of water scarcity and tensions on the resource, it is essential to  
31 search for ways to facilitate the management of surface irrigation and to favour water  
32 savings.  
33  
34  
35  
36  
37  
38  
39  
40  
41  
42  
43  
44

45  
46  
47 The rise of precision agriculture in recent decades has led to explore different ways to  
48 improve the performance of irrigated systems. Several monitoring and decision support  
49 tools such as model-based control strategies, field and remote sensing, or automatic  
50 irrigation systems have been studied (Ihuoma and Madramootoo, 2017; Zinkernagel et  
51 al., 2020). However, the adoption of these technologies remains limited at the field and  
52 farm levels, notably because of insufficient economic and technical accessibility (Tey and  
53 Brindal, 2012). Recent technological advances in embedded electronics,  
54  
55  
56  
57  
58  
59  
60  
61  
62  
63  
64  
65

1 telecommunication and the Internet of Things (IoT) has enabled the emergence of low-  
2 cost and energy-efficient wireless sensor networks (WSN) increasingly used in precision  
3 irrigation (Abioye et al., 2020; Hamami and Nassereddine, 2020; Bwambale et al., 2022;  
4 Vandôme et al., 2023). Some studies have shown that performance gains are achievable  
5 using remote automatic irrigation systems based on real-time soil moisture measurements  
6 (Liao et al., 2021; Nawandar and Satpute, 2019).  
7  
8  
9

10  
11  
12  
13 However, most studies have focused on systems suitable for modern localized irrigation  
14 systems (drip, micro sprinkler, hydroponic), and few have attempted to introduce these  
15 technologies within surface irrigation systems. Such systems, though, account for the vast  
16 majority of irrigated systems in the world, with particular challenges in applying  
17 technologies for small-scale basin irrigation of rice, or for furrow irrigation of crops with  
18 low added value. This context raises questions about the possibility of implementing  
19 simple, self-repairing systems that are technically and economically accessible for surface  
20 irrigation management. The objective of this study was therefore to develop an IoT  
21 sensor-based system to improve surface irrigation management that is affordable, reliable  
22 and easy to use by farmers. The overall methodology, based on new open-source  
23 developments and field implementation, is presented first. The results include the  
24 description of the sensors and their performance evaluation over a complete irrigation  
25 season, as well as their combination with an actuator for the automation of gate operation.  
26 The potential, limitations and perspectives of the prototypes are then discussed.  
27  
28  
29  
30  
31  
32  
33  
34  
35  
36  
37  
38  
39

## 40 **Materials and methods**

### 41 Overall approach

42  
43 The technologies described in this article were designed and tested through a participatory  
44 process involving iteratively the farmers of the agricultural territory over the course of  
45 the 2021 and 2022 irrigation seasons (Vandôme et al., 2023a). The aim of this co-design  
46 approach was to shape the innovation to match the territories, i.e. to adapt the  
47 technological solutions to the needs and constraints of the users in the field in order to  
48 encourage their later adoption.  
49  
50  
51  
52  
53  
54  
55  
56  
57  
58  
59  
60  
61  
62  
63  
64  
65

## Experimental field overview

The study area (43.643748N 5.016744E, WGS84) was located in the Crau plain, South of France, in a farm producing surface irrigated hay from an area of 150ha. The cropping system, and particularly the irrigation practices, are representative of that found within the Crau plain comprising 14,000 ha of irrigated hay. The experiments were carried out on an irrigation block of 8 ha, divided into seven fields irrigated successively thanks to a series of six gates. When closed, a gate causes the rise of water level in the channel, and then its overtopping from the canal into the field, at its highest section (Fig.1.b). Water then flows by gravity toward the lowest section of the field following the slope (around 0.3 % in the NE-SW direction). When water arrives at a certain distance from the incoming canal (after a time that can be of a few hours, depending on the slope, the vegetation density, the flow rate and the plot length), irrigation can be stopped by closing the gate located upstream in the canal. Water inflow to this field hence stops, and the next field starts to be irrigated (Fig.1.c). The irrigation efficiency is therefore largely controlled by the time when gates are operated.

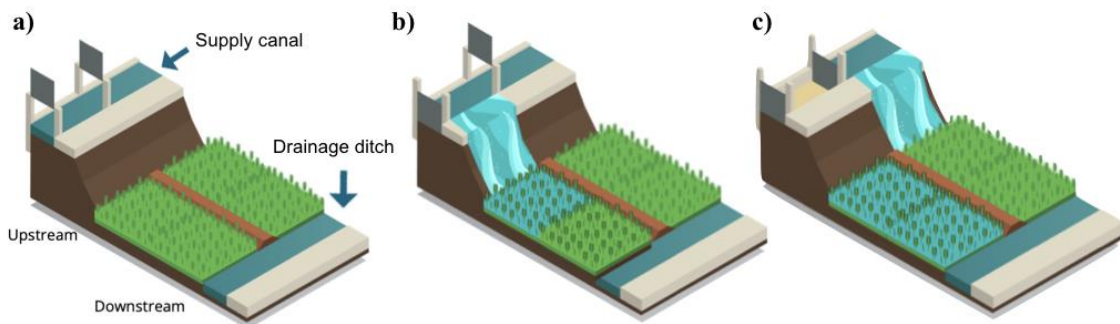


Figure 1. Schematic representation of border irrigation operation.

## Prototype specifications

The specifications of the prototype, built with the support of farmers, were as follows: (i) the system must allow surface water detection and wireless data transmission (ii) at a sufficiently high frequency (5 to 10 min) to monitor water flows without risking excessive losses through drainage and (iii) from fields located at a great distance from the farm building (within a radius of 50 to 1000m); (iv) it must be affordable (< 200 €/ha); (v) reliable and robust; (vi) easy to design and maintain and (vii) energy self-sufficient throughout the whole irrigation season.

## Hardware components

The components that were selected to meet the specifications are listed in Figure 2.a). The Cubecell-HTCC01 microcontroller, which enables remote data transmission via the LoRaWAN network, was selected. A passive float sensor was chosen for its simplicity and its low cost. A 2700 mAh LiPo 18650 battery was used for the power supply, allowing a theoretical autonomy of 10 months. Figure 2.b) shows the schematic diagram of the system - hereafter called “*WatAr*”.

<b>Id</b>	<b>Model</b>	<b>Function</b>	<b>Manufacturer</b>	<b>Cost</b>
1	Cubecell HTCC01	Microcontroller	Heltec, China	11.43€
2	Breadboard	Connector	HMTI, China	1.61€
3	Water level	Sensor	SeeSensor, China	0.77€
4	Resistor	Power limiter	Eiechip, China	0.01€
5	Wires	Connector	Xnbada, China	0.01€
6	LiPo Battery	Power Supply	DaweiKala, China	2.70€
<b>Total</b>				<b>16.53€</b>

Figure 2. Hardware description for the water detection system (“*WatAr*”) design: a) components and costs table; b) electronic diagram.

## Software components and dataflow architecture

The programming of the Cubecell microcontroller was performed in C/C++ language through the open-source Arduino software (IDE) 1.8.19. The LoRaWAN communication protocol was chosen for its low energy consumption and long range ~10 km, suitable for agricultural use (Tao et al., 2021). The commercial solution The Things Network (TTN, the Netherlands) was chosen because it does not require any subscription fee and allows the implementation of a private network with suitable coverage over the study site with one antenna.

The dataflow architecture is shown in Figure 3. The purpose of this architecture was to transmit the *WatAr* data from the field to the user's phone, while storing information to enable data processing and analysis. The dataflow developed can be divided as follows:

(i) data produced at the field level by the *WatAr* was sent through the LoRa network. Network coverage was provided by specific LoRaWAN antenna on the roof of the farm building, 360m far from the most remote sensor position. The antenna is linked to a “The Things Network Gateway” (The Things Industries, The Netherlands), selected for its simplicity of use: once powered and connected to the internet via Wi-Fi, the data can be downloaded directly from the dedicated web platform of The Things Network. (ii) The data was then transmitted to a server using a MQTT protocol for processing and storage. Data storage was done using Influxdb (InfluxData, USA), an open-source database for time series. (iii) A script was developed to compare each *WatAr* status data with the previous one. In the case of status change (i.e. when water arrived to the water sensor), an alert was sent to the Telegram smartphone application by means of a Telegram bot. The latter was implemented with the Node-RED (IBM, USA) programming tool.

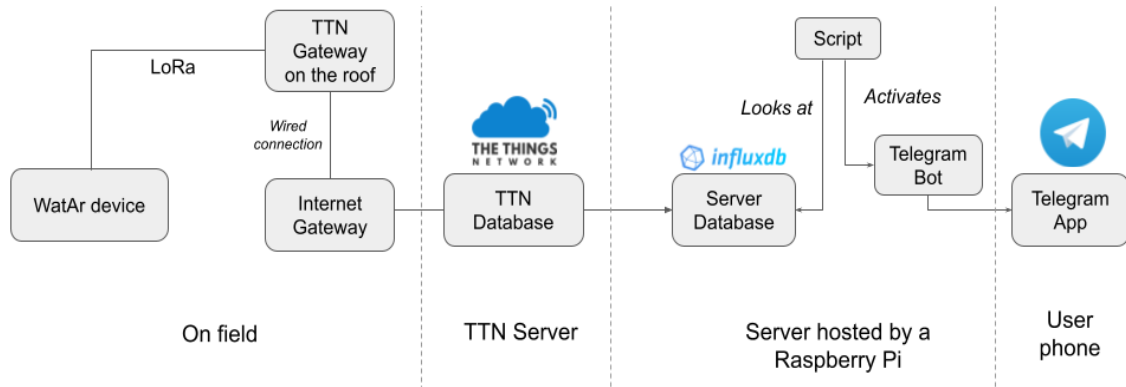


Figure 3. Dataflow architecture: from the device on field to the user’s smartphone.

### Assessing the usability of the *WatAr* through in-field tests

Goals of in-field tests were threefold. First, the sensitivity of the sensor was tested. To this end, six *WatAr* were installed in the field during one irrigation event. The time of reception of the alert was recorded and compared to the real observed time of arrival of the water at the *WatAr* location. This experiment was repeated 10 times.

Second, the robustness of the *WatAr* was tested. To this end, seven fields were equipped with one *WatAr* each during the whole irrigation season, corresponding to 15 irrigation events, from March to October 2022. Monitoring the functioning of the *WatAr* over the whole season allowed to identify any limitations (autonomy, malfunction, etc.).

1 Use cases: from decision support to automation for surface irrigation

2  
3  
4 Different use cases for the water detection system were tested, as described below. First,  
5 the suitability of the *WatAr* as a decision support tool was assessed, which corresponds to  
6 its simplest use. Then, a system for the remote control of irrigation gates based on the  
7 information provided by the *WatAr* was also tested in order to study the feasibility of a  
8 more sophisticated use case.  
9

10  
11  
12  
13  
14  
15  
16 *Suitability of the WatAr as a decision support tool*

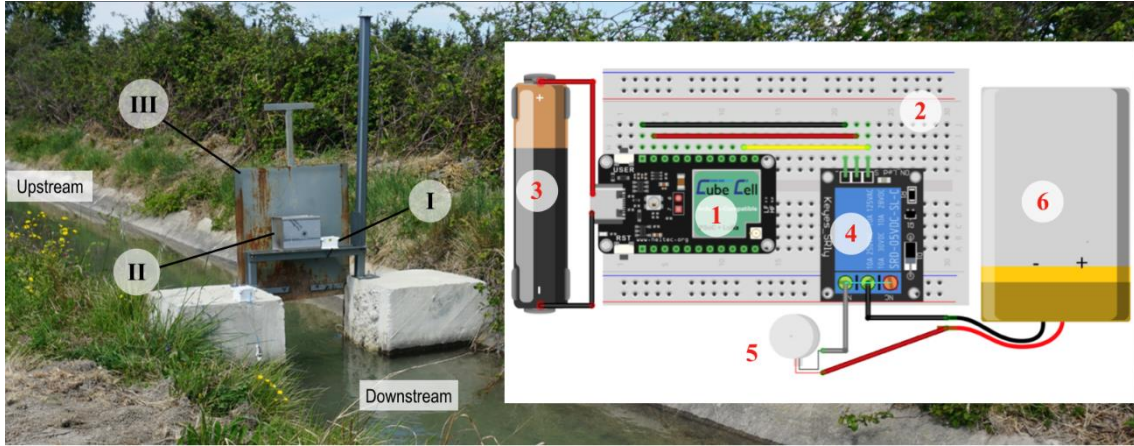
17  
18 In this first case of use, the suitability of the *WatAr* as a decision support tool was tested.  
19 To this end, a *WatAr* was installed at 80% of the length of the field with respect to the  
20 inflow canal. The arrival of the water layer at this location should in practice lead to stop  
21 irrigation, the inertia of the water flow allowing to cover the remaining 20% of the field.  
22 During the irrigation event of July 12, 2022, the position of the water front was recorded  
23 regularly using a GNSS RTK system (Centipede, France) with a centimetric accuracy. In  
24 this controlled situation, the farmer was asked to proceed as usual, and therefore does not  
25 have the information provided by the *WatAr*. The frequency and duration of his visits to  
26 the field to manage irrigation were recorded in order to assess the potential labour time  
27 savings resulting from the adoption of the *WatAr* as a decision support tool.  
28  
29  
30  
31  
32  
33  
34  
35  
36  
37  
38

39 *Coupling the WatAr sensor with a low cost automated irrigation gate*

40  
41 A surface irrigation gate automation system, hereafter called the "*Lancelot*", was  
42 developed as a complement to the "*WatAr*" water detection system. Based on feedback  
43 from farmers, the aim of the prototype was to develop a system that: (i) limits the number  
44 of irrigation operations that need to be carried out at a specific time (and even more so at  
45 night or at weekends), (ii) has low energy consumption (to limit the risk of theft of  
46 batteries or solar panels, recharging operations and costs), and (iii) can be adapted to  
47 existing manually operated hydraulic gates. The prototype was designed to remotely  
48 operate a gate with a descending slide: the operation usually carried out manually by the  
49 irrigator during the water turn consists of closing the gate to irrigate the field upstream at  
50 a given time, and re-arming between water turns is done in the high-open position - this  
51  
52  
53  
54  
55  
56  
57  
58  
59  
60  
61  
62  
63  
64  
65



second operation being less constraining because the farmer has several days to do it (around 10 days in the study case). The *Lancelot* automation system, described in Figure 4, consists of a hanging case and a remote control module.



<b>Id</b>	<b>Model</b>	<b>Function</b>	<b>Manufacturer</b>	<b>Cost</b>
1	Cubecell HTCAB01	Microcontroller	Heltec, China	11.43€
2	Breadboard	Connector	HMTI, China	1.61€
3	LiPo Battery	Power supply	DaweiKala, China	2.77€
<b>I</b>	<b>Sub-total control module</b>			<b>15.74€</b>
4	Relay 5VDC KY-019	Relay	Songle, China	1.79€
5	ITS-PE-5029-12VDC	Deactivation electromagnet	Conrad, Germany	61.19€
6	VRLA AGM 12V 4.5ah	Magnet power supply	Lucas, France	9.00€
7	Small mechanics	Hanging device	Misumi, France	18.59€
<b>II</b>	<b>Sub-total hanging system</b>			<b>90.57€</b>
<b>Total Lancelot system</b>				<b>106.31€</b>

Figure 4. Hardware description for the automated irrigation gate (“*Lancelot*”) design: control module (I), hanging system (II) and surface irrigation gate (III).

The *Lancelot* principle was designed as follows: the gate was held in the open position by a hanging device. A rotary axis allowed the hanging device to pivot in order to support or release the gate. A permanent electromagnet prevented the axis from rotating, which ensured that the gate was held open. Applying an electric current to a solenoid temporarily deactivated the magnet, releasing the hanging device and closing by gravity the slide gate. The application of this current was conditioned by the control module, which comprised the micro-controller and an electrical relay.

1 Similarly to the *WatAr* system, the *Lancelot* data was transmitted locally via the LoRa  
2 network, then redirected online for storage, display and analysis (Fig.3). The distinctive  
3 feature of the *Lancelot* system is that the microcontroller was programmed in “receiver”  
4 mode (downlink): the sensor was designed to wake up every three minutes and check the  
5 data received. This reverse dataflow made it possible to send data from the user, via the  
6 Telegram messaging application, to the connected irrigation gate for its operation.  
7  
8  
9  
10  
11

12  
13 In order to test the *Lancelot* system in real-life conditions, the six irrigation gates of the  
14 experimental site were each equipped with the automation system on 21 March 2023.  
15 These gates were selected in order to i) study the feasibility of fully automating a gravity  
16 irrigation block of around 8 ha, ii) test the adaptability of the *Lancelot* system to steel  
17 down-slide gates of varying dimensions (width between 400 and 700 mm) and mass  
18 (between 10 and 25 kg). The automation system was tested in the course of irrigation  
19 events on 21 March and 17 April 2023, for a total of 18 repetitions.  
20  
21  
22  
23  
24  
25  
26

## 27 **Results**

### 28 Design of the *WatAr* prototype

29  
30  
31  
32  
33 Figure 5.a) shows the *WatAr* prototype under field experiment conditions. The *WatAr*  
34 includes two parts: (i) The acquisition module with the microcontroller and its LoRa  
35 telecommunication chip, packed in a black 3D printed waterproof package, and (ii) the  
36 water sensor in its white 3D printed shell. The sensor is placed on the ground to detect  
37 the presence of water. The water sensor contains a magnet that rises along the vertical  
38 axis with the level of the water. A magnetic switch sensor is then activated, which allows  
39 the presence of water to be detected, defining a high position (Fig 5.b) or low position  
40 (Fig. 5.c).  
41  
42  
43  
44  
45  
46  
47

48 In order to save power, the *WatAr* is in a standby mode by default, it checks every five  
49 minutes the status of the water sensor (low or high) and send the information through the  
50 LoRa network. If the sensor status changes, the information is transmitted to the operator  
51 through the Telegram smartphone messaging application (Fig. 5.d). Looking for a  
52 compromise between simplicity of design, robustness and cost, the final system costs less  
53 than 20€.  
54  
55  
56  
57  
58  
59  
60  
61  
62

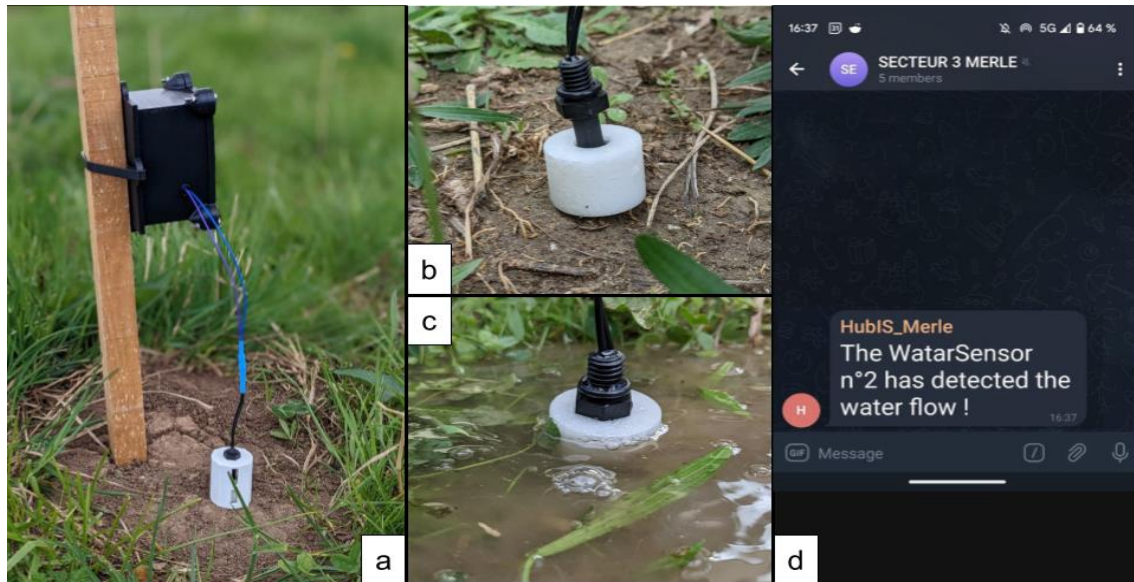


Figure 5. Operational prototype (“*WatAr*”) in use during the 2022 irrigation season: a) the *WatAr* on the experimental site; b) the sensor (without its protective shell) in low position (absence of water), and c) in high position (presence of water) which leads to d) water detection alert in the Telegram application on user's smartphone.

### Sensitivity analysis of the *WatAr*

The field trials showed that the *WatAr* effectively detected surface water (100% of the irrigation events were detected by the *WatAr* after 60 repetitions). Messaging alerts were received on average 5 minutes after the observation of water arrival at the sensor location. The minimum recorded delay was 2 minutes, and the maximum was 10 minutes after observation. Delays of more than 5 minutes could occur due to the unstable nature or an insufficient water height to keep the water sensor in the upper position.

### Robustness over the season

The monitoring of *WatAr* sensors throughout the irrigation season allowed to identify any dysfunctions over a long period. On average, 2.5 maintenance operations per sensor over the 8 months season were necessary. Different types of problems were observed and a maintenance protocol was set up to address them. The batteries of some sensors discharged faster than expected in the first months, which accounted for 80% of maintenance operations. The objective was for the power supply to last for the 8 months of the season. In response, the Arduino code was optimised and initial cheap batteries (1.4€/unit) were replaced with higher quality ones (2.7€/unit). Other maintenance

1 operations were necessary in relation to external events, which are not specific to the  
2 *WatAr* system, but which may occur in agricultural conditions of use: (i) a storm caused  
3 a power outage at the farm that powered the gateway, which led to a 24-hour gap in the  
4 data; (ii) a cable connecting a sensor to its acquisition module was accidentally cut,  
5 probably during a trimmer operation. At the end of the season, the occurrence of  
6 maintenance operations decreased significantly as a result of the continuous improvement  
7 of the *WatAr* (no maintenance required during the last two months of the season). Besides  
8 the robustness inherent to the technology, some improper irrigation detection occurred in  
9 the case of heavy rainfall events. Such outliers were easily identified and cleared as there  
10 is no irrigation during rainy days.  
11  
12  
13  
14  
15  
16  
17  
18  
19  
20

### 21 Suitability of the *WatAr* as a decision support tool

22  
23 The results of the in-field tests (Fig.6) showed that the relationship between water  
24 advance and time is not linear, meaning the surface water velocity was not constant. In  
25 these conditions, it was particularly complex for the farmer to follow the progression of  
26 water in each of his fields. This led the farmer to regularly visit his field under irrigation  
27 to check the progress of the water and try to anticipate the right moment to operate the  
28 water gates.  
29  
30  
31  
32  
33

34 The farmer came twice to start and stop the irrigation, and twice more to check the  
35 progress of the water through the field. In total, the farmer spent 32 minutes on site. This  
36 is more than an hour of labour to irrigate a single field, considering the time it takes to go  
37 back and forth from the field to the farm (about 10 minutes each time). Two hours and 32  
38 min. after the irrigation start, the *WatAr* released a water detection alert at its location  
39 (80% of the plot length), whereas the farmer, not informed about the position of the water  
40 front at that time, turned off the irrigation 28 min. later. Considering the time needed for  
41 the farmer to come to operate the gate, the potential gain on the irrigation is 18 min i.e.  
42 10% of the actual irrigation time, representing around 130m<sup>3</sup> of water i.e. 10% of the  
43 actual inflow.  
44  
45  
46  
47  
48  
49  
50  
51  
52  
53  
54  
55  
56  
57  
58  
59  
60  
61  
62  
63  
64  
65

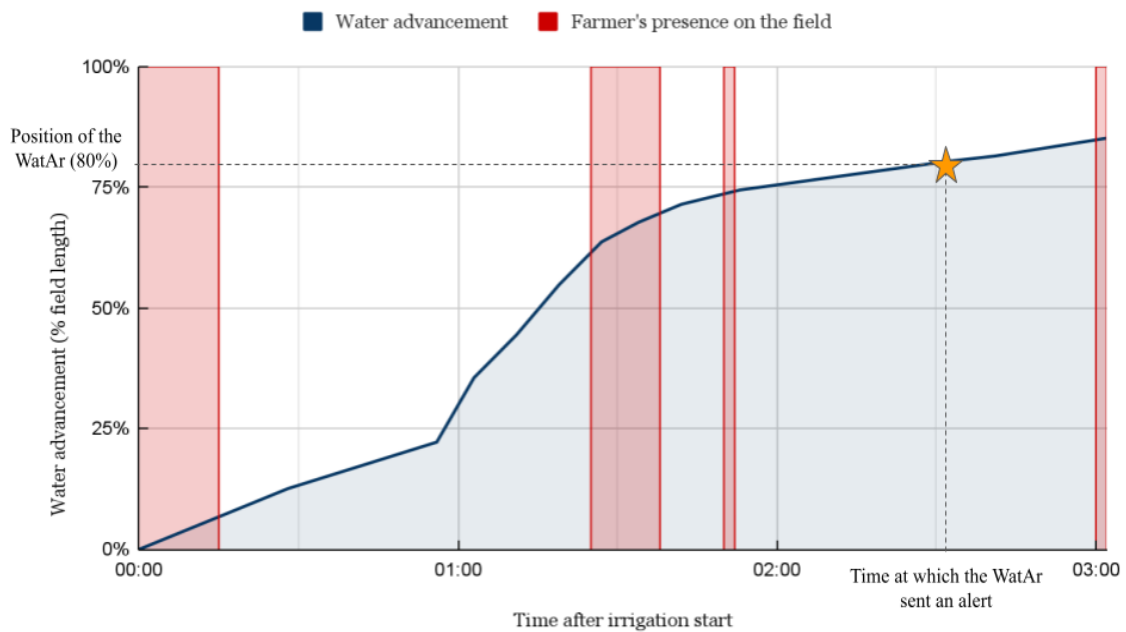


Figure 6. Progression of surface water advance front over time on an irrigated field (total length 270m; area: 1ha). The red zones indicate the farmer's visits to the field. The star indicates when the *WatAr* alert was sent, the farmer not having the message.

### Design and testing of the *Lancelot* prototype

Field trials of the *Lancelot* system highlighted the feasibility to remotely control surface irrigation gates using simple connected devices. Figure 7 describes the steps involved in operating the automatic gate. The control interface on the Telegram messaging application enabled the farmer to select the gate he wished to operate following receipt of the water detection alert on the field downstream provided by the *WatAr* system. A validation step by the user was required before the gate was actually closed, to prevent any errors.

The results of the experiments carried out during the irrigation events showed that 89% of the gates equipped with the *Lancelot* system were closed successfully on the first attempt. The average time delay between validation of the command on the user's smartphone and the actual closing of the gate was 4 minutes and 50 seconds, with a minimum of 1 min. and a maximum of 7 min. The remaining 11% of the gates were released on the second attempt, after they have been rebalanced on their hanging brackets.





Figure 7. Operational « *Lancelot* » prototype in use during the 2023 irrigation season : a) surface irrigation gate in open position; b) the gate to be operated is selected by the farmer via the messaging interface ; c) the selected irrigation gate is remotely closed after user validation.

The one-month interval between the two irrigation events studied allowed us to check that the irrigation gates were properly maintained in the open position by the electromagnets over time. Furthermore, the experiment showed that the *Lancelot* system was adaptable to different formats of sluice gates, with complete closure of the gates (down to the canal bed) being verified for the entire range of dimensions and masses studied.

## Discussion

The *WatAr* allows surface water detection and wireless transmission of this information. The use of low cost components and free software makes the system very affordable (<20€). The data generated is reliable (100% detection of irrigation events), and the information is transmitted quickly to the user (5 min on average). The transmission speed could be improved by changing the frequency of data emission by the microcontroller, but at the expense of battery lifetime. The continuous improvement of the system during the irrigation season improved its robustness over time, especially the battery autonomy, whose recharge represented 80% of the maintenance operations. In addition, the accessibility of the prototype is improved by its low-tech nature. The *WatAr* is indeed easy and quick to design and maintain. To confirm this point, further work led to production of a tutorial for the design and use of the *WatAr*, validated during participatory

1 workshops with different categories of stakeholders in the study area. The open-source  
2 aspect makes it a "white box" that can be understood and adaptable. The system  
3 developed therefore meets the established specifications and appears to be one of the  
4 answers to the constraints of surface irrigation.  
5  
6  
7  
8  
9

10 The system could reduce labour time and irrigation duration. According to the results of  
11 our experiment, the use of the *WatAr* would have saved two return trips and about 50%  
12 of the time spent on the field. This enables the farmer to focus on other activities without  
13 interruption and to be relieved of water flow verification. Extrapolating these results to  
14 the scale of the irrigation season (around 15 water turns for hay production in the region)  
15 and to the scale of a representative farming system like the study area (150 ha of irrigated  
16 hay), the savings in working time could represent 1350 hours/season.  
17  
18  
19  
20  
21  
22  
23

24 Regarding water savings, the potential gain with the use of *WatAr* was around 10% of the  
25 irrigation amount in the experiment. Given that a hay field is irrigated around 15 times  
26 per season under the conditions of the experimental hay production region, the adoption  
27 of the *WatAr* would result in a potential water saving of 2000 m<sup>3</sup>/ha/season. This rough  
28 estimate needs further refinement (e.g., considering the effect of field characteristics), but  
29 it is assumed that the gain could be even larger with an optimal positioning of the *WatAr*.  
30  
31  
32  
33  
34  
35  
36

37 *WatAr* sensors were placed at 80% of the length of the fields. This position was  
38 determined empirically by the water users to account for the inertia of the water, which  
39 should allow the remaining 20% of the field to be covered after irrigation has stopped.  
40 However, the generalisation of this location appears limited given the diversity of factors  
41 involved when estimating this inertia (Mailhol and Merot, 2008). For this reason, the  
42 positioning of the sensor along the field should be based on farmer's experience. In  
43 addition, modelling work could allow to formulate recommendations for the optimal  
44 positioning of the sensor (Salahou et al., 2018). We argue that the installation of several  
45 sensors may also be used in more advanced strategies, for example using the *WatAr* for  
46 real-time water location data to better predict the progression of the water front, or placing  
47 it at canal overflow level to monitor large-scale irrigation schedules.  
48  
49  
50  
51  
52  
53  
54  
55  
56  
57  
58  
59  
60  
61  
62  
63  
64  
65

1 With the *WatAr* system only, the farmer's intervention to activate the water gates is still  
2 necessary after receiving the alert provided by the sensor, and delays in reaction are to be  
3 expected when the farmer is busy elsewhere. Further, the *WatAr* does not provide a  
4 solution for night-time water management which remains a significant constraint. For  
5 these reasons, the *Lancelot* system was developed. It allows the remote control of the  
6 water gates by the farmer after receiving information on the presence of water  
7 downstream from the *WatAr*. Our results provide a proof of concept for the design and  
8 operation of the automation system under field conditions. The prototype appears to be a  
9 low-cost (< €110), open-source alternative for reducing heavy labour and superfluous  
10 water volumes in small irrigation systems, compared to existing “proprietary” high-tech  
11 solutions for large farms and high added-value irrigation systems (Koech et al., 2014).  
12 However, it would be interesting for future studies to investigate the robustness of the  
13 *Lancelot* over time after several irrigation seasons. Our experiments have also highlighted  
14 the risk of the gate not being released if it is not precisely balanced on its support. For this  
15 reason, we suggest that the *Lancelot* system should be backed up by a warning system to  
16 ensure that the desired gate is operating correctly. The positioning of a *WatAr* system at  
17 the level of the canal overflow on the field might be appropriate for this purpose.  
18  
19  
20  
21  
22  
23  
24  
25  
26  
27  
28  
29  
30  
31

## 32 **Conclusion**

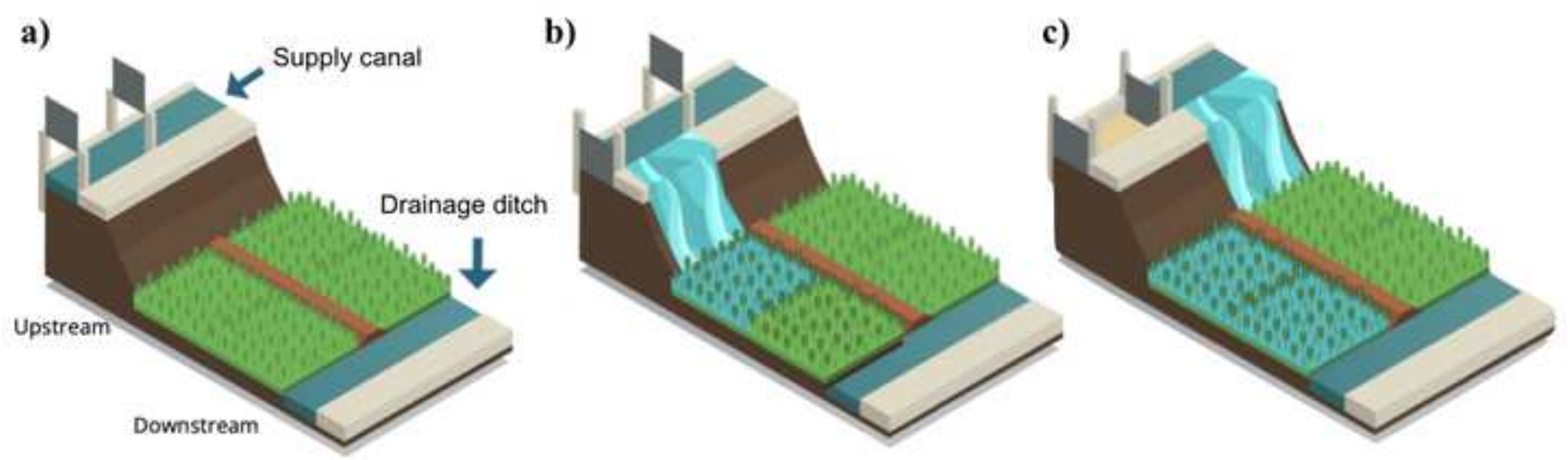
33  
34 A low cost sensor (*WatAr*), detecting the presence of water at a specific location within a  
35 field aiming to facilitate surface irrigation management, was developed and tested in real  
36 conditions over a whole irrigation season. The *WatAr* meets several specifications: it  
37 allows the detection of surface water and the transmission of the data remotely. Field tests  
38 confirmed the robustness and reliability of the system. The low-tech and low-cost  
39 hardware and the free open-source software make the *WatAr* highly reproducible,  
40 affordable and accessible. Its use can be combined with the *Lancelot* system, which  
41 allows remote control of irrigation gates by the water user. Their adoption should help to  
42 improve the performance of surface irrigation systems by saving water and labour time.  
43 To go further, the developed system would benefit research into strategies for optimising  
44 sensor positioning. New questions are also being raised about the evolution of agricultural  
45 advisory services to support farmers in the self-construction and maintenance of such  
46 accessible systems.  
47  
48  
49  
50  
51  
52  
53  
54  
55  
56  
57  
58  
59  
60  
61  
62  
63  
64  
65



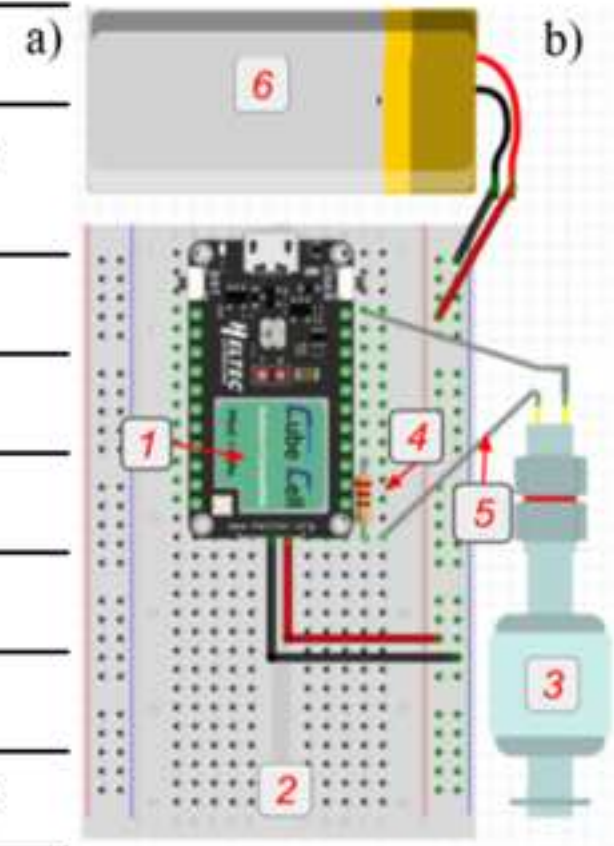
## References

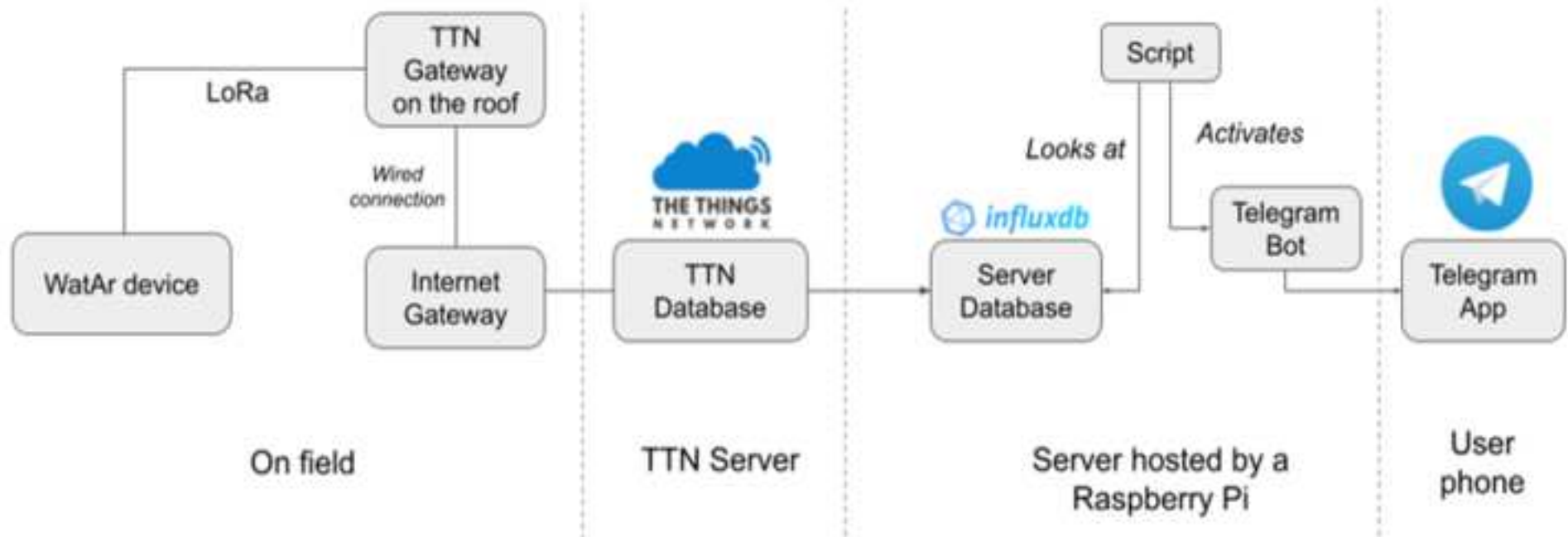
- Abioye, E.A., Abidin, M.S.Z., Mahmud, M.S.A., Buyamin, S., Ishak, M.H.I., Rahman, M.K.I.A., Otuoze, A.O., Onotu, P., Ramli, M.S.A., 2020. A review on monitoring and advanced control strategies for precision irrigation. *Computers and Electronics in Agriculture* 173, 105441.  
<https://doi.org/10.1016/j.compag.2020.105441>
- Bwambale, E., Abagale, F.K., Anornu, G.K., 2022. Smart irrigation monitoring and control strategies for improving water use efficiency in precision agriculture: A review. *Agricultural Water Management* 260, 107324.  
<https://doi.org/10.1016/j.agwat.2021.107324>
- Clemmens, A.J., 1998. Level basin design based on cutoff criteria. *Irrigation and Drainage Systems* 12, 85–113. <https://doi.org/10.1023/A:1005986006030>
- Hamami, L., Nassereddine, B., 2020. Application of wireless sensor networks in the field of irrigation: A review. *Computers and Electronics in Agriculture* 179, 105782. <https://doi.org/10.1016/j.compag.2020.105782>
- Ihuoma, S.O., Madramootoo, C.A., 2017. Recent advances in crop water stress detection. *Computers and Electronics in Agriculture* 141, 267–275.  
<https://doi.org/10.1016/j.compag.2017.07.026>
- Koech, R.K., Smith, R.J., Gillies, M.H., 2014. A real-time optimisation system for automation of furrow irrigation. *Irrigation Science* 32, 319–327.  
<https://doi.org/10.1007/s00271-014-0432-6>
- Liao, R., Zhang, S., Zhang, X., Wang, M., Wu, H., Zhangzhong, L., 2021. Development of smart irrigation systems based on real-time soil moisture data in a greenhouse: Proof of concept. *Agricultural Water Management* 245, 106632.  
<https://doi.org/10.1016/j.agwat.2020.106632>
- Mailhol, J.C., Merot, A., 2008. SPFC: a tool to improve water management and hay production in the Crau region. *Irrigation Science* 26, 289–302.  
<https://doi.org/10.1007/s00271-007-0099-3>
- Nawandar, N.K., Satpute, V.R., 2019. IoT based low cost and intelligent module for smart irrigation system. *Computers and Electronics in Agriculture* 162, 979–990.  
<https://doi.org/10.1016/j.compag.2019.05.027>

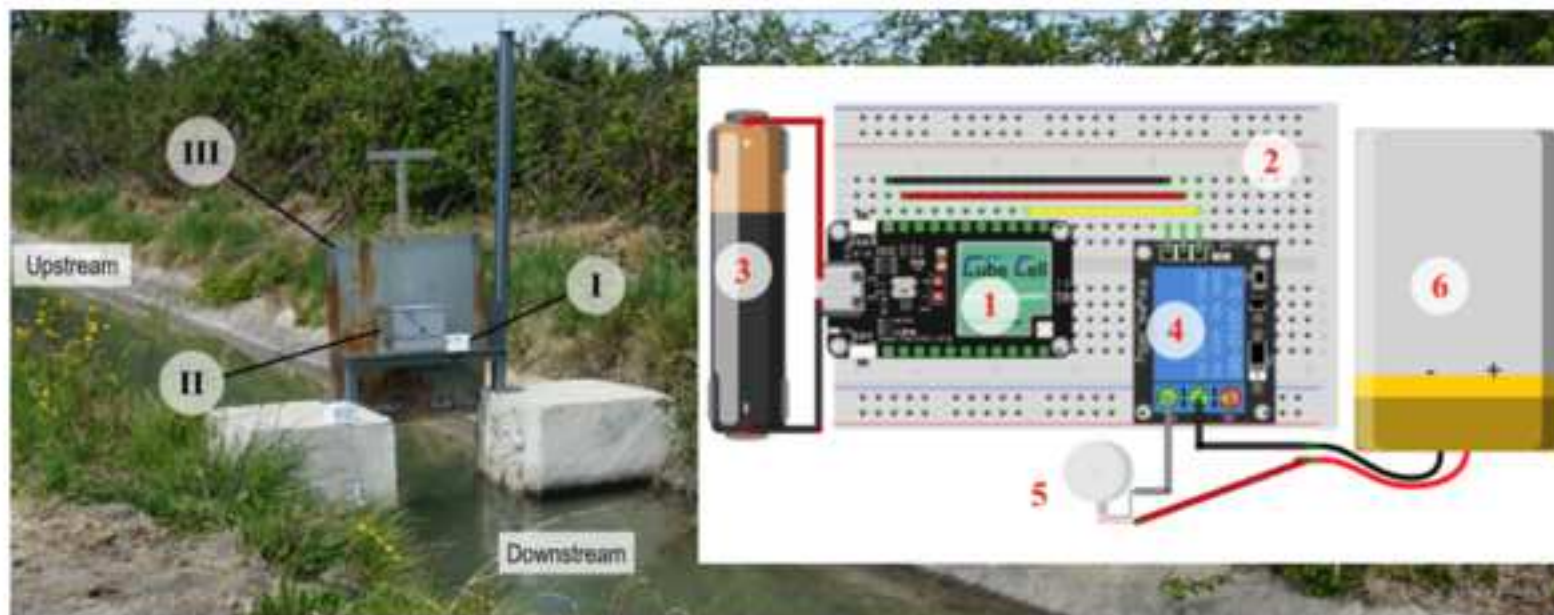
- 1           Pereira, L.S., Gonçalves, J.M., 2018. Surface Irrigation. Oxford Research Encyclopedia  
2           of Environmental Science.  
3  
4           <https://doi.org/10.1093/acrefore/9780199389414.013.248>  
5  
6           Salahou, M.K., Jiao, X., Lü, H., 2018. Border irrigation performance with distance-  
7           based cut-off. *Agricultural Water Management* 201, 27–37.  
8  
9           <https://doi.org/10.1016/j.agwat.2018.01.014>  
10  
11           Tao, W., Zhao, L., Wang, G., Liang, R., 2021. Review of the internet of things  
12           communication technologies in smart agriculture and challenges. *Computers and*  
13           *Electronics in Agriculture* 189, 106352.  
14           <https://doi.org/10.1016/j.compag.2021.106352>  
15  
16           Tey, Y.S., Brindal, M., 2012. Factors influencing the adoption of precision agricultural  
17           technologies: a review for policy implications. *Precision Agriculture* 13, 713–  
18           730. <https://doi.org/10.1007/s11119-012-9273-6>  
19  
20           Vandôme, P., Leauthaud, C., Moinard, S., Mekki, I., Zairi, A., Charron, F., Leconte, J.,  
21           Ferchichi, I., Ajmi, T., Belaud, G., 2023a. Exploring ways to improve  
22           agricultural water management in two Mediterranean irrigated systems:  
23           promises of wireless low-tech sensor networks. *Proc. IAHS* 100, 1–5.  
24           <https://doi.org/10.5194/piahs-100-1-2023>  
25  
26           Vandôme, P., Leauthaud, C., Moinard, S., Sainlez, O., Mekki, I., Zairi, A., Belaud, G.,  
27           2023b. Making technological innovations accessible to agricultural water  
28           management: Design of a low-cost wireless sensor network for drip irrigation  
29           monitoring in Tunisia. *Smart Agricultural Technology* 4, 100227.  
30           <https://doi.org/10.1016/j.atech.2023.100227>  
31  
32           Zerihun, D., Sanchez, C., Farrell-Poe, K., Yitayew, M., 2005. Analysis and design of  
33           border irrigation systems. *Transactions of the ASAE* 48.  
34           <https://doi.org/10.13031/2013.20009>  
35  
36           Zinkernagel, J., Maestre-Valero, Jose.F., Seresti, S.Y., Intrigliolo, D.S., 2020. New  
37           technologies and practical approaches to improve irrigation management of open  
38           field vegetable crops. *Agricultural Water Management* 242, 106404.  
39           <https://doi.org/10.1016/j.agwat.2020.106404>  
40  
41  
42  
43  
44  
45  
46  
47  
48  
49  
50  
51  
52  
53  
54  
55  
56  
57  
58  
59  
60  
61  
62  
63  
64  
65



<b>Id</b>	<b>Model</b>	<b>Function</b>	<b>Manufacturer</b>	<b>Cost</b>
1	Cubecell HTCC01	Microcontroller	Heltec, China	11.43€
2	Breadboard	Connector	HMTI, China	1.61€
3	Water level	Sensor	SeeSensor, China	0.77€
4	Resistor	Power limiter	Eiechip, China	0.01€
5	Wires	Connector	Xnbada, China	0.01€
6	LiPo Battery	Power Supply	DaweiKala, China	2.70€
<b>Total</b>				<b>16.53€</b>







<b>Id</b>	<b>Model</b>	<b>Function</b>	<b>Manufacturer</b>	<b>Cost</b>
1	Cubecell HTCAB01	Microcontroller	Heltec, China	11.43€
2	Breadboard	Connector	HMTI, China	1.61€
3	LiPo Battery	Power supply	DaweiKala, China	2.77€
<b>I</b>			<b><i>Sub-total control module</i></b>	<b>15.74€</b>
4	Relay 5VDC KY-019	Relay	Songle, China	1.79€
5	ITS-PE-5029-12VDC	Deactivation electromagnet	Conrad, Germany	61.19€
6	VRLA AGM 12V 4.5ah	Magnet power supply	Lucas, France	9.00€
7	Small mechanics	Hanging device	Misumi, France	18.59€
<b>II</b>			<b><i>Sub-total hanging system</i></b>	<b>90.57€</b>
			<b><i>Total Lancelot system</i></b>	<b>106.31€</b>



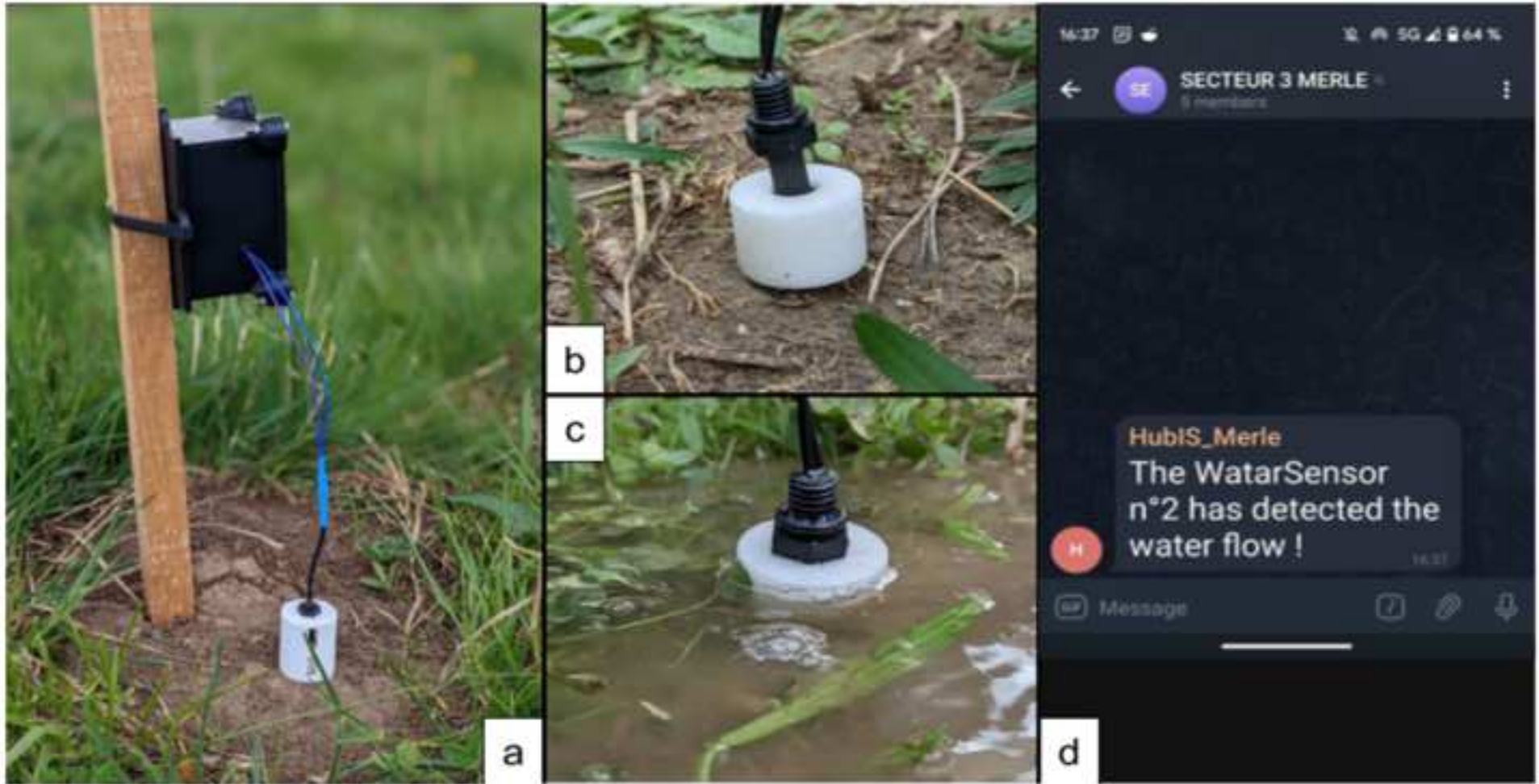
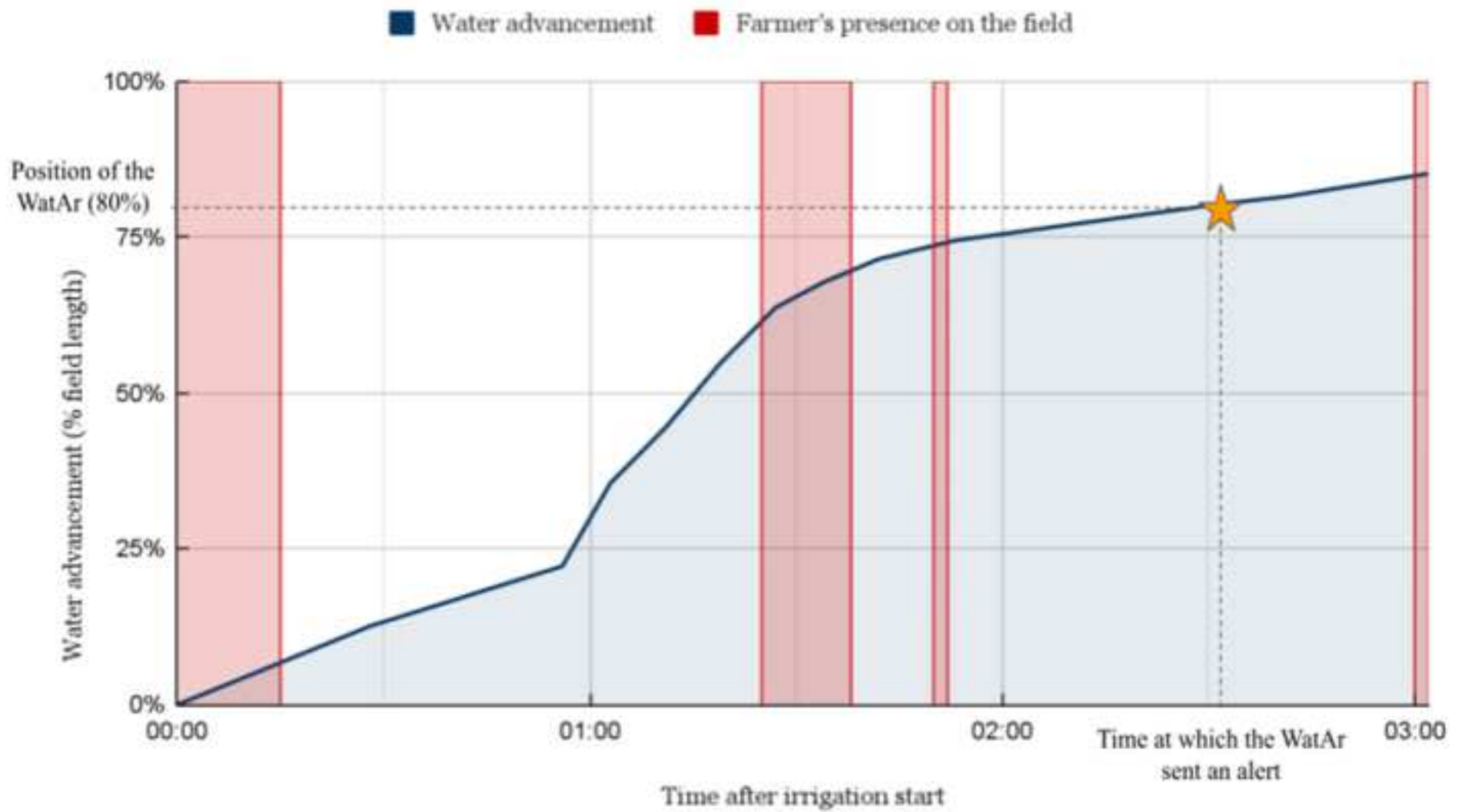


Figure 6









Click here to access/download  
**Supplementary Material**

