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Deploying Low-Cost and Full Edge-IoT/AI System for Optimizing Irrigation in Smallholder Farmers Communities

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Abstract. About 35% of the world's food are produced in small-scale farms while only occupying about 12% of all agricultural land. However, smallholder farmers usually face a number of constraints and the water resource is one of the major constraints. The usage of smart technologies and especially sensor systems in so-called Smart Farming Technologies can be applied to the optimization of irrigation. Regardless of the irrigation technique, soil sensors are promising in providing data that can be used to further reduce the usage of water. However, despite all these possibilities, the smallholder community are still reluctant to step into technology-based systems. There are various reasons but prohibitive cost and complexity of deployment usually appear overwhelming. The PRIMA INTEL-IRRIS project has the ambition to make digital and smart farming technologies attractive & more accessible to these communities by proposing the intelligent irrigation "in-the-box" concept. This paper describes the low-cost and full edge-IoT/AI system targeting the smallholder farmers communities and how it can provide the intelligent irrigation "in-the-box" concept.

Keywords. IoT, low-cost, edge-AI, irrigation optimization, LoRa

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1. Introduction

According to many studies small-scale farming has an enormous contribution to food security and to rural economy [1]. Recent figures from FAO stated that about 35% of the world's food are produced in small-scale farms while only occupating about 12% of all agricultural land [2]. However, smallholder farmers (SHFs) usually face a number of constraints that are impeding their productivity, profitability and contribution to economic growth. Water resource is one of the major constraints and the lack of water is foreseen to worsen in the next years. In order to feed humanity by 2050, optimized irrigation will be paramount to guarantee the agricultural production of intensive crops that need water to grow, mature and yield. Optimized irrigation can also limit soil erosion and salinization on the long-term.

Traditional irrigation practices will usually involve compartmentalizing land into elementary basins with an average size of 50-60 m^2 and supplying water (flooding) to these basins, one by one. Furrow irrigation is a version of this flooding approach and is well-known to exhibit a low efficiency in the usage of the water resource. Lack of water is obviously pushing for more efficient irrigation techniques and the usage of sprinklers, pivots and ultimately drip irrigation is increasing. Taking the case of the Mostaganem area in Algeria, in 2021, the use of drip irrigation surpassed that of sprinkler and furrow irrigation according to the Direction of Agricultural Services. The use of localized drip irrigation is developing particularly for market garden crops considered as speculative and the percentage of use of this technique (in term of irrigated areas) has increased from 70% to 75% between 2016 and 2021. In contrast, the furrow irrigation system has decreased from 17% to 9%. The sprinkler technique increased too from 13% to 16%. However, although a majority of SHFs are accustomed to the more efficient drip irrigation system, they still rely solely on their past experience with limited data on the current soil and climatic conditions which became unreliable in the context of climate change. This inevitably leads to an over-exploitation of water resources with negative impacts on their yield and benefits, but also on the quality of their soils.

The usage of smart technologies and especially sensor systems is not new in agriculture and so-called Smart Farming Technologies (SFT) cover a wide range of data-oriented technologies targeting optimization of agricultural processes, including the optimization of irrigation. Regardless of the irrigation technique, monitoring of environmental characteristics – for instance soil water content or matric potential sensors – are promising in providing data that can be used to limit and optimise the usage of water ("more crop per drop"). In addition to field monitoring, it is also possible to take into account a larger variety of parameters (soil texture, crop type, salinity of the irrigation water, satellite data, weather forecast, etc.) and include agricultural models/knowledge with corrective predictive analytic. And finally, with disruptive AI techniques integrating all these information, it will be possible to provide better decision-making feedbacks [3,4].

Despite all these possibilities and promising results offered by SFT, the smallholder community usually still rely on traditional agricultural practices learned on the field mostly from indigenous knowledge and are reluctant to step into technology-based systems mainly because commercial solutions for smart farming easily cost several thousand euros, with most of these solutions relying on cloud servers and proprietary software platforms requiring SHFs to be bound to the infrastructure provider.

It is in that context that the PRIMA INTEL-IRRIS project (http://intel-irris.eu/) has the ambition to make digital and smart farming technologies attractive & more accessible to SHFs. To address the needs of this community, the proposed solutions must be affordable, simple to use in the field and, most importantly, must be able to be integrated into existing farming practices. Therefore, by developing a low-cost, autonomous and smart irrigation control system INTEL-IRRIS seeks to change the perception SHFs usually have for what was until recently very high cost technologies. By implementing the "intelligent irrigation in-the-box" concept, INTEL-IRRIS wants to make smart irrigation system as simple to install and use as a household appliance with very limited investment compared to their income. In addition, through a participatory piloting approach, INTEL-IRRIS will strongly involve SHFs into the innovation process itself to reach larger dissemination of this technology with a network of farmers able to support each other.

The rest of the paper is organized as follows. Section 2 will elaborate on how smart technologies can be efficiently proposed and deployed for SHFs by presenting the INTEL-IRRIS objectives & approach and by describing the main technological components. Section 3 will then present the INTEL-IRRIS edge-enabled IoT/AI gateway that is at the core of the edge-IoT/AI system addressed in this article. This section will show a proof-of-concept demonstrating the development and integration of custom applications using edge-AI features. Conclusions are given in Section 4.

2. Providing smart technologies to smallholder farmers

2.1. Overview of INTEL-IRRIS project

As indicated previously, INTEL-IRRIS has the ambition to make digital and smart farming technologies attractive & more accessible to SHFs. Therefore, a trade-off will be made to meet the main objective which is to provide a low-cost irrigation system that can be deployed by SHFs in an out-of-the-box manner. While the soil moisture sensing part adopts a simple yet robust and efficient low-cost design largely inspired by many do-it-yourself initiatives and previous contributions [5,6,7]. Unlike those low cost sensors that too often provide non-reliable data, INTEL-IRRIS will contribute in greatly improving the quality of the collected data with (i) advanced calibration of the different sensors and (ii) allowing more plant and soil parameters to be pre-configured into the control system. Two versions will be provided, using different soil moisture sensors. Version 1 will use a low-cost (less than 12 euro) capacitive soil moisture sensor (the waterproof Gravity SEN0308 from DFRobots) where the soil bulk density has to be known in order to provide the required level of accuracy. Calibration procedures on various soil types are currently developed in the laboratory by IRD. A review on calibration of low-cost capacitive sensors can be found in [8]. Version 2 will use a medium-cost (less than 40 euro) Watermark tensiometer which measures directly the force holding water in the soil (thus avoiding the need of measuring the soil bulk density). The Watermark is a widely used tensiometer due to its high efficiency vs cost ratio and numerous documentations and tutorials describing its installation can easily be found [9,10,11].

In addition to providing calibrated sensors at low cost, another major contribution of INTEL-IRRIS will be to provide the "out-of-the-box" feature, i.e. the control part making the irrigation recommendation is embedded in the IoT gateway which consequently does not require any internet connection. Here, with soil specialists and agriculture experts, the complex soil-water-plant-atmosphere interaction model will be integrated into the gateway itself to provide increased accuracy on recommended actions. The ultimate objective of INTEL-IRRIS is to include agricultural models/knowledge with corrective predictive analytic – from simple computer-based decision models to more advanced AI-based processing – to adapt the applied control to local conditions practices (dry region, open field or greenhouse) and crop/plant varieties that usually have different water need profile at their various stage of development. To work towards this objective, INTEL-IRRIS is developing a versatile and full edge-IoT/AI system. This is the contribution we are presenting in this paper.

Finally, INTEL-IRRIS will run a participatory approach with a Smallholder Piloting Program of the innovative solutions in at least 20 small-scale farms to take into account region-dependent technical, agricultural, social, climatic and environmental aspects. The piloting program will run for 30 months. This will ensure that the proposed irrigation systems are well tailored for the specificities of the regional context.

2.2. The low-cost soil moisture sensing part

The low-cost soil moisture sensing part is based on an DIY IoT hardware platform that has been developed and validated in 2 EU projects (EU H2020 WAZIUP and EU H2020 WAZIHUB) with piloting sites deployed in several sub-Saharan countries.

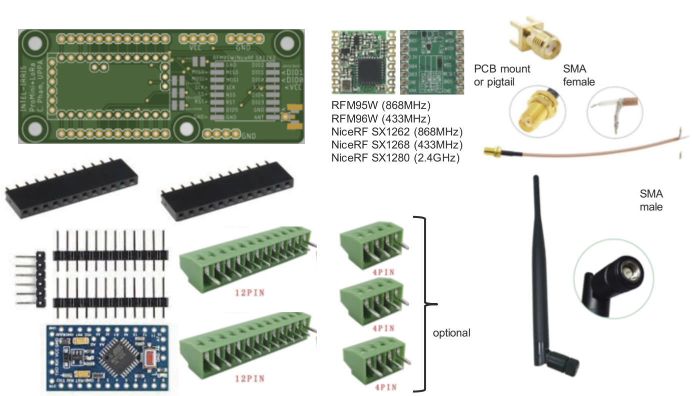

Figure 1. The generic IoT platform.

The microcontroller is the Arduino ProMini in its 3.3V and 8MHz version. Software building blocks include long-range data transmission with LoRa radio technologies (possibly in 868MHz, 433MHz and 2.4GHz bands; and using LoRaWAN specification) and advanced power management that allows the device to be fully autonomous for more than 2 years when running on 2 AA batteries and transmitting data once every 60 mins [12]. The hardware parts are illustrated in Figure 1. The PCB are available as open-source and technology adaptation to local market availability will be realized by UORAN1 Algerian and ENSA Safi Moroccan partners.

The resulting low-cost soil moisture sensor device is illustrated in Figure 2. Cost of Version 1 is under 25 euro while Version 2 would be under 55 euro. An additional soil temperature sensor can be attached to improve calibration. The low-cost, generic and robust design has been showcased in several tutorial videos [13] targeting developers, tech-enthusiasts and local entrepreneurs willing to build innovative IoT without any technology lockdown.

Figure 2. The INTEL-IRRIS soil sensor device.

2.3. Intelligent irrigation in-the-box

INTEL-IRRIS will implement the "intelligent irrigation in-the-box" concept that will be demonstrated by a starter-kit distributed to selected SHFs and illustrated in Figure 3. The starter-kit consists in 1 soil moisture sensor device and 1 versatile IoT gateway ready to be deployed. Core to this "intelligent irrigation in-the-box" concept is the fully edge-enabled IoT gateway that will receive, store, process and display sensor data in a user-friendly manner. Here, a "fully edge-enabled IoT gateway" means that, by default, the operating mode of the gateway is without Internet access: all processing and advanced features are embedded on various containerized applications running on the gateway. Then, when targeting SHFs, the gateway should be able to display simple irrigation notifications on a small embedded OLED screen as well as on an intuitive embedded web dashboard interface with more functionalities, locally accessible through a smartphone or a tablet by connecting to the gateway's WiFi access point.

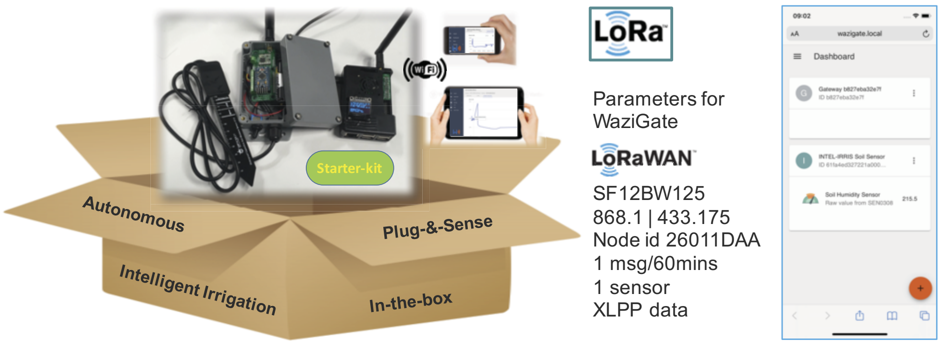

Figure 3. The INTEL-IRRIS starter-kit and out-of-the box deployment.

When powered on, the soil moisture sensor device will measure and transmit soil moisture data once every 60 mins. This value can be changed when configuring the starter-kit. With a 60 mins interval, the soil moisture sensor can run continuously for more than 2 years on 2 AA batteries. Data transmission is realized in LoRaWAN mode with encrypted payload ensuring security and confidentiality.

3. The edge-enabled IoT gateway approach

The INTEL-IRRIS edge-enabled IoT gateway is based on the WaziGate framework that has been developed over the years by WAZIUP in the context of several international research development projects. WaziGate itself took its root from the early "Low-cost LoRa IoT gateway" framework [12] developed by University of Pau since 2015 for building open and versatile LoRa IoT gateway with a RaspberryPi board. WaziGate is now a separate development line with maturity level of TRL8-9 [14]. The WaziGate framework is highly suitable for implementing the edge-enabled IoT gateway approach as customized applications can be hosted in the gateway and use the gateway's innovative features for edge approach such as embedded database, embedded web-based data visualization module, software container management and cloud synchronization features as well as remote management if this is desirable.

3.1. Architecture

WaziGate software framework uses a microservice architecture to manage all local applications (referred to as WaziApps). This architecture allows each WaziApp to operate independently and in isolation using Docker containers. WaziApps can be written in various programming languages and they communicate through a set of restful APIs. Actually, even WaziGate's system components are considered as independant WaziApps interacting with each other through APIs. Figure 4 shows the component diagram of the WaziGate software architecture. The top level is the user domain, the middle level represents the WaziGate software and the bottom level is the hardware, i.e. the RaspberryPi. On top of the RaspberryPi OS is a

Docker Engine, which handles all necessary images/containers. All WaziGate's components expose a well-defined API enabling efficient and secured calls to all WaziGate's services by user-defined WaziApps.

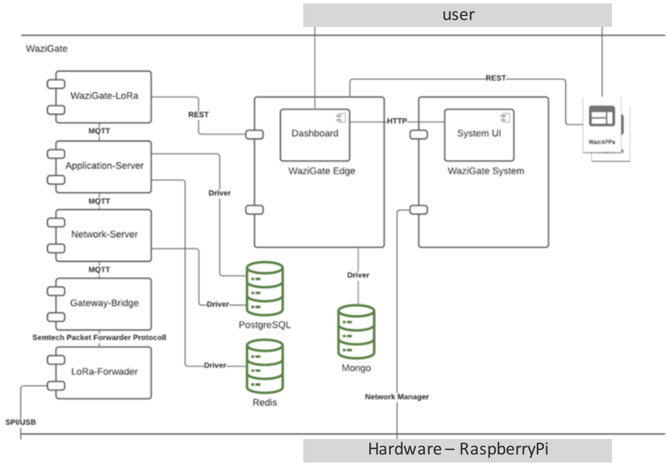

Figure 4. The WaziGate's architecture.

3.2. Generic device & sensor dashboard

For the SHFs, the WaziGate's main component is the dashboard to visualize sensor data. Fully integrated and offering generic device & sensor management, the dashboard offers an intuitive interface with a simple data visualization module. Figure 5 illustrates the dashboard and also shows the responsive web interface allowing SHFs to use a smartphone to interact with the dashboard.

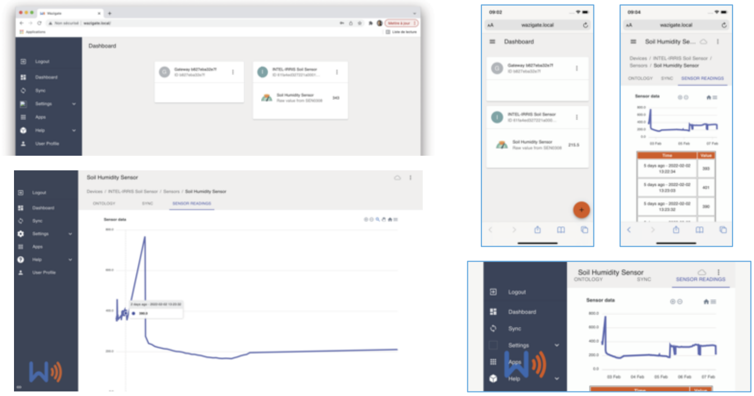

Figure 5. The WaziGate's dashboard with generic sensor data visualization.

The INTEL-IRRIS starter-kit come with a pre-configured dashboard where the soil moisture sensor device is already registered into the dashboard. After powering on the INTEL-IRRIS WaziGate, new data will be received and displayed in the dashboard without any additional configuration needed.

3.3. INTEL-IRRIS Irrigation WaziApp

On top of the generic dashboard, INTEL-IRRIS develops a dedicated WaziApp for the project, referred to as the INTEL-IRRIS Smart Irrigation WaziApp. The purpose of an additional WaziApp on top of the generic sensor dashboard is to offer additional features specific to a particular application domain: better data visualization charts, additional data filtering & processing tasks, configuration of application-dependant parameters, etc. This approach appears more flexible and simpler to maintain than a separate mobile app. Running locally on the WaziGate itself, the WaziApp will have access to all collected sensor data.

As shown in Figure 6, all WaziApps are listed in the dashboard and user can select which waziApp to launch and display. The proof-of-concept of the INTEL-IRRIS Smart Irrigation WaziApp allows the user to select a particular device that they want to link the WaziApp with, using the device id. For the purpose of irrigation optimization, the INTEL-IRRIS Smart Irrigation WaziApp will offer advanced calibration and parameter configuration features: sensor type, soil type, soil salinity, soil bulk density, crop type, etc. These parameters can be defined both at a global level and at each sensor level. Of course, in the case of the starter-kit, many of these parameters will be pre-configured for the SHFs in the context of the Smallholder Piloting Program. It is expected that some parameters would still need to be manually selected by the end users among a list of propositions, e.g. soil type: clay, sandy, silty, peaty, chalky or loamy.

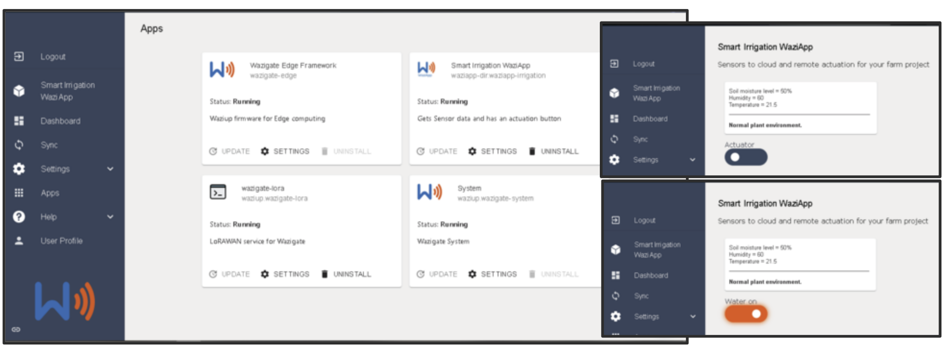

Figure 6. The INTEL-IRRIS Smart Irrigation WaziApp.

Here, the INTEL-IRRIS Smart Irrigation WaziApp offers the possibility to also remotely control irrigation with an actuator if the farm infrastructure has the adequate installation (water valve that will be controlled by a LoRaWAN actuator/relay device for instance). The Smart Irrigation WaziApp will be continuously improved during the project's duration to include agricultural knowledge as well as a multiple knowledge streams framework for more accurate sensor calibration procedures leading to more reliable irrigation recommendations. The INTEL-IRRIS Smart Irrigation WaziApp is built as a Python microservice with Docker. It primarily includes a Python program with HTML/CSS and JavaScript for the user-interface. It accesses to sensor's data using the well-defined WaziGate REST API.

3.4. Edge-AI processing framework

The Edge-AI framework is a new component of the WaziGate's ecosystem and provide both online and offline AI training capability. It consists in an environment for developers/users to conduct artificial intelligence and machine learning tasks. A dedicated system-oriented WaziApp with the full Jupyterlab functionality has been packaged as a Docker container where various machine learning packages with several regression models are available for developers. Again, several programming languages can be used and Python being pre-installed. There are also numerous pre-cooked notebook files available, for a variety of applications, to choose from. As it is considered as a normal WaziApp, it is straightforward to query the WaziGate' sensors data from inside the developed application to conduct different data processing tasks.

To demonstrate the Edge-AI features, we implemented a separated soil moisture prediction WaziApp using the results of the EU H2020 WAZIHUB Soil Moisture Prediction Challenge held on 2019 on Zindi platform [15]. The objective of the competition was to create a machine learning model capable of predicting the soil moisture for a particular plot in the next few days, using data from the past. A part of the challenge was to design algorithms that are resilient and can be trained with incomplete data (e.g. missing data points) and unclean data (e.g. lot of outliers). Resulting models will enable farmers to anticipate water needs and prepare their irrigation schedules. The model proposed by Hamadi (2nd place) [16] was chosen because of its overall good performance and easy integration into the WaziGate Edge-AI framework based on Python and Jupyterlab. It uses regression and the XGBRegressor Python library which provides the XGBoost (Extreme Gradient Boosting) implementation of gradient boosting trees algorithm. The whole Soil Moisture Prediction application is then run on the WaziGate as a regular WaziApp as shown in Figure 7.

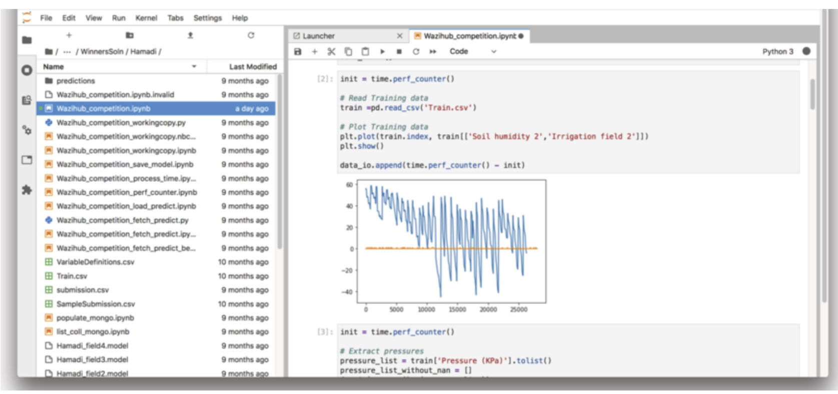

Figure 7. Testing the Edge-AI framework with Soil Moisture Prediction.

Results from the soil moisture prediction WaziApp can then be fed back into the INTEL-IRRIS Smart Irrigation WaziApp to include AI-based prediction model into the Smart Irrigation application. It is also possible propose several prediction models (separated WaziApps) and having the Smart Irrigation WaziApp select which model to use depending on local conditions.

4. Conclusions

The INTEL-IRRIS low-cost and full edge-IoT/AI system targeting the smallholder farmers communities was presented in this article. We show how all the Edge features can provide the intelligent irrigation "in-the-box" concept that is key for SHFs adoption of these advanced technologies. Without the need of Internet access, cloud servers nor lockdown with proprietary software platforms, the proposed solution can be quickly deployed with a minimum of technological infrastructure, even in very remote and rural areas. Interaction with the control system is realized through an intuitive, simple and locally hosted web-based interface accessible with a simple smartphone. With the possibility to develop and host third-party applications on the edge-IoT/AI gateway itself, dedicated applications with specific data processing chain and user interface can offer a higher level of customization for a particular application domain.

Acknowledgments

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