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CIDEA : Robot behavior adaptation from interactive communication with buried sensor nodes. Application to smart agriculture.

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Abstract — The combination of the recent advances in Wireless Underground Sensor Networks (WUSNs) and mobile robotics enable today to consider the development of more efficient and accurate systems. In particular, the measurement to the ground conditions from a set of sensor nodes buried at a few dozens of centimeters deep and distributed in a farm field would enable to adapt the behavior of some agricultural robots accordingly. To that end, this paper presents the development of a buried sensor node operating in LoRa with a collector node embedded on a mobile robot. When the robot is close to the sensor node, the soil moisture measurement is taken into account by the collector node to adapt the speed of the robot accordingly. The experimental results reported in this paper demonstrate the capabilities of the proposed system.

Keywords— Wireless Underground Sensor Networks, Soil moisture, Mobile robotics, LoRa, Agriculture.

I. INTRODUCTION

In recent years, the development of mobile robotics has increased significantly in agriculture, whether it be to increase farm productivity, perform environmentally friendly operations or relieve human operators from tedious and unhealthy work (Oliveira et al., 2021). Many challenges remain, however, to be faced to obtain fully operational robots. One of them is to provide for the robot the capacity to take into account the ground conditions in the field to adapt its behavior accordingly. In particular, when the soil moisture varies significantly, the speed of the robot and the tuning of its agricultural tool have to be adapted, see the illustration in Figure 1.

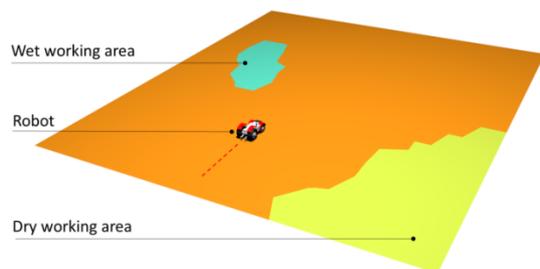


Figure 1. Variability of the soil moisture in a field requiring to adapt the working speed of the robot and its tool accordingly

Nevertheless, the access to the information of soil moisture, locally and in real time, is a real issue. Microclimate weather stations and connected devices can be positioned at the edge of the field, but they are not sufficient to obtain local and accurate information of the soil moisture within the areas (Tenzin et al., 2017). In addition, such systems can obviously not be positioned and multiplied inside the field as they represent obstacles for the farming activities.

The recent advances in Wireless Underground Sensor Networks (WUSNs) and Internet of Underground Things (IoUT) have however opened new opportunities. These approaches are based on the development of sensor nodes able to operate underground at a few dozens of centimeters deep; see Figure 2 and (Moiroux-Arvis et al., 2022), (Saeed et al., 2019), (Salam et al., 2020). Different measurements can be carried out, as the soil moisture and temperature. The data are emitted by the radio modules, also buried underground, using Low-Power Wide Area Networks (LPWAN) as LoRa technology (Augustin et al., 2016). A device located aboveground, e.g. a gateway or a data collector embedded on an Unmanned Aerial Vehicle (UAV), can communicate with the buried sensor nodes and retrieve the measurements, see (Cariou et al., 2022), (Popescu et al., 2020).



Figure 2. Buried sensor node measuring the moisture of the soil and emitting the data through radio communication

The advantage to bury and dissimulate all the components underground, including the radio modules and the antennas, is to protect the system against potential

damages due to farming activities but also adverse weather conditions, animals, theft and vandalism. The main current applications of WUSNs are smart irrigation, landslide detection, and monitoring of underground infrastructure, see (Akyildiz et al., 2006), (Ferreira et al., 2019) and (Silva et al., 2010).

The development of buried sensor nodes is, however, a challenging task as the electromagnetic radio waves are highly attenuated in the soil, about 20-300 times worse than in the air (Da Silva et al., 2014). This attenuation is, moreover, dependent on numerous environmental factors (e.g. volumetric water content (VMC), burial depth, soil composition). The communication ranges are therefore considerably reduced and highly variable. In practice, the Underground to Underground (UG2UG) communication link between two buried sensor nodes is limited to a few meters. However, as highlighted in our last work (Moiroux-Arvis et al., 2022), the Underground to Aboveground (UG2AG) communication link can reach more than 250 meters under certain conditions, i.e. 868-MHz radio modules with LoRa communication, transmit power of +14 dBm/25 mW and a burial depth about 15 cm.

Based on these first results, the objective of this paper is to demonstrate that a data collector node embedded on a mobile robot is able, in real time, to retrieve the soil moisture of a buried sensor node when passing at proximity and adapt the working speed of the robot accordingly. This is the objective of the project named “CIDEA” which is funded by the CAP 20-25 International Research Centre - Innovative Transportation and Production Systems (CIR-ITPS). The principle scheme is presented in Figure 3.

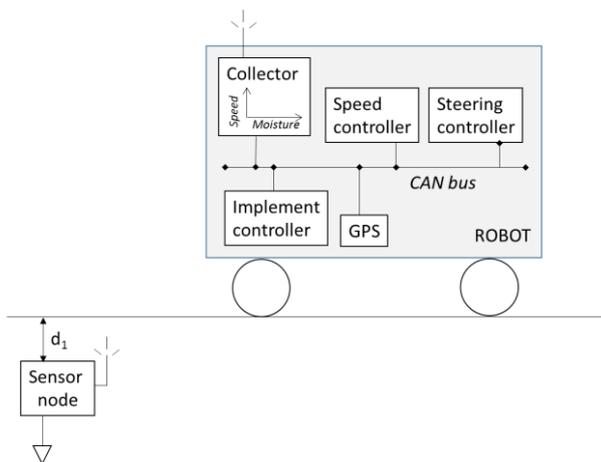


Figure 3. The robot adapts its working speed with respect to the soil moisture information collected from a buried sensor node

This paper is organized as follows. The sections II, III and IV present respectively the methodology, the experimental design and the experimental results. The sections V and VI present the conclusion and the discussion.

II. METHODOLOGY

The methodology consists first to bury underground a sensor node at a depth d_1 below the surface, see Figure 3. This sensor node regularly measures the soil moisture and emits a data frame using its LoRa radio module.

A collector node is embedded on the mobile robot and connected to its CAN bus. It has reading access to various information on the CAN bus (e.g. GPS position, status of the implement, robot's speed) and can write a CAN message to change the speed of the robot if required.

When the robot is inside the coverage range of the buried sensor node (a_1 in Figure 4), the collector node receives and decodes the data frames which contain the soil moisture information. It will take the control of the speed of the robot with respect to the RSSI (Received Signal Strength Indication) signal level: if the strength of the RSSI signal is above a threshold (-65 dBm), the soil moisture information is taken into account and the speed of the robot is adapted according to the curve presented in Figure 5. When the robot leaves the delock area (-80 dBm), the collector node gives back the control of the speed to the controller of the robot.

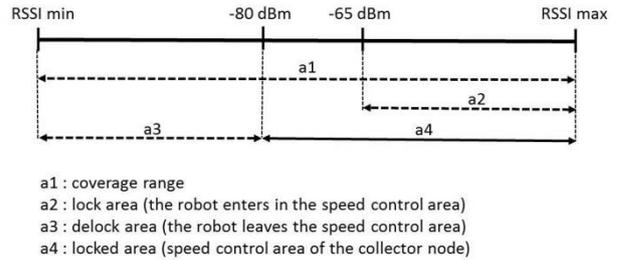


Figure 4. Speed control area of the collector node

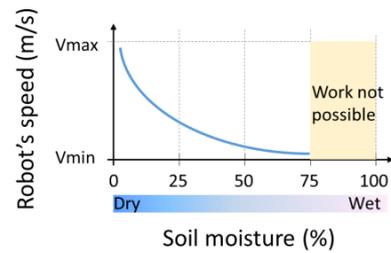


Figure 5. Speed of the robot with respect to soil moisture

III. EXPERIMENTAL DESIGN

A. The buried sensor node

We developed a buried sensor node based on a microcontroller Atmega328-AU 8 MHz (Microchip) and a LoRa radio module RFM95W (HopeRF) operating at 868 MHz, see Figure 6 and (Cariou et al., 2022) for more details.

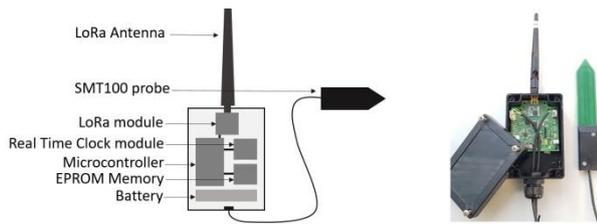


Figure 6. The buried sensor node

A Truebner SMT100 probe is connected to measure the soil moisture. The sensor node is powered with a rechargeable lithium battery 3.7 V/8.8 Ah. A temporal reference DS1378 is implemented to switch between the deep-sleep and active modes. The node is activated during the measurement of soil moisture (the measurements are stored on a 8 bit memory EEPROM with I2C-bus interface) and during predetermined time-windows to communicate the data from the radio module. When a time-window is active, the sensor node puts its radio module in listening mode and waits for a message from the collector node. When the communication is established, the sensor node transfers the data to the collector node.

B. The collector node

The collector node is built around a microcontroller Atmega328-AU (Microchip) running at 8 MHz, see Figure 7. It is powered through a rechargeable lithium battery 3.7V / 8.8Ah. It is equipped with a LoRa radio module RFM95W (HopeRF) to communicate with the buried sensor node, and a CAN bus interface to exchange information with the robot (read and write access). All the data of the experiments are stored in a SD card in the collector node enabling to analyze the results afterwards.

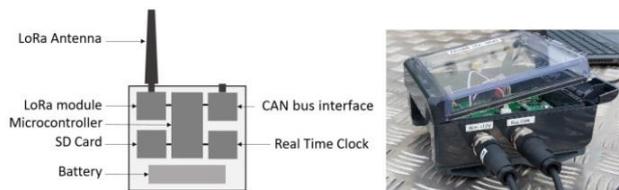


Figure 7. The collector node on the robot

The sequence of operations and decisions made by the collector node is presented in Figure 8. The collector node scans on the RF communication (LoRa radio module) the proximity of a sensor node. When a sensor node is detected, the quality of the radio signal is measured (RSSI signal) to determine the speed control area. Every second, an interruption routine reads different data on the CAN bus (e.g. GPS position, actual speed of the robot) and stores them on the SD card.

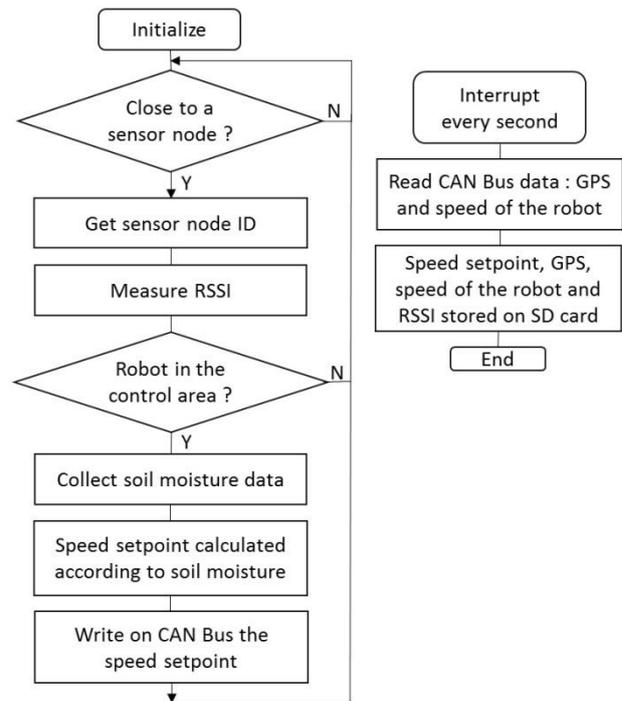


Figure 8. Diagram of the program in the collector node

C. The mobile robot

The mobile robot used for the tests is presented in Figure 9. This robot is electrically propelled (Lithium-ion batteries 12.8 kWh). The wheelbase is 1.40 m for a total length of 2.50 m. The track is adjustable from 0.70 m to 1.30 m. It weighs about 550 kg with a maximal payload of 150 kg. It has four independent wheeled-motors and four independent steering actuators. It is able to reach speeds up to 10 m/s in the wide track configuration. The implement at the rear is a horizontal sprayer. Four nozzles are placed at different working distances, they can be activated independently.

The architecture of this robot is built around three main controllers (steering, speed, implement) joined by two CAN bus. The collector node is connected to the CAN bus enabling to take the control of the speed of the robot.



Figure 9. Experimental robot used for the tests

IV. RESULTS

A. The experimental setup

The sensor node is buried at the depth $d_1=15$ cm. Four soil moistures were tested: 0%, 5%, 10% and 20%. At the beginning of each experiment, the robot is manually controlled with its joystick (speed and steering). When the collector node detects the buried sensor node with a RSSI value higher than -65 dBm (i.e. very good reception, that enables to limit the size of the experimental area), it controls the speed of the robot in place of the joystick (from 0 to 1 m/s, see Figure 10). When the RSSI signal becomes lower than -80 dBm, the collector node gives back the control of the speed to the joystick.

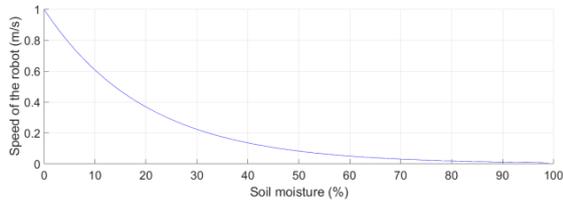


Figure 10. Speed of the robot with respect to the soil moisture

B. Results with 0% soil moisture

For the first experiment, the probe is not connected leading to a measured soil moisture of 0%. According to Figure 10, that leads to a setpoint for the speed of 1 m/s. Figure 11 presents the trajectory of the robot and Figure 12 the RSSI level measured by the collector node. The time during which the collector node controls the speed of the robot is depicted in red. The speeds of the robot (setpoints and measurement) are presented in Figure 13.

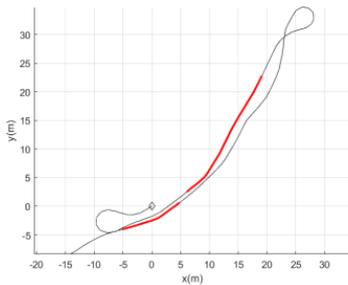


Figure 11. Trajectory of the robot – Test 0%

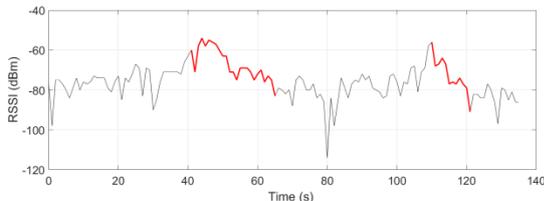


Figure 12. RSSI received by the collector node – Test 0%

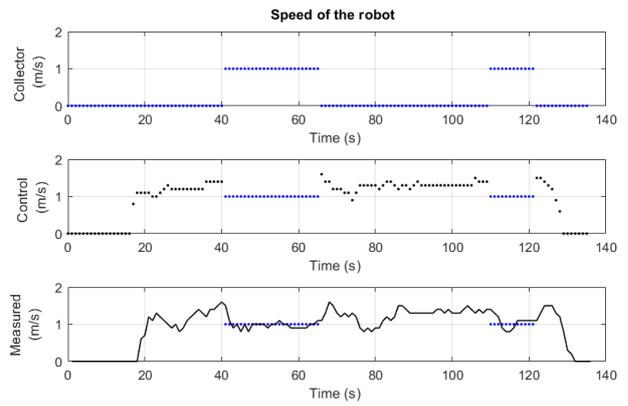


Figure 13. Speed controls and measurements – Test 0%

Up: speed calculation by the collector node (0 if not active), Middle: speed control from the joystick (black) and the collector node when active (blue), Down: measured speed of the robot

At the beginning ($t=0$ s), the buried sensor node is detected but with a RSSI value equals to -80 dBm (i.e. not taken into account), see Figure 12. The robot is then moved and controlled with the joystick. At $t=40$ s, the RSSI signal becomes upper than -65 dBm. The robot is then controlled by the collector node until the time $t=65$ s (i.e. the RSSI value becomes lower than -80 dBm). This is also the case between $t=110$ s and $t=122$ s. On the top of Figure 13, we clearly observe the commands of the collector node ($v=1$ m/s), the commands of the speed of the robot from the joystick and the collector node (middle of Figure 13), and the effective speed of the robot (bottom of Figure 13).

C. Results with 5%, 10% and 20% soil moisture

The probe is then connected to the buried sensor node. Successively, three experiments are carried out with a dry soil (5% humidity), a slightly wet soil (10% humidity) and a wet soil (20% humidity). The results are presented in the Figures hereafter. For the three experiments, it can be clearly observed that when the buried sensor node is detected with a RSSI value higher than -65 dBm, the collector controls the speed of the robot.

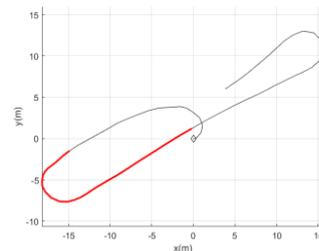


Figure 14. Trajectory of the robot – Test 5%

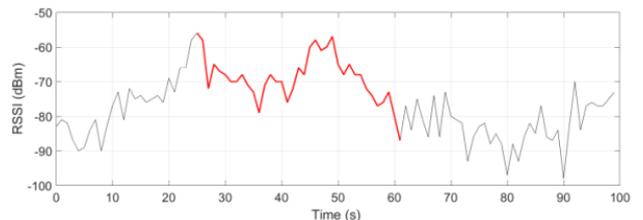


Figure 15. RSSI received by the collector node – Test 5%

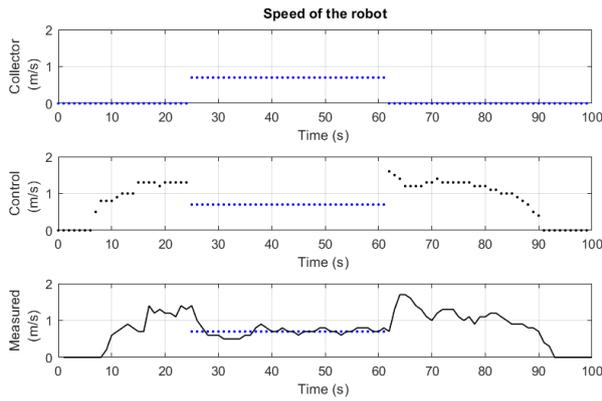


Figure 16. Speed controls and measurements – Test 5%

In Figure 16, it can be observed for example that the speed of the robot was about 1.5 m/s at the beginning of the experiment. When the robot enters in the speed control area with the buried sensor node, its speed is constrained to be reduced at 0.7 m/s. In Figure 19, the speed is reduced to 0.5 m/s, and to 0.3 m/s in Figure 22.

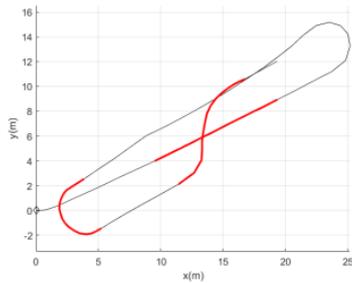


Figure 17. Trajectory of the robot – Test 10%

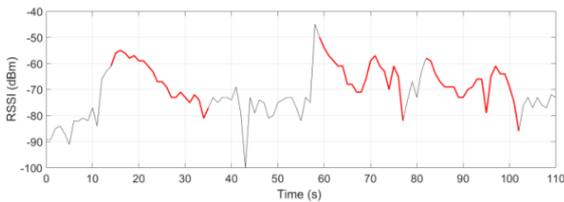


Figure 18. RSSI received by the collector node – Test 10%

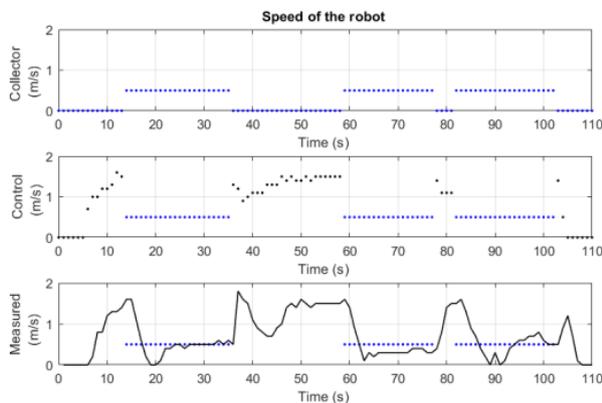


Figure 19. Speed controls and measurements – Test 10%

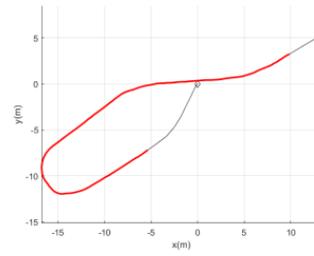


Figure 20. Trajectory of the robot – Test 20%

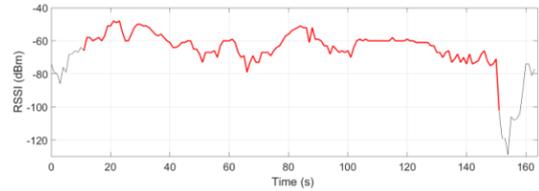


Figure 21. RSSI received by the collector node – Test 20%

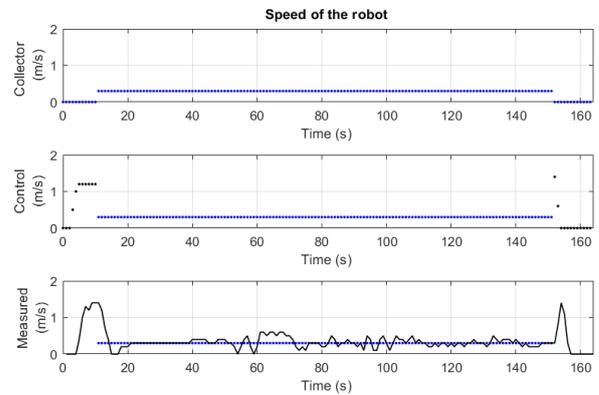


Figure 22. Speed controls and measurements – Test 20%

V. CONCLUSION

The objective of this paper was to demonstrate the possibility to adapt the behavior of a mobile robot to the variations of the soil moisture encountered in a field. To access information on soil status as close as possible to the intervention area of the mobile robot, we proposed to develop a system based on sensor nodes buried at a few dozens of centimeters deep. The main challenge is however to develop these underground objects with relevant communication ranges. Constraints on energy consumption and transmit power also have to be considered as the nodes have to work ideally several years without battery replacement.

We developed a set of buried sensor nodes able to measure the soil moisture and transmit that information to an aboveground collector node. The radio communication is based on the technology LoRa at 868-MHz. The collector node is embedded in a mobile robot and connected to its bus CAN. It has read and write access, in particular to control the speed of the robot when required. The first experimental results are presented. When the robot is in the communication range of a buried sensor

node with a RSSI value upper than a threshold, the moisture information is collected and used to adapt the speed of the robot accordingly.

VI. DISCUSSION

The first results obtained in this paper have considered a single sensor node located underground. In the future work, we intend to study several sensor nodes positioned in a field. That requires to carefully study and manage the overlapping areas. In particular from the knowledge of the position of the robot and the locations of the different moisture sensors in the field, the setpoint for the robot's speed could be determined with precision. Obviously, the speed curve with respect to the soil moisture could also be adapted to the situation. The exponential shape of Figure 8 was only used to rapidly reduce the speed of the robot with respect to the soil moisture. A more in-depth study on the evolution of the speed of the robot according to the humidity of the soil could be carried out.

Moreover, the system can take advantage of the circulation of the mobile robot in the field to collect the soil moisture data. These measurements are local and accurate, and are particularly useful to improve the management of the crops (e.g. irrigation planning, spatial distribution of the water).

Funding: The work presented in this paper is part of the project called "CIDEA". This research is financed by the French government IDEX-ISITE initiative 16-IDEX-0001 (CAP 20-25) - Innovative Transportation and Production Systems (CIR-ITPS). It aims to demonstrate a proof-of-concept applied to an agricultural context. The opportunity to bury and dissimulate a panel of sensors underground also opens new perspectives in other activity sectors.

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