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Farmer-oriented innovation: outcomes from a first bootcamp

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Abbreviations

ACTA: Association de Coordination Technique Agricole, the French network of plant and animal production institutes (<http://www.acta.asso.fr/>); **AgTech**: agricultural technologies; **CO₂**: carbon dioxide; **HMI**: Human-Machine Interface; **INS’Pir**: Innovation Numérique et Sociale, a Hauts-de-France Regional Program for Digital and Social Innovation; **IoT**: Internet of things.

1 Introduction

Agriculture is challenged by breakthrough changes that require farmers to expand their knowledge to be able to master recent farming innovations such as digital machine control, embedded sensors, big data management, etc. Thanks to the lowering cost and miniaturization of advanced technologies, farmers are pushed and eager to shift from intuitive to fact-based farming practices: chemical inputs, genetic responses and environmental condition can finally be controlled and accounted for at the intra-field level (Bencini et al. 2012; Aqeel-ur-Rehman et al. 2014). The increased data collection and monitoring capacities

are indeed answering the need for a better use of natural resources to reduce farming trade-offs, thus meeting the society expectations for sustainable development. Yet, the fast increasing amount of harvested data remains largely unexploited because the first users, the farmers, are poorly involved in the development of processed information relevant for their decision making. This overwhelming dynamic is being addressed by innovation in training and educational programs, as well as by new forms of knowledge transfer. This paper aims to characterize the innovation processes that are changing the way of farming, with a focus on the impacts and expectations for the agricultural knowledge and information systems.

2 Background

Technologies are allowing agriculture to be more precise and smart. The development of precision agriculture and its support, the digitalization of agriculture, is leading to the emergence of many new approaches that combine agronomic knowledge and agricultural know-how with computer skills. The emergence of such trends is seen by the publication of recommendations or works by actors and specialists of the agriculture domain, by the creation of many start-ups since 2010 and by the development of new applications and platforms (Damave 2017; Isaac et Pouyat 2015). In their recent white paper, the French Agricultural Technical Institutes analyze the problematics related to the explosion of the available quantity of data on farms and their source of capture, eventually feeding the Agricultural Big Data (Lejeune, Brun, et Villain 2016). They formulated ten recommendations on three key areas of improvement: (a) *innovate*, namely addressing the open-innovation to co-build the services by mobilizing new partnerships and skills, (b) *fluidize* the exchanges of data, and (c) *reassure*, by clarifying the question of data property and process transparency. In this regard, Séronie

(2016) analyzes how technologies related to agriculture data are able to transform the profession of farmers and also that of companies in the sector: cooperative or private agricultural distribution companies, agro-industrial firms (traceability for crisis prevention), consumer relations (personalized marketing), etc. The emergence of a sort of "Facebook" of the agricultural data is a possible consequence of the emergence of agricultural big data. The overview of some major startups of the French Agtech, based on the recent analysis by FrenchWeb.fr (Spohr 2017) can help illustrating the expansion of the issue on agricultural data management (table 1).

Table 1. Overview of major French start-up involved in agricultural digitalization (source: elaborated from Spohr, 2017)

Innovation field	Start-up name	Mission statement
E-commerce/ marketplaces	<i>Agriconomie</i>	Web platform specialized in agricultural supplies
	<i>CompareurAgricole.com</i>	Web marketplace where farmers sell their grain at the best price
	<i>Les Grappes</i>	Community platform for the direct purchase of wine from winemakers
	<i>Monpotager.com</i>	Concept of kitchen garden connected between the producer and the consumer
	<i>La Ruche qui dit Oui !</i>	Short distribution channel through direct exchanges between local producers and consumer communities
	<i>Myfood</i>	Selling connected greenhouses to those who wish to produce their own food
	<i>YourMachine.com</i>	Digital platform of localization / mutualization of agricultural equipment
Internet of Things	<i>Naïo</i>	Selling agricultural robots helping farmers to weed, hoe and harvest
	<i>NeXXtep</i>	Offering smart and connected objects for farms (traceability, supervision, security)
	<i>Weenat</i>	Ultra-local sensors for real time data transmission to farmers
Drone	<i>Airinov</i>	The first multi-spectral sensor carried by a drone to measure crop growth
Social networks/ Serious game	<i>Agrifind</i>	Web platform that allows experienced farmers to maximise the value of their know-how and/or to help other farmers who need reliable and operational information
Software/ Data processing/ Open Source	<i>Ekylibre</i>	Open source tools to enable more efficient and simpler management of farms
	<i>Piloter sa ferme</i>	Robot consulting platform in agriculture dedicated to risk management
Crowdfunding	<i>MiiMOSA</i>	Crowdfunding platform dedicated to agriculture and food
Consulting firms	<i>CarbonBee</i>	Hyperspectral sensors for the automated monitoring of crop deficiencies, diseases and weeds
Robotics	<i>Vitirover</i>	the robot which maintains the inter-rows of vineyards
Equipment maintenance	<i>Karnott</i>	the connected notebook, allowing to share agricultural machines

Companies are developing new applications in many areas. All stages of agricultural activity are now transformed by the use of digital tools. The association “La ferme digitale” is federating some of them and organizes every year a meeting called “LFD” (<http://lfd.fr>) to promote networking among the concerned stakeholders. However, can these startups provide solutions to farmers' problems? Such question is worth because, according to a recent survey carried out in the USA and Canada (Stratus Ag Research 2016), only 41% of the farmers are satisfied with their current methods for analysing and interpreting their agronomic data to make decisions.

In addition, the proposed solutions, which are technically very advanced, mean that farmers are only users and not actors during the innovation process: consequently they risk not only to lose data control (e.g. data privacy, property rights) but also the decision process ("black box" effect of decision support tools) (American Farm Bureau Federation 2018). To overcome this, agricultural machinery producers have proposed to overcome such limitations by developing interoperability between information systems, e.g. via open standards, interoperable data exchange formats (Sonnen 2017).

Our vision is different: we explored building solutions around farmers' issues on the principle of open innovation. Open innovation is a concept developed in the early 2000s (Chesbrough 2003). The idea is: to innovate, a companies can no longer rely solely on its R&D department but they have also to open and call for new external (students, developers, startups, general public) and internal (employees, all services combined) profiles. Innovation may born from this mix of profiles, paths, different points of view and divergent views. The principle of open innovation has so far not been applied to agriculture.

3 Challenges

Current solutions, such as service providers where data is retrieved by reselling companies either as decision support systems or to other companies for marketing / commercial purposes, are unsatisfactory to the farmers:

(1) Such solutions are based exclusively on technological advances, yet the farmers' participation in the innovation process and the technology customization on their needs appear to be quite limited.

(2) Farmers have generally to adapt to standard solutions suited for the greatest market share. As a consequence, the proposed solutions do not fully suit the local heterogeneous agricultural needs. Nevertheless, customized solutions realized by businesses would be too expensive.

(3) The role of farmers in the innovation process is not clearly defined: proposed solutions (software, innovations, data involved, and decisions via a "black box") are often proprietary, the farmer is rather considered as end-user more than an innovation actor, which would promote their autonomy.

(4) Farmers collaboration/participatory control on hardware/data/knowledge sharing /decision support is then low. Indeed providers centralize both data and "black box" decision tools, without great collaboration between farmers of same regions. In addition, farmers are growing awareness and concerns about the access to and the use of their farm data (American Farm Bureau Federation 2016) and the related major shift in role and power relations. "As a result of these asymmetries, farmers' own particular needs and rights may be ignored, and

inequalities are at risk of growing due to data-driven insights, rather than be reduced” (Kritikos 2017, 41).

Our approach is different: we have explored the construction of solutions around farmers' questions about the culture of knowledge sharing (Open Source & Open Hardware Initiatives). To tackle such challenges, UniLaSalle has almost finished building the AgriLab® platform. AgriLab® is a “new generation” laboratory which is, among others, a rapid prototyping platform in digital technologies (robotics, collaboration platforms, big data processing and decision support tools) and in agro-equipment. Dedicated to open innovation, this platform promotes the culture of knowledge sharing. It is part of the worldwide movement of free knowledge exchange for a more sustainable agriculture.

Following, we will present and discuss the major outcomes from a first bootcamp, as an example of farmer-oriented event designed upon the open-source IoT in smart farming.

4 Bootcamp organisation

Cost and lack of knowledge are widely identified as the two main obstacles that farmers have to overcome to involve into new technologies (Doye et al. 2000; Reichardt et al. 2009; Pignatti, Carli, et Canavari 2015). We put farmers at the heart of innovation by proposing them low cost and do-it-yourself tools as a way to start mastering innovation. We aimed at correcting a common research and development approach that considers farmers as end-users, which main limit is to fail at embracing the complexity of their decision-making (Douthwaite et Hoffecker 2017).

Building upon the UniLaSalle educational mission, a team of researchers and teachers sought to propose to experienced farmers an open learning environment to explore new technologies. The goal was to allow them to overcome possible knowledge barriers with a learning-by-doing approach and to facilitate experience exchange and capitalisation.

The bootcamp involved 6 voluntary farmers (members of UNEAL, NORIAP and Agora cooperatives), 39 students in agronomy, 10 coaches and experts in digital technology and agronomy⁴. The subject of this first workshop was the development of connected sensors for smart agriculture. The AgriLab[®] team organized the workshop with the support of the Agricultural Machinery and New Technologies Chair and boosted by the Hauts-de-France Region through the INS'Pir program. Finally, the Wolfram Company and RS Components provided their technological expertise.

The farmers were prompted to address their main current need for the farming management, namely by exploring the use of connected sensors to improve the monitoring of physical environmental variables and to better inform their decision-making. They were equipped with the latest cheap and open source technology “building blocks”: sensors, Arduino and Raspberry Pi, gateways and LoRa radios, a 3D printer, etc. In addition, they had access to a cloud data repository (Wolfram DataBin, InfluxDB time-series database) and accelerate data analysis by using Wolfram technology (Mathematica and Wolfram Cloud). The perspective

⁴ Connected agriculture: a bootcamp on the Internet of Things in agriculture at UniLaSalle: <https://www.unilasalle.fr/lasalleactus/agriculture-connectee-bootcamp-linternet-objets-lagriculture-a-unilasalle/>

was to starting a free and open knowledge base shared under Creative Commons licence⁵. Experience like Open Source Ecology (<http://opensourceecology.org/>) and the French homologue Atelier Paysan (<https://www.latelierpaysan.org/>) show the interest for boosting grassroots innovation path drawing upon free access to others' experiences. In this regard, the workshop rationale was to promote the open source development of innovation, so as to facilitate the emergence of farmers' tests and experiences.

The workshop was held over two and a half days (24-26 November 2017). On the first afternoon, the participants presented various projects and practical examples dealing with IoT and Big Data in agriculture. In particular, CongDuc Pham (University of Pau, LIUPPA, France) provided a wide array of examples concerning the use of low-cost antenna technology for low-power wide-area network IoT in rural applications (Pham et al. 2017) issued from the WaziUp H2020 research project (<http://www.waziup.eu>). Then, each farmer was associated to a group of about 10 students to brainstorm and formalize his/her current need that could be addressed using connected sensors. Four projects were identified. The second day each group explored the farmer's need with a design thinking method. Then, the groups focused on digital development and prototyping learning exploiting online resources, digital interfaces, 3D design and electronics, backed by the team of experts. The last day, each group presented its outcomes and an early version of the connected sensor. The workshop ended with a round table of farmers and the organization team about the planning of the upcoming steps and

⁵ Open IoT in Smart Farming: <http://agrilab.unilasalle.fr/projets/projects/open-iot-in-smartfarming/news>

workshops. The both low-cost and mostly open source technologies involved are listed in the following figure:

The following diagram illustrates the general technical architecture of our projects, from the acquisition of physical data by sensors to the decision support system interpreted by farmers.

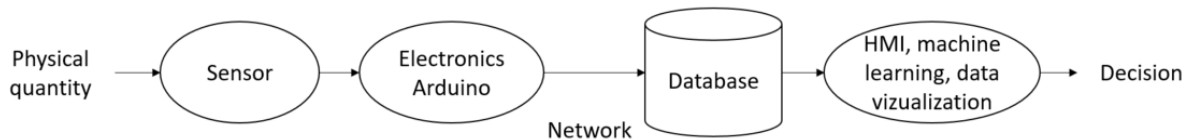


Figure 1: general technical architecture of our projects

Some elements of this common architecture may evolve according to the specifications of the each project. Indeed, the physical variables may be a temperature, CO₂, humidity, a distance, etc. Sensors are directly connected to a programmable electronic board (Arduino) which acquires data and sends them to a database via a network, which may be a wired network or a wireless network (Wifi, Lora), depending on the needs. The database and data mining processes may either be installed locally or in the cloud.

5 Results

Four open source projects of connected sensors have been made by and for farmers. Developed solutions have been prototyped and tested in simulated environment and almost finalized. The main phases of each implemented project are the following:

- Specification draft, which consists in three steps: context definition, input variables definition and output variables definition.

- Implementation, which consists in three steps: sensors & packaging, connectivity and finally data analyses.

A bird's eye view of the projects is presented into the table 2.

Table 2. Overview of the outcomes from the 2017 bootcamp

Project name, issue	Specifications		Implementation
	Physical data	Output	
"iPatate", potato stocks quality monitoring	Temperature, CO2, humidity and phyto-hormones	Intervention of the operator	<ul style="list-style-type: none"> • Retrieve and sort data • Data analyses to send alerts
"SiloTeam", remaining quantity of food in poultry food storage silos monitoring	Height of food remaining in the silo	Exact tonnage of food remaining in the silos	<ul style="list-style-type: none"> • Algorithm calculating the filling rate of the silo, as well as a comparative display of the filling of every silos of the farm • HMI/data visualization
"VegData", early rot detecting in salads	Temperature of both air and soil and humidity of both air and soil	Raising soil moisture to warn the farmer when the moisture reaches a threshold that requires irrigation	<ul style="list-style-type: none"> • Protection for sensors • 3 temperature and Humidity sensors (atmosphere and soil) • HMI/data visualization
"Decisio" soil moisture monitoring to (1) manage flax sowing and (2) monitor potatoes vegetation	Soil moisture and temperature, moisture and air temperature, foliar development and rainfall	<ul style="list-style-type: none"> • Concerning flax: knowing the best period for sowing. • Concerning potatoes: predicting the stoppage of vegetation growth and thus the harvest 	<ul style="list-style-type: none"> • Soil temperature and moisture sensors, measured every 15 minutes • Data storing in a cloud database • HMI/Data visualization • Alerts/warning SMS • Web access

5.1 "iPatate" project

"iPatate" project consists in developing sensors to monitor the quality of potato stocks. The main innovation of this project is the remote management of agricultural activities.

5.1.1 Specifications

The final desired product is the global and autonomous management of a potato storage building: monitoring of physical quantities involved in the sprouting of potatoes, managing the shutters of buildings, etc.

First, we would like an HMI (Human-Machine Interface) that displays the following physical quantities: temperature, CO₂, humidity and phyto-hormone sensors (e.g. Cytokinin, abscisic acid) (Suttle 2004).

Data should be recorded every five minutes to avoid missing an incident. The system will have to intervene on the following indicators:

- Knowledge of CO₂ threshold, temperature (for example, if it is hot in and cold outside, it will air), humidity.
- Calculating the average of all data collected as and when.
- Check every 10 minutes if the parameter threshold (CO₂, Temperature and Humidity) is respected.
- Make a diagram of the checks made on each parameter.

The output variable is to indicate to the operator whether to intervene. The intervention decision will be made if we have a value difference recovered between two probes higher than a threshold to be defined, then display an alert on the interface.

5.1.2 Implementation

The code running on the Arduino PCB with humidity and temperature sensors and their library, as well as the CO₂ sensor simultaneously, has been completed⁶.

The main difficulty about connectivity is to take into account the fact that the buildings are isolated, which requires a relay to allow communication from the inside to the outside of the silo.

Data analyses are computed through a computer program written under Mathematica, which aims to retrieve the raw data from the sensors that are taken every minute. Since these data are not very significant for the program, it is advisable to average it over 30 minutes to get a graph to follow the evolution of temperature, CO₂ level and humidity over 24 hours. Following this, we assign minimum and maximum threshold values, values that will trigger an alert (by SMS if possible) that will allow the farmer to accurately track his storage.

Finally, the developed code is able to retrieve data, sort them but the final analyses to send alerts is not implemented yet.

5.2 “SiloTeam” project

“SiloTeam” project consisted in making sensors to monitor the remaining quantity of food in poultry food storage silos. The main innovation of this project is the remote management of agricultural activities.

⁶ Please refer to http://agrilab.unilasalle.fr/projets/attachments/download/320/Codage_Arduino.txt and https://github.com/Seeed-Studio/Grove_Temperature_And_Humidity_Sensor

5.2.1 Specifications

The problem is to get the amount of food remaining in the silos of poultry food storage at a time t (volume). In the long term, this system will be associated with a calculator to know the exact tonnage remaining in the silos and thus allow the farmer and the cooperative to anticipate and optimize deliveries. In order to answer the problem, the real needs of the farmer have been defined: silo height criterion, user interface, storage silo capacity (18 and 35 m³).

5.2.2 Implementation

The first step is to look for sensors compatible with the requirements and constraints of the farmer, the idea being to place 2 distance sensors using laser technology, one at the center of the silo and the other at its edge in order to calculate the volume remaining in the silo.

The algorithm calculating the filling rate of the silo, as well as a comparative display (please refer to following figure) of the filling of every silos of the farm have been developed.

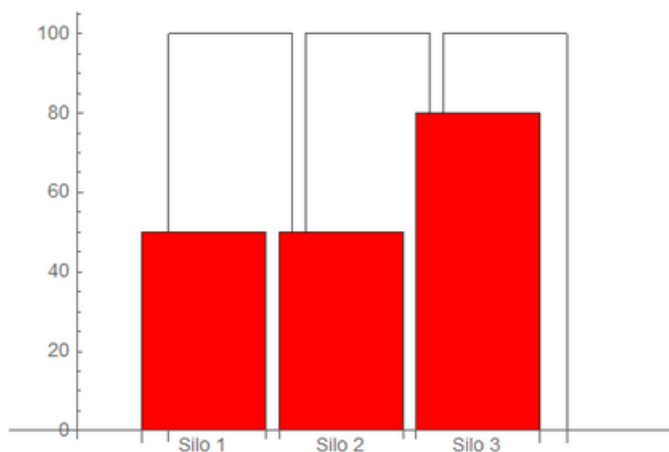


Figure 2: comparative display of the filling of silos

5.3 “VegData” project

“VegData” project consists in developing sensors that detect early rot in salads. The main innovation of this project is the possibility to network farms data sensors in the same region to ensure collection of large data amounts and thus the control of both hardware and statistical decision processes.

5.3.1 Specifications

The studied farm is located at the bottom of a valley (organic farming). Both studied parcels are surrounded by ditches and have a peaty soil (clay, acid and rich in organic matter). The rotation of the first parcel (12% organic matter) is mown alfalfa / poirot / salad. The rotation of the second parcel (6% organic matter) is carrot / lettuce / cabbage / pumpkin.

The problem is the appearance of a disease on salad crops that develops at the base of the leaves. The disease particularly affects the oak leaf variety of salad. It appears towards the end of May after transplanting during March / April and towards the end of August, after transplanting during and August.

Several hypotheses explaining the occurrence of this disease have been issued:

- The disease is caused by parasites such as fungi (botrytis).
- The disease is caused by the couple moisture (rainfall and irrigation management) / temperature (soil and air), e.g. over-irrigation.
- The disease is caused by the combination of the two hypotheses above

The physical variables to study are therefore the following: the temperature of both air and soil and the humidity of both air and soil.

Humidity and temperature sensors that will be installed will be solutions for conducting irrigation. They will be placed in three places in relation to the salad plant (please refer to the illustration below). The three predetermined places are: in the ground, at the level of the sheet in contact with the ground and between several leaves.

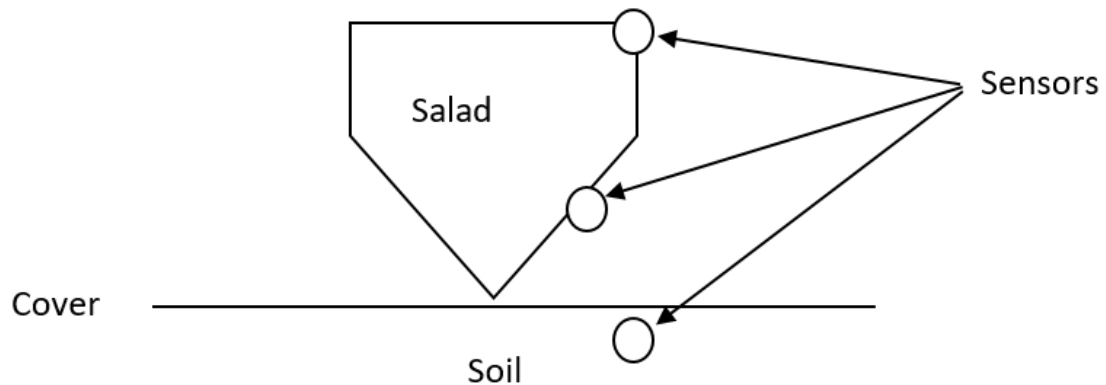


Figure 3: location of sensors on the salad and underground

The sensing frequency of the sensors will be every hour for 2 months. This period corresponds to the interval between the start of transplanting and the appearance and development of the crop.

The first objective is to continually raise soil moisture to warn the farmer when the moisture reaches a threshold that requires irrigation. This threshold depends on the characteristics of the soil. In our case, it is a predominantly clay soil. The wilting point not to be reached corresponds to 20% soil moisture. The goal is warn the farmer a little before reaching this threshold to proceed with an irrigation.

Saving the history of previous values will constitute a database. The database will therefore have to be sufficiently fed with data to allow an artificial intelligence to propose relevant decisions for farmers, which is our second objective. Indeed, an artificial intelligence

(developed with mathematica software) will have to correlate irrigation management data with those recovered by the sensors (precipitation and evapotranspiration data) in order to realize a water balance and to determine when the disease appears, allowing farmers to adapt their practices to understand the development of the disease.

The following scoreboards presents data from three sensors, each placed on one of the three predetermined places.

Table 3. Scoreboards about sensors

# sensor	Temperature	% humidity
00:00		
1:00		
2:00		
...		
23:00		
Average		

5.3.2 Implementation

Implemented sensors are three Temperature and Humidity sensors (atmosphere and soil) as described in the paragraph before. The chosen temperature sensor for leaves is designed for interiors. It must not stay outside for a long time without adequate protection. So that these sensors evolve in good conditions (similar to inside conditions), they are placed in a case.

To protect the Arduino, it is possible either to design a protection thanks to the Agrilab 3D printer, or to buy one (for example on Thingiverse.com Website). The ground temperature and humidity sensor does not require any additional protection because it is already waterproof. The next step consists in feeding a database via Lora wireless network. Finally,

data treatments (data visualization to detect variables which have an influence on salads disease for now) have been implemented via Mathematica software.

5.4 “Decisio” project

“Decisio” project consists in developing sensors to monitor soil moisture with a dual purpose: (1) better management of flax sowing and (2) potatoes vegetation monitoring. The main innovation of this project is to design one sensor for several purposes.

5.4.1 Specifications

Regarding flax, the study concerns the temperature and humidity of the soil in order to know the best period for sowing.

Concerning potatoes, the study concerns the dry matter of the potato to predict the stoppage of vegetation growth and thus the harvest. Among the reflections that have been conducted, the hypothesis of putting a sensor directly in the potato, would destroy it. Indirect parameters such as weather or foliage need to be found to determine the dry matter of the potato.

The physical variables involved are: soil moisture and temperature, moisture and air temperature, foliar development (color, surface) and rainfall.

The sensor-to-OAD package is illustrated below:

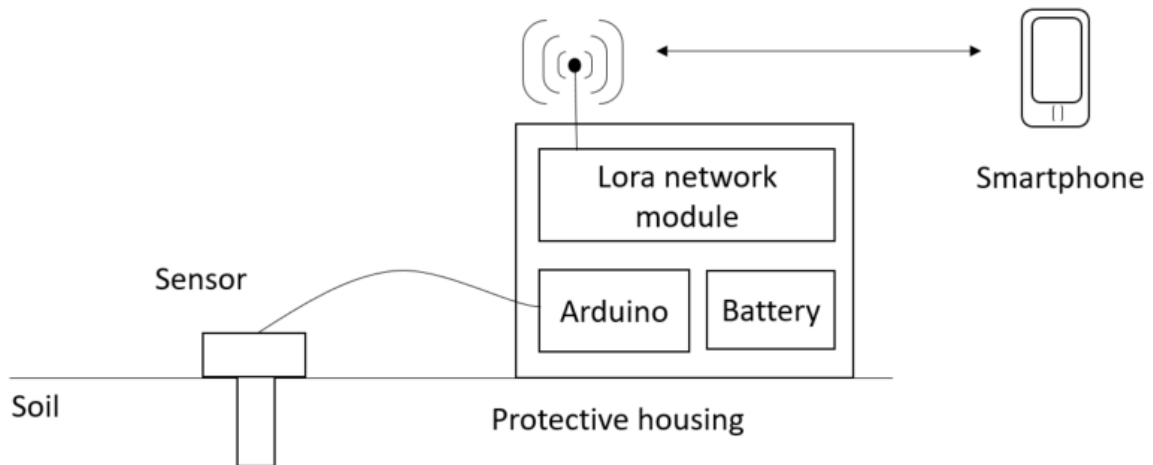


Figure 4: Decisio sensor-to-OAD package

5.4.2 Implementation

The needs for the flax project may be integrated into those for potatoes. Sensors may also be used for other crops such as wheat to measure moisture and then make decisions about harvesting.

Once soil temperature and moisture sensors have been implemented, data may be combined with those of meteorological stations collecting rainfall, temperature and air humidity, as well as satellite imagery for foliar development. Thanks to data collected over several years, it will be possible to develop, in the long term, a model to warn farmers about the optimal time allowing them to check that there is a good dry matter content in potatoes.

Regarding the programming of the Arduino electronic board, sensors measure soil temperature and humidity every 15 minutes. Data are stored in a cloud database and processed via Mathematica software. Subsequently, the average of these physical variables of the last 24 hours is updated every 15 minutes. An average per day is also calculated to create a graph showing temperature and humidity as a function of days. On a graph, farmers

may be able to display the desired variables. The last step on HMI is to allow farmers to determine a threshold value so that, when reached, the software sends a warning SMS. Finally, all these data (values, means, graphs), are permanently viewable by farmers via a URL.

5.5 New opportunities

All the participants to the bootcamp agreed that it is relatively easy to design and implement the most appropriate connected solutions suited to the farmers' needs. Through this process, it can be shown that the farmers can be involved in the agriculture digitalization, and even more that they can participate to a problem-solving approach to broaden their skills. In addition, relating this to the students' training, by project learning, can help raising their confidence in their capabilities to acquire new knowledge and new know-how and to realize new solutions.

Such an open innovative model farmer-oriented can benefit from the involvement of students and experts in agronomy and in digitalization technologies. In the end, this approach to innovation leads to a large range of new business models, among which the creation of a start-up becomes just one of the multiple possibilities through which the involved actors can create a new activity. For instance, the farmer-oriented concept prototypes can be adopted by established industries for the development of improved solutions.

6 Conclusion and perspectives

Digitalization is revolutionizing agricultural practices and the related innovation processes. We believe that one of the keys to the success of such a revolution is the mastery of technological innovations by all the actors and stakeholders of the agricultural equipment sector. Open IoT

is a way to achieve this. Indeed, thanks to our approach, the farmers designed customized and low-cost prototypes. In addition, the participants highlighted the interest to use open IoT to favours collaborative aspects.

In conclusion, we can summarize the outcomes from the bootcamp on three axes:

- An agronomic axis: low-cost sensors are expected to enable farmers to better monitor the environment, thus to facilitate the implementation of precision farming. The main outcome of the first workshop was to improve the farmers understanding of sensor technology and data management. They were finally helped to focus their needs, so as to clarify their expectations from the new technology providers and advisors.
- An economic axis: digitalization could provide added value; this can explain why farmers, or their children, adopt such new technologies. The implementation of AgriLab® platform can play a part of the adoption and the dissemination of technology by farmers, students and experts in digitalization technologies.
- A technological axis: proposed indicators are still descriptive data. It will be necessary to develop predictive analyses (machine learning), which will require bigger data sets, sometimes involving data collection over several years.

Future challenges during 2018 are to prototype Lora network nodes and gateways, then deploy Open TimeSeries database platform, next putting all together the four sensor projects in the farms. The mid-term perspective would be to use the AgriLab® platform to reiterate practical workshops to explore the role of sensors and IoT in the various components of the farming systems, from the crop management to the dynamic agricultural machinery management and regulation.

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