ROMI
ROBOTICS FOR MICROFARMS

# Vision and scenarios

The ROMI project is entering its second year. During the first year the partners got to know each other's work better and elaborated a shared vision through the many work sessions. The aim of this document is to give shape to this vision and to help us focus our work in the second year.

The guiding principle behind the ROMI project is **sustainability** and, in particular, **sustainable food systems**. It is good to keep this principle in mind when choices have to be made: the solution that ultimately leads to more sustainable food systems should the prefered one. It goes without saying that both food and sustainability are hugely important societal issues and therefore ROMI has the opportunity be highly relevant.

Within sustainable food systems, we decided to work with **microfarms**: these are small (<2 ha) organic farms that grow a large variety of vegetables. We have several good reasons to focus on these type of farms and we listed the main ones at the end of this document.

ROMI is also a **technology project**. Many of the partners have a strong background in computer sciences and robotics. The more narrowly defined goal of the project therefore is how to use technology to help microfarms. And, in particular, what technologies to make these farms more sustainable, productive and economically viable[1].

We are working on two main applications. The first one is a robot for **mechanical weeding**. The second one could be described summarily as a tool for **outdoor phenotyping**. As we will see later, this description is too restrictive of what we aim to accomplish but it is a quick way of explaining the project.

To give a deeper understanding of the philosophy of ROMI it is important to mention how we distinguish our approach from industrial agriculture. The Green revolution has reached a high level of productivity by reducing the variability of the natural environment. It uses large fields of monocultures for efficiency, artificial fertilizers to control the levels of nutriments in the soil, pesticides to keep unwanted insects, fungi and weeds out of the field, and irrigation systems to be less dependent on the weather. Indoor farming pushes this search for control even further. Using these techniques industrial agriculture has managed to make the agricultural environment more predictable, which resulted in more predictable harvests. This would be excellent news if it weren't for the fact that these techniques have reduced the biodiversity and soil health and increased groundwater pollution (among other problems) to alarming levels.

One of the yet-to-be-proven assumptions of ROMI is that rather than increasing our control over the environment we can match the needs of a complex organic environment with a complex computational environment. Our aim is to develop **flexible, smarter, adaptive tools to manage more natural environments**. This in turn allows farms to increase the level biodiversity and gradually establish a more natural environment. The increased complexity can be compensated for by using tools with advanced **sensing and modeling** capabilities, and by **sharing information**

[1] Some may say that technologies are not needed to make farming more sustainable. This is a valid point. The use of technology in farming is a societal issue that merits a larger public debate and that we will not discuss in this text. During the ROMI project, we will engage in - and even organize - public debates on this topic.

**between farmers and scientists**. We hope that during the ROMI project, we will be able to develop a proof of concept of this approach.

Another important feature of ROMI is that all the tools (software and hardware) will be made openly available under a **free license**. We believe that this is the best approach to have a wide impact. It facilitates the access to our results for the many small farms worldwide and facilitates the collaboration between farmers, scientists, engineers, and industry. The validate our vision and achieve the desired impact, we will **sell the platform as a kit** to those who are interested.

## Approach

We have chosen to work on two short-term applications and a more long-term development.

The first short-term application is a **robot for mechanical weeding**. The reason for this choice is that weeding is a time-consuming and physical task without a lot of added value for farmers. It is also important for us to have a concrete application early on to get feedback from farmers.

The second short-term application is a **3D plant scanner**. The scanner is a stepping stone to develop the outdoor phenotyping application. We believe that the scanner is a useful object in itself that can be proposed to biology labs.

The long-term vision is to develop **intelligent robotics platform for farming**. For that we need sensors and algorithms that give the robot advanced capabilities. Observation is the first law of permaculture and is also the basis of scientific investigation. It makes sense then that we aim to give the robot the capabilities to observe the plants and the field.

We choose to observe the shape of the plant (Phenotype) over time using techniques from computer vision, 3D vision, plant modeling, active vision, and AI. We will combine a top-down approach with a bottom-up approach: using an air-borne device we obtain a large-scale view of the field, and using a ground-based rover we obtain detailed information from individual plants.

We have defined **three usage scenarios** that put our work in concrete context. We will start with the description of the most challenging and complete scenario, the farm scenario. The two other scenarios - the 3D scanning station and the LettuceThink weeder - will be discussed afterwards.

> **Note**: Many important details are missing from the scenarios below. It would be good if we can agree on these short descriptions before we expand the scenarios and the tasks further.

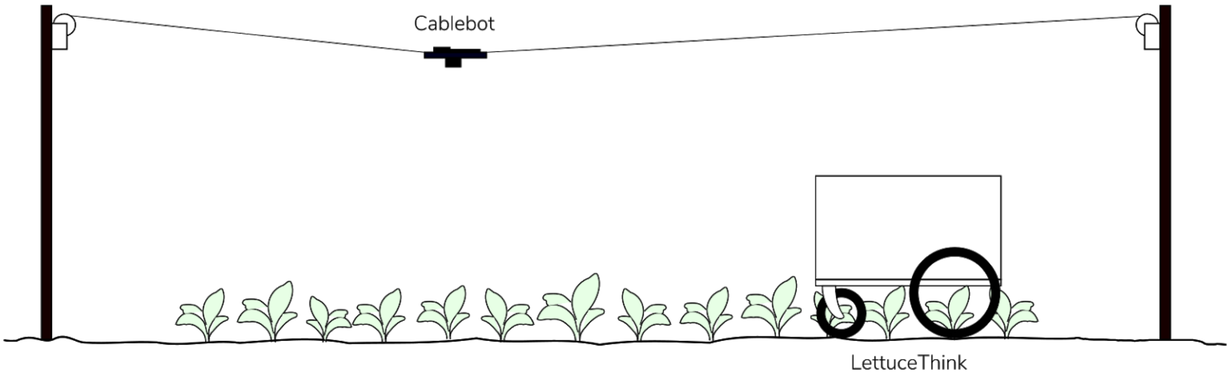
## Scenario 1 - The farm

### Set-up

In this scenario, we prepare a bed of vegetables. On the test site at Chatelain Maraîchage, we prepare an area of 1 m x 15 m inside the greenhouse. At Valldaura, we prepare an outdoor area of 3 m x 5 m. In the bed we grow one or more cultivars: radishes, carrots, … and also chenopods. A

**cablebot** is installed to move over the beds. In the bed, we will also place several temperature, humidity and luminosity sensors at different locations[2].

A number of witness plants will be planted at precise locations and will be registered on the map at the server. These plants are one of the cultivars[3] that is grown isolated from the rest to make it easier to locate and scan.




## Operation

- **The cablebot collects aerial views of the field**: Every day, the cablebot scans the bed using at least an RGB camera[4]. The images are uploaded to the database server[5].
- **The server produces various maps**: From the images of the cablebot, various maps are produced: a 2D+time map (using image stitching) and 3D+time map (using Colmap) of the field. The images are also segmented to detect the cultivars and other plants. The goal is to produce additional health maps from these images. In this scenario, we are particularly interested in a map that indicates the amount and the level of weeds. This *weed map* indicates in which areas the unwanted plants are developing most.
- **The rover removes weeds**: The server uses the weed map to decide when (and where) to weed and sends a notification to the rover. The rover navigates to the indicated locations, does a local assessment of the weed status and cleans the area. The collected local information is uploaded to the database server.
- **The rover obtains 3D plant information:** Every day, the rover also goes into the field and performs a 3D scan of the witness plants (using plant location, map and navigation capabilities). The image data gathered by the rover are also uploaded to the image database.
- **Environmental data is collected**: The temperature, humidity and luminosity data are stored also in the database.
- **The server produces layered visualisation of the field**: A web site or GUI to the database allows to navigate and overlay the recorded data. Ideally a geographical maps displays the different layers of information and their evolution over time (2D images, points clouds,

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[2] Either FlowerPowers or SmartCitizen/GROW sensor boxes.
[3] Later, we may consider another species that are known to be a good indicator for pests or environmental stress. Examples needed.
[4] Additionally, NIR or thermal cameras may be used, also.
[5] Still to be defined whether we will use the Omero or QGIS database systems, or whether we use an application specific API to abstract the underlying implementation. The database server will most likely run on a seperate server. We will have to define how the cablebot and the rover will communicate with the server.

weed map, 3D plant data, ...). This data serves initially to document and visualise the evolution of the farm over time and can be used by farmers and scientists.

- **The server computes indicators using the witness plants**: The 3D scan data of the witness plants is used to obtain more detailed 3D information of the plants. This data is used to compute various indicators, for example, growth stage of the plants or of the rest of the crop based on their height, volume, projected leaf area, leaf area, number of leafs, list of organs, etc. We may develop other plant indicators based on the plant's morphology, such as hydric stress.

The cablebot and the rover remain independent and autonomous (each can be used separately) and share information through a shared database (the layer map of the field).

## Rationale

- **What is the goal of this system?** First, time saving. The system should help the farmer to gain time. A weeding robot reduces a time-consuming task for the farmer.
- **Why a combination of cablebot and rover?** The cablebot produces a map of the field more quickly, more reliably, and using less energy than the ground-based rover. The cablebot also has a fixed frame of reference, which facilitates the alignment of images in space and time. However, the rover can obtain detailed information about individual plants (for example, it can look underneath leaves) and it can perform physical operations that are hard to realise with an aerial device (e.g. remove weed).
- **Why develop a weed map?** The weeding robot isn't necessarily fast (it currently isn't) and it makes sense to send it off for weeding only when and where necessary. The weed map also gives an indication to the farmer about how much work to expect in the coming days and where and when interventions may be needed.
- **Why use witness plants?** Witness plants are used by farmers as an early indicator of pests (example, the use of roses in vineyards to detect mildew). Although human expertise is certainly essential for the inspection of witness plants, a regular feedback sent by the rover may help the farmer in busy times. The witness plants can also be used to help evaluate the growth profile of the rest of the crop. It is easier to obtain this information from isolated plants than from a packed population of plants. (It needs to be shown that the witness plant is a good indicator for the rest of the crop.)
- **Why store so much data?** We believe that documenting the crops and the environment of the farm over many years may help the farmer to better understand the specificities of her farm. Using the data, correlations may become apparent that are not easy to deduce from qualitative observations or from memory. The data collection is motivated by a data science approach but still requires further clarification (the objectives, the data quality, and temporal/spatial resolutions of the measurements). We aim to develop a proof-of-concept during the project.

## Scenario 2 - 3D plant scanning

The scanner is our development environment for the 3D scanning algorithms. The installation is an accessible (meaning: not too expensive) solution for plant phenotyping that may useful for research labs.

### Set-up

The scanner consists of

- a fixed aluminium frame,
- a CNC device for XYZ movements,
- a pan-tilt gimbal with an RGB camera,
- a PC,
- control software, and
- a software toolbox for image and plant analysis.

### Operation

**Run a 3D scan**: a 3D scan can be made of a plant positioned in the center of the frame.

**Store data in a structured database**: The images and all the metadata are stored in a database back-end.

**Run analyses to extract plant traits**: Post-processing pipelines can be applied to the scanned image sets to extract relevant plant characteristics. We will discuss the data processing in more detail below.

The first full pipeline we will develop and test is for the scanning of the Arabidopsis thaliana.

## Scenario 3 - weeding robot

Scenario 1 already covers the use of the robot for weeding but there is a need to test the weeding robot without a cablebot, database server or weeding map. Scenario 3 is therefore a more “conventional” scenario in which the robot navigates autonomously and combines 1) the use of classical, mechanical weeding tools in between the rows of plants and 2) the CNC arm to weed in between the plants on a row.

### Set-up

A four-wheeled robot is equipped with a CNC and a precision weeding tool. It also carries a rack with classical weeding tools. It has various sensors (GPS, IMU, cameras, encoders) for autonomous navigation.

### Operation

**Move from the barn to the field and back**: Using GPS and a list of waypoints, move autonomously from the barn to the field. For security, obstacles will be detected but not circumvented. The robot has to be connected manually to the charging station.

**Move along a bed of crops**: Using various sensors, move in a straight line along a vegetable bed. Possibly, we will place poles and/or tags in the field for more robust positioning using cameras.

**Weed inter-row**: Weed using classical tools (finder weeder, oscillating stirrup hoe, collinear hoe blade, ridger, harrow springs, ...). The lateral position of the tools may be adjusted manually.

**Weed intra-row**: Weed with high precision in between the plants using the CNC mechanism and the rotating weeding hoe.

## Data acquisition and processing

To make our vision concrete, we will develop a number of bricks that together make up our platform for microfarms: technological objects (discussed above), software components, algorithms, and infrastructure.

Concerning the software, there are too many components to detail them all in this summary. We will just mention the **data acquisition and processing components** that are unique to ROMI. We have chosen to focus on the morphology of single plants, and the evolution of the morphology over time. We also perform analyses of larger areas (field, population of plants) to produce health maps, as mentioned above.

Some of the plant scanning algorithms that we need don't exist, yet, and their development is preceded by fundamental research. We are testing a several data processing pipelines in parallel, each drawing upon the state-of-the-art in machine learning, plant modeling, robotics, and computer vision. The reason to work on several methods in parallel is to obtain robust, accurate and fast scanning techniques that can be used in varying conditions outdoor.

The 3D processing pipeline can be roughly divided in three parts (even though for some of the approaches, this distinction is not clear-cut)[6]. First, an acquisition phase where a 2D or 3D sensor is used to obtain a series of images. Second, these images are used to build a 3D representation, most likely a point cloud. Lastly, the 3D data is analysed to extract plant traits.

For each of these phases, we develop the following bricks that will be combined to build the complete data processing pipelines:

**Classical methods to obtain 3D plant data**: Using well-known techniques of structure-from-motion and space carving to obtain an initial 3D representation of the plant as a point clouds or set of voxels.

**Adaptive methods to obtain for 3D plant data**: Use exploration techniques from adaptive robotics and active vision to optimize the scanning.

**Geometrical methods to extracting plant traits from the 3D data**: Use novel geometrical techniques to segment the 3D plant data into its constituent organs.

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[6] In ROMI, we also apply 2D analysis techniques that extract plant traits from 2D images.

**Plant-model based methods to extracting plant traits from the 3D data**: Analyse the 3D data by imposing morphological constraints derived from plant models.

**Plant-model based methods to following the time evolution of plants**: Predict the changes between two time-consecutive scans using plant models.

**Using virtual plant models to train neural networks for image segmentation and feature extraction**: Use plant models to generate sets of 2D images to train neural networks used for image segmentation and feature extraction.

**Use additional sensors to inform the 3D scanning**: We use additional sensors to measure additional features, such as whiskers to measure mechanical plant properties.

The scanning of the **Arabidopsis thaliana** will be used to evaluate and compare the different approaches. The phyllotaxy of the main stem of A. thaliana can be characterised as a list of angles and internode distances. The values calculated by the different approaches will be compared to manual measurements.

The **analysis of larger areas** is needed for the weeding algorithm and to create the weed maps. The construction of this map is currently based on segmentation using color and plant size. Additional techniques are tested, including a deep learning approach for segmentation and classification using 2D images, and 3D point clouds.

## Data science for farming

Besides the work mentioned above, the ROMI project faces several additional challenges:

1. Integrate information from several data sources.
2. Provide an easy access to this data.
3. Extracting meaningful information from the data.
4. Link field observations to the needs and information for the farmer.
5. Use field observation for scientific research including plant phenotyping.

We will therefore develop a programmable GIS Interface for farmers.

## Microfarms

As mentioned in the introduction, we close off this document with a short discussion of why we decided to work with microfarms:

- **Sustainability**: Most microfarms are concerned about sustainability, apply agroecological principles, and tend to experiment with novel and traditional farming techniques in order to become more sustainable.
- **Human scale**: They are of a manageable size for the ROMI project.
- **Challenging open-ended environment for robotics**: Microfarms tends to much more varied than large monoculture farms and provide a challenging, open-ended environment for robotics research.

- **Scientific research**: They provide a rich environment for agronomical research. The study of some of the practices used in microfarms, such as polyculture, may benefit from a data-driven approach.
- **Impact**: There are many microfarms worldwide (475M farms of less than 2 ha producing 84% of the world's food).
- **Transition**: They can be easily implanted at the edge of the city - and even inside the city - and renew the link between the city and food production. This allows ROMI to be relevant also in the discussion on urban agriculture and the future of cities (see also the Capitale Agricole exhibition at the Pavillon de l'Arsenal in Paris, to which we contributed).
- **Reduced investment**: Small farms present a smaller risk for farmers who are starting outside of a family context. The capital investment needed to start a microfarm is relatively low. This fact combined with the use of novel technologies may attract young farmers to enter the profession.

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