1. Executive Summary

1.1 Summary of deliverable content and initial objectives

WP1 is responsible for the day-to-day management of the project. Its objectives are:

- To monitor the progress of the project, with the aim of ensuring that the stated project objectives are achieved.
- To monitor and adjust the timing of deliverables.
- To monitor the budget expenditure of all partners with the aim of a balanced distribution of resources according to the budget and the needs that may arise during the project.
To monitor the risks and apply remedial actions when necessary.

After the first year of the ROMI project, we defined three scenarios, each with a clear purpose: the Rover for weeding, the Farmer’s Dashboard and its cablebot to monitor crops, and the 3D Scanner with its Smart Interpreter to analyse plants. Although the scenarios complement each other to provide a complete solution for microfarms, we have given each a separate management document. These documents cut across all WPs to provide a coherent, global view of the status of the work on each of these scenarios and of the priorities and challenges that remain to be addressed. The following documents are provided:

- D1.2 - Management Document - The Rover and its primary application: weeding (The current document)
- D1.3 - Management Document - The Farmer’s Dashboard and its primary tool: the cablebot
- D1.4 - Management Document - The 3D Scanner and its primary application: a smart interpreter

2. Introduction

The purpose of this document is to provide a holistic overview of the progress of the Romi Rover project. The Romi Rover is one of the three marketable products that are targeted by the ROMI project.

The Romi Rover, as an end product, must deal with technical issues, testing, regulations, market studies, documentation, user feedback, communication… These aspects are treated in different work packages of the ROMI project. For example, WP2 concentrates on the technical implementation, but the exploitation of the rover is prepared in WP8. The first objective of this document is to tie together these various aspects to offer a global overview.

The second objective is to provide clear specifications of the Romi Rover. This includes clear descriptions about who are the clients that we are targeting. How will they use the rover? What can the rover do or cannot do? How much will it cost? Etc.

Lastly, this document serves to track our progress in the implementation of the Romi Rover. How far are we? What are the priorities and the remaining work?

The management document detailed below consists of the following parts:

1. The **Project Management**: Tracks the progress of the different aspects of the rover development..

2. The **User Manual & Feature Development**: The User Manual is updated as the work progresses. Desired and upcoming features (from a user perspective) are described in the accompanying Feature Development document. Both documents play an important role to refine the specification and guide our design process.
3. **The Technical Specifications:** At the end of this document you find a more detailed technical specification. Many of the elements of the technical specifications have already been incorporated into the User Manual.

4. **The Cost Analysis:** This analysis estimates the costs and financial benefits for the farmer associated with the use of the Romi Rover.

5. **The User Studies:** The User Studies provide feedback from professionals on their needs and on the design of the rover. These studies have been taken into account into the User Manual and the Technical Specifications. For privacy reasons the text has been anonymized. The complete version can be found in the Annex of Deliverable D8.4.

6. **The Market Study:** The market studies draws a portrait of the future users of the rover and analyses the potential for dissemination. A summary can be found below; for details, please refer to D8.4.
3. Project Management

Dashboard current status

Figure 1: Current estimated TRL level of the Romi Rover. The expected TRL level by the end of the ROMI project is 7 to 8.

![Figure 1: Current estimated TRL level of the Romi Rover. The expected TRL level by the end of the ROMI project is 7 to 8.](image)

Figure 2: The progress of the different aspects of the Romi Rover.

![Figure 2: The progress of the different aspects of the Romi Rover.](image)

The performance indicators for each of these aspects are detailed next.

Specifications

**Details:** Please see also The Specifications below ([online working document](#)).

**Current status:** Please see the below table.

**Priorities:** See Software and Hardware section.

<table>
<thead>
<tr>
<th>Hardware</th>
<th>60 %</th>
<th>The specifications for the hardware are reasonably well defined but there</th>
</tr>
</thead>
</table>

ROMI - D1.2 Management Document - The Rover
remaining uncertainties on the following issues:
  - the navigation (high impact), and
  - feedback on the position and force of the CNC.
See the Hardware section below for more details.

| Software | 90 % | The specifications for the software are complete. Remaining uncertainties:
  - the image segmentation in edge cases, for example, when strong sunlight passes underneath the cover of the rover.
See the Software section below for more details. |
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>75 %</td>
<td></td>
</tr>
</tbody>
</table>

**Hardware**

**Current status**: Making good progress towards a device that we can hand over to farmers.

**Priorities**:
- Run a focused evaluation campaign to fine-tune the rail-based navigation system (high priority).
- Improve the design of the CNC for better feedback and faster execution (medium priority).

<table>
<thead>
<tr>
<th>Specifications</th>
<th>Status</th>
<th>Notes</th>
<th>Challenges (table below)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A 4-wheeled rover with electrical motors that is able to receive software commands:</td>
<td>60 %</td>
<td>The 4-wheeled rover has been built and is being tested. Challenge HW1 is not completely resolved, yet, and may require changes in the design of the steering, sensing, or guidance system. These changes may impact the software and the final costs.</td>
<td>HW1</td>
</tr>
<tr>
<td>- to drive along a straight vegetable bed over a given distance (precision: 5 cm) and</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- at a given speed of up to 1 m/s or 3.6 km/h (precision: ±5%)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- on mostly flat (slope &lt;5%) and mostly leveled agricultural terrains.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>An electrical weeding system</td>
<td>60 %</td>
<td>The weeding system is used and tested regularly. The image segmentation sometimes fails because light conditions can vary widely. See Software section.</td>
<td>HW2, HW3, HW4, HW5</td>
</tr>
<tr>
<td>- using a camera (RGB, depth or other) and</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- a rotating weeding hoe that is</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- able to receive software commands to</td>
<td></td>
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<td></td>
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<tr>
<td>- detect the contours of vegetable plants (lettuce)</td>
<td></td>
<td></td>
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<tr>
<td>- based on size, color, and/or shape, and that</td>
<td></td>
<td></td>
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<tr>
<td>- computes a path for the weeding hoe to</td>
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</tbody>
</table>
cover the soil between the detected plants, and that
• moves the hoe at soil-level along the computed path with a precision of <1 cm, and that has
• a working speed of 5000 m²/week (8h/day).

NOTE: The vegetable bed must be clean of weeds when planting out. The weeding system must be used at least once a week to assure that the size of the sprouting weeds is small (cotyledon growth stage).

<table>
<thead>
<tr>
<th>Specification</th>
<th>Progress</th>
</tr>
</thead>
<tbody>
<tr>
<td>A tool carrier that can be attached to the rover and that uses classical mechanical weeding tools.</td>
<td>75 %</td>
</tr>
<tr>
<td>A controller that lets a human operator select a weeding program.</td>
<td>100 %</td>
</tr>
<tr>
<td>A controller that lets a human operator steer the rover remotely.</td>
<td>100 %</td>
</tr>
<tr>
<td>A battery system that can power the 4-wheeled rover and weeding system for 8h/day and that can recharge overnight.</td>
<td>80 %</td>
</tr>
<tr>
<td>The combined cost of the components should not exceed 5000 €.</td>
<td></td>
</tr>
</tbody>
</table>

Technical challenges

- The tool carrier has been designed and is being tested. Some (small) changes are needed to improve the design.
- Two interfaces to the rover: physical on-board control panel and a web interface on phone.
- Using reliable RC hardware. HW6
- Battery system is in place and power measurements have been made to dimension the battery. Additional work is required to reduce the energy consumption and thus battery size and cost. HW7
- The current prototype is within the same order of magnitude but using components from more expensive local resellers. The set target seems attainable when components are group-purchased from volume resellers. HW8

The average progress of the list of specifications above | 75 %
<table>
<thead>
<tr>
<th>ID</th>
<th>Challenge</th>
<th>Exposure</th>
<th>Mitigation</th>
</tr>
</thead>
</table>
| HW1 | Failure to drive along a straight path in agricultural terrains without expensive navigation technology (ex. commercial GPS RTK: hardware: 3k€, license: 600 €/year) | L: High  
I: High  | - bootstrap the use of the rover with use of rails or other guiding system along the beds,  
- evaluate use more complex steering mechanisms than caster wheels  
- test available Open Source navigation solutions with reasonably priced GNSS systems (ArduPilot, U-blox)  
- Use higher-end navigation technology such as GPS RTK |
| HW2 | Failure to work on beds with large variations in soil level               | L: High  
I: High  | Request farmers to prepare beds using tools such as the “cultirateau” or “vibroculteur” (S-type cultivator with rolls to level the soil).                                                               |
| HW3 | Failure to detect plants (lettuce) in camera image                        | L: Medium  
I: High  | Develop more advanced ML technologies for image segmentation. These may have an impact on the required on-board computing power of the rover.                                                               |
| HW4 | Device too slow to weed 5000 m²/week                                       | L: Medium  
I: Medium | Evolve the design of the CNC:  
1. Faster motors and stronger belts  
2. Use several arms  
Both are feasible but require extra time.                                                                                                                  |
| HW5 | Outdoor conditions are too difficult for precise movement of the weeding tool. | L: High  
I: Medium | - use stronger motors  
- use sensors for more precise feedback  
- relax the 1 cm precision constraint                                                                                                                   |
| HW6 | Unreliable remote control                                                 | L: Low  
I: Low  | Use proven RC technology                                                                                                                                                                                  |
| HW7 | The dimensions, weight, or the cost of batteries are too big.             | L: High  
I: Medium | Offer battery-pack option between more expensive, long-lasting battery and less expensive pack with shorter work span.                                                                                  |
| HW8 | Total cost exceeds the given limit.                                       | L: Medium  
I: Medium |                                                                                                                                                                                                            |
Software

Current status: The rover's software is reaching alpha status. The core algorithms have been integrated. The architecture of the software is stable. The development process uses standard frameworks for continuous integration and deployment. We are using test driven design for new software development and automated testing. The quality of the code has made significant progress.

Priorities:

- Testing, testing, testing.
- Set up a database and testing framework to systematically evaluate different weeding algorithms.
- Evaluate the use of CNNs on the rover.
- Continue the unit and integration testing framework.

Links:

- Project dashboard at GitHub https://github.com/orgs/romi/projects/2
- Code repository at https://github.com/romi/romi-rover-build-and-test

<table>
<thead>
<tr>
<th>Specifications</th>
<th>Status</th>
<th>Notes</th>
<th>Challenges (table below)</th>
</tr>
</thead>
</table>
| Algorithm for image segmentation to detect plants versus background. | 70 %   | - Color-based segmentation, SVM and CNN based methods tested in development environment  
- integration of color segmentation and SVM  
- CNN-based segmentation not integrated, yet | SW1, SW2 |
| Integration of the algorithm for path computation             | 90 %   | - three algorithms have been tested with good results                | SW3                      |
| Navigation control                                           | 90 %   | Current navigation control (using rails) is stable.                  | SW4                      |
| The menu selection                                           | 80 %   | Menu selection is possible on the control panel and a mobile phone.  |                          |
| The rover should have a power on/off procedure that detects the available components and assures the safe start-up of the rover. | 70 %   | - We are finalizing detection of components  
- Separate power circuits activated by software upon initialisation status  
- Watchdog component still being                               |                          |
The rover should perform a power-up self-test to assure all components are functioning correctly. 30 %
- Detection of components and start-up sequence in place.
- Self-testing must be reinforced.

The software should detect software and hardware failures, notify the operator, try to recover, and if not continue gracefully into a degraded mode. 30 %
- Components: Error detection and gracefully going into degraded mode is implemented.
- System level: to be tested.
- Notification: insufficiently implemented.

The software should keep a detailed trace of its actions and state for debugging and remote maintenance. 70 %
- Detailed logs are stored
- Framework for dumping messages in place

The rover should be accessible remotely for maintenance. 100 %
Relying on service provided by Dataplicity

The software should be modular and maintainable with modules performing single, well-defined and documented tasks. 90 %
- Software developed and architecture stable
- Documentation in progress

Online code repository, project management and testing 100 %
- repository: https://github.com/romi/romi-rover-build-and-test
- project management: https://github.com/orgs/romi/projects/2
- online testing: https://travis-ci.org/github/romi/romi-rover-build-and-test

Unit testing 60 %
Finalizing unit tests and code coverage for base libraries

Integration testing 30 %
Framework in place. First scripts written.

The average progress of the list of specifications above 70 %

### Technical challenges

<table>
<thead>
<tr>
<th>ID</th>
<th>Challenge</th>
<th>Exposure</th>
<th>Mitigation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>L: Likelihood</td>
<td>I: Impact</td>
</tr>
</tbody>
</table>

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100% reliable plant segmentation may not be attainable. Define confidence levels to hierarchize the risk of potential errors and take decisions accordingly.

Reliable plant segmentation methods may require a high computation power with an impact of power consumption and price. Color-based segmentation and SVM-based methods

Path computation using adaptive methods may fail and cut across crop plants. It can be detected beforehand whether a path cuts across a plant. A fail-back strategy can be devised using an alternative method.

More complex navigation control (without rails) is required for effective use of rover

Validation

Current status: Feedback from farmers validated the need for the rover. Real world testing at a farm confirmed its efficiency in weeding.

Priorities: Make the rover available to farmers for a first round of alpha testing.

Related documents: D8.4 (User Studies), D7.3 (Field studies)

<table>
<thead>
<tr>
<th>Specifications</th>
<th>Status</th>
<th>Notes</th>
<th>Challenges</th>
</tr>
</thead>
<tbody>
<tr>
<td>Evaluate the need for weeding tools by farmers (min. 20 farmers and/or agri professionals)</td>
<td>100 %</td>
<td>Feedback from 20 organic farmers is clear: tools for weeding is number one on the wishlist. See also User Studies in Exploitation</td>
<td></td>
</tr>
<tr>
<td>Obtain feedback on the specifications from farmers (min. 20 farmers and/or agri professionals)</td>
<td>50 %</td>
<td>Feedback from 10 farmers (see User Studies)</td>
<td></td>
</tr>
<tr>
<td>Evaluate that the weeding strategy using the CNC is effective</td>
<td>100 %</td>
<td>Tests have been performed for two consecutive years.</td>
<td></td>
</tr>
<tr>
<td>Evaluate the efficiency of the plant segmentation and path computation algorithm</td>
<td>70 %</td>
<td>The evaluation scripts have been written and used. We are finalizing a database of test images to streamline the evaluation.</td>
<td></td>
</tr>
</tbody>
</table>
Evaluate the performance specifications (weeding speed, power consumption ...) 20 % Basic measurements have been taken to assure that we are on target. An in-depth study will follow.

Run tests in operational environment with 5 farmers outside the consortium (in addition to tests performed within the consortium with Chatelain maraichage and IAAC) 0 % A test campaign is scheduled for Summer 2021 and 2022

Average progress for the given specifications 57 %

### Documentation

**Current status:** We are making steady progress in completing the documentation (see below).

**Priorities:** Finalize developer docs, and put design files on-line.

<table>
<thead>
<tr>
<th>Specifications</th>
<th>Status</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>User Manual</td>
<td>60 %</td>
<td>See below. First draft has been written. It is waiting to be completed when the specifications and evaluation are finalized.</td>
</tr>
<tr>
<td>Developer documentation</td>
<td>40 %</td>
<td>See online <a href="https://github.com/romi/romi-rover-build-and-test">Documentation Project</a></td>
</tr>
<tr>
<td>Open Hardware Design Files</td>
<td>20 %</td>
<td>The files still have to be put online.</td>
</tr>
<tr>
<td>Average progress for the given specifications</td>
<td>55 %</td>
<td></td>
</tr>
</tbody>
</table>

### Communication & dissemination

**Current status:** We have targeted our dissemination efforts mostly towards professionals to obtain feedback. Up to this point we have kept a low-key profile for general communication to enable us to concentrate on the research of the prototype.

**Priorities:** Broaden our communication strategy and start online campaigns using small video tutorials.
### Specifications

<table>
<thead>
<tr>
<th>Specifications</th>
<th>Status</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scientific publications: journal or conference paper (1), conference talk (4), posters (4)</td>
<td>45 %</td>
<td>- journal or conference paper (0) - conference talk (2) - posters (2)</td>
</tr>
<tr>
<td>Demonstrations for farming community (5)</td>
<td>60 %</td>
<td>Three demonstrations so far</td>
</tr>
<tr>
<td>Workshop for farming community</td>
<td>0 %</td>
<td>Workshops are planned. We received EU funding through the CENTRINNO project to organize workshops.</td>
</tr>
<tr>
<td>Workshop for Maker/DIY/designer community</td>
<td>0 %</td>
<td>Workshops are planned. We received EU funding through the CENTRINNO project to organize workshops.</td>
</tr>
<tr>
<td>Online videos (2 teaser videos, 4 tutorials)</td>
<td>15 %</td>
<td>1/6 videos</td>
</tr>
<tr>
<td>Online campaign through social networks</td>
<td>40 %</td>
<td>Regular posts through Twitter and Facebook. This campaign will intensify in the end stages of the project.</td>
</tr>
</tbody>
</table>

### Exploitation

#### Details:
- Details of the **Romi Rover User Study** (survey of farmers and their expectations) can be found in D8.4.
- Details of the **Romi Rover Market Study** (study of the future users of the rover) can be found in D8.4.
- A study of relevant active companies which propose competing solutions can be found in D8.4.
- A study on current regulations to be applied can be found in D8.4.

#### Current status:
- Market study finalized for the rover. The results show that
  - Europe counts more than 52,000 small farms <5ha which produce fresh vegetables and which have a sufficient revenue to invest in the rover. This is our target market.
  - The five EU countries with the highest number of targeted farms are Italy, Spain, France, Greece, and Poland with a combined total of 40,000 farms.
- We created the Romi Organisation (a French association) with the objective to bring the ROMI
results to the market.

Priorities:
- Study the structure of the retail network for small farming equipment in the EU
- Seek advice on regulations.
- Structure the newly created organisation to prepare for exploitation.
- Seek additional financing.

<table>
<thead>
<tr>
<th>Specifications</th>
<th>Status</th>
<th>Notes</th>
<th>Challenges</th>
</tr>
</thead>
<tbody>
<tr>
<td>User studies.</td>
<td>80 %</td>
<td>See User Study document: interview with 22 French professionals (16 micro-farmers, 1 farmer, and 5 advisers working in support organisations)</td>
<td></td>
</tr>
<tr>
<td>Regulation:</td>
<td>60%</td>
<td>We started collecting information about the relevant standards and directives (see D8.4). The next step is to seek advice from experts. EX1</td>
<td></td>
</tr>
<tr>
<td>Market studies:</td>
<td>90 %</td>
<td>The market study to prepare the exploitation of the rover is achieved. It uses the Eurostat databases to accurately assess the market size and the profile of future users (see the D8.4). Only updates have to be realised until the end of the project</td>
<td></td>
</tr>
<tr>
<td>Legal entity: Create legal entity to continue the exploitation after the ROMI project</td>
<td>70 %</td>
<td>Entity created (an association), further work required to activate its activities and attract members</td>
<td></td>
</tr>
<tr>
<td>Distribution / Production: Seek advice and prepare first agreements</td>
<td>0 %</td>
<td>Build the network for the production of pieces necessary for the rover manufacturing Find the retailers in the most dynamic countries</td>
<td></td>
</tr>
<tr>
<td>Additional financing:</td>
<td>60 %</td>
<td>- Minor funding secured (EU CENTRINNO project). - One large EU H2020 project submitted. - One smaller EU H2020 project submitted - Studying the availability of regional funding</td>
<td></td>
</tr>
</tbody>
</table>
### Challenges

<table>
<thead>
<tr>
<th>ID</th>
<th>Challenge</th>
<th>Exposure</th>
<th>Mitigation</th>
</tr>
</thead>
</table>
| EX1 | Regulations are more difficult to implement than expected, or having a big impact on the software and hardware design. In addition, some relevant regulations are still work-in-progress. | L: High  
I: Medium | Making the rover conform to the relevant regulations is always possible. However, it may require more time and effort than planned and therefore push back the release date of the market-ready rover. Input from experts is needed. |
This manual describes the usage of a fully assembled and ready to use rover. In addition to usage instructions it contains information on planned future development.

The information on how to build your own rover can be found in a separate document. Visit the ROMI web site at https://docs.romi-project.eu for more information.

Short description

The ROMI Rover is a farming tool that assists vegetable farmers in maintaining vegetable beds free of weeds. It does this by regularly hoeing the surface of the soil and thus preventing small weeds from taking root. It can do this task mostly autonomously and requires only minor changes to the organization of the farm. It is designed for vegetable beds between 70 cm and 120 cm wide (not including the passage ways) and for crops up to 50 cm high. It currently handles two types of crops, lettuce and carrots. The lettuce can be planted out in any layout, most likely in a quincunx pattern. In this configuration the rover uses a precision rotary hoe to clean the soil both between the rows and the plants. For carrots, the rover uses classical mechanical tools, such as stirrup hoe, to regularly clean the soil in between the rows. In this configuration, the carrots should be sown in line.

A weekly passage of the robot should be sufficient to keep the population of weeds under control.

In addition to weeding, the rover provides the following useful functions: It can draw quincunx patterns or straight lines in empty vegetable beds to speed up seeding and planting out. The embedded camera can be used to collect images of the vegetable beds. It can also be used as a motorized tray.

The ROMI Rover is targeted at farms that grow small crops, such as lettuce and carrots, on a relatively small surface, between 200 m² and 5 ha (Utilized Agricultural Area).
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User Manual
Introduction

This section details the technical specifications, operating instructions and configuration of the current version of the Romi rover: V2.

Technical specifications

<table>
<thead>
<tr>
<th></th>
<th>1.2m x 1.00 m x 1.40 m</th>
</tr>
</thead>
<tbody>
<tr>
<td>Size (Width x Length x Height)</td>
<td>With tool carrier: add 1 m to length</td>
</tr>
<tr>
<td>Weight</td>
<td>80 kg (estimate)</td>
</tr>
<tr>
<td>Battery life</td>
<td>4 h (approx. dependent on use case)</td>
</tr>
<tr>
<td>Charging time</td>
<td>TODO</td>
</tr>
<tr>
<td>Weeding speed</td>
<td>Precision weeding: 235 m²/day</td>
</tr>
<tr>
<td></td>
<td>Classical weeding: 6400 m²/day</td>
</tr>
<tr>
<td>Width vegetable beds</td>
<td>0.80 m</td>
</tr>
<tr>
<td>Handled crops</td>
<td>Precision weeding: Lettuce</td>
</tr>
<tr>
<td></td>
<td>Classical weeding: Carrots</td>
</tr>
<tr>
<td>Turning space at end of bed</td>
<td>2.8 m (3.5 m with tool carrier)</td>
</tr>
</tbody>
</table>

Functional specifications and requirements

The following configuration is required for the use of the ROMI rover.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th>Price</th>
<th>Features/Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bed of vegetables</td>
<td>Width of the bed:</td>
<td></td>
<td>Width of the bed:</td>
</tr>
<tr>
<td></td>
<td>● 0.8 m</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Handled crops</td>
<td>1. Lettuce: The lettuce can be planted out in any layout, most likely in a quincunx pattern</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>2. Carrots: The carrots should be sown in line.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Item</td>
<td>Price Range</td>
<td>Description</td>
<td></td>
</tr>
<tr>
<td>----------------------------------------------------------------------</td>
<td>-------------</td>
<td>-----------------------------------------------------------------------------</td>
<td></td>
</tr>
</tbody>
</table>
| ROMI rover with a remote control, a battery charger, and a protective cover | 5000 € (estimate) | - The selling price includes:  
  - The rover  
  - Maintenance support for the first year (30 €/month after the first year of use)  
  - Prevents weed development  
  - Draw patterns for seeding and planting out  
  - Takes image scans of the beds |
| Tool carrier                                                        | 1000 € (estimate) | Used with the rover to carry the mechanical weeding tools (optional but needed in most configurations) |
| Mechanical weeding tools (from Terrateck or other manufacturers)    | 400-1000€ (estimate) | The weeding tools that will be fixed to the tool carrier. Sold by other manufacturers, for example, by Terrateck (catalogue) |
| TOTAL cost of an equipped rover                                     | 6400 – 7000 € |  |
| Guides                                                              | Photo       | Stainless steel tubes (45x1.5): 3 €/m  
  Tuyau irrigation PE HD 50mm : 4.4 €/m  
  The guides consist of either stainless metal tubes (preferred) or wooden boards. They facilitate the navigation of the rover along the bed so that it can operate accurately and reliably. |
| A mobile phone                                                      | Existing phone: 0€  
  Dedicated phone: 200 € | • Used to control the rover  
  • To browse the archived images of the online service |
### WiFi

<table>
<thead>
<tr>
<th>WiFi</th>
<th>Rover as hotspot: 0 €/month</th>
<th>WiFi connectivity in the field</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Existing WiFi: 0 €/month</td>
<td>To connect the mobile phone to the rover (required)</td>
</tr>
<tr>
<td></td>
<td>GSM WiFi router: 120€ (router) + 10 €/month (SIM card)</td>
<td>To archive the images taken by the rover (optional)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>To provide remote assistance (optional)</td>
</tr>
</tbody>
</table>

### Operation instructions

#### Overview of the components

![Diagram of the Rover](image)

*Figure 1: The main components of the rover.*
Overview of the rover’s usage

The basic usage of the rover is to position it on a vegetable bed and let the machine clean the top-soil with a rotating precision hoe. The rover must be taken to the field using the remote control or by simply pushing it. The robot currently expects the vegetables to be grown in “beds” of 0.8 m wide (though it is planned that V3 of the rover will feature an adjustable width). The robot is designed for smaller market farms of less than 5 ha but the size of the farm depends on the number of rovers that you will use, and the amount of crop you want to cover. To assist the rover in navigating along a bed, it is necessary to install rails (tubes or wooden boards) along the bed. Without the rails, the risk exists that the rover deviates from its course and drives into the vegetable bed. An ongoing issue with autonomous farming machinery is the possibility of the vehicle slipping due to the type of terrain inherent in farming under different weather conditions. The use of rails mitigates this issue.

Once the rover is positioned along the rails in the beginning of a bed, it hoes the surface of the soil so that small weeds cannot take root. It can perform this action along the entire length of the bed. Note that the rover cannot remove mature weeds that have already established themselves. It is therefore necessary to start with a vegetable bed that has been cleaned from all weeds. This can be done with various classical techniques to prepare the vegetable beds. Once the beds are clean, the rover can be used to maintain them as such.

Two weeding methods are available. First, a precision weeding method in which the top-soil is turned over in between the plants and the rows. Second, a classical weeding method in which standard weeding tools are dragged behind the rover between rows of vegetables.

For the precision weeding method, the rover uses a camera to detect the plants that are underneath the rover. It then moves the precision weeding tool over the surface whilst passing closely around the detected vegetables.

Although the rover is autonomous for weeding a single bed, it is important to stay in proximity to the rover. A U-turn must also be manually performed at the end of the bed and the rover repositioned in line with the rails of the next bed.
Setting up the vegetable beds

The use of the rover requires relatively flat beds. Precision weeding works best if the surface of the culture beds is flat. Ideally, the alleys between the beds should also be flat, to facilitate navigation of the rover. The precision weeding tool can mechanically adjust in height for small deviations in soil level but there is less risk that the tool will detach from the soil or that it will dig into the soil when care has been taken to level the surface. There is no precise measure of how flat the beds should be but small holes in the ground should be avoided. The presence of stones should also be avoided. Small stones (approx. 1 cm) should not perturb the rover very much.

NOTE: The width of the vegetable beds should be constant so that the width of the rover remains the same for all the beds.

Laying out the rails

The rails guide the wheels and allow the rover to navigate extremely accurately. It greatly increases the reliability of the navigation and the precision of the rover. We recommend the use of stainless-steel tubes with a diameter of approximatively 5 cm and thickness of 1.5 mm.

There are two options to lay out the tubes¹.

A rail on both sides of the bed: The most intuitive organisation is to place a tube on each side of the bed. The tubes should be positioned on the edge of the bed, one on each side, along the length of the bed. A bed of 10 m long will require 20 m of tubes. Care should be taken to assure that the tubes are parallel. There is no recommended method for fixing the rails in the soil so they remain in place. A simple solution is to drill a hole in the end of the tube and fix the tube in the soil using reinforcing bars such as rebar.

¹ We are testing a third option that uses only one rail for two beds.

Figure 2: Left: The rover with two tube rails on each side of the bed. Right: Two stainless steel tubes fixed to the ground with a “staple” of reinforcement steel wire
Two rails every two beds: The second layout comprises two rails between every second bed. The rails are laid in parallel centrally between two beds. The spacing between the two tubes must be such that they fit the width of the front and rear wheel. In effect, the tubes squeeze the two wheels of one lateral side of the rover. The two wheels on the other side of the rover run freely. The tubes should be centred in the middle of the alley such that one pair can be used for two beds, on either side of the rails. Two beds of 10 m long (20 m total) will require 20 m of tubes, or half as much as when using rails on both sides of the bed.

Figure 3: Left: The rover with a stainless tube on each side of the wheel. Right: An example of the two rails lay-outs.
An alternative option is to use wooden boards instead of steel tubes, although this solution is more prone to issues as the wheels tend to get stuck when they slide against the angular edge of the board. The boards can be stuck partially in the ground with about 5 cm sticking out to guide the wheels.

The use of plastic tubes, for example PVC or polyethylene irrigation tubes, can also be considered.

Maximizing the use of rails

To reduce the number of rails to be purchased, it is possible to buy 1/5th of the total amount and move the rails every day. For a bed of 40 meters long, it takes about 7 minutes to lay out the rails.

Setting up the Wi-Fi access point

The use of a Wi-Fi access point is optional but strongly recommended. The rover must be connected to a Wi-Fi access point with Internet access for the following functionality:

- To automatically upload the images taken by the rover to the Farmer’s Dashboard web application.
- For remote maintenance.

Both features are optional and can be left out when the rover is used for weeding only.

However, if you decide to use an access point, it is important that the Wi-Fi signal is strong enough in all the zones where the rover will be used. If not, it may be impossible to connect to the rover’s web interface with a phone or tablet to the rover to send instructions to the rover. It will still be possible to send instructions to the rover using the control panel (see “Controlling the rover through the control panel”).

The set-up of the Wi-Fi network is not part of the Romi Rover package. In case of doubt, you should seek advice from a professional about the best solution for your premises. However, below, we briefly discuss several options.

Using an existing Wi-Fi router: If the zone where you wish to use the rover is adjacent to existing infrastructure (home, barn) and you have the possibility to install an Internet connection at the premises (ADSL modem over a phone line or any other solution), the Wi-Fi capabilities of the modem can be used to offer Internet access to the rover.

Expand the reach of an existing Wi-Fi network: An existing Wi-Fi can be extended to increase its reach using Wi-Fi range extenders. They pick up and retransmit an existing Wi-Fi signal. Most extenders require a standard power supply although some can be powered using an USB battery. Using an Ethernet cable of up to 100 meters long, it is possible to position a secondary access point. Some of the Wi-Fi access points can be powered directly over the Ethernet cable.
(PoE, Power over Ethernet) removing the need for a power socket. It is also possible to send the network signal over existing electricity cables using a technology called power-line communication (PLC). Finally, there exist also long-range wireless outdoor WiFi extenders that transmit the network between two antennas designed for transmission over distances from a 100 meters to over a kilometer.

Install a GSM Wi-Fi router: If there is a good mobile phone signal strength in the field, a GSM Wi-Fi router is a viable option. A GSM Wi-Fi router connects to the Internet over mobile data link (GPRS, EDGE, 3G, HSDPA, 4G, ...) and provides access to other devices over Wi-Fi. Separate routers with good antennas can be purchased at reasonable prices but generally require a power plug. Smaller, USB-powered routers are available also and can be plugged directly into a USB port inside the rover. A mobile phone configured as a hotspot is an alternative solution (although with a smaller range than a dedicated router with good antennas). The downside of this option is that it requires a SIM card and a subscription with a mobile network operator.

Using a USB GSM modem: In contrast to the solution above, a USB GSM modem is not a stand-alone router but, when plugged in, the Raspberry Pi will see the modem as an additional network interface. The rover remains the hotspot for the Wi-Fi network and will route any Internet traffic through the GSM data connection. This solution may require additional changes to the network configuration of the Raspberry Pi.

Charging the rover

The rover uses two 12 V Lithium batteries (the internal working voltage is 24 V). Use the supplied Victron Energy Blue Smart IP67 24V 5A Charger to reload the batteries. Plug 230 V side of the charger in a regular power plug. The 24 V side must be plugged into the POWER CHARGER plug on the battery box. The charger has LED indicators to show the status of the charging cycle. It is also possible to follow the status using a mobile phone using a Bluetooth connection. Check the official manual provided by Victron Energy charger for details.

Protection cover

The rover comes with a PVC protection cover. The cover must always be placed on the rover when the precision weeding is used. If the precision weeding is not used, it can be removed if there is no risk of the CNC becoming wet. The CNC, on its own, is not waterproof. If the CNC is removed, it is possible to use the rover without cover in light rain conditions (TODO: IP level?...)

Attendance (TODO: regulations?)

IMPORTANT: The rover must be used only in the presence of an operator (TODO). The operator must be within a distance of XXX meters of the rover and must be able to reach the rover quickly in case of an emergency (TODO). The operator should carry the remote control with them at all times whilst the rover is on. This is in order to be able to recover the navigation control of the rover in all circumstances (TODO: add emergency button on the remote control?). The rover should not be used in proximity to people who have not been instructed to use the
rover (TODO).

IMPORTANT: The rover must be used only during the day in good light conditions.

Storage

The rover should be kept in a covered and dry space when not in use.

Emergency button

The emergency button on the back of the rover can be used to cut the power to the motors and CNC at any time. To cut the power, push the red button. To power up the motors, the button must be reactivated. This can be done by pulling the button out again.

CAUTION: Before reactivating the button, make sure that the CNC and wheel motors are not moving (TODO: how?...)

Engaging/disengaging the motor lock levers (freewheeling mode and drive mode)

The two wheel motors each have a lock lever that allows them to switch between freewheeling mode or motor drive mode. When the lock lever is in the horizontal position the wheels are freewheeling. In freewheeling mode, the robot can be moved simply by pushing it. Turn the lever 90° into the vertical position to switch the drive mode. In the drive mode, the wheels are powered by the motors and to move the rover you must use the remote control or the command interface.

CAUTION: Only switch to the drive mode when the rover is “off” to assure that the motors are powered off. (TODO: is there no simpler way to power off the motors without shutting down the rover?)

The control panel

The control panel provides a means to turn the rover on or off, to view status messages, and...
request the rover to perform a preconfigured action.

![Image of the control panel]

Figure 6: The control panel

It has a display and five buttons, including the On/Off button. Please skip to the section “Controlling the rover through the control panel” for more information on how to use the control panel.

Control panel state message

The display of the control panel is divided in two lines. The upper line shows current status of the rover:

<table>
<thead>
<tr>
<th>State display (1st line)</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>..</td>
<td>The control panel has been powered up and is initializing.</td>
</tr>
<tr>
<td>Off</td>
<td>The on-board computer is powered down and the motors are off.</td>
</tr>
<tr>
<td>Starting up</td>
<td>The on-board computer is starting up. The power to the motors is cut.</td>
</tr>
<tr>
<td>On</td>
<td>The rover is ready for use. The on-board computer is running and the motors can be powered up.</td>
</tr>
<tr>
<td>Shutting down</td>
<td>The power to the motors has been cut and the on-board computer is shutting down.</td>
</tr>
<tr>
<td>Error</td>
<td>The rover is in an error state.</td>
</tr>
</tbody>
</table>

Start-up procedure

Before starting up, the rover should be in the following state:

1. Verify that the emergency button is deactivated (pushed in).
2. Verify that the rover is off (the control panel display shows “Off”). If not, see “XXX”.
3. Verify that the lock levers on the motor are disengaged to put the motors into freewheeling mode.

The start-up can now proceed:

4. Engage the lock levers on the motor to put the motors into drive mode.
5. Activate the security button by pulling it out.

6. Turn the rover on by holding the on/off button pressed for 5 seconds (see Fig. 1). At that point, the rover begins the start-up sequence and the display says “Starting up”. When the start-up is completed, the display will show “On”.

7. The motors of the wheels and the CNC are now powered up. The start-up is now finished. You can either do the following:

   8. If it is the first usage of the rover, you should go to the section “First time configuration”.

   9. You can use the remote control to move the rover (see “Remote control mode and software control mode”), or

   10. Use the control interface to send commands to the rover (see “Controlling the rover through the control panel”).

**Shut-down procedure**

To turn off the rover, press the On/Off button for 5 seconds. The display will briefly display the message “Shutting down”, followed by the message “Off”.

**Switching from drive to freewheeling mode**

When the rover is in drive mode (motors powered on, the lock levers on the motor engaged/vertical), it is possible to go to freewheeling mode as follows:

   1. Turn off the power of the motors by pressing the red emergency button.
   2. Turn the motor lock levers in the horizontal position (disengaged).

Once these steps are completed, you can move the rover by pushing it.

**Switching from freewheeling to drive mode**

To switch from freewheeling to drive mode, the rover’s state should be "On", the user may then perform the following operations:

   1. Ensure that the motors are not moving by sending a STOP command.
   2. Turn the motor lock levers in the vertical position (engaged).
   3. Pull the red security button to power the motors.

**Connecting a phone, tablet, or computer to the rover**

Adapt the Wi-Fi settings of the device such that it connects to the same Wi-Fi network as the rover. The interface of the rover is accessible through a web browser. On the mobile device,
open up your preferred web browser (see “Supported web browsers”) and in the address field enter the following URL: https://romi-rover.local.

To facilitate the access to the interface, you can add the address to your bookmarks.

**Moving the rover to the field**

The rover can be moved to the field either by simply pushing it with the motors in the freewheeling mode or by using the remote control to steer the rover.

CAUTION: When you use the remote controller, you must stay close to the rover (less than 3m away?). TODO: regulations? But don’t stay too close?

**Positioning the rover on a vegetable bed**

Manually push the rover onto the beginning of the vegetable bed. Make sure that the front wheels (caster wheels) and the rear wheels slide nicely along the rails of the bed.

**Remote control mode and software control mode**

The navigation of the rover can be controlled either by the remote control or by the rover’s software.

TODO: Must add an indicator to know what mode the rover is in.

TODO: How do we switch from one to another mode?

**Emergency control recovery with the remote control**

When the rover is in software control mode it is possible at any time to switch back to remote control mode by pushing the speed or direction controller to the maximum position. The rover will stop and remain immobilized for 3 seconds before listening to the commands of the remote control again.

**Using the remote control**

The rover comes with the Spektrum STX3 remote controller (RC).
The RC’s steering wheel lets you define the direction in which the rover moves. The trigger lets you set the speed, both backward and forward.

Please check the Spektrum STX3 official user manual for detailed information on its use.

The RC is powered by 4 AA batteries.

**Change the weeding tool head**

**Controlling the rover through the control panel**

You can send commands to the rover using the control panel as follows.

**MAIN SCREEN**

The rover must be in the On state. Then press the MENU button.

**MENU SCREEN**

The name of the first task will appear on the bottom line of the display. Use the UP and DOWN buttons to navigate in the list of possible tasks. To cancel and return to the main screen, press MENU.

To start the task, press the SELECT button. To return to the menu screen, press MENU.
CONFIRM SCREEN
Press the SEL button a second time to confirm the action, or press MENU to cancel the start of the action and return to the menu screen.

PROGRESS SCREEN
If the action is confirmed, the display will show the progress status. When the task is finished, the display will return to the main screen.

**Controlling the rover through the web interface**

The web interface is a convenient way to send commands to the rover. The interface consists of large buttons to facilitate its use on a mobile phone in the field. The buttons and associated actions are programmable (see “Editing the rover scripts”). By default, a couple of generic buttons are provided (see Fig. 3). When you press a button, a confirmation will be asked, this is to avoid launching an action inadvertently. Upon confirmation, a progress screen will be shown with information on the advancement of the action.

![Figure 8: The web interface. Left: The main screen. Centre: The confirmation screen. Right: The progress screen.](image)

The list of buttons and associated actions can be programmed. This is useful to adapt them to your needs. See “Editing the rover buttons and actions” for more information.

**Using the tool carrier**

The tool carrier can pull classical weeding tools along the soil. It is best adapted for cultivars that are grown in dense lines, such as carrots. The weeding tools are not part of the Romi Rover package and must be purchased separately.

The tool carrier must be attached to the main frame of the rover using the clamps that are welded on the carrier. Attach the power cable to the frame using the available clamps and plug it into the TOOL.
CARRIER socket on the control box of the rover.

The tools must be fixed to one of the horizontal bars of the tool carrier using the dedicated clamps.

**The USB memory stick**

The on-board computer stores all editable and generated data on a USB memory stick. When the rover is turned off, it is possible to remove the stick in the electronics box of the rover and connect it to another computer. This should normally not be necessary but can be convenient to make a backup of the recorded data or to edit the configuration files manually.

The default organisation looks as follows.

```
bin/
config/
  +- config.json
  +- scripts.json
  +- wifi.json (TODO)
database/
lib/
sessions/
  +- 2020-08-15_08-47-51/
    +- logs/
    +- dumps/
  +- 2020-08-16_08-53-03/
    +- logs/
    +- dumps/
```

The config directory contains several configuration files including:

<table>
<thead>
<tr>
<th>Filename</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>config.json</td>
<td>The main configuration file of the rover. It is not advised to change this file.</td>
</tr>
<tr>
<td>scripts.json</td>
<td>This file defines the list of buttons and their associated actions that are shown on the user interface (web interface and control panel).</td>
</tr>
<tr>
<td>wifi.json</td>
<td>The wifi set-up of the rover. (TODO)</td>
</tr>
</tbody>
</table>

The database directory contains the images and analyses generated either by the weeding tasks or by the camera recorder. Do not make any changes to this directory or its contents.

The sessions directory contains the log and dump files that are used for the rover’s maintenance. Do not make any changes to this directory or its contents.

**Manually editing the configuration**

In some cases, it may be necessary or more convenient to edit the rover’s configuration file directly instead of using the web interface (see “The configuration page of the rover”). In that
case, you can remove the USB memory stick as discussed above and edit it on a personal
computer using a plain text editor (on Windows: Notepad, on MacOS: TextEdit).

**Editing the rover buttons and actions**

Turn off the rover and open the box with the electronic components to recover the USB stick
(see “The USB memory stick”). Open the file `config/scripts.json` on the memory stick
using a plain text editor (On Windows, use Notepad, for example).

The file uses the JSON format to describe the list of scripts and the associated sequences of
actions. The general structure is as follows:

```json
[
  {
    "name": "move-forward",
    "display_name": "Forward",
    "script": [ {
      "action": "move", "distance": 0.60 }
    ]
  },
  {
    "name": "move-backward",
    "display_name": "Backward",
    "script": [ {
      "action": "move", "distance": -0.60 }
    ]
  },
  {
    "name": "scan",
    "display_name": "Scan",
    "script": [ {
      "action": "start_recording" },
      { "action": "move", "distance": 3.6 },
      { "action": "stop_recording" }
    ]
  }
]
```

The file contains a list of scripts. Each script has a **name** that is used to identify the script, a
**display_name** that is shown in the user interface, and a **script** field that consists of a list
of actions. The list of available actions and their parameters is out of the scope of this manual.
Please refer to the online documentation at [https://docs.romi-project.eu/Rover/configuration/](https://docs.romi-project.eu/Rover/configuration/) for
details.

If you make modifications to the file, it is very important that the new content is a valid JSON
file. If not, the rover will fail to load the file and no buttons will be shown in the user interface.
Supported web browsers

The interface of the rover should be viewable in any modern, compliant HTML5-compliant web browser with support for ECMAScript 5 (Javascript), XMLHttpRequests, and WebSockets. The following versions and more recent versions of commonly used browsers should work with the rover (TODO: verify!):

<table>
<thead>
<tr>
<th>Browser name</th>
<th>Version</th>
<th>Release date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chrome</td>
<td>23</td>
<td>Sep 2012</td>
</tr>
<tr>
<td>Firefox</td>
<td>21</td>
<td>Apr 2013</td>
</tr>
<tr>
<td>IE / Edge</td>
<td>10</td>
<td>Sep 2012</td>
</tr>
<tr>
<td>iOS</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>Safari</td>
<td>6</td>
<td>Jul 2012</td>
</tr>
<tr>
<td>Opera</td>
<td>15</td>
<td>Jul 2013</td>
</tr>
</tbody>
</table>

The Farmer’s Dashboard web site that is used to browse archived images has its own requirements that are documented on the Farmer’s Dashboard web site.

Installing a new SD card

The rover uses a Raspberry Pi as its main computer. The control software of the rover is installed on an SD card that sits in the card slot of the Raspberry Pi 4. You can replace the SD card with a new one. For details, please refer to the developer documentation at https://docs.romi-project.eu.
Future Development

Whilst the Romi rover project is a research based project, it is not purely academic. As the rover is prototyped and developed, feedback from farmers in real world usage scenarios is taken and applied to further development of the project. Thus the project uses iterative development in a continual feedback cycle to change and improve the rover as it is developed and tested by users.

Using this kind of practical iterative approach necessitates a degree in flexibility in both planning and design.

This section details design changes and improvements in both hardware and software currently scoped for the next iteration of the rover: V3. Specific changes from the existing rover are highlighted using V2 and V3 indicators. Some of the new developments have already started at the time of writing (October 2020). For example,

It should be noted that whilst these improvements are currently scoped, they may change in future should feedback or design choices necessitate a change.

Hardware & Specification changes V3

<table>
<thead>
<tr>
<th>Technical specifications</th>
<th>V3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Size (Width x Length x Height)</td>
<td>Min.: 1.45 m x 1.60 m x 1.46 m</td>
</tr>
<tr>
<td></td>
<td>Max.: 1.70 m x 1.60 m x 1.46 m</td>
</tr>
<tr>
<td></td>
<td>With tool carrier: add 1 m to length</td>
</tr>
<tr>
<td>Weight</td>
<td>80 kg (estimate)</td>
</tr>
<tr>
<td>Battery life target</td>
<td>8 h with enhanced optimisation (4h V2)</td>
</tr>
<tr>
<td>Charging time</td>
<td>TODO</td>
</tr>
<tr>
<td>Weeding speed</td>
<td>Precision weeding: 600 m²/day (235 m²/day V2)</td>
</tr>
<tr>
<td></td>
<td>Classical weeding: 7200 m²/day (6400 m²/day V2)</td>
</tr>
<tr>
<td>Variable width vegetable beds</td>
<td>Min.: 0.70 m - Max.: 1.2 m (0.8 m fixed V2)</td>
</tr>
<tr>
<td>Handled crops</td>
<td>Precision weeding: Lettuce</td>
</tr>
<tr>
<td></td>
<td>Classical weeding: Carrots</td>
</tr>
<tr>
<td>Turning space at end of bed</td>
<td>2.8 m (3.5 m with tool carrier)</td>
</tr>
</tbody>
</table>
Configuration and costs

The configuration of hardware is largely the same for V3 however the addition of the online service will incur an additional monthly cost should this service be required.

<table>
<thead>
<tr>
<th>Romi Online Service</th>
<th>1 €/month</th>
<th>Monthly fee for the use of the Romi remote server (optional):</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>● To archive and browse the images taken by the rover</td>
</tr>
<tr>
<td></td>
<td></td>
<td>● To receive remote assistance</td>
</tr>
</tbody>
</table>

Overview of components

Figure (V3) 1: The main components of the rover.

TODO: Motor lock lever, Carrier tool, Carrier tool clamp, Control panel, Protection cover, Top camera, Recharging plug, Motor sockets (power & data), CNC socket (power & data), Tool carrier socket (power & data), Components inside the electronics box.

Main differences with V2: welded stainless steel frame instead of aluminium profiles, frame with adjustable width and height, more powerful motors, larger wheels, and easily detachable CNC.
Disassembling and reassembling the rover

Rationale: Feedback that has been echoed a number of times is that it would be useful to be able to disassemble and reassemble the rover for transport or storage purposes. To this end V3 of the rover has been designed such that it can be disassembled into its main components.

Since the mechanical design of V3 has been finalised and the prototype is currently being manufactured, the following is an outline of how the rover may be disassembled.

CAUTION: Disassembly should be undertaken by a minimum of two people.

CAUTION: Unplugging the power cables whilst the rover is powered on may cause sparks and may damage the rover’s control circuits.

1. Ensure that the rover is powered off.
2. Remove the protective cover.
3. Unplug all the cables from both the electronics and battery housings.
4. Untighten the screws of the arcs and of the top bar and remove them.
5. Remove the pins that fix the CNC to the main frame and remove the CNC.
6. Untighten the U-brackets of the wheel modules and remove them.

Following the steps above, the main components are now separated: two wheel modules, the main frame, the CNC, the top bars, the arcs, and the protective cover.

Adjusting the width of the rover

Rationale: Based on design requirement changes and feedback, Version 3 of the rover introduces the concept of variable width and height adjustments. This enables the rover to be used in more varied scenarios and thus makes it more attractive to a wider market.

Status: Frame is being built as we write this.

The wheel-base of the rover can be adjusted to fit the variable width of the rails and beds.

To adjust the width of the rover, loosen the four U-brackets that fix the wheel modules to the main frame and slide the wheel modules to the desired position (see Figure V3 1). Ensure that the position of the modules is symmetric relative to the main frame.

After a change to the width of the wheel-base, the CNC will need to be recalibrated (see “Calibrating the CNC”)

Adjusting the height of the rover

Further, taking into account usage scenarios that have become obvious during the development and use of V2, and additional user feedback, V3 of the rover features height adjustment.
Software changes

Since developing V2 of the rover, and introducing it to its target audience, it has become clear that improvements can be made to the onboard software in order to increase operating or configuration simplicity. This section details software improvements that are currently slated to be implemented for V3 of the rover.

Verifying the Wi-Fi connection

Rationale: Feedback on the current connectivity state of the rover is currently limited, therefore it was decided that to improve usability the connectivity status should be displayed.

Status: Planned for Spring 2021

If the Wi-Fi fails to connect, the control panel will display “No network” (TODO). The user should verify the network name and password as detailed in the software configuration section above.

This status message does not necessarily indicate a problem and can be ignored if this happens occasionally, for example, when the rover is far away from the access point. As soon as the rover is in proximity of the access point, the connection will be re-established. If the message continues to appear when the rover is in proximity of the access point and after the rover has been restarted, the Wi-Fi configuration should be verified.

First time configuration

Rationale: We currently configure the rover over a developer connection. In order for the rover to be more user-friendly, a graphical web interface should be provided on a mobile phone instead.

Status: Planned for Spring 2021

To configure the robot, you need a mobile phone, tablet, or computer with Wi-Fi capabilities, a recent web browser (see “Supported web browsers”) and a screen of minimum 320x240 (TEST) pixels.

Connect your device to the “Romi” wireless network, using the password “rover”. Once you are connected, open a web browser and navigate to the page https://romirover.local.
The configuration page of the rover

![Configuration Page]

This page will be shown on the first connection to the rover’s web address, or when you select the “Configuration” button in the main page on subsequent access to the rover’s interface.

The configuration page enables a user to:

- Change the password of interface
- Change the name of the rover
- Change the WiFi settings
- Change the settings for the Farmer’s Dashboard.
- Run the CNC-to-Camera calibration (see below)

**Changing the password of the interface**

The first thing you should do is change the default password to something more secure but still easy to remember.

**Changing the rover’s name and address**

The name of the rover can remain unchanged unless you have several rovers. In that latter case, you should give each a distinct name in order to access the web interface of each. In the
configuration page you can enter the following two strings:

- Short name: A short string that satisfies the following constraints: minimum 5 characters and maximum 32 characters long, only letters (a-z, A-Z), digits (0-9), and the underscore character (_) are allowed. The name should start with a letter.
- Name: A free-form name of maximum 64 characters.

When the name of the rover is changed, the address of the web interface will change to https://NEWNAME.localhost. The value of NEWNAME must be replaced with the short name you have given to the rover. This change will be active after the rover has been turned off and then turned on again.

Using a Wi-Fi access point / Enabling Internet access

To change the Wi-Fi configuration, open the web page https://romirover.local (TODO: Raspian doesn’t have Avahi installed by default) (or its new location, see “Changing the rover’s name and address”). In the configuration page, check “Use access point” and enter the name of the Wi-Fi network (the SSID) and the password.

In case the rover fails to connect to the access point, the configuration will revert to the default configuration that initializes the rover as a local access point. (TODO: verify/configure with Raspian, similar to Ubuntu)

Calibrating the CNC-to-Camera mapping

Rationale: The calibration is still a bit of an ad-hoc operation in the current version that is difficult to perform. Software and hardware support should be provided to assist farmers.

Status: The calibration procedure has defined and tested. A low-level software implementation is available. Its integration in the web interface is planned for Spring 2021.

The weeding algorithm must be able to map the position of a pixel in the image to a XY coordinate of the CNC. The following steps are required to configure the camera mapping:

- Replace weeding tool with the pink ball tool.
- In the configuration page, press “Run CNC-to-Camera Calibration” (TODO).

Once the procedure is finished, the weeding tool can be placed back on the motor arm.

The calibration should be done before the first use of the rover. Normally, it should not be repeated afterwards. However, if the camera moved you will have to redo the calibration.

Remote maintenance

A feature added to V2 of the rover to aid development and diagnosis of problems has proven to be so useful that it has secured its inclusion in the V3 software feature list.

The ability to connect to the rover remotely is added by inclusion of the remote service provided
by Dataplicity. For a nominal fee of 3 euros per month the rover will automatically connect to the Dataplicity service, enabling remote viewing and configuration of the rover internals.

**Farmer’s Dashboard**

Status: A significant leap forward in terms of usability and marketability, the Farmer’s Dashboard is currently in development and in an experimental “Alpha” version. Integration planned for Summer 2021, when the new data model and web API developed in WP5 is stable.

The Farmer’s Dashboard is an online website that allows a farmer to view and analyse image scans of crops. The images collected by the rover can be uploaded to the Farmer’s Dashboard allowing them to be analysed and archived. The dashboard offers a means to browse archived images and historical data.

The Farmer’s Dashboard is a complementary service offered by the Romi Organisation. Since the software for the Farmer’s Dashboard is Free and Open Source Software, it is possible to install it locally on an existing system or to rely on a third party.

For more information, please visit the Farmer’s Dashboard information page at XXX.

**Automatically uploading the images to the Farmer’s Dashboard**

To automatically upload images to the dashboard the user must first create an account on the Farmer’s Dashboard web site.

Under the account settings, click the “API key” tab then enter the name of the web site and the API key in the configuration page of the rover (see “The configuration page of the rover”).

**Manually uploading the images to the Farmer’s Dashboard**

It is also possible to manually upload the images to the Farmer’s Dashboard web site.

First, turn off the rover. Then recover the USB memory stick of the on-board computer of the rover. Put the memory stick in a PC. Finally, follow the upload instructions on the Farmer’s Dashboard web site.

CAUTION: Make sure to put the USB memory stick back into the rover. If not, the rover may fail to function properly upon its next use.
This document details what the robot must be capable of.

Keywords to indicate requirement levels

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described by RFC 2119.

Functional specifications

Field

- The robot is designed for flat surfaces. It may be able to perform well on fields with small slopes.
- Field must be organized in parallel beds as follows:
  - The width of the beds MUST be constant and between 120 cm and 70 cm.
  - A passage of 30 cm MUST be left in between beds
  - A space of 2.8 m wide space MUST be left at the beginning and at the end of the beds so that the robot can turn.
- Guides MUST be placed along-side the beds to guide the rover. This guide can be a wooden board, a metal tube, a PVC tube... These guides must be securely fixed in the soil, using wooden battens or metal "staples". The space between the two guides must be equal to the space between the wheels. These guides aid the robot to navigate along the bed.
- The width of the robot MAY be adaptable (i.e. the wheels can be moved inwards or outwards to adapt to smaller or larger bed widths).
- Soil type & soil conditions: The soil MUST NOT contain too many stones, or large stones
Networking

- A WiFi connection MUST be available in the field. A WiFi connection can possibly be established using the 4G-to-WiFi router. Additional WiFi repeaters can be placed in the field.
- Rover accessible on the local network as romirover.local. Default login “romi”, password “romi-rover”.

Navigation

- The robot MUST be able to drive along the vegetable beds. It MAY use the guides that are placed along the bed to facilitate the navigation. Additional visual support (landmarks) may be placed in the farm to aid the navigation.
- The robot MAY be able to turn autonomously at the end of a bed and position itself at the beginning of the next bed.
- To move the rover to the field, it may be pushed. It MAY also be possible to steer it using a remote control or through a web interface.

Robustness (hardware)

- The robot MUST be waterproof
- The robot MUST be able to drive on various grounds from sand to mud
- The robot MUST be able to work reliably in temperatures ranging from -10 °C to 50 °C.
- The robot MUST be able to work in humid environments (greenhouses, rain...)

Farmer-Robot interface

- The robot MUST have waterproof, easy-to-press buttons and a visual return (small screen, lights, ...) to start all major programs of the robot or to change important configuration settings. These buttons and the screen/light must be usable in direct sunlight, under wet conditions (wet surface, wet hands) and while wearing gloves.
- The robot MUST have a web interface that can be displayed on mobile phones that shows detailed system information and through which less common programs can be activated.
- The robot MAY use visual markers that are positioned in the field to activate a program. For example, the farmer may position a visual tag at the beginning of a bed to indicate what weeding program to perform on the bed.
- It MUST be possible to shut down the robot using a switch on the robot, and using the web interface.
- The robot MUST have a battery indicator.

Tools

- The robot MUST be able to move a tool precisely between the plants and over the soil.
- Precision weeding: The robot MUST be able to move a mechanical weeding tool precisely between the plants. When the crops are planted in rows, the robot MUST be able to weed both inter-row (in between two rows) and intra-row (in between plants on the same row).

- The robot MUST be able to move a marking tool precisely over the soil. The marking tool allows to draw a furrow for seeding or draw a quincunx pattern on the soil for transplanting.

- Classical weeding: The robot MUST be able to drag a classical weeding tool such as a spring harrow. It must be able to lift the tool at the end of the bed in order to turn.

- The robot MUST be able to carry a tiller tool.

Data processing
- The robot MUST be able to detect the position of the crop.
- Using the position of the detected plants, the robot MUST be able to compute a path for the weeding tool around the plants.
- The robot MUST have a database system that stores images, metadata, logs and other useful information. This database MUST be accessible over the web-based interface. The robot MUST be able to transfer the data to another server over the internet. It MUST be possible by the farmer to activate/deactivate this transfer and to easily configure the address of the remote server. The transfer MUST use a known and open protocol.
- The robot MUST be able to record images of the bed and transfer the images to a database. It MUST add the following metadata:
  - The time at which the image was captured
  - Estimated position and orientation of the image
  - The camera and camera settings
  - It MAY add additional metadata.

Physical security
- The robot MUST have a safety button to turn it off.
- The robot MUST stop immediately and emit a visual or auditory signal when a software component malfunctions.
- The robot MUST be able to stop instantly when it touches something.

System integrity
- The software MUST recover from unforeseen situations and execution errors.
- The WiFi network MUST be secured.
- Joining network: connecting to network (WPA2? Certificates?)
- Data Encryption: encrypt data transfer between processes on the same machine? between processes on different machines? Encryption at the application layer or at the network layer?
- Authentication: local applications must authenticate? Remote nodes?

Software
- The software code MUST be available under a Free license
- The robot MUST have an easy and robust procedure to update the software.
- The robot MUST have an easy-to-use calibration procedure (automatic?)
  - To configure the navigation (encoders, motors...)
  - To set the dimensions of the CNC
  - To match coordinates of the camera image with the corresponding coordinates of the CNC/tool.
- The robot MUST have an easy-to-use procedure to test and verify the hardware and software components. The procedure MUST produce a human-readable diagnosis that can be used for problem solving.
- The rover system MUST be accessible over a remote connection to update the software, examine the log files, and, in general, provide assistance remotely.

Image processing pipeline
To facilitate the comparison between various algorithms for precision weeding, we propose that they export the following intermediate data (shown in yellow in the figure below):
1. The image taken by the camera
2. The binary, segmented image with white pixels for the crop and black pixels for the soil and weeds
3. A list of contours of the crop, either as a list of circles (center and radius) or a list of polygons
4. The path as a list of points that should be taken by the weeding tool
Other

- The robot can be recharged using a standard power plug. An external adaptor may be used.

Units

The interface, the configuration files, and the communication between software/hardware modules MUST use the International System of Units (SI). In particular, lengths and distances MUST be measured in meters and time in seconds. Angles MUST be measured in radians.

Data visualisation tools and user interfaces MAY show values in alternative units in between parenthesis along-side the values in SI units.

Performance requirements

- The weeding robot should be able to work 8 h/day.
- The precision weeding should be able to cover 5000 m²/week
- The classical, mechanical weeding should be able to cover 5 ha/week
- The weeding robot should be transportable.
- The weeding robot should not weigh more than X kg (80 kg?)
- The weeding robot should be able to work on

Sale requirement

- The robot MUST cost less than X euros
- The total cost of ownership MUST be less than XXX (WiFi, rails...)
- The robot should be easy to assemble : done by 2 persons in X hours
- The robot should be available as a kit and already assembled, ready to use
# Measurable goals

| Weight | < 100 kg for 1.2 m bed size  
|        | < 80 kg for 0.8 m bed size  
|        | < 25 kg for small robot for rooftop farms |
| Price  | < 4000 € for robot in kit  
|        | < 6000 € for assembled robot |
| Navigation | Maximum speed  
|          | Speed along bed  
|         | 5 km/h = 1.4 m/s  
|         | 1 m/s |
| Precision weeding | Surface hoed per day  
|                  | Battery autonomy  
|                  | Weeds suppressed  
|                  | Crops unrooted  
|                  | Maximum deviation at path junctions  
|                  | Precision positioning  
|                  | Farm of 5000 m²/week = 3000 m² beds/week = 600 m²/day = 1.25 m²/minute = 2 workspaces/minute = 25s weeding + 3s displacement + 2s processing = 0.6 m/s tool + 0.16 m/s rover (*)  
|                  | 10 h  
|                  | 90 %  
|                  | < 3%  
|                  | 10 mm  
|                  | 1 mm |
| Classical weeding | Speed  
|                  | Battery autonomy  
|                  | 0.5 m/s (1.8 km/h) = 1440 m²/h (beds of 0.8 m)  
|                  | 5h (7200 m²/day, 3.6 ha/week) |

(*) | 1 week = 5 days, 1 day = 8h, beds are 0.8 m wide and have a 0.4 m passage between them, a workspace measures 0.8 m x 0.8 m, maximum length path (5cm tool): 16 x 0.8 m + 2 x 0.8 m = 14.4 m
Romi Rover
Cost analysis

In the following analysis, we look at the cost/benefits for investing in a Romi Rover. The costs are compared to examples of expenses and workload in existing configurations in organic farms.

It is worth noting that in many countries, there is public financial support for farmers who want to invest in robotics. For instance, in France, several local organisations give funding for the purchase of agricultural robots. We can quote the departmental council of Yvelines or the MSA insurances (https://ssa.msa.fr/) that propose financial support corresponding to 50% of the equipment price (with a maximum of 3 k€ of funding). However, this support is not taken into account here.

This analysis only considers the financial aspects. Other factors such as the reduction of physical labor or the attractiveness of the tasks (difficulties to appeal to workforce) must be considered in the final evaluation.

We will continue to update this analysis, in particular, by seeking additional feedback from our network of organic market farmers.

NB: In the analysis below, the cost of the guides corresponds to the market price for small volumes. Our goal in the future is to negotiate directly with the providers to obtain more advantageous prices and reduce these costs, which today still represent a significant investment.

Growing lettuces on 5000 m²

- Field size 100 m x 50 m, 64 beds of 44 meters (beds of 1.1 m wide, pathway of 0.40 m between beds, 3 m space at each end of the row): 3320 m² cultivated.
- Outdoor field
- Length of season: 6 months (planting out in mid-April, last harvest mid-October), number of working days: 6 x 20 days = 120 days
- Sales of 45 000 lettuces (see this document, p. 10) at an average price of 0.50 € (see this analysis): Turnover of 22 500 €
Cost analysis, without ROMI Rover, using plastic soil cover (reference):
- Total revenues per year: 22.5 k€, total costs 13.6 k€, gross income 8.9 k€.
- Total number of work hours: 347 h (695 h/ha, this equals 8.5 weeks at 40 h/week)
- Time spent on weeding-related activities: 22 h: installing ground cover: 7 h, weeding: 15 h => Cost labour: 22 h at 12.5 €/h = 275 € every year
- Cost material: ground cover: 600 € every year (not reusable next season)
- TOTAL cost related to weeding: 875 €/year

Cost analysis, without ROMI Rover, manual weeding (reference):
- Total revenues per year: 22.5 k€, total costs 14.12 k€, gross income 8.38 k€.
- Time spent on weeding-related activities: it is estimated that 25% is spent on manual weeding (using 347-11 h as a reference time without weeding): (0.25 x 326 h) / 0.75 = 108 h
- Cost labour: 108 h at 12.5 €/h = 1358 €
- TOTAL cost related to weeding: 1358 €/year

Cost analysis, with ROMI Rover:
- Total revenues per year: 22.5 k€, total costs 15.32 k€, gross income 7.18 k€.
- Cost rover: 5000 € - one time
- Guides: 4224 € one time (1408 m, rails on whole field, 1 rail for two beds, reusable next season)
- Cost material (depreciation over 5 years): rover: 1000 €/year, guides: 845 €/year
- Cost labour: turning rover: 30 minutes per day x 120 days (season of 6 months): 60 hours: 750 €/year
- TOTAL cost related to weeding: **2595 € during the first 5 years, 750 €/year the following years**

Conclusion:
- For lettuce production, the use of the ROMI rover is profitable only after 5 years of use, before it represents a slight investment compared to the use of plastic soil cover. The cost of plastic cover is so low that this method of weed suppression will be hard to beat by any means.
- The advantage of the ROMI rover relies rather on its environmental benefits: it enables to save plastics and thus to eliminate a significant pollution source (In France, 30 000 ha use plastic soil cover (reference)).
- The rover will be attractive at first for small farms that perform manual weeding and that do not require many rails. For larger farms, we will have to investigate alternative solutions to the use of rails, including autonomous navigation. We must evaluate available Open Source solutions, including ArduPilot Rover. The additional hardware cost might be less than 1000 €.
- Lettuces have a relatively fast growth cycle and are not the most sensitive crop with regards to competition from weeds. The rover will be more advantageous for sensitive crops, such as spinach, persil, chive, or lamb’s lettuce (“mâche”), when compared to manual weeding.
- We should not forget it remains difficult to hire workforce for weeding tasks.
Growing carrots on 5000 m²

- Field size 100 m x 50 m, 64 beds of 44 meters (beds of 1.1 m wide, pathway of 0.40 m between beds, 3 m space at each end of the row), 3320 m² cultivated.
- Outdoor field
- Length of season: 9 months (seeding in Mars, last harvest end of November), number of working days: 9 x 20 = 180 days
- Sales of 17500 kg (see this document) at an average price of 1.00 €/kg (see this analysis):
  Turnover of 17 500 €

- **Cost analysis, without ROMI Rover, mechanical + manual weeding (reference):**
  - Total revenues per year: 17.5 k€, total costs 11.875 k€, gross income 5625 €.
  - Time spent on weeding activities: 200 h
  - Cost labour: 200 h (minimum) at 12.5 €/h = 2500 € (it is worth noting that in the quoted reference document it is indicated that weeding labour can represent up to 500-1000 hours per ha)
  - TOTAL cost related to weeding: 2500 €/year

- **Cost analysis, with ROMI Rover:**
  - Total revenues per year: 17.5 k€, total costs 12.345 k€, gross income 4755 € (first 5 years), then gross income 7000 €.
  - Cost rover: 7000 € - one time
  - Guides: 4224 € one time (1408 m, rails on whole field, 1 rail for two beds, reusable next season)
  - Cost material (depreciation over 5 years): rover: 1400 €/year, guides: 845 €/year
  - Cost labour: turning rover: 30 minutes per day x 180 days (season of 9 months): 90 hours: 1125 €/year
  - TOTAL cost related to weeding: 3370 € during the first 5 years, 1125 €/year the following years

**Conclusion:** The use of the rover is almost profitable from the first year of use. After the cost of the rover has been depreciated, the rover represents a clear gain and becomes very interesting for the production of carrots.

**Table 1: Detailed breakdown of the numbers for the lettuce farm**

<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface</td>
<td>0.5h</td>
</tr>
<tr>
<td>Plantation</td>
<td>65 000 plants</td>
</tr>
</tbody>
</table>
Harvest | Without the rover | With the rover | Turnover: 22 500 €
--- | --- | --- | ---

**Operational costs**

<table>
<thead>
<tr>
<th></th>
<th>Without the rover</th>
<th>With the rover</th>
</tr>
</thead>
<tbody>
<tr>
<td>65 000 plants</td>
<td>2 925 €</td>
<td>2 925 €</td>
</tr>
<tr>
<td>Manure (fumure)</td>
<td>650 €</td>
<td>650 €</td>
</tr>
<tr>
<td>phytosanitary</td>
<td>225 €</td>
<td>225 €</td>
</tr>
<tr>
<td>irrigation</td>
<td>35 €</td>
<td>35 €</td>
</tr>
<tr>
<td>Soil cover</td>
<td>600 €</td>
<td>0</td>
</tr>
<tr>
<td>Packaging</td>
<td>3 750 €</td>
<td>3 750 €</td>
</tr>
<tr>
<td>Equipment depreciation</td>
<td>0</td>
<td>1 845 €</td>
</tr>
<tr>
<td><strong>TOTAL operational costs</strong></td>
<td>8 185 €</td>
<td>9 430 € the first 5 years (7 585 € after the first 5 years)</td>
</tr>
</tbody>
</table>

**Personnel costs (12.5 €/h)**

<table>
<thead>
<tr>
<th></th>
<th>Without the rover</th>
<th>With the rover</th>
</tr>
</thead>
<tbody>
<tr>
<td>Work on the ground</td>
<td>117 €</td>
<td>117 €</td>
</tr>
<tr>
<td>Manure</td>
<td>30 €</td>
<td>30 €</td>
</tr>
<tr>
<td>Soil cover</td>
<td>86 €</td>
<td>0</td>
</tr>
<tr>
<td>Plantation</td>
<td>1108 €</td>
<td>1108 €</td>
</tr>
<tr>
<td>Monitoring</td>
<td>387 €</td>
<td>387 €</td>
</tr>
<tr>
<td>weeding</td>
<td>192 €</td>
<td>0</td>
</tr>
<tr>
<td>harvest</td>
<td>2 843 €</td>
<td>2 843 €</td>
</tr>
<tr>
<td>Conditioning</td>
<td>453 €</td>
<td>453 €</td>
</tr>
<tr>
<td>close-up</td>
<td>253 €</td>
<td>253 €</td>
</tr>
<tr>
<td>Positioning of the robot / rails</td>
<td>0 €</td>
<td>750 €</td>
</tr>
<tr>
<td><strong>TOTAL personnel costs</strong></td>
<td>5 469 €</td>
<td>5 941 €</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td>13 654 €</td>
<td>15 371 € the first 5 years (13 526 € after the first 5 years)</td>
</tr>
</tbody>
</table>
Introduction

A survey of several stakeholders (micro-farmers, support organisations of farmers) has been realised all along the project so as to better understand their expectations in terms of robotics, more particularly for activities such as weeding (as it is quite difficult to mobilise farmers time for such surveys, we then decided to focus our questions on a first activity: the weeding). Results were therefore first used for the rover developed in the WP2 (definition and continuous update of specifications). Nevertheless, stakeholders are also questioned about the use of new technologies in their activities as a whole: results are also therefore useful to prepare the exploitation of all tools developed in ROMI.

In total, up to now (the 30 september 2020), 22 French professionals have been interviewed (16 micro-farmers, 1 farmers, and 5 advisers working in support organisation).

Interviews have been realised during two distinct periods:

- A first period before the project inception, notably so as to update rover specifications before first developments in the project: organisation costs related to these ones are not declared. Analysis of results has nevertheless been realised during the project.
- A second period in the year 2019 to complete first answers and to assess to evolution of received answers

In addition we have three farmers involved in the ROMI project which gives us regularly their feedback.

For the first period (before the project), interviews were quite informal whereas for the second period we used an accurate questionnaire defined by SONY CLS, FEI and Chatelain (open questions). Information obtained in the first period has been integrated in questionnaires when possible (some information is lacking, but they do not impact the relevance of the survey).

Because of the COVID-19 outbreak, no interview has been organised in 2020.

Farms
List of interviewed people is the following one (chronological order):

<table>
<thead>
<tr>
<th>Name</th>
<th>Profile</th>
<th>Date of the meeting</th>
</tr>
</thead>
</table>
| NL   | Urban farmer, president of a NGO  
Professional retraining (worked in communication), farming background from her family  
Created the NGO in 2010  
Very different small surfaces, 10 FTE | 12th of May, 2017 |
| CB   | market farmer, Ile de France Area  
Agricultural background from studies and family  
Installation in 2017, new installation  
5ha certified 'Organic Agriculture', 1 permanent FTE | 1st of June 2017 |
| EH   | Organic market farmer, Ile de France Area  
Professional retraining (electrical engineer), got an agricultural diploma  
Installation in 2012, new installation  
2,5ha, 1 seasonal FTE and 2 interns | 9th of June 2017 |

Meeting on the farm, interview with the Sony team
<table>
<thead>
<tr>
<th></th>
<th>Name</th>
<th>Description</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>OH</td>
<td>Organic market farmer, Normandie</td>
<td>Agricultural studies background</td>
<td>Installation in 2015, took over the family farm 85 ha, work in a farm cooperative, 3 permanent FTE, more than 50 seasonal workers with the cooperative</td>
</tr>
<tr>
<td>LC</td>
<td>Organic market farmer. Farm close to Amiens.</td>
<td>Agricultural studies background</td>
<td>Installation in 1997, took over the family farm 10ha, 3 permanent FTE and 6 seasonal workers</td>
</tr>
<tr>
<td>NB</td>
<td>Organic market farmer, Haut de France</td>
<td>Professional retraining (studied philosophy), learned while working in farms</td>
<td>Installation in 2008, took over another farmer 4ha, 1 permanent FTE and 5 seasonal workers</td>
</tr>
<tr>
<td>LH</td>
<td>Urban farm manager. Farm set up along train tracks in Paris linked to a restaurant.</td>
<td>Agricultural studies background</td>
<td>Installation in 2015, new installation 1000 m², 1 FTE</td>
</tr>
<tr>
<td>RL</td>
<td>Organic market farmer, Normandy Area</td>
<td>Agricultural studies background</td>
<td>Installation in 2014, new installation 1.5 ha</td>
</tr>
</tbody>
</table>

2nd period
<table>
<thead>
<tr>
<th>FB</th>
<th>Organic farmer, Haut de France Area</th>
<th>12th June 2019, meeting on the Chatelain farm</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>New installation</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1.7 ha - 2 greenhouses, 0 FTE (his wife)</td>
<td></td>
</tr>
<tr>
<td>CG</td>
<td>Organic market farmer, Pays de la Loire area</td>
<td>25th of July 2019</td>
</tr>
<tr>
<td></td>
<td>Agricultural studies background</td>
<td>Phone meeting with Lisa Garlanda</td>
</tr>
<tr>
<td></td>
<td>Installation in 2014, took over a farm</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1.8 ha with 4000 m² in greenhouses, 1.5 FTE</td>
<td></td>
</tr>
<tr>
<td>SB</td>
<td>Market farmer, Haut de France area</td>
<td>12th July 2019</td>
</tr>
<tr>
<td></td>
<td>Agricultural studies background</td>
<td>Meeting on the farm, interview with Lisa Garlanda and FEI</td>
</tr>
<tr>
<td></td>
<td>Installation in 2013, took over a farm</td>
<td></td>
</tr>
<tr>
<td></td>
<td>4 ha, 1 FTE</td>
<td></td>
</tr>
<tr>
<td>EV</td>
<td>Organic market farmer, Haut de France area</td>
<td>7th August 2019</td>
</tr>
<tr>
<td></td>
<td>Agricultural studies background</td>
<td>Meeting on the farm, interview with Lisa Garlanda and FEI</td>
</tr>
<tr>
<td></td>
<td>Installation in 2009, took over a farm</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1.5 ha with greenhouses, 0 FTE (his wife)</td>
<td></td>
</tr>
<tr>
<td>PV</td>
<td>Organic farmer in a school, Pays de la Loire area</td>
<td>29th October 2019</td>
</tr>
<tr>
<td></td>
<td>Agricultural studies background</td>
<td>Phone meeting with Lisa Garlanda</td>
</tr>
<tr>
<td></td>
<td>new installation</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3 ha and 2500 m² in greenhouse, 1 FTE</td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>Permanent feedbacks</strong></td>
<td></td>
</tr>
</tbody>
</table>
SO - LChat
Organic market farmer, Paris Area
Professional retraining (computer engineer), got an agricultural diploma
Installation in 2016, new installation
6000m², in the process of being certified ‘Organic Agriculture’, 1FTE and 2 interns
Meeting on the farm, interview (During ROMI)

GC - LChat
Organic market farmer, Paris Area
Professional retraining (anthropology studies), got an agricultural diploma
Installation in 2017, new installation
7 ha in the process of being certified ‘Organic Agriculture’, 2 permanent FTE

JM
Permaculture farmer, Barcelona area, manages the farm of a project of defense of the Can Masdeu valley
Professional retraining (mechanical engineer), learned while doing
The project started in 2001

Agricultural chamber

<table>
<thead>
<tr>
<th>Name</th>
<th>Profile</th>
</tr>
</thead>
<tbody>
<tr>
<td>CGuer</td>
<td>An Engineer in innovative and reglementation for the National Federation of Seed Multiplier Farmers (FNAMS)</td>
</tr>
<tr>
<td>MC</td>
<td>An Agricultural Adviser from the department of Vendée</td>
</tr>
<tr>
<td>RD</td>
<td>An Agricultural Adviser in vegetable productions of the Maine et Loire department.</td>
</tr>
<tr>
<td>BL</td>
<td>A Project Manager at The French Research Institute for perfume, medicinal and aromatic plant (Iteipmai)</td>
</tr>
</tbody>
</table>
User stories

NOTE

A user story is an informal, natural language description of one or more features of a software system. User stories are written by or for users or customers to influence the functionality of the system being developed.

As <who> <when> <where>, I <want> because <why>

As <who>, I can <what?> so that <why?>

Acceptance criteria define the boundaries of a user story, and are used to confirm when a story is completed and working as intended. Every user story must have acceptance criteria, allowing the developer to test when the user story is done and allowing the customer to validate it.

Farmer-Robot Interaction, autonomy of the robot

<table>
<thead>
<tr>
<th>I want the robot to follow me when I walk to the field, so that it learns what path to take</th>
<th>GC (market farmer)</th>
</tr>
</thead>
<tbody>
<tr>
<td>I want the robot to work in the field when I am there so that I can see what it is doing</td>
<td>SO (market farmer)</td>
</tr>
<tr>
<td>I want the robot to work in the field when I am there so that it doesn’t get stolen</td>
<td></td>
</tr>
</tbody>
</table>
| I need the robot to be as fast as me when I walk so that I don’t have to wait for it | GC  
(market farmer) |
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>I want the robot to be fast enough so that it works efficiently when the weather allows it</td>
<td>OH (market farmer)</td>
</tr>
<tr>
<td>The movement speed of the robot is an important criteria</td>
<td>BP (adviser of support organisation in agricultural field)</td>
</tr>
<tr>
<td>I don’t want to use a cell phone to control the robot when I’m in the field because my hands are dirty, I’m wearing gloves, and it is difficult to grab my phone</td>
<td>SO (market farmer)</td>
</tr>
<tr>
<td>I want to place a physical marker in front of the field so that the robot knows what bed to weed</td>
<td>SO (market farmer)</td>
</tr>
<tr>
<td>I want to robot to work in autonomy in large exploitation</td>
<td>PV (market farmer)</td>
</tr>
<tr>
<td>I want to monitor the movement and actions of the Robot, more particularly during the harvest period</td>
<td>SB (market farmer)</td>
</tr>
<tr>
<td><strong>Hardware Design</strong></td>
<td></td>
</tr>
</tbody>
</table>
| I want the robot structure to fit with different crop bed widths so that I can use it everywhere in the farm. Indeed crop bed widths can be different according to types of vegetables | GC  
(market farmer) |
<p>| | SB (market farmer) |
| | PV (market farmer) |
| | CG (market farmer) |
| I want the robot could be able to treat different types of cultures. It has to be versatile | |
| I want the robot to have a small size adapted so that it is adapted to very small farms, in particular, to urban farms | NL (urban farmer) |</p>
<table>
<thead>
<tr>
<th>I want a robot that I can pick up and take with me so that I can easily move it between places.</th>
<th>NL (urban farmer)</th>
</tr>
</thead>
<tbody>
<tr>
<td>I prefer the use of caterpillar, rather than tracks</td>
<td>SB (market farmer)</td>
</tr>
</tbody>
</table>

**Usage situations**

<table>
<thead>
<tr>
<th>Reliability of the robot</th>
<th>NB (market farmer)</th>
</tr>
</thead>
<tbody>
<tr>
<td>I want the robot to be resistant to dust, water, rust so that maintenance is easy</td>
<td>LChat (market farmer)</td>
</tr>
<tr>
<td>I want the robot to heavy and powerful so that it can drive in different type of soil (mud, stones, slope, etc)</td>
<td></td>
</tr>
<tr>
<td>I want the robot to powerful and resistant so that it so it can work in all weather conditions</td>
<td></td>
</tr>
<tr>
<td>I want the robot to be able to work on soils with mulch (straw or wood chips) so that I can continue to benefit from the advantages of mulching</td>
<td>JM (permaculture farmer)</td>
</tr>
<tr>
<td>I want the robot to work at night so that it gets more things done</td>
<td>LChat (market farmer)</td>
</tr>
<tr>
<td>I want the robot is directly adapted to the configuration of the farm, the farm configuration has not to be modified</td>
<td>FB (market farmer)</td>
</tr>
<tr>
<td>CG (market farmer)</td>
<td></td>
</tr>
<tr>
<td>I prefer to adapt the configuration of the farm to the robot because I have no skills to adapt the robot.</td>
<td>PV (market farmer)</td>
</tr>
</tbody>
</table>

**Additional tasks**

<table>
<thead>
<tr>
<th>I want the robot to carry boxes / equipment autonomously from the field to the storage area so that it helps me (limitation of movement), more particularly during the harvest period</th>
<th>CB (market farmer)</th>
</tr>
</thead>
<tbody>
<tr>
<td>EV (market farmer)</td>
<td></td>
</tr>
<tr>
<td>LH (urban farmer)</td>
<td></td>
</tr>
<tr>
<td>SB (market farmer)</td>
<td></td>
</tr>
<tr>
<td>Requirement</td>
<td>Respondent</td>
</tr>
<tr>
<td>----------------------------------------------------------------------------</td>
<td>-----------------------------------</td>
</tr>
<tr>
<td>I want the robot to send me images of the field so I can do crop monitoring so that I don’t have to go in the field. But I consider this tool could be useful only for large exploitation. For smaller exploitation, the farmer has time to monitor the farm without dedicated tools.</td>
<td>CB (market farmer)</td>
</tr>
</tbody>
</table>
| I want the robot to draw straight furrows in the soil before transplanting in the crop bed so that I can follow those straight lines when I transplant (easier to use mechanical tools) | EH (market farmer)  
NL (urban farmer)  
GC (market farmer) |
| I want the robot to create marks in straight lines for the transplants so that it helps me transplanting better and faster | EH (market farmer)  
GC (market farmer)  
RL (market farmer) |
| I want the robot to do precision seedling for small seeds so that it’s easier to do crop monitoring | EH (market farmer)  
NL (urban farmer)  
RL (market farmer) |
| I want the robot and the software to record and keep the pictures of the crops from year to year so that I can have a record of the crop evolution and growth. | OH (market farmer)                |
| I want the robot to be modular and multi-purpose so that I can use it for several tasks | Farmer at demonstration day, Chambre Agri, 19/6/2019 |
| I want the robot for detection of diseases and pests to be able to treat very locally. Detection of the particular behavior of the plant when it is attacked and before the expression of symptoms and with damage | BP (adviser of support organisation in agricultural field)  
MC (adviser of support organisation in agricultural field) |

**Cost**

---

ROMI - D1.2 Management Document - The Rover
<table>
<thead>
<tr>
<th>Requirement</th>
<th>Stakeholder(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>I want the robot to be economically interesting compared to human workforce</td>
<td>OH (market farmer)</td>
</tr>
<tr>
<td></td>
<td>CG (market farmer)</td>
</tr>
<tr>
<td></td>
<td>FB (market farmer)</td>
</tr>
</tbody>
</table>

**Restriction of use**

- **Use rather in large exploitation, low tech philosophy**
  - FB (market farmer)
  - RL (market farmer)
  - CB (market farmer)
  - EV (market farmer)

- I consider that weeding robots are not useful for farm < 3h with diversified productions.
- The robot is more interesting for large farm in monoculture
- I consider that monitoring tool could be useful only for large exploitation. For smaller exploitation, the farmer has time to monitor the farm without dedicated tools
- I consider that weeding robot is not useful form small farms

- The robot has to be adaptable (size issues) to very small farms (urban farms)
  - LH (market farmer)
  - NL (market farmer)

- Capacity of investment of small farms in organic production
  - RD (adviser of support organisation in agricultural field)

- Negative experience from some farmers in the use of other robotic solutions
  - MC (adviser of support organisation in agricultural field)
Romi Rover
Market study

The rover is first intended to microfarms < 5ha which produce various types of fresh vegetables. A set of Eurostat data bases enable to better understand the market of potential users of such tools:

Farms and microfarms as a whole, with and without cattle (2016):


Farms under the classification V0000_S0000: which produce Fresh vegetables (including melons and watermelons) and strawberries (2016):


Organic production:

Farms equipped of polytunnel/greenhouses


Global overview

There are in Europe more than 10 millions of farms whatever their nature of production. Among them, 60% are microfarms of less than 5ha which are mainly settled in Romania (more that 3M - 46% of microfarms). Following countries are Poland (460 k), Italy (707 k), Greece 523 k), Spain (469 k), Hungary (285 k), Portugal (183 k), Bulgaria (151 k), France (102 k), Croatia (91 k). 2/3 of microfarms are less than 2h. Between 2013 and 2016 (more recent figures), the number of farms significantly decreased in most
countries with an average of 5%. Among the top ten, the more significant decrease is in Bulgaria (-27%), we can nevertheless note the particular dynamism of Italy (+20%)

If we consider farms without cattle, they represent 48% of microfarms (3.1 M).

SO (Standard output)

The higher SO, the fewer the micro farms: more than half micro farms belong to the "less than 1 999 euros" SO category, less than a quarter belong to the 2000 euros – 4000 euros SO category and so on.

Farms able to invest in ROMI tools are mainly the ones with a SO superior to 25 k€: they are 166 990 in Europe (2% of microfarms). Top 10 countries, with three new incomings (Germany, Austria, and the Netherlands), are Italy (54 000 farms), Spain (27 820), France (25 780), Greece (13 500), Germany (9 040), Poland (8 530), The Netherlands (6 040), Portugal (4 340), Romania (3 390), Austria (2 950). If we consider only microfarms without cattle, there are 119 380 farms with a SO > 25 k€.

AWU (Annual work unit)

There is an average of 0.53 AWU per microfarm (0.43 for farms less than 2ha, 0.72 for farms between 2 and 5ha). Among the Top 10 countries evoked above, we can remark a significant number of AWU in microfarms in Germany (1.68) and Netherlands (2.65). The average increases with the SO:

<table>
<thead>
<tr>
<th></th>
<th>&lt;2ha</th>
<th>2-5ha</th>
</tr>
</thead>
<tbody>
<tr>
<td>25kE - 50kE</td>
<td>1.42</td>
<td>1.23</td>
</tr>
<tr>
<td>50kE - 100 kE</td>
<td>1.87</td>
<td>2.05</td>
</tr>
<tr>
<td>100kE - 250kE</td>
<td>2.53</td>
<td>2.93</td>
</tr>
<tr>
<td>250 kE - 500kE</td>
<td>3.22</td>
<td>3.54</td>
</tr>
<tr>
<td>500+ kE</td>
<td>4.24</td>
<td>7.53</td>
</tr>
</tbody>
</table>

Self-consumption

58% of European microfarms are mainly dedicated to self-consumption (Farms whose household consumes more than 50% of the final production). The share of micro farms with more than 50% of self-consumption decreases with higher SO category: If we consider our target for robot sellers (microfarms with a SO superior to 25 k€), the self-consumption is very weak (less than 2%): farms are dedicated entirely to professional activities.

Age and sex
Microfarms holders are an aging population, mainly with an age superior to 55 years and 35% of them are women.

**Focus on vegetable microfarms**

In Europe and in 2016, there were 501 830 microfarms which produce Fresh vegetables (including melons and watermelons) and strawberries (less than 10% of the total microfarms). We note that the 10 countries which are leaders in number of vegetable farms are also those which are leaders in terms of the number of microfarms whatever the activity produced. There is only one exception: Lithuania which has a very high % of vegetable microfarms (32 500).

Regarding their SO, there were 52 730 micro farms in 2016 which SO was more than 25 000 euros, among which 20 150 were smaller than 2ha and 32 580 were between 2ha and 5ha. Leaders identified in previous paragraphs (in term of microfarms, microfarms without cattle) are leaders for vegetables microfarms with a SO >25k€, except for Bulgaria and Croatia which leave the classification. Like in section 1, we can add three additional countries: Germany, Austria, and Netherlands and a new one (Belgium).

<table>
<thead>
<tr>
<th>Country</th>
<th>Number of microfarms which produce fresh vegetables with a SO &gt;25k€</th>
</tr>
</thead>
<tbody>
<tr>
<td>Italy</td>
<td>14 960</td>
</tr>
<tr>
<td>Spain</td>
<td>14 170</td>
</tr>
<tr>
<td>France</td>
<td>6 500</td>
</tr>
<tr>
<td>Greece</td>
<td>4 490</td>
</tr>
<tr>
<td>Poland</td>
<td>4 090</td>
</tr>
<tr>
<td>Portugal</td>
<td>1 540</td>
</tr>
<tr>
<td>Germany</td>
<td>1 370</td>
</tr>
<tr>
<td>The Netherlands</td>
<td>950</td>
</tr>
<tr>
<td>Hungary</td>
<td>730</td>
</tr>
<tr>
<td>Romania</td>
<td>590</td>
</tr>
<tr>
<td>Austria</td>
<td>560</td>
</tr>
<tr>
<td>TOTAL</td>
<td>49 950</td>
</tr>
</tbody>
</table>
Focus on organic farms

The biggest producers of organic fresh vegetable are Spain, Italy, the Netherlands and Germany (no data for France in Eurostat data bases).

It is noteworthy to mention several specific points related to previous paragraphs:

- A strong production in the United Kingdom whereas it has only 6800 vegetable farms
- A strong production in Germany and the Netherlands whereas they are not the most agricultural European countries
- Weak production in Romania whereas it is the first agricultural European country.

Countries whose agricultural areas dedicated to organic farming (for the production of fresh vegetables) are higher than 9% are:

- The Netherlands (43%)
- Poland (21%)
- Belgium (19%)
- Austria (16%)
- Denmark (15%)
- Spain, France, Germany and Portugal (9%)

Focus on greenhouses

In 2016, there were 118,810 farms whatever their size which produces fresh vegetables (including melons) and strawberries - under glass or high accessible cover. For 70% of them, their size is less than 5ha. Most dynamic countries are Romania, Spain, Italy, Hungary, Poland, Greece and France. We can remark the position of Greece and Hungary which do not appear as leaders in other chapters of this study.