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Alignment of a Roombot
Metamodule & Extendable Grid

Author: Thanh-Khai Dinh
Supervisors: Rico Möckel, Alexander Spröwitz, Stéphane Bonardi
Professor: Auke Ijspeert
Abstract

The Roombot is a modular robot that needs a grid to perform its sequence to build furniture. It can get out of its grid but it has not any way to return properly on its workstation. Its grid may take a lot of space depending on the size of furniture which it has to build. From this observation, my semester project was divided in two parts. Both are about extension for Roombot, they are:

1. To design a system that helps an RB-metamodule to return on its grid.

2. To find some ideas and open ways for an extendable grid.

The aim of the first part was reached with a sink where the RB-metamodule can fall into and has to follow a particular sequence to return on its grid. A lot of time was spent on drawings and on 3D pieces to ease processing. A setup was built and tests were made successfully. For the second part, motivations for an extendable grid were clearly defined. For this project, which deserves more than half-semester, some ideas were advanced and compared but, due to lack of time, only one was developed in more details.
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Chapter 1

Introduction

In this introduction, I explain what is modular robotic and present the Roombot and its characteristics. Then motivations and timeline of my semester project is developed. Motivations explain why my semester project was divided in two different subjects. The goal of the first part is to design a system that helps a modular robot to return to its workstation. The goal of the second part is to make a study about an extendable grid.

1.1 Modular Robotic

1.1.1 Definition and Goal

A robot is usually a machine that fulfills a task instead of a human operator. If the task is always the same and well-known, we generally prefer an optimized design that fulfills the task without consideration of other tasks. This kind of robot, called monolithic robot, is composed of pieces with some clear functions. An example of monolithic robot is humanoid robot Nao that looks like a human and plays soccer. When the task may change a lot of times and not well-known during design of robot, some problems of adaptation appear. Taking inspiration from nature, a new way of thinking about robotic grew.

Figure 1.1: Collaboration of ants. As small as they are, together they can build something useful for many others. [1]
Modular Robotic is a field of research since many years. It consists to have many independent robots (modules), with same or specialized functions, that fulfill some tasks together. The advantages of this concept, opposed to *monolithic robot*, is that a module can be replaced by another and that the number of different configurations is very large. An easy way to understand the concept is to think about Lego [9]. It is a simply structure, but we can construct complex shape [10] by combining a lot of them. Despite an heavy, expensive, and hard to design robot, modular robot has great advantages like robustness and adaptation’s ability. [11]

Figure 1.2: Simple structures like Lego can make complex shape. [10]

1.1.2 Classification

There are many ways to classify modular robots. One of them is based on attaching location (lattice/chain/mobile), another on moving methods (stochastic/deterministic). We can see on Figure [1,3] that there are many kind of self-reconfigurable systems. In **lattice** configuration, the robot has some discrete position to occupy on a 2D or 3D structure. It generally simplifies kinematics and collision detection, and also the reconfiguration process. In **chain** configuration, the robots are connected in serial chains, forming tree or loop structure. It’s harder to coordinate reconfiguration. In **mobile** configuration, disconnected robots can move separately in an environment. When they attach together, the configuration can be lattice or chain. In **deterministic** class, position of all modules is known all the time as well as the duration of reconfiguration. The modules need to communicate with their neighbors. In **stochastic** class, the robots move randomly in a 2D or 3D environment in a passive state. When a module meets another, it decides to bind with or not.
1.2 The Roombot (RB)

The Roombot is a project of modular robotics where some modules attach each other to build different furniture up to the needs (desk, bench, chair, bed, wardrobe, ...). Modules assemble with each other to make the desired shape. The aim is to have right thing at right time. We can think about the Swiss army knife. This tool can be used differently depending on needs. The Roombot follows same idea for furniture. A daily situation: in morning we do not need anymore our bed but a table to have breakfast. This bed takes space in room and is useless at this moment. It should be nice to leave his bed, to take a shower and to have a breakfast-table when being back. Using the classification above, the Roombot is a lattice and deterministic robot because it needs a grid where it can build furniture. There are three laboratories for the Roombot project: LASA of Aude Billard, CRAFT of Pierre Dillenbourg and Biorob of Auke Ijspeert. Some responsible assistants or PhD students are also involved: Alex Sproewitz, Rico Moeckel, Soha Pouya, Stéphane Bonardi. An ancient post-doc, Masoud Asadpour, was in this project but is now at the University of Tehran.

1.3 Motivations and Schedule

There is a part of Roombot’s project on which some improvements can be made: its workstation. This grid is essential for many reasons:

- it is a reference in space;
- it is a structure with which RB-metamodules can be consolidated;
- it can be used as place of battery recharge;
• it is necessary for self-reconfiguration of Roombot.

But this grid has also some disadvantages. It do not allow the Roombot to return on it easily and takes a lot space. From this observations, I explain in more details motivations of both project in beginning of chapter 2 and 3.
Figure 1.5: Schedule that shows distribution of my efforts on both projects. Few days were spent to familiarize myself with Solidworks® in beginning.
Chapter 2

Alignment of a Roombot-Metamodule

In this chapter, problematic of alignment is developed and requirements are defined. Strategy is discussed and a solution is highlighted. Details about some tests are explained with a final conclusion for this problematic.

2.1 Project’s Problematic

Metamodules of RB need to be aligned on a grid to attach themselves together. When the desired shape is done, the furniture can get out of the grid and be placed where the user wants. If we do not need this furniture and want another, the metamodules have to detach from each other and return on the grid to build the new furniture. A RB-metamodule can move in unstructured environment but can not make a sequence of assembly without its grid-reference. The goal of this project is to design a system where a metamodule of Roombot can easily be aligned on the grid where the furniture is built.

Figure 2.1: A table composed by RB-metamodules and passive elements on the grid used for reconfiguration. [11]
2.2 Requirements

The system that aligns the metamodules on the grid has to:

- be passive, no energy required,
- be attached to the already built structure,
- be safe for the metamodule,
- allow the metamodule to return on the main grid,
- work independently of the metamodule configuration (parallel, perpendicular, shear-S, shear-Z),
- allow modifications.

Choice to have a passive system is to avoid to control another robot than the roombot and thus made a new interface for it. As it is passive, there is no need to think about electronic or control problems and can be used as long as pieces are not violently broken.

![Figure 2.2: The four configurations of a RB-metamodule.](image)

2.2.1 Structure

The structure is composed by an extruded aluminum of 30x30 mm, a wood plate and a PCB of 1.6 mm thick. From my point of view, the best way to attach something to the structure is to use the aluminum extrusion. There are some angle pieces that allow attachment by screw. In this way, we do not need to make modifications on the structure and the screws are easy to remove. The diameter of a circle in wood plate is 70 mm. The height between the floor and the top of PCB was about 150 mm but can vary.

2.2.2 Roombot’s characteristics

A Roombot is composed of two "cubes" with 3 degrees of freedom (DOF) and 4 latches that allow connection with another module. The dimensions of a "cube" is 110x110x110 mm with rounded shape in corner. The diameter of its plane surface is 68 mm. There are four configurations when a module attaches with another to form a RB-metamodule that can perform more tasks than just one module and move itself in unstructured environment.
Figure 2.3: Structure where the alignment system has to be attached.

Figure 2.4: Degrees of freedom of a RB-module: rotation around the red and blue axis. Rounded shape in corners. Two RB-modules assembled form a RB-metamodule. [11]
2.3 Strategy

The required system must be passive. It means that the RB-metamodule goes itself at location of the system. There are two approaches:

- the metamodule rolls against a wall until it’s aligned;
- use of the gravity: the metamodule falls in a hole.

I preferred the second option for the following reasons:

- it does not depend on the way the metamodule comes;
- the gravity, thanks to slopes, pushes the metamodule at the right place;
- the roombot is heavy, thus the force of alignment is bigger;
- the roombot can make many movements while staying at the same place.

Weaknesses of this approach are that RB-metamodules has to fall and can be damaged after a lot of times and that its grid need to be higher than floor. We have to provide a space for the hole.

The metamodule shape composed of 4 aligned cubes is the easiest to replace on the grid. The weight of a RB-metamodule is about 2.8 kg. 4 kg is used for calculations to be sure. The dimensions of a “cube” is 110x110x110 mm. The diameter of its plane surface is 68 mm.

![Figure 2.5: A RB-metamodule out of its grid.](image)

2.4 Design

The design was made in an iterative way. It means that one problem after another was taken and correction on the design was made in consequence. The design was made step by step without simulation. In agreement with my supervisor, we did not want lost time with many simulations and preferred a design with a lot of pieces that can be easily modified. The CAD software for this project is Solidworks®. I never used it before this project, but I learned with Pro/ENGINEER®. Both are similar but I needed few days to familiarize myself with Solidworks®.
2.4.1 First Design

In Figure 2.6, we can see the two vertical plates that guide the RB-metamodule to the slopes. The little sink allows the RB-metamodule to be straight inside. However the RB-metamodule can not move anymore when it is straight inside.

![Figure 2.6: First design. RB-metamodule comes from yellow arrows.](image)

2.4.2 Second Design

Some improvements were made. At first, a soft slope of $30^\circ$ guides the RB-metamodule to the bottom. The proper alignment is made with small slopes of $45^\circ$. In this way, the RB-metamodule is aligned but can still move. On Figure 2.7, we can see that the RB-metamodule will be pushed against the vertical wall (not drawn on Figure 2.7) where it can connect the latches. There are two gaps to the bottom of the sink that allow rotation to both extreme "cubes" without misalignment of central "cubes". This function removes the dependence to the RB-metamodule configuration: it can always turn until having a right state to get out. There are still many problems: the small $45^\circ$ slopes are not sufficient to align the entire RB-metamodule. The distance between the bottom and the high plateform is too long. The vertical guiding plates are too large and a collision can occur if we the RB-metamodule tries to get out.

![Figure 2.7: Second Design.](image)
### Table 2.1: Some properties of POM

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density</td>
<td>1.42 kg/dm$^3$</td>
</tr>
<tr>
<td>Young’s Module</td>
<td>2.9-3.1 GPa</td>
</tr>
<tr>
<td>Poisson’s ration</td>
<td>0.35</td>
</tr>
<tr>
<td>Rockwell Scale</td>
<td>M80</td>
</tr>
<tr>
<td>Thermal expansion</td>
<td>80 nm/°C</td>
</tr>
<tr>
<td>Cost (in ATPR workshop)</td>
<td>21 CHF/dm$^3$</td>
</tr>
</tbody>
</table>

#### 2.4.3 Third Design

All the problems mentioned above were resolved in the third design. The general design seems good but the pieces had to be drawn for assembly and there are still mechanic choices to make.

**Material**

In this case, we need a material that is easy to cut, enough stiff to avoid too much deformation and that allows the RB-metamodule to slide easily on it. Firstly we thought about wood but there was not many workshops that work with it. I asked to a workshop what kind of material they work with and they made me a list. From this list, the material that we had to use was obvious: POM. This plastic costs a bit more than wood but its properties matched very well with the requirements. The workshop, ATPR, can order easily POM plate. POM is also known for its slide property. Some properties of POM are in Table 2.1.

**Thickness of plate**

As the material was chosen, the thickness of "base" piece and the 45° slopes were calculated with a charge that makes a deformation less than 1 mm. The worst case of this configuration is taken. It means that the charge of 4 kg is placed at the point where it makes the most deformation. In this configuration, the security factor could be low (1.2). Here the equation for a charge in middle:

$$y = -\frac{F \cdot L^3}{3 \cdot EI}$$

with E Young’s Module of POM, F the force, and

$$I = \frac{bh^3}{12}$$

($b=$ base, $h=$ height) from Equations 2.1 and 2.2

$$h = \sqrt{\frac{4 \cdot F \cdot L^3}{b \cdot E \cdot y}}$$

In case of the piece "base", $F = 4 \cdot 9.81$, $b = 0.38m$, $L = 0.5m$, $h$ had to be bigger than 30 mm. In case of the pieces "45° slope", $F = 4 \cdot 9.81 \cdot 0.5 \cdot \sin 45$, $b = 0.022m$, $h = 0.38m$. 

---

1. [16]
2. [18]
$L = 57$, $h$ had to be bigger than 65mm. Because the thickness of "base" and 45° slopes needs to be huge, more support pieces were put in strategic place for alignment of the RB-metamodule: in middle of the two "central cubes" for the slopes and in middle of the pieces "base". In this case, the thickness of the plate was not important. For the pieces "base" and "sortie", a thickness of 15 mm is stiff enough but costs less than a plate of 30 mm. The thickness of the other plates was normally 8mm and allows enough spiral (at least seven) of M6 screws, but the workshop received plates of 8.6 mm thick from supplier. This explains why the drawings contain this weird dimension and why I had to redesign all pieces.

![Figure 2.8: Final design. Feet and angles are missing.](image)

**Orders**

I asked a workshop at EPFL to cut the sink pieces. From my previous experiences, I know that the people answer kindly to questions. This workshop is ATPR (Atelier de l’Institut de production et robotique) in building BM. They are used to work with very small pieces and when they had a piece as large as my "base" piece, they can easily work with another workshop. Because this is a semester project, we had priority on other kind of work and the labor was free. We had only to pay the material. The pieces were made in three weeks. I ordered the feet of the sink from Misumi. This supplier takes usually more time to send items, but is cheaper than the others according to ATPR. The reference of the feet in Misumi catalog is: FJSN8-60. I chose them because they allow a height adjustment, do not slide on the floor thanks to rubber and their thread (M8) is perfect for the thickness of the "base" piece.
Assembly

The design was made in such a way that most part of pieces can be placed and removed by hand without tools. Sometimes, there are some angles with screw that make us sure that everything is rigid. We ordered a modified PCB that can be placed on the vertical wall. Screw-feet are placed under the ”base” piece. They allow to modify easily the height. Attachment with the structure is made by angles and screws.

Figure 2.9: An angle attaches the sink with the structure and a foot allows height adjustment.

2.4.4 How It Works

The RB-metamodule has to come and to fall into the sink. It wiggles until being straight inside, helped by 45° slopes. Then it can make its sequence to get out.

Figure 2.10: A RB-metamodule comes from the yellow arrow and falls inside.

2.4.5 Sequence to Get Out

Depending on the configuration and the direction of the RB-metamodule in the sink, there are many possible sequences. The “cube” against the wall has to rotate until being at the
Figure 2.11: Two 45° slopes place the RB-metamodule straight.

Figure 2.12: A little 45° slope at the left pushes the RB-metamodule against the right wall. We can see a gap under the "cube" against the wall. It allows the cube to rotate without misalignment of the other cubes.
right position. Here an example. The order and the DOF can change but the sequence will always look like this one.

Figure 2.13: The RB-metamodule is attached to the wall with the PCB and makes its first step to get out.

Figure 2.14: The top cube can rotate freely to be in the position that allows the RB-metamodule to return on the main grid.
Figure 2.15: The RB-metamodule can approach the high platform without collision with guiding plates.

Figure 2.16: In this position, the RB-metamodule has to remove the latches from the wall and attaches itself with the high platform.

Figure 2.17: The RB-metamodule is attached to the high platform and can perform this movement.
Figure 2.18: That is the final movement to be out of the sink. The configuration of the bottom "cube" is very important, because it allows to return on the main grid via the grid of the high platform.

Figure 2.19: The sink is attached with the structure of the main grid.

2.5 Tests

The attachment to the structure should be easy but a mistake in the design appeared: the high platform was too large. We needed to remove 5 mm and change the pieces that attached the sink with the angles. When we saw that, the workshop had not enough time to do it although it should be done very fast. We just needed to wait end of January. I changed the design of the incorrect pieces. The tests did not take many times. The alignment worked well and there were many sequences for the RB-metamodule to get out. The rotation of the "cube" against the vertical wall showed that there was little friction, but it did not misalign anything. We believed about a collision between the RB-metamodule and the 45° slopes when we tried the sequence to get out but it was not the case. It explains why one of the 45° slopes is planed down in one side, but we only had to return this pieces. The control of RB-metamodule was made by hand for the tests. It explains why I had to accelerate the videos. It seems that the RB-metamodule falls hardly. I think that the best and easiest way to soften it is to put a thin foam on
the 30° slope. There were some problems to attach rightly the latches to the PCB of the high platform. As mentioned before, the control was made by hand and it was difficult to make the robot really as straight as on Figure 2.16. Thus, we helped sometimes the RB-metamodules with its latches. We succeed once in attach latches with the top PCB without help.

**Example of Sequence to Get Out**

We tested the sequence to get out. There was a problem with the first step: the motor can not move the metamodule with three extended "cubes". We simply change the steps order to decrease the length of the arm. The following pictures come from a video of the sequence to get out.

![Figure 2.20](image1)

**Figure 2.20**: The RB-metamodule is straight inside and the "cube" against the wall is at the right position.

![Figure 2.21](image2)

**Figure 2.21**: The latches are connected to the wall. The RB-metamodule can perform a rotation that decreases the length of the arm.
Figure 2.22: The RB-metamodule touches the high platform. It has to remove the latches from the wall and makes attachment with the high platform. During the test, it was difficult to control the RB-metamodule by hand. We helped it to place its latches. However, we succeed in attaching the RB-metamodule to the high platform without help.

Figure 2.23: As the connection with the high platform is strong enough, the RB-metamodule can get out easily.

Figure 2.24: The final step is done here.
2.6 Conclusion

The aim of this semester project is reached. The RB-metamodule can easily fall inside and be aligned without problems. Of course, some improvements can be made:

- some materials can still be removed where there is unintended friction;
- a spring-system can be added to soften the fall of the RB-metamodule.

I also made a mistake with the piece "sortie". 5 mm has to be removed. But all drawings have been modified in consequence. The two pieces "attach" have also to be re-ordered. As I spent a lot of time on drawings, they are clear for manufacturing. This project brought me a lot of satisfaction and was an opportunity to apply many things that I learned especially in mechanic part of Microengineering and I had chance to learn a software that I never used before: Solidworks®.

Figure 2.25: Late improvement: foam added to soften falling.
Chapter 3

Extendable Grid

This chapter is about second part of my semester project. Motivations are explained and some approaches are advanced. More details with an idea are developed and some ideas are given for future work in conclusion.

3.1 Motivations

One advantage of modular robots is that they do not take place when they are not used. The idea of extendable grid follows the same concept. Instead of a cumbersome grid, an extendable grid allows to place the grid where the user wants and where the Roombot needs and also to take less space when it is not used. Saving place can be very important if we think that the user do not want a grid instead of his floor, maybe for aesthetic reason, and do not want let too much space for the building of his furniture. It allows also to have the grid near the furniture if needed. Another use is to make a plane plate, for instance to make a table or a chair. Thus, the RB-extension has two main tasks:

• to create deployable grid that can be carried;
• to create plane plates.

In this half semester project, because of short time and the lot of problems that can appear with the gravity, I worked on the grid that is used only on the floor and not used for plane plate. Of course, the final aim is to have a single extension fulfilling the two tasks. The aim of this project was to develop the concept and to open different ways. Some technical problems where shown but at the end of this project there was not any final design that can be built. I really think that a project like this deserves more time than seven weeks.

As the aim of this project is to open ways for the goal described above, we can take inspiration from everything we see that has a stored and extended shape (ladder, accordion, sliding door, ...). For instance, the space solar panels for satellite are stored in a rocket that will extend in space. I made some research to finally find that there are two huge differences with my project:

• Because after being extended the panels have not to be stored again, they usually use explosive charge for deployment. [21]
Another idea comes from military. They made a tank that has to carry a deployable bridge. The problem is that the bridge is composed by only two huge plates and of course I have not any access to the details of this military vehicle. We can also take inspiration of existing modular robots and their attachment system.

3.2 Approaches

I think that there are two main approaches to make the extendable grid. One close to monolithic robot, the other closer to modular systems. Of course, there are many systems between both. In both approaches, from the fully passive system until the full electronic system, there are many ways to make an extendable grid. For instance, we can make a grid close to design of accordion. It is passive and easy to design but has to be extended by two RB-metamodules or more. Some ideas subsequently shown deserve more time to be developed.

3.2.1 A self-deploying grid

This kind of grid has to move and deploy itself. This approach needs a lot of time to be developed because of its complexity. We need to design an entire robot that can be as complex as the RB itself. Shape and surface of this grid can not really be modified. The advantages are in its independence and in the fact that it can be stored and extended quickly. This grid can move itself where needed without disturbing other RB-metamodules and it does not need to have another robot. We can summarize the advantages and disadvantages of the robots designed with this kind of approach.

- ⊕ Independent
- ⊕ Fast deployment
- ⊖ Need place inside for actuators, battery and electronics
- ⊖ Heavy
- ⊖ Complex
- ⊖ Always same shape

Different ideas are developed right there.

Rolling Grid

This robot is composed by two motorized wheels that allow it to move, another wheel for stability and cylinder that contains the grid. The grid is made with lamellas. In this way, we can store the grid in a close space and extend it quickly. The problem comes from the stiffness of the grid: it can not be stable when the RB-metamodule is on it without sticks on edges. This sticks can be added in a way that allow them to fall on floor and be removed quickly. The size of lamellas determine how the grid will bends and where.
Figure 3.1: Sketch of rolling grid’s idea. The motors are in black and

Figure 3.2: On top sketch, sticks are stuck in this position. When wire do not hold them anymore, stick closest to wheels falls first and leads others to fall.
Mobile stack

The idea is to have a robot with a lot of squares like the grid. It has to assemble the grid by itself by placing the squares on the floor and attaches them together. When the grid does not need to be used anymore, the mobile robot takes the squares inside back. This robot might be very complex and we need also to design the square to make it easy to place, to take and to attach together.

Mobile four squares grid

This concept is easy to understand: some four-square plates with wheels can move themselves and have active attachment system. Attachment allows them to be stiff together. The problem comes from storing them: they take the same place, stored or not.

![Figure 3.3: A grid with wheels that can move itself to attached with another.](image)

3.2.2 Little modules

The idea is to have some little modules, stored on a stack, that can make a plate together and be placed by a RB-metamodule. They have generally the same advantages and disadvantages:

- ⊕ light module
- ⊕ flexible
- ⊖ need of a RB-metamodule for deployment
- ⊖ need of another robot to move the stack of modules

In this approach, there is a problem if we want to use a RB-metamodule as a hoist. The RB-metamodule needs to be stable enough, thus fixed on the floor, with another RB-metamodule or already on a grid. We can also think to use the stack-robot as a reference and as foot for the RB-metamodule used as hoist. In this case, a system to attach this stack-robot with a RB-metamodule has to be developed. The flexibility of this kind of module allows to have a shaped grid as large as there are enough modules.
The grid is not only composed of modules placed one near each other, but there is a mechanical connection between them that makes them consolidated (Puzzles system or something else). In this way, the RB-metamodule can directly use two or three assembled modules as stable foot. If this approach is chosen, there are three parts to develop. First, modules have to be designed. Secondly, we need to think about the stack-robot. Maybe we can take an existing robot and change few things to allow it to transport the stack of modules. Thirdly, the sequence of RB-metamodule to take and put the modules has to be developed.

**Attachment between modules**

Attachment between modules needs to be stiff and allows facility to place and to remove squares. I tried directly to make them symmetric. In that way, we do not have to worry about their direction in the grid. I classify many attachment systems in two categories, active and passive. Passive attachment keeps modules light and cheap, but the design has to ease the grid deployment.

- magnets
- Lego
- puzzles
- Velcro
- hook

![Figure 3.4: Magnets on edges of square. Symmetry allows a positioning without problem of orientation.](image)

With an active attachment, placement of squares are easy but they will be heavier.

- some latches like Roombots;
- little plate that gets out from the module and goes inside other.
Figure 3.5: Puzzle idea with symmetry. A RB-metamodule has to take it and place from the top to attach it with another. [22]

Figure 3.6: Piece with Lego-attachment. The stiffness is better but the RB-metamodule has to put pressure to assemble pieces together.
3.3 Puzzle idea

As I had little time for this project and according to my supervisor, I decided to develop the idea of puzzle in more details than the others. As it was difficult for me to decide the space between squares, I asked this to someone with more feelings with this kind of problem: Sébastien Aeppli of the ATPR workshop. He told me that 0.1 mm between pieces is largely sufficient to ease placement without problem. Then I calculated the thickness of square that makes less than 0.5 mm in horizontal displacement. Variables are explained by figure 3.7.

![Figure 3.7: To determine thickness. $\alpha = \text{angle}, d = \text{space between squares}, h = \text{thickness}$.](image)

With an angle less than $2^\circ$ and a gap between squares of 0.1 mm, we can determine thickness in this way:

$$\alpha = \arctan \frac{2d}{h} \quad (3.1)$$

<table>
<thead>
<tr>
<th>criterion/ideas</th>
<th>rolling grid</th>
<th>mobile stack</th>
<th>4-squares</th>
<th>Puzzle</th>
<th>Lego</th>
<th>Magnet</th>
<th>Velcro</th>
<th>latches(RB-like)</th>
</tr>
</thead>
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Table 3.1: Comparison of ideas for attachment between squares.
\[ \alpha < 2^\circ \text{ and } d = 0.1 \]  

(3.2)

\[ h > \frac{2d}{\tan \alpha} = 5.72[mm] \]  

(3.3)

Thickness must be at least 5.72 mm, but we can take a thickness of 8 mm:

\[ \alpha = \arctan \frac{2d}{h} = \arctan \frac{2 \cdot 0.1}{8} = 1.43^\circ \]  

(3.4)

A plate of 8mm is largely stiff, but it is hard for the Roombot to make vertical movement with only 1.43° of error. We can help it by putting chamfer of 2mm at bottom of squares. We keep thickness of 6 mm and we have a help for placement. In this configuration, the horizontal displacement between two squares is only of 0.2 mm.

Grid deployment seems fine, but there was still a problem to store squares in stack. How to make a stack stable enough and how to move this stack? Is it better to have another mobile robot with a unique task of storing the stack or can a RB-metamodule move a stack of squares? There is a locomotion for the Roombot as quadruped or as car, but the stack has to be stable enough on it. That is not clever to have a robot only for stack: there is a problem when it fails and there is an additional robot to control. Thus, the next step was to develop a way to build stack and move it only with Roombot.

Figure 3.8: A configuration of Roombot. It can move as quadruped or as car.

There are many ways to hold squares as stack, I sketched some ideas and compare them in Table 3.2.
Build stack of squares with magnet has a great advantage: the RB-metamodule used as hoist can drop the square. It will be aligned with other squares by the magnets. If the pull force of magnet is too strong, it will be difficult to pick squares. But if it is too weak, when the stack bends a bit, everything will fall down. Square has some magnets with weak pull force and an outgrowth at the bottom of it and a gap at the top of it.

We can build stack and grid with this kind of square. But how to move them from storing place to deployment place? As mentioned before, a way to move stack is to use a
Figure 3.13: Bottom view. Attachment by puzzle mechanism. In black, magnets that help to hold squares as stack. Little outgrowths in corner that stabilizes stack and chamfer of 2 mm that helps for placement.

Figure 3.14: Top view. Gap at corners that stabilizes stack.
A particular configuration of Roombots. But first, we needed a piece that makes connection between stack of squares and Roombot. The idea was simply to have piece with same properties (magnets, outgrowth and gaps) than squares but without puzzle mechanism and put on the bottom a PCB that is already drawn. A Roombot can hold it with its latches.

![Figure 3.15](image.png)

Figure 3.15: This piece makes junction between Roombot and stack of squares.

A configuration of RB that can hold stack of squares and move them is shown on Figure 3.16.

When RB-quadruped reaches its target position, it can deploy its grid. A previous work was made about reachable positions of a RB-metamodules [27].

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Table 3.2: Comparison of ideas for stack.
Figure 3.16: RB in quadruped configuration. It can move as a car or as a quadruped. Two “cubes” in the center can be horizontal and hold the stack. In this case, RB-metamodule knows where is its stack and can put the first square as a reference.

Figure 3.17: A vision of grid deployment. It may be needed more than only one RB-metamodule to extend grid.
3.4 Conclusion

This part of my semester project is more a study about some grid deployment possibilities than a real project. Nothing can be produced unchanged. I tried to open ways for designs in more details without anything being tested. My solution is a square with passive connection and able to be stacked and deployed by RB-metamodules. Sizing of magnets lacks, because it is better to test some kind of magnets with a gap between them before making the design of square. Of course, some improvements can be made on my square. For instance, a puzzle connection shorter that avoids collisions with the RB-module on grid when it needs to place another square just near to it. Because my solution is purely passive, there is some work to make sequence of deployment and storing. I really think that an extendable grid is a good extension for RB project and hope there it will be more works on that. As future work, we can:

- build some functional sample of my square,
- try to improve others ideas,
- and make an RB-sequence for deployment of grid.

Figure 3.18: A modified puzzle mechanism. As connection is shorter, it avoids collision with RB-metamodule during deployment.
Chapter 4

Conclusion

The first part of my semester project works very well and I am very proud of it, but it took more time than I thought. Therefore, the second part seems sloppy and does not come to a final product. However this part deserves more than seven weeks to achieve its goal. Anyway, both projects were very motivating because the goal was clear and the greatest part was about imagination and creativity. Liberty that I had for both project was really a good opportunity to explore different sources of patents, publications or everything that can bring inspiration. I had the chance to apply several concepts that I learned during my Bachelor years. As it is my first semester project, it was instructive to discover how an EPFL-lab works and I had chance to familiarize myself with \LaTeX.

4.1 Acknowledgment

Many thanks to my supervisor Rico Möckel who supported me well and reminded me how to work on a real project. Thanks to Alexander Spröwitz who helped me a lot with mechanical design and who said directly what was wrong. Thanks to Stéphane Bonardi who speaks French and who answered kindly to my questions. Thanks to Alessandro Crespi who helped me with particular things of the lab. Thanks to Professor Auke Ijspeert who gave me a project with tangible aim. Many thanks to Sébastien Aeppli who answered to my several questions, was really patient and made an excellent work with the sink and also to Alfred Thomas, the ATPR workshop’s leader. Spending a lot of time on both projects was funnier with my comrades of this lab.
Bibliography


4.2 Appendix A: Sink’s Drawings

The first drawing shows all designed pieces, screws and their number. Next drawings are pieces that compose the sink.
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QUAL.
HAB.
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07.11.2010
NOM
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AUTEUR

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SAUT I INDICATION CONTRAIRE:

A

B

C

D

E

F

1102

support gauche

COUPE A-A

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2X M6 A TRAVERS TOUT

4X M2 A TRAVERS TOUT

79.3
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36.5
36.5
30
30
8.600
7218
8.7
14
35.8
125
60
45
30°
30°
5
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320
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105.5
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0.70
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- **Longueur** : 20

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- Reste de matière disponible

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- **Acteur** : EPFL - Biorob

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2 pièces

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- Angular: Mach: Bend:
- Two place decimal:
- Three place decimal:

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Application: Do not scale drawing

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sortie_support

3 pièces

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