



Belrobotics	
Leader in the automatic maintenance of large grounds	
1	<i>Automatic lawn mowers. How does it work?</i>
2	<i>Installation rules</i>
3	<i>Appendices</i>



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Belrobotics

Leader in the automatic maintenance of large grounds

1

Automatic lawn mowers. How does it work?

a.

Peripheral wire and magnetic field

b.

Random pattern and wire detection

c.

Return to the docking station at the end of the work cycle

d.

Detection of obstacles. Operation and safety sensors

e.

Critical obstacles to detect

f.

Narrow paths and long lanes

g.

Islands and pseudo-islands

h.

Obstacles, islands and pseudo-islands

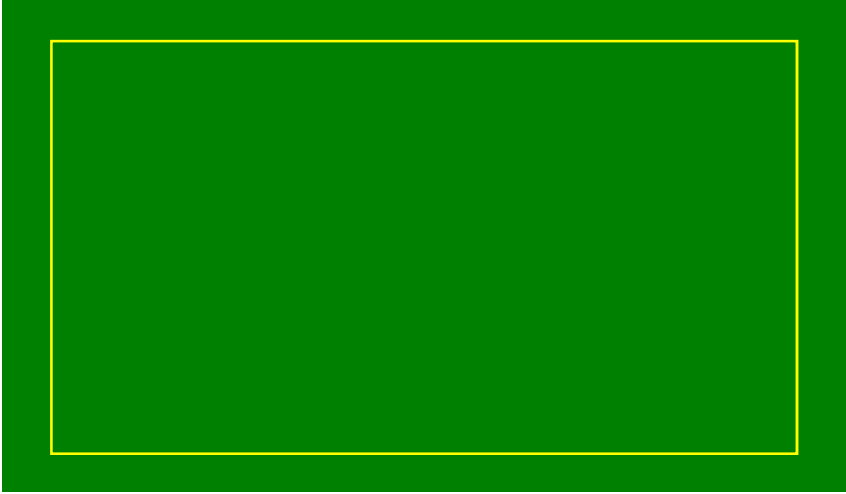
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How does it work?

A peripheral wire surrounds the ground to be maintained



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How does it work?

The docking station generates a signal creating a magnetic field

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How does it work?

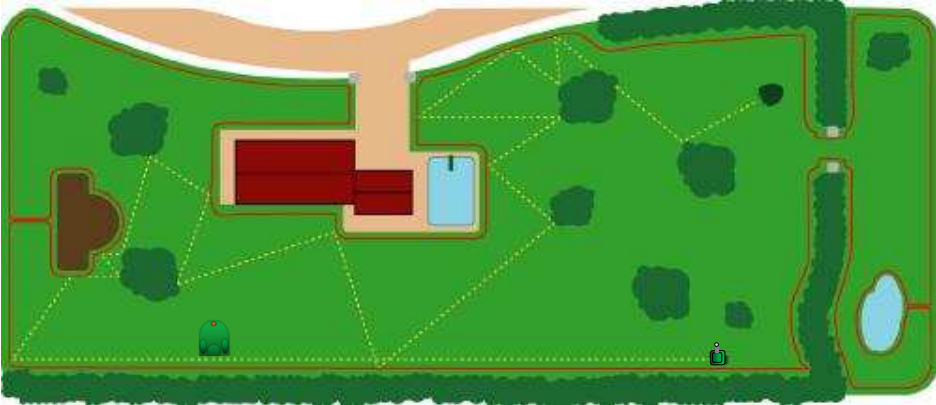
The robot works its way out randomly on the surrounded area

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How does it work?

The robot works its way out randomly on the surrounded area



The diagram shows a green lawn area with a red building and a blue pond. A small green robot is positioned on the lawn. A dashed yellow line indicates a random path the robot takes as it mows the area. The path starts from the robot and moves in a series of connected line segments, covering the lawn area in a non-linear fashion. The path ends near a small blue pond on the right side of the lawn.

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How does is work?

At the end of its work cycle, the robot returns to its docking station



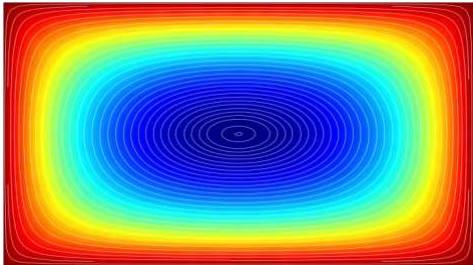
The diagram shows a green lawn area with a yellow rectangular boundary. A small green robot is positioned in the center of the lawn. A small blue square with a white dot is located on the left side of the lawn, representing the docking station. A dashed yellow line indicates the path the robot takes as it returns to the docking station. The path starts from the robot and moves in a series of connected line segments, eventually leading to the docking station.

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How does it work?

What does the robot see inside this electro-magnetic field?



Theoretical concept

- Each line has the same electro-magnetic field strength (like isobarics, isotherms, etc.)

In practice

- Soil configurations can sorely interfeerer with this electro-magnetic field (sources, rills, water pipes, electric cables, metal frameworks,...)
- Nearby transmitters could interfere with this electro-magnetic field (antennas, high voltage power lines, radio/TV emitters, other robots signal,...)

Use

- The electro-magnetic lines closer to the wire are called «track borders». Robots follow them while coming back to its docking station.
- Belrobotics robots can be adapted (via parameters set-up) to work safe despite electro-magnetic interferences (this is a unique feature of Belrobotics robots)

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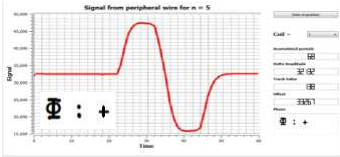
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How does it work ?

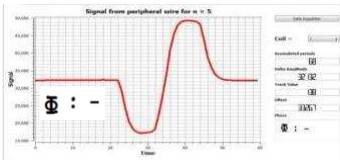
The robot knows its distance from wire by analysing the EM-field

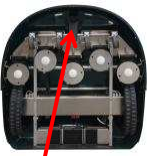


Inside of working area



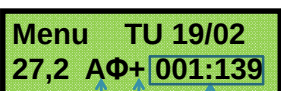
Outside of working area





Inductor

- The embedded inductor senses the EM-field. It send information to the electronic filters on the main board to analyse the relative position (to the peripheral wire) of the robot.
- The « **track value** » is an approximation of the distance between the robot and the nearest wire.
- Phase** of the signal can be positive or negative, depending on the position of the robot : if it is inside or outside of its working area.
- Track Value and Phase can be read using "F3"**



Working Zone (2013 SW) Phase Sign Track Value

When the inductor moves from one side of the wire to the other side, the signal changes phase: this is why the robot needs to pass the wire to know it has passed the wire!

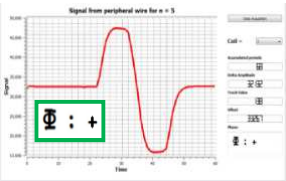
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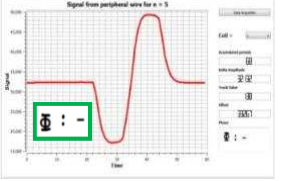
How does it work

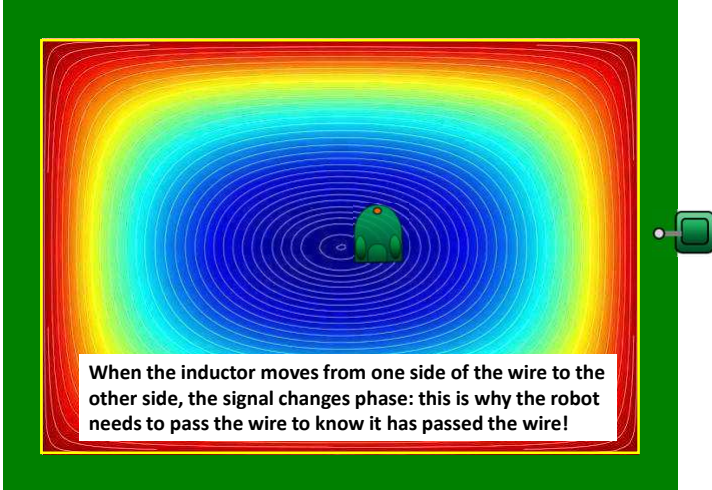
The robot knows its distance from wire by analysing the EM-field

INSIDE



OUTSIDE



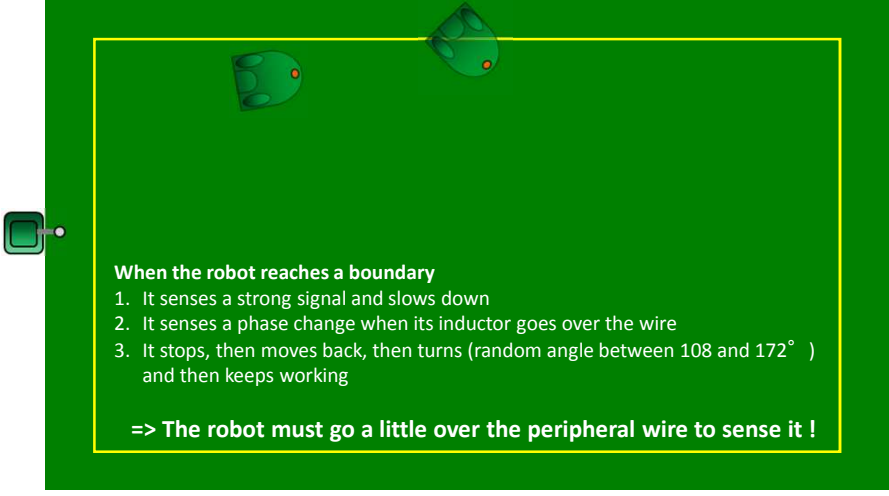


When the inductor moves from one side of the wire to the other side, the signal changes phase: this is why the robot needs to pass the wire to know it has passed the wire!


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How does it work?

Robot moves as the peripheral wire approaches



When the robot reaches a boundary

1. It senses a strong signal and slows down
2. It senses a phase change when its inductor goes over the wire
3. It stops, then moves back, then turns (random angle between 108 and 172°) and then keeps working

=> The robot must go a little over the peripheral wire to sense it !


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How does it work?

At the end of a work cycle, the robot gets back to its docking station



The diagram shows a green lawn with a yellow rectangular boundary line. A small green robot with a red light on top is positioned in the center of the lawn. To the left of the lawn, there is a green square representing the docking station, connected to the lawn by a small line.

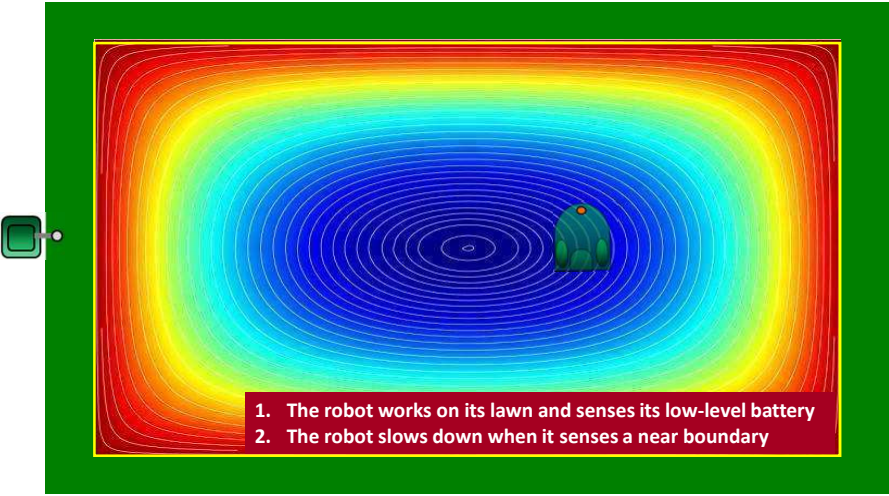


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How does it work?

At the end of a work cycle, the robot gets back to its docking station



The diagram shows a green lawn with a yellow rectangular boundary line. A small green robot with a red light on top is positioned in the center of the lawn. To the left of the lawn, there is a green square representing the docking station, connected to the lawn by a small line. The lawn is filled with concentric lines and a color gradient from blue in the center to red at the edges, representing a field or sensor data.

1. The robot works on its lawn and senses its low-level battery

2. The robot slows down when it senses a near boundary



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How does it work?

At the end of a work cycle, the robot gets back to its docking station

The diagram illustrates a robot (green) moving along a track defined by concentric EM-field lines (color gradient from blue to red). The robot is positioned near the top right corner of the track. A docking station (green square) is located on the left side of the track. A red arrow indicates the robot's path following the field lines towards the docking station.

3. The robot follows a given EM-field line (track border)

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How does it work?

At the end of a work cycle, the robot gets back to its docking station

The diagram illustrates a robot (green) moving along a track defined by concentric EM-field lines (color gradient from blue to red). The robot is positioned near the top right corner of the track. A docking station (green square) is located on the left side of the track. A red arrow indicates the robot's path following the field lines towards the docking station. A blue semi-circular area labeled 'U' docking Standard mode' is shown on the left side of the track, with a red arrow indicating the robot's path following the field lines towards the docking station.

'U' docking
Standard mode

4. The robot follows the wire when it senses the station

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How does it work?

At the end of a work cycle, the robot gets back to its docking station

The diagram illustrates the 'S' docking alternative mode. A large blue semi-circle represents the robot's field of view or sensor range. A red arrow indicates the robot's path as it follows a wire back to the docking station. The background is a color-coded field representing signal strength, with concentric lines indicating the range of the signal. The docking station is shown as a small green rectangle on the left.

'S' docking
Alternative mode

4. The robot follows the wire when it senses the station

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How does it work?

At the end of a work cycle, the robot gets back to its docking station

The diagram illustrates the 'S' docking alternative mode. A large blue semi-circle represents the robot's field of view or sensor range. A red arrow indicates the robot's path as it follows a wire back to the docking station. The background is a color-coded field representing signal strength, with concentric lines indicating the range of the signal. The docking station is shown as a small green rectangle on the left.

5. The robot gets near the station to get a physical contact
6. The robot recharges for 50' up to 90'

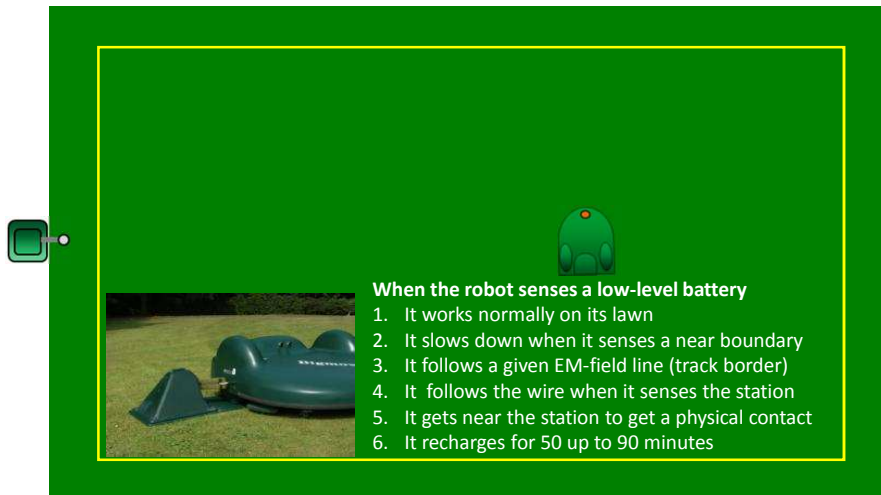
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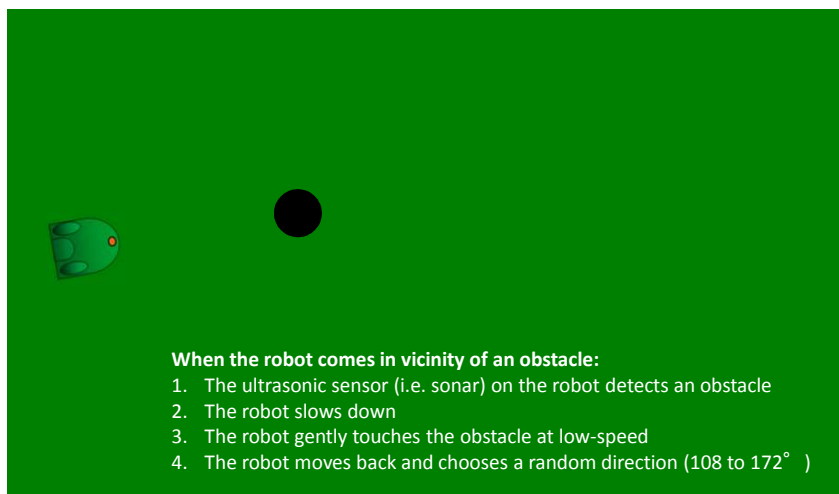
How does it work?

At the end of a work cycle, the robot gets back to its docking station



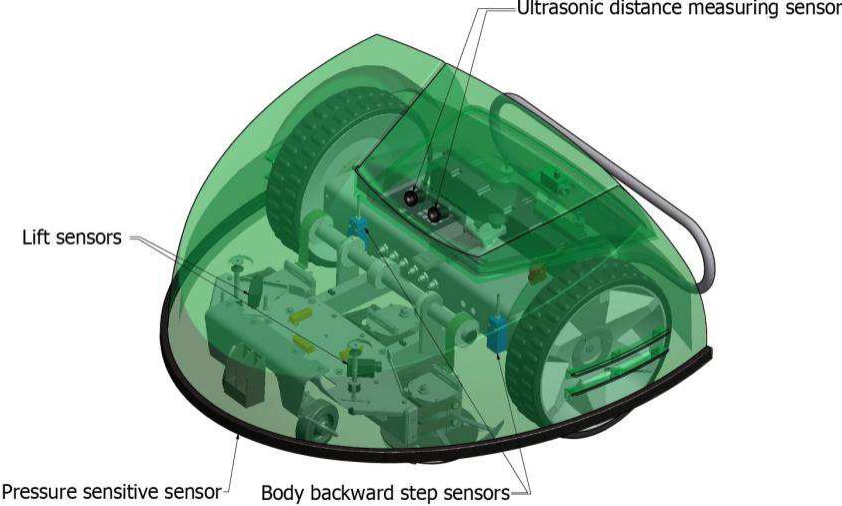
How does it work?

Detection of an obstacle



How does it work?

Sequential operation of 4 sets of sensors + wheel torque



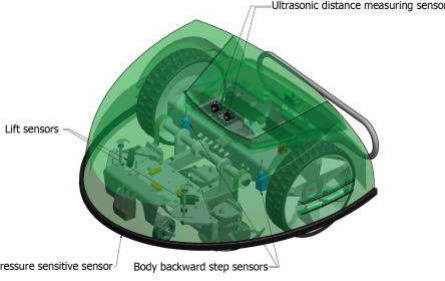
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How does it work?

Sequential operation of 4 sets of sensors + wheel torque

- The sonar (ultrasonic distance measuring sensor) detects one obstacle and slows the robot down.

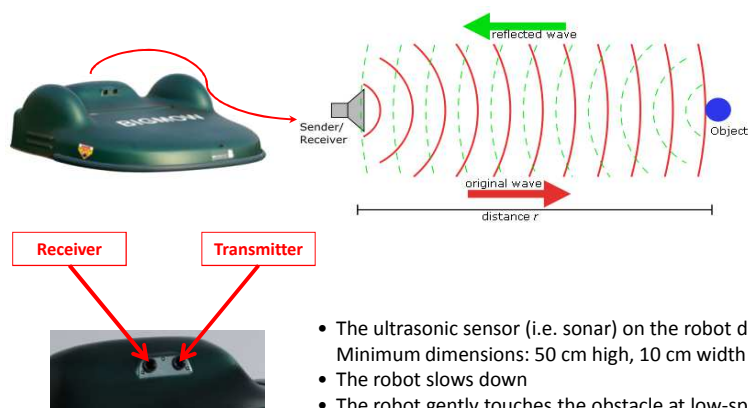


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How does it work?

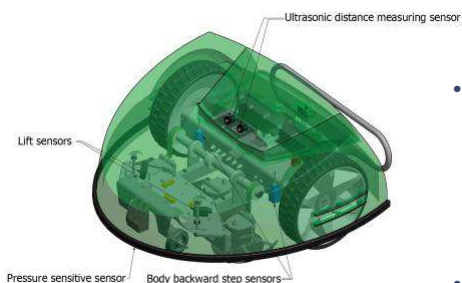
Detection of an obstacle



- The ultrasonic sensor (i.e. sonar) on the robot detects an obstacle. Minimum dimensions: 50 cm high, 10 cm width
- The robot slows down
- The robot gently touches the obstacle at low-speed
- The robot moves back and chooses a random direction (108 to 172°)
- The sonar frequency (40 kHz) does not perturbate animals

How does it work?

Sequential operation of 4 sets of sensors + wheel torque



- The robot gently touches the obstacle: the pressure sensor triggers and the robot manoeuvres.
- With higher obstacles (e.g. tree branches), the body touches the obstacle, the body backward step sensor triggers and the robot manoeuvres.
- When robot is lifted up, the lift sensors trigger, the cutting heads stop spinning and the robot pulls back. If lifting is caused by an obstacle, the robot keeps pulling back, manoeuvres and resumes mowing. If lifting up results from a human intervention, the robot stands still.
- When no sensor triggers and torque on driving wheel reaches its limit (e.g.. steep slope), the robot manoeuvres (takes an angle) to reduce torque and to keep mowing.

How does it work?

Obstacles. Best practices

- The sonar system detects obstacles
 - at least 50 cm high
 - at least 10 cm wide (from all angles)



> 50 cm



How does it work?

Critical obstacles found in gardens



- US wave from the sonar is reflected to the sky: the robot does not see the footage of the swing
- Protection poles cannot be used as they are too dangerous for children
- Solution: island or pseudo-island (see next section)



- The robot sees the horizontal mattress of the trampoline, when it is low height (the sonar sees low tree branches as well)
- Trampoline footage trap cutting heads and damage heads and blades
- Solutions: (i) island/pseudo-island (see next section), (ii) protection planks attached to footage around the trampoline, (iii) burry horizontal footage sections

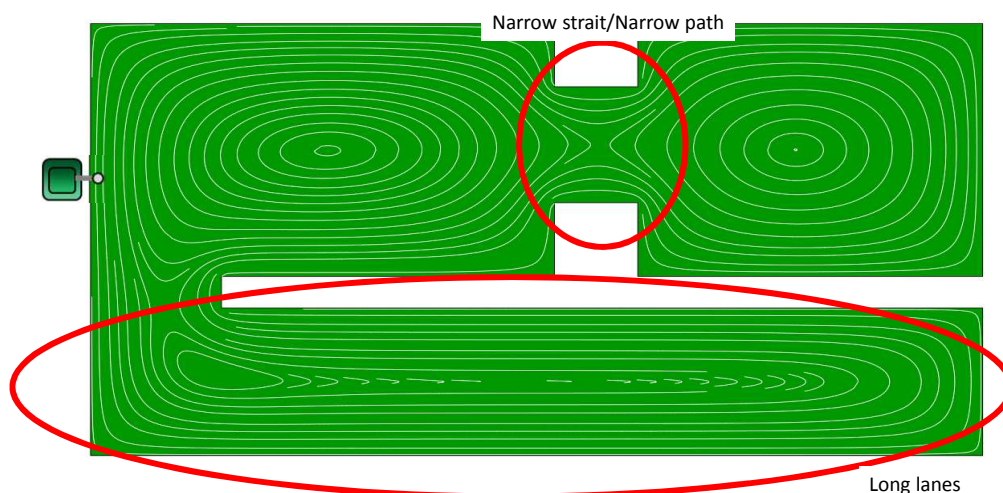
How does it work?

Obstacles. Best practices

- An alternative to island and pseudo-island is to put protections (obstacles) preventing the robot from entering the protected zone.
- The maximum distance between two adjacent obstacles must be
 - Maximum 30 cm for Greenmow
 - Maximum 40 cm for Parcmow
 - Maximum 50 cm for Bigmow

How does it work?

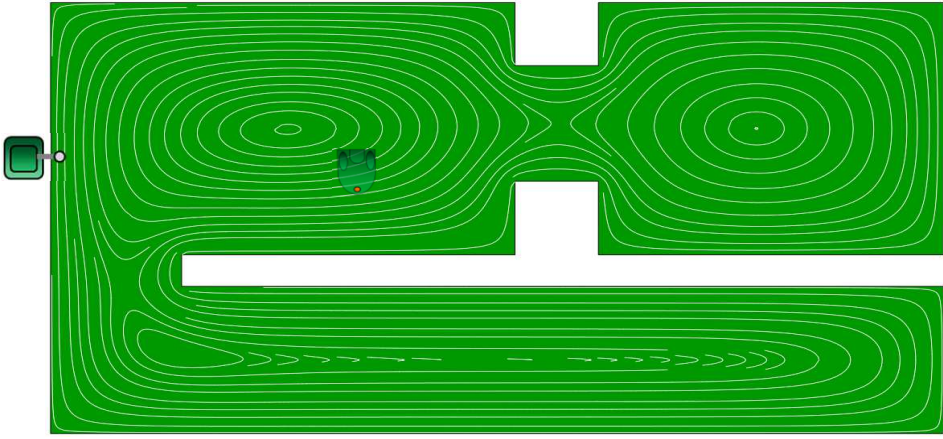
Narrow straits and long lanes



How does it work?

When the strait is wide enough and the EM-field is slightly deformed

- The robot correctly identifies boundaries – the mowing operation is not affected.
- If the electro-magnetic field is only slightly deformed by the strait, and if the track border “passes through this strait”, the robot follows its track border and gets back to its docking station as usual.



The diagram shows a green lawn area with a white track border. A strait is cut through the lawn. Concentric white lines representing the electro-magnetic (EM) field are shown. The lines are slightly deformed by the strait but remain mostly concentric. A small robot icon is positioned on the track border within the strait. A docking station icon is located on the left side of the lawn.

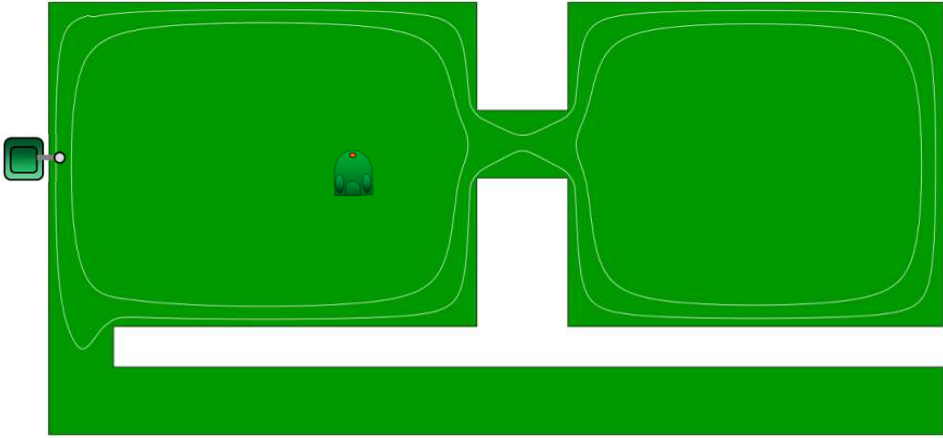
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How does it work?

When the strait is narrow and the EM-field is significantly deformed

- The robot correctly identifies boundaries – the mowing operation is not affected.
- If the electro-magnetic field is significantly deformed by the strait, and if the robot is in the docking station zone, the robot follows its track border and gets back to its docking station as usual.



The diagram shows a green lawn area with a white track border. A narrow strait is cut through the lawn. The white lines representing the EM field are significantly distorted and compressed within the strait. A small robot icon is positioned on the track border within the strait. A docking station icon is located on the left side of the lawn.

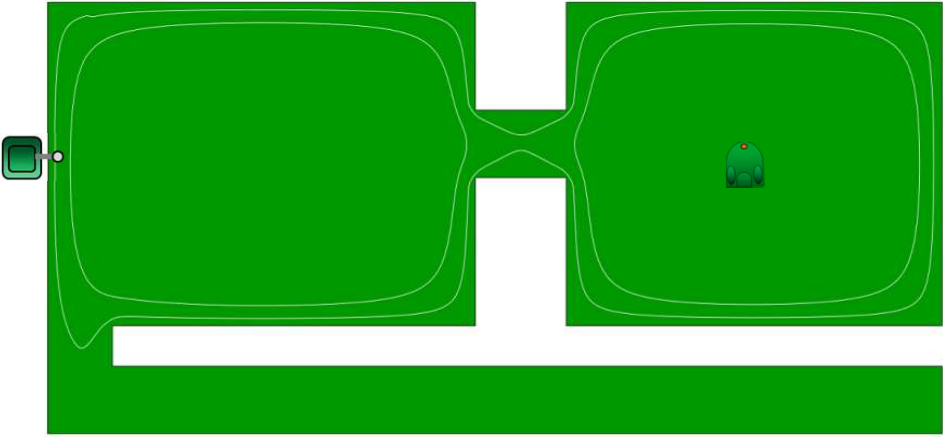
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How does it work?

When the strait is narrow and the EM-field is significantly deformed

- The robot correctly identifies boundaries – the mowing operation is not affected.
- If the electro-magnetic field is significantly deformed by the strait, and if the robot is not the docking station zone, the robot follows its track border and will never get back to its docking station.

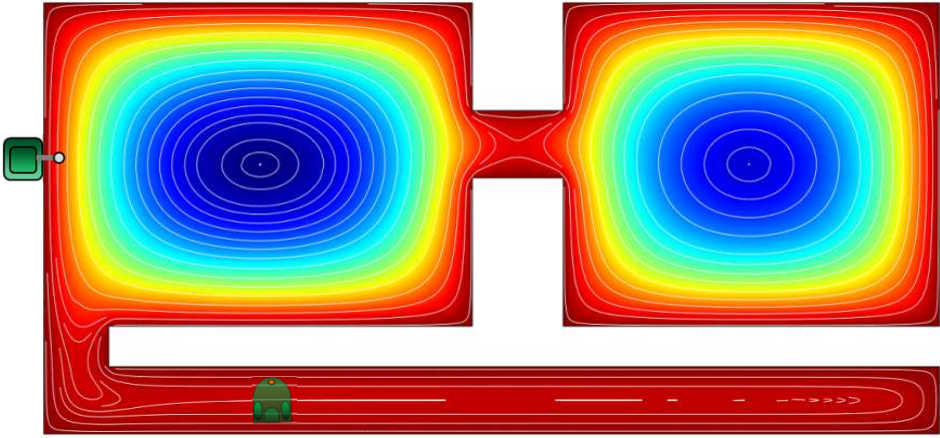


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How does it work?

Long lanes isolated from other areas: risk of discharging the battery



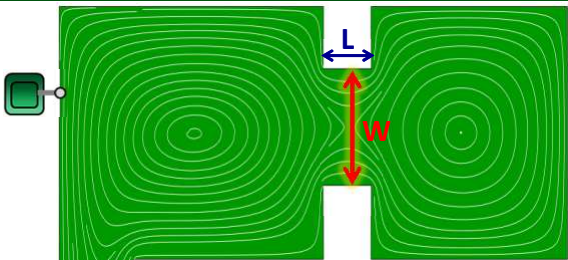
The signal strength is very high in this long lane and the robot does not find its track border. The robot keeps on mowing while moving randomly in search of its track border. If the robot does not leave the long lane on its own, it will end up with a low battery in the long island!

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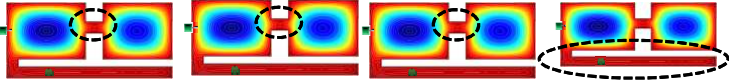
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How does it work?

Minimum distances in narrow straits – for robots made as from 2012



	Minimum distance between wires (W)			
<i>Strait length (L)</i>	< 1 m	1 < x < 5 m	5 < x < 15 m	> 15 m
Bigmow (BM)	4,0 m	4,5 m	5,0 m	10,0 m
Parcmow (PM)	3,0 m	3,5 m	4,0 m	8,0 m
Greenmow (GM)	2,0 m	2,5 m	3,0 m	6,0 m

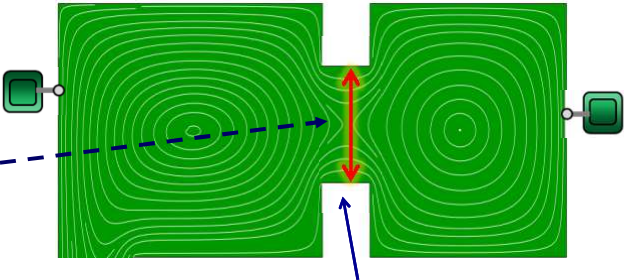


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How does it work?

First alternative solution to critical narrow straits: additional docking stations

	Minimum distance between wires
Bigmow (BM)	2,5 m
Parcmow (PM)	2,5 m
Greenmow (GM)	2,0 m



Maximum strait length is 5,0 m

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How does it work?

Second alternative solution to critical narrow straits: option “return on wire”

	Minimum distance between wires
Bigmow (BM)	2,5 m
Parcmow (PM)	2,5 m
Greenmow (GM)	2,0 m

If the strait is longer than 5,0 m or if the strait is narrower than values in this table, the option “return on wire” (OPT 14) should be selected.

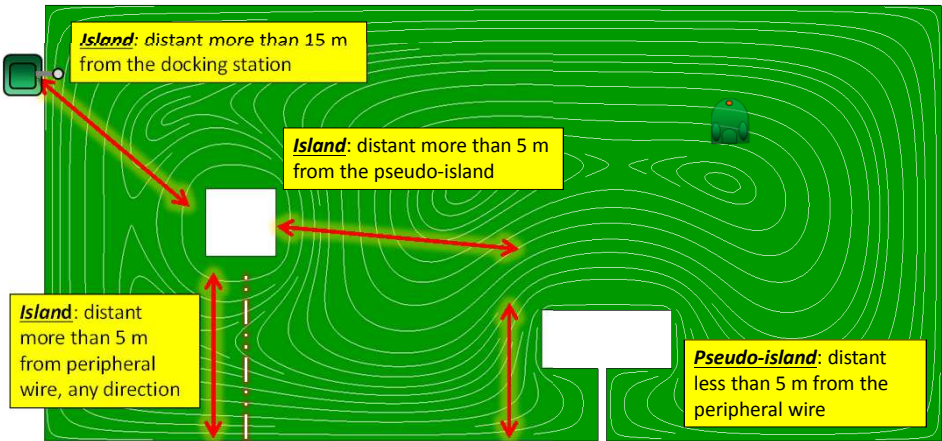
In this instance, the robot will travel back to its docking station on the wire.

When option “return on wire” is selected

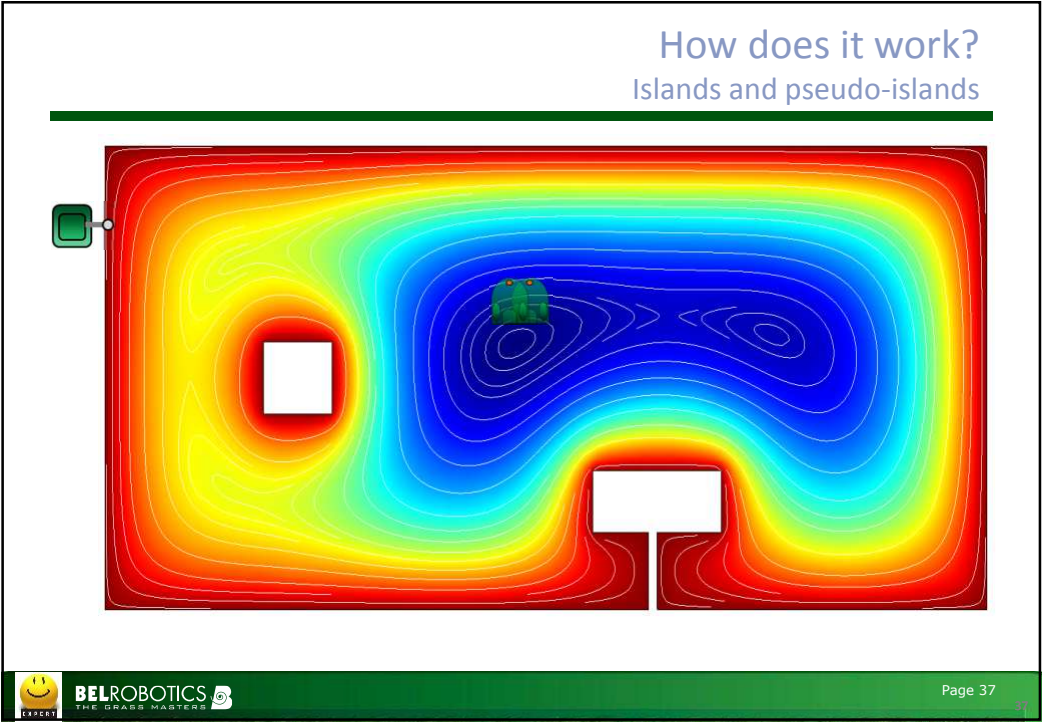
- there can be no obstacles/wall/fence in the way of the robot (the robot will not be allowed to deviate from its wire)
- the absolute minimum width in the narrow path is 0,6 m.

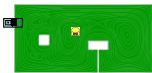
How does it work?

Islands and pseudo-islands



Refer to installation rules for the layout of the peripheral cable around the field to be mowed, the islands and the pseudo-islands





Islands and pseudo-islands

Best practices

Islands	Pseudo-islands
Application: to isolate an area that cannot be protected by a physical barrier, that could damage or trap the robot or that cannot be detected by the sonar/touch sensor	
General condition: the area does not form a long lane neither a narrow strait with the peripheral wire	
Other conditions: • Diameter or side < 5 m • Area edge at least 5 m away from boundary wire or other island and at least 15 m away from the docking station • No bean-shaped (see next slides) • No more than 5 islands	Other conditions: • Diameter or side > 5 m • Smaller areas that are not eligible to islands because too close to the boundary wire or to another island, or to the docking station • Any size with critical shape (bean or alike) that excludes island configuration • No more islands allowed
Examples: flower bed in the middle of the lawn, tree with roots over the ground level	Examples: swimming pool, tennis court, tight grove of trees, greenhouse, large flower bed



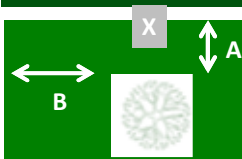
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Obstacles, islands and pseudo-islands

How to treat islands/pseudo-islands near corners?



Let's assume a tree next to a corner with distance A shorter than distance B:

- If ($A < 5\text{ m}$) and ($B < 5\text{ m}$) : a pseudo-island must be used, ideally starting from point X to provide easier access to the zone between the tree and the corner
- If ($A < 5\text{ m}$) and ($B > 5\text{ m}$) : no island may be used because there is wire at less than 5 m from the island. A pseudo-island must be used, ideally starting from point X to provide easier access to the zone between the tree and the corner
- If ($A > 5\text{ m}$) and ($B > 5\text{ m}$) : an island can be used, ideally starting from point X to minimize wire length



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Obstacles, islands and pseudo-islands

How does the robot spin around an island and leave the island?

The diagram shows a green rectangular field with a yellow border. A small green robot is positioned on the right side of the field. A large brown circle labeled "Island" is in the center. A dashed line extends from the left side of the island to the left edge of the field, with a double-headed arrow below it labeled "> 5m". A small green square icon is located on the right edge of the field.

Assume the robot is on its way to the peripheral wire to the docking station. Assume it comes to the island. It then follows the wire clockwise (or counter-clockwise), make a 360° turn, goes a little further and understands it is spinning around an island. It then quits the island to the nearest peripheral wire. From there on, it follows the wire to the docking station.

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Obstacles, islands and pseudo-islands

How does the robot spin around an island and leave the island?

The diagram shows a green rectangular field with a yellow border. A small green robot is positioned on the right side of the field. A large blue bean-shaped island is in the center. A dashed line extends from the left side of the island to the left edge of the field, with a double-headed arrow below it labeled "> 5m". A small green square icon is located on the right edge of the field.

The same robot comes to a island of a "bean" shape. The robot follows the wire clockwise and after some time goes counter-clockwise, before spinning clockwise again. The robot does not immediately understand it is spinning around an island. It may either keep spinning till battery is exhausted, or end up exhausted somewhere else after dilapidating too much energy by spinning too long around the island.

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Obstacles, islands and pseudo-islands

How does the robot spin around an island and leave the island?

The diagram shows a green rectangular field with a yellow border. A blue curved arrow indicates a 180-degree turn around a small green island. A double-headed arrow on the left indicates a distance of $> 5m$ from the left edge to the start of the turn. A small robot icon is positioned at the top right corner of the field.

Solution: make this shape a pseudo island!

Refer to rules for distances between parallel wires to a pseudo-island, and specifically for pseudo-islands remote from peripheral wire

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Obstacles, islands and pseudo-islands

How to treat trees? Obstacles, islands or pseudo-islands?

A photograph of a large, open garden with many trees of varying sizes. The ground is covered in grass and some low-lying shrubs. The sky is overcast.

Large garden with many trees. Most trunks are large and detected by sonars. They go straight into the ground, without surface roots → they are treated like obstacles. Islands and pseudo-islands should be avoided every time possible to facilitate the evolution of the robot on the field

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Obstacles, islands and pseudo-islands

How to treat trees? Obstacles, islands or pseudo-islands?

Large trunks going straight into the ground, surrounded by a level-off zone: the best solution is to fill the cavity with ground or wooden chips to level off the ground.



Obstacles, islands and pseudo-islands

How to treat trees? Obstacles, islands or pseudo-islands?



Weak trunks cannot be detected by sonars: protection poles should be used

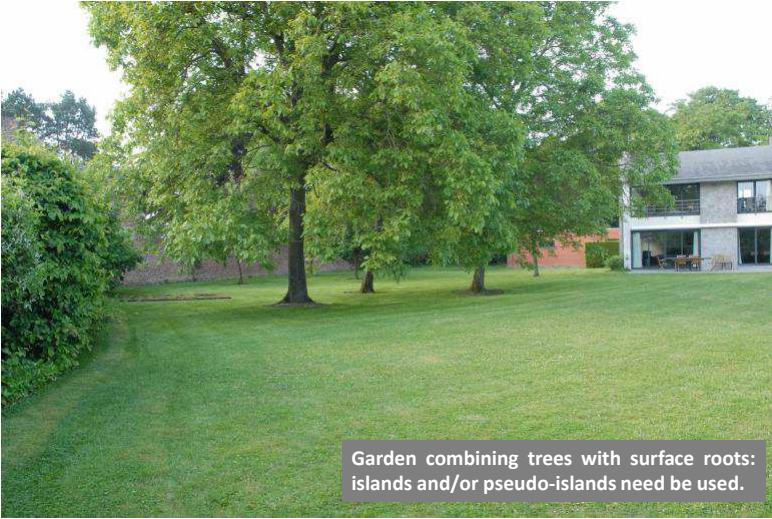


Some obstacles feature pedestals or base that could damage the robot: protection poles must be used preventing the robot coming in contact with the obstacle



Obstacles, islands and pseudo-islands

How to treat trees? Obstacles, islands or pseudo-islands?



Garden combining trees with surface roots:
islands and/or pseudo-islands need be used.

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Obstacles, islands and pseudo-islands

How to treat trees? Obstacles, islands or pseudo-islands?



These two trees are too close one to each
other to be treated like 2 islands (minimum
distance between 2 islands is 5 meters).

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Obstacles, islands and pseudo-islands

How to treat trees? Obstacles, islands or pseudo-islands?



Zoom on surface roots: putting protection poles was rejected by the customer: islands and/or pseudo-islands need be used.

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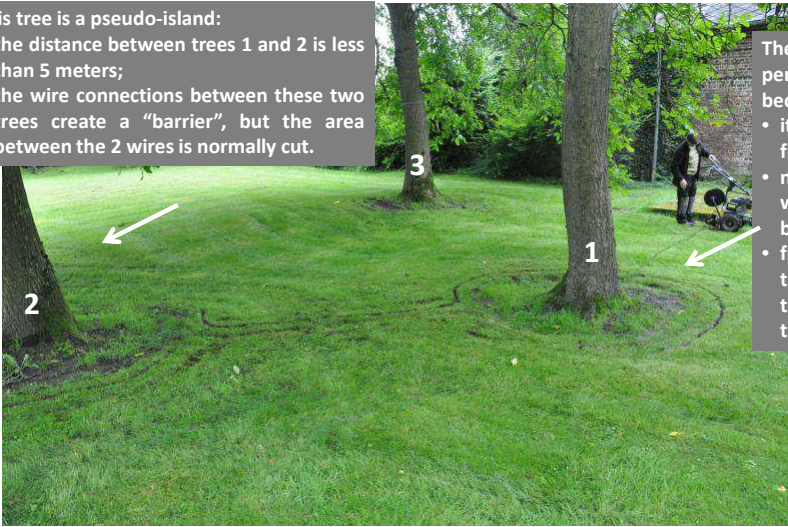
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Obstacles, islands and pseudo-islands

How to treat trees? Obstacles, islands or pseudo-islands?

This tree is a pseudo-island:

- the distance between trees 1 and 2 is less than 5 meters;
- the wire connections between these two trees create a “barrier”, but the area between the 2 wires is normally cut.



The tree next to the peripheral wire becomes an island:

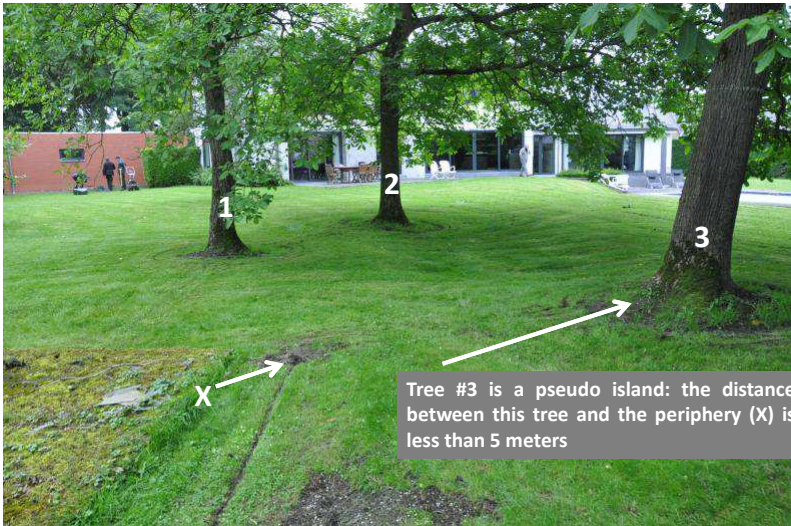
- it is at more than 5 m from periphery;
- no waste of time when robot gets back to its station
- free access to mow the area between the periphery and this tree

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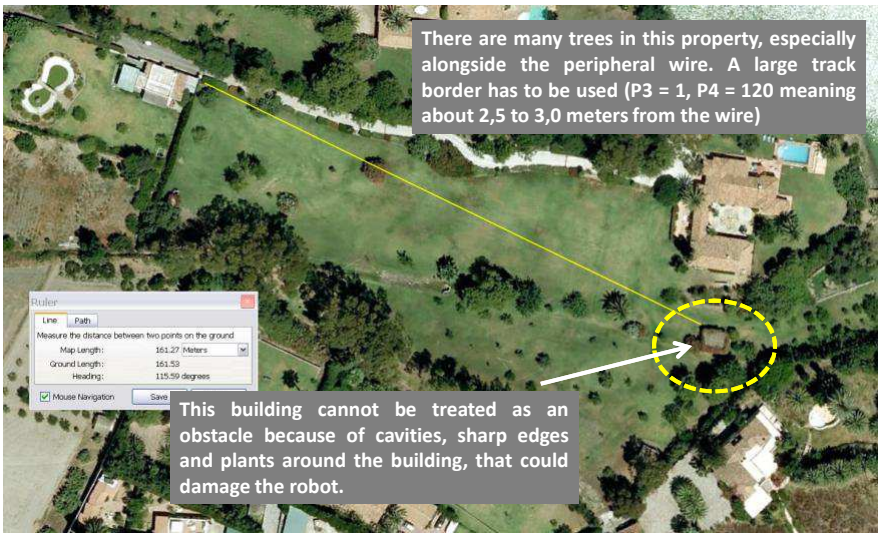
Obstacles, islands and pseudo-islands

How to treat trees? Obstacles, islands or pseudo-islands?



Obstacles, islands and pseudo-islands

Constructions inside the mowing area



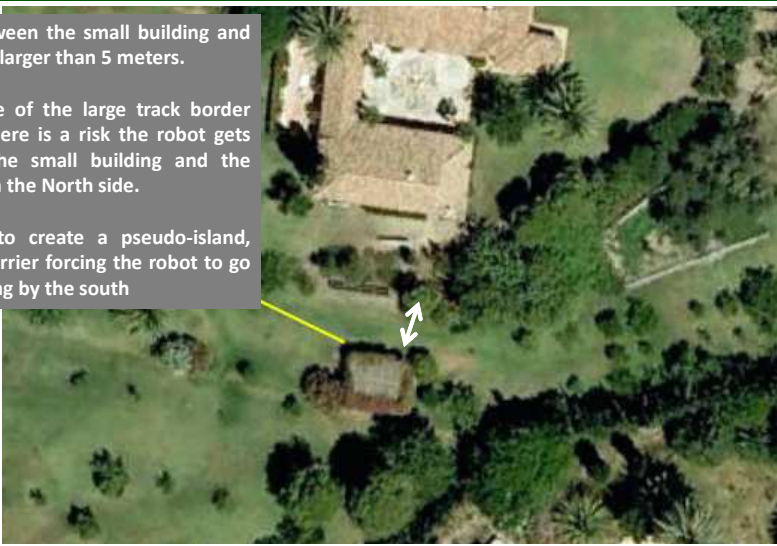
Obstacles, islands and pseudo-islands

Constructions inside of the mowing area

The distance between the small building and the nearby villa is larger than 5 meters.

However, because of the large track border (2,5 to 3,0 m), there is a risk the robot gets stuck between the small building and the peripheral wire on the North side.

The solution is to create a pseudo-island, which makes a barrier forcing the robot to go around the building by the south

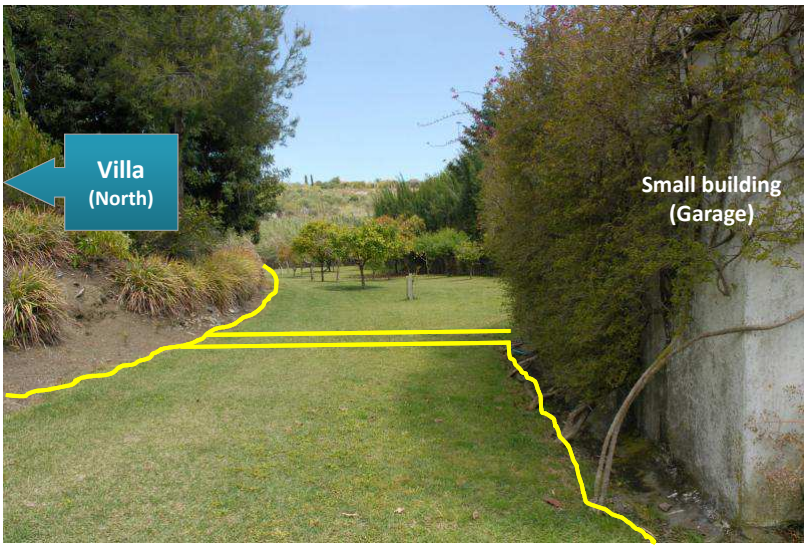


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Obstacles, islands and pseudo-islands

Constructions inside of the mowing area



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Obstacles, islands and pseudo-islands

Unusual items: sculptures



In this instance, the sonars will not detect the sculpture when coming from left or right. Consequently, the robot would hit the sculpture at full speed. This is not acceptable neither for the robot ... nor for the sculpture.

When customers accept to put protection poles around the sculpture, it is technically speaking the best solution.

When they do not accept protection poles for aesthetics, sculptures must be treated as islands or pseudo-islands depending on their location.

Obstacles, islands and pseudo-islands

Unusual items: sculptures

No matter in this instance: the sonars will detect the sculptures.

No specific precautions required.



Obstacles, islands and pseudo-islands

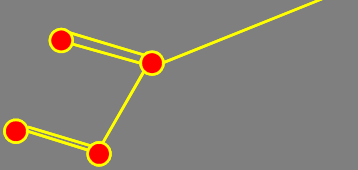
Unusual items: sculptures



Serious matter in this instance:

- the sonars will not detect detect the sculptures when coming from “parallel angles” to the sculpture;
- protection poles are not feasible (for aesthetics);
- a unique island/pseudo-island is feasible, but would force gardener to use a trimmer to cut grass under the sculpture.

For experts: assuming the four feet of the sculpture are spread with at least 5 meters two by 2, a combination of islands and pseudo-islands could be considered



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2	Installation rules
a.	Peripheral wire
b.	Docking station, islands, pseudo-islands, boundaries, distance rules
c.	Steep grounds
d.	Narrow straits
e.	Location of the docking station
f.	Position of the docking station on the wire
g.	Docking station: connections and settings

Installation rules

A well-done installation avoids 90% of potential problems

- Specific study before installing
 - Path for peripheral wire, docking station location, islands and pseudo-islands choice, parameters, slope, peripheral wire length needed, etc.
- Practical training of a dealer on two installations:
 - First installation made by a importer's technician with the assistance of the dealer's technician (as an assistant)
 - Second installation made by the dealer's technician with the importer's technician attending (as a supervisor)
- Show daily operations to the end user (on/off, start, return to station, keyboard, cleaning and inspection)
- Sell the installation for what it's worth and include a provision for customer support during the first month. Typical budget of 1.000 to 3.000 € excl. VAT

Installation rules

Peripheral wire – Specifications

- **Length of peripheral wire**
 - Minimum length is 200 m.
For shorter lengths (ex: on a booth of a trade show), use a special inductance (BR99129)
 - Maximum length is 1.200 m.
Extreme shapes (such as very long and narrow stripes, typically 20 m x 500 and more meters long) can limit wire length: see Belrobotics
- **A second docking station is recommended**
 - When the total length of peripheral wire (including islands and pseudo-islands) exceeds
 - 500 m for Greenmows
 - 750 m for Parcmows
 - 1.000 m for Bigmows and Ballpickers
 - When there are more than 5 obstacles on the track border on the way back to the docking station and when the length of peripheral wire “approaches” limits here above

Installation rules

Peripheral wire – Specifications

- **Depth of peripheral wire**
 - Recommended depth: 50 to 70 mm
 - Minimum depth:
 - 20 mm in all instances. Cable should never be able to come to ground surface where it could be damaged by robots and/or by end-users, hence cutting/damaging the wire
 - Deep enough for grounds/locations exposed to heavy duty applications (e.g. in front of goals on football pitches)
 - Maximum depth:
 - A cable buried at 100 to 150 mm (e.g. horse race tracks) should work. This was never tested
 - We know a cable buried at 400 mm does not operate anymore
- **Critical angles**
 - Angles must be wider than 90° . Acute angles may trap robots when mowing
 - Angles must be rounded with a minimum angle of 1,0 m for every robot (GM, PM, BM)

NOK

OK

Installation rules

Peripheral wire – Recommended cable

- Certified for low voltage, underground
- Recommended cable section : 1,5 mm² (max 2,5 mm²)
- Provision for sliding between the external cable casing and the conductors, to avoid breakings caused by local landslides
- Efficient external protection against/no appetite for rodents, etc.
- We recommend red cable on coil of 500 meters:
 - Tinned copper 1,5mm²
 - Resistant
 - Easy to use with a Zuchetti machine



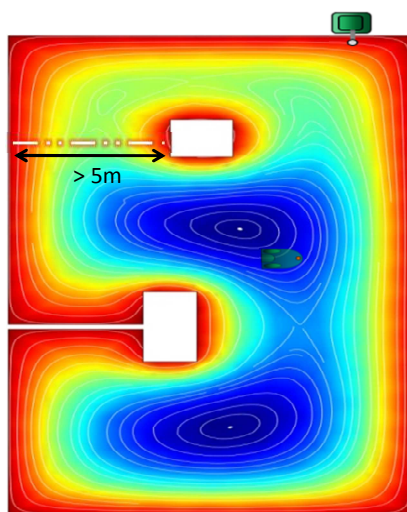
Installation rules

Laying in the peripheral wire. Best practices

- The peripheral wire cannot be crossed and cannot form loops
(except for twisted wire connecting the boundary wire to an island)
- We recommend to
 - Either always lay in peripheral wire **clockwise** from the docking station and always lay in wire **counter clockwise** around islands and pseudo-islands. This is Belrobotics standard
 - Or always lay in peripheral wire **counter clockwise** from the docking station and always lay in wire **clockwise** around islands and pseudo-islands

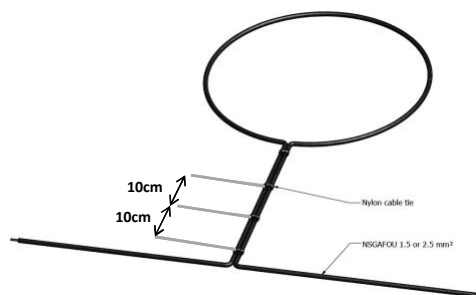
Installation rules

Islands



Maximum 5 islands

To save time while returning to the docking station
AND to avoid bouncing off from island to island



Best practice: twist the cable instead of using cable straps (see picture on next slide)
When using cable straps anyway, position them every 10 cm to avoid distance between the two wires

Installation rules

Islands: prefer twisted cable instead of cable straps



How to twist a pair of cables?

- Put the cable in the ground with the laying machine from the peripheral line to the island
- Give yourself 15% over-length on the section between the peripheral line and the island
- Put the cable in the ground around the island
- Take the cable above the ground to the peripheral line and give yourself 15% over length
- Put the cable in the ground on the peripheral line over a few meters
- Take the two cables connecting peripheral line and island at midway. Insert a screwdriver between the two wires and twist the pair till it is fully twisted over its entire length, with no space between the turns
- Replace the screwdriver by a cable strap
- Lay down the twisted pair into the ground. Done!

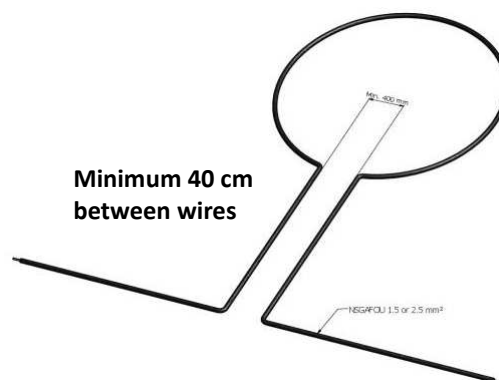
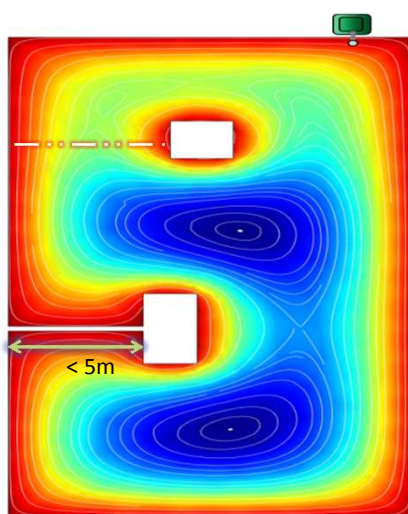


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Installation rules

Pseudo-islands



When using Bigmow on a field with over 5 meters distance between the peripheral wire and the pseudo-island, position wires at 0,6 m from one each other (instead of 0,4 m)

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Installation rules

Pseudo-islands: 0,4 m between wires (0,6 m when length > 5 m)



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Installation rules

Distances reference table

	General rule	Not mowed
Bigmow	60 cm	7 cm
Parcmow	45 cm	7 cm
Greenmow	40 cm	18 cm
Ballpicker	100 cm	

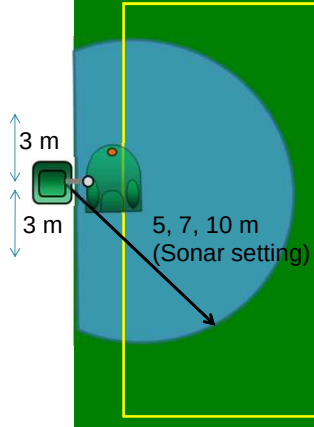
	Path, terrace, flush with lawn level	Not mowed	Flower bed flush with lawn level	Not mowed	Higher level boundaries	Not mowed	Spillover robot wrt peripheral wire
Bigmow	30 cm	0 cm	50 cm	0 cm	65 cm	12 cm	53 cm
Parcmow	15 cm	0 cm	30 cm	0 cm	50 cm	12 cm	38 cm
Greenmow	15 cm	0 cm	25 cm	3 cm	45 cm	23 cm	22 cm
Ballpicker	30 cm		100 cm		100 cm		

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Installation rules

Positioning the docking station. Best practices



Docking station position on a lawn

- ✓ In a free area, without obstacles
- ✓ Adjust docking station sonar signal power setting to 5, 7 or 10 m in function of the distance to the opposite wire
- ✓ On a straight line with 2 times 3 m free sides (see limit configurations in following slides)
- ✓ In a flat area (absolute max. 10% slope)



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Installation rules

Steep ground. Best practices

- The maximum slope of the ground is 30% (17° angle)
 - When the whole ground is a severe slope, disregard our robots
 - If the sloppy area is a limited section of the ground, remote from the boundary wire, no specific action needs be taken
 - If the sloppy area is near the boundary wire, the robot should return to docking station by descending the slope (See Options OPT010 and OPT011)
 - It helps to attach weights on the front wheel to stabilize the robot. 450 g lead rings can be supplied, to be fixed on front suspension beams
- The maximum slope near the docking station is 10% (6° angle)
 - Make the robot connect to the station in the descending direction
 - The docking station can be located either on the "high plateau" or the "low plateau" of the ground, but never in the slope: the robot has no "brake" in charge mode, and could easily slide off its contacts on sloppy ground





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Installation rules

Steep ground. Best practices

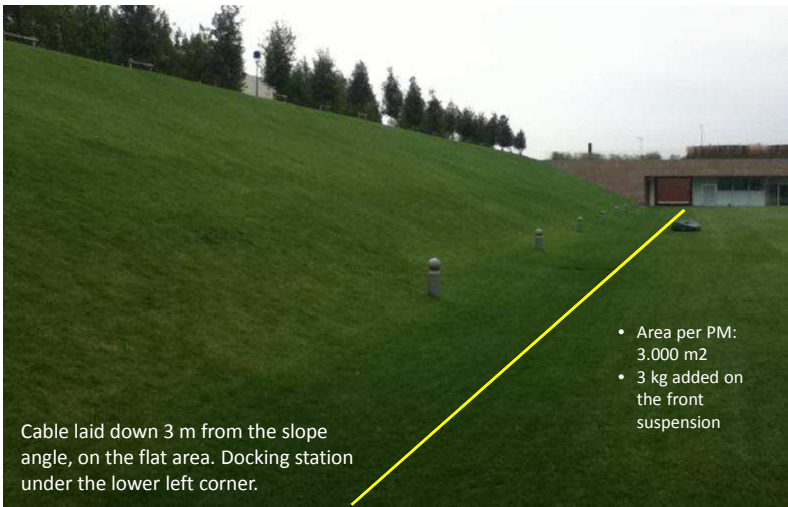


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Installation rules

Steep ground. Extreme example (Italy). Slope > 30%



Cable laid down 3 m from the slope angle, on the flat area. Docking station under the lower left corner.

- Area per PM: 3.000 m2
- 3 kg added on the front suspension

One of the two slopes must be taken in ascending direction. Slippery marks (slope > 30%) cannot be avoided.



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Installation rules

Steep ground with many obstacles (Marbella, Spain)



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Installation rules

Steep ground with many obstacles (Marbella, Spain)



Docking station

**Docking station installed on a “flat” area.
Robot takes the descending slope to the station.
Sonar orientated towards the incoming robot.
S return.**



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Installation rules

Steep ground with many obstacles (Marbella, Spain)



The robot goes back clockwise to take descending slopes towards the docking station. This prevents the robot from possibly slipping in uprising slopes.





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Installation rules

Steep ground with many obstacles (Marbella, Spain)



Very congested area by multiple trees, in the middle of the lawn, and alongside the boundary wire. In addition, two narrow straits and steep ground. Settings of P3-P4 was critical





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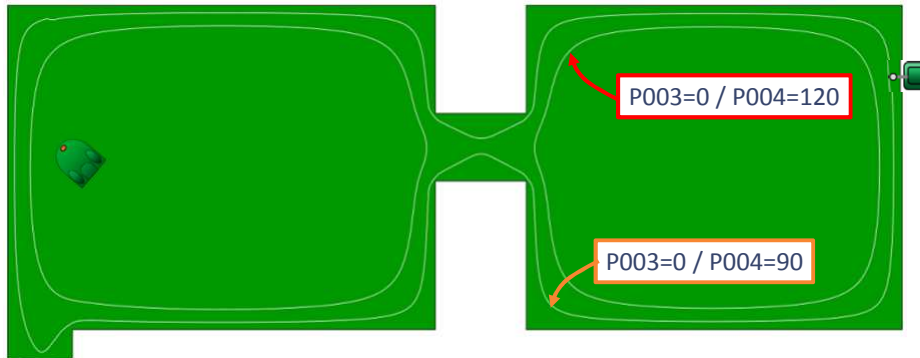


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Installation rules: return to the docking station

Going through a narrow path

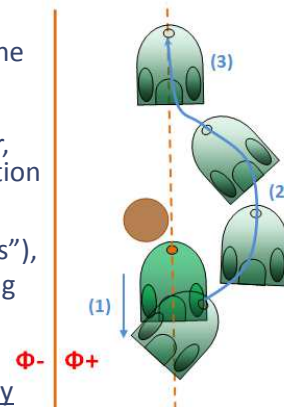
- Strictly apply installation rules for the path length and width
- When required, reduce track border to make sure the robot follows the right track border going through the narrow path: for detailed process of setting, see « Parameters and Options »

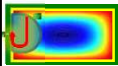


Installation rules: return to the docking station

Meeting obstacles on the way

- When the robot meets an obstacle on its way back to its docking station:
 - It moves back 1 m
 - It turns round the obstacle via the inner side of the lawn (going away from the wire). The robot rides on a circle of 1,5 m radius
 - When robot crosses again its original trackborder, it resumes following such trackborder to destination
- When the trackborder is set at a too low value (ex. P003=0 & P004=80 – See “Parameters & Options”), the robot may get lost and pace up and down, ending up with a “NO STATION” alarm
- Best practice: avoid obstacles on the trackborder way
 - Either by removing the obstacle
 - Or, when obstacle is intangible, by positioning the wire adequately and/or by adjusting the trackborder

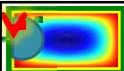
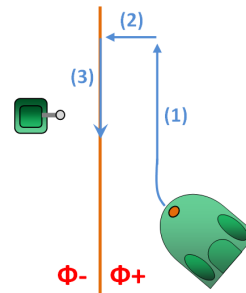




Installation rules: return to the docking station

How does the robot manoeuvre to dock at the station in "U" mode?

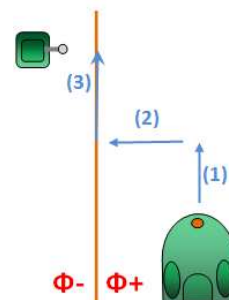
- The robot travels alongside the wire on its track border
- If no station was found (no station sonar heard) after 120% x P001, robot stops and issues a « NO STATION » alarm
- When robot hears the station sonar, it slows down and keeps going on the same trackborder. Two simultaneous conditions: (i) station sonar heard and (ii) straight wire for at least 0,5 m before the docking station
- At (1), the robot does not hear the sonar anymore
It moves ahead on the same track border for 3 m
It takes a 90° turn towards the wire (2)
It detects the wire (phase inversion)
It takes a second 90° turn
It travels on the wire to the station (3)
Till it detects 30V on the arm of docking station
- If total distance run on wire (3) is longer than 28 m, robot stops and issues a « NO CONTACT » alarm



Installation rules: return to the docking station

How does the robot manoeuvre to dock at the station in "S" mode?

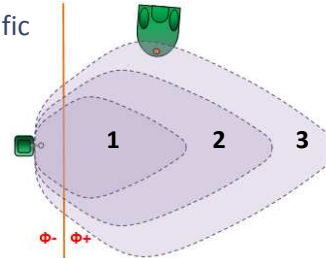
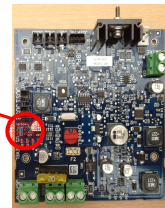
- The robot travels alongside the wire on its track border
- If no station was found (no station sonar heard) after 120% x P001, robot stops and issues a « NO STATION » alarm
- When robot hears the station sonar, it slows down and manoeuvres as follows. Two simultaneous conditions: (i) station sonar heard and (ii) straight wire for at least 0,5 m before the docking station
- The robot moves ahead for 30 cm
It takes a 90° turn towards the wire (2)
It detects the wire (phase inversion)
It takes a second 90° turn
It travels on the wire to the station (3)
Till it detects 30V on the arm of docking station
- If total distance run on wire (3) is longer than 28 m, robot stops and issues a « NO CONTACT » alarm



Installation rules: return to the docking station

First one of the two simultaneous conditions: sonar sensing

- The robot detects the station by sensing a specific sonar pattern, different from signal emitted by robot sonar
- The emission range of the station sonar can be adjusted by JPUS bridge
 1. Open sonar or Short range (~ 5 m)
 2. Average range (~ 7 m)
 3. Long range (~ 10 m)



- Detection distances vary according to
 - Temperature : better detection at high temp
 - Humidity : better detection at low humidity
 - Wind and rain



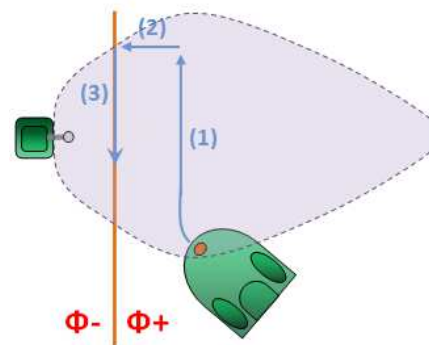
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Installation rules: return to the docking station

Second one of the two simultaneous conditions: straight trajectory

- The trajectory of the robot on line (1) approaching the station must be straight: consequently, the peripheral wire must be on a straight line at least 3 meters before and after the docking station, whatever the robot model



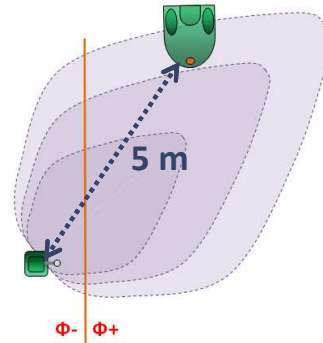
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Installation rules: return to the docking station

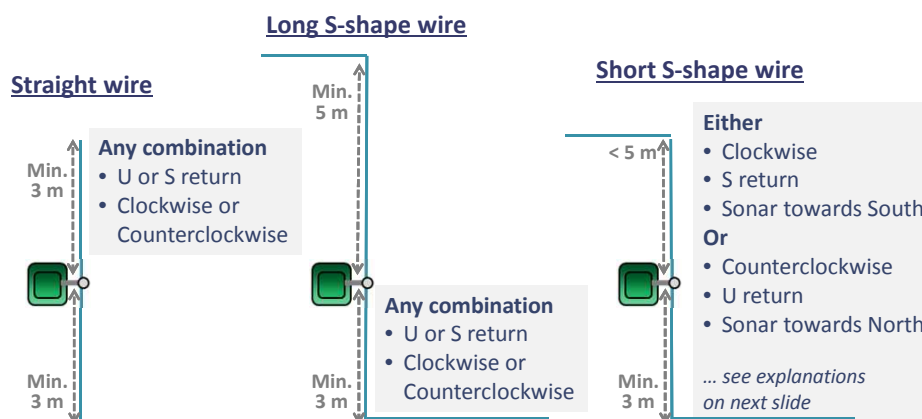
Orientation and position of the sonar emitter

- It is useful, and sometimes required, to orient the sonar emitter towards the incoming robot when this one is set in one side docking mode.
- This can be used both for « S » (most common) or « U » docking approaches
- In such instance, the sonar emitter must point towards a target zone 5 m from the docking station, on the trajectory of the incoming robot
- The sonar emitter either remains on top of the docking station and is turned to the right direction (standard) or is removed from the docking station, is positioned on an appropriate support and be connected to the station card by an extension wire



Installation rules: positioning the docking station

Critical distances upstream and downstream of the docking station



Always OK!

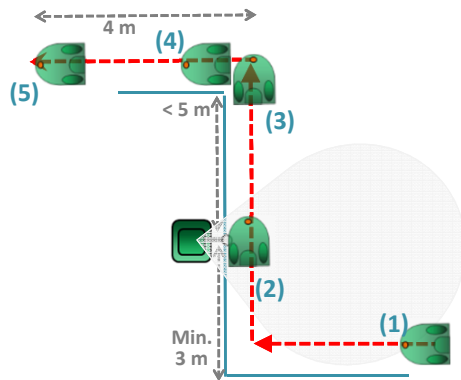
Be cautious!

Can be tricky!



Installation rules: positioning the docking station

Critical distances upstream and downstream of the docking station



Why does combination “Clockwise – “U” return” do not work?

- (1) The robot hears the station sonar. It slows down and keeps listening to the station sonar
- (2) The robot stops hearing the station sonar. It moves ahead 3 m till point (3)
- (3) The robot turns left 90° to the wire
- (4) However, the robot does not find the wire and travels 4 m on the 90° trajectory
- (5) After 4 m without crossing the wire, the robot stops and sends a “WIRE LOST” alarm

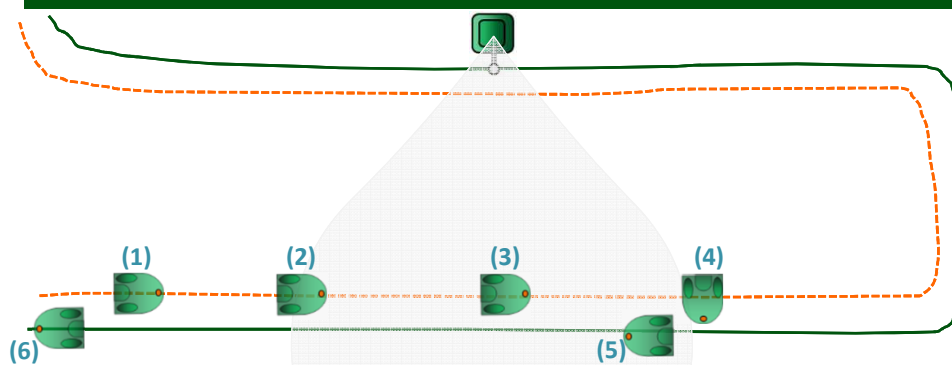


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Installation rules: return to the docking station

Peripheral wire on opposite sides. “U” return shape selected



- (1) The robot is back to the docking station on its trackborder. “U” return shape is applicable
- (2) The robot hears the station sonar. It slows down and keeps listening to the station sonar
- (3) The robot stops hearing the station sonar. It moves ahead 3 m till point (4)
- (4) The robot turns right 90° to the wire: it believes the station is on its right hand side
- (5) After turning right another 90° , the robot travels on the wire, looking for the station
- (6) After travelling 28 m since point (5), the robot stops and sends a “NO CONTACT” alarm

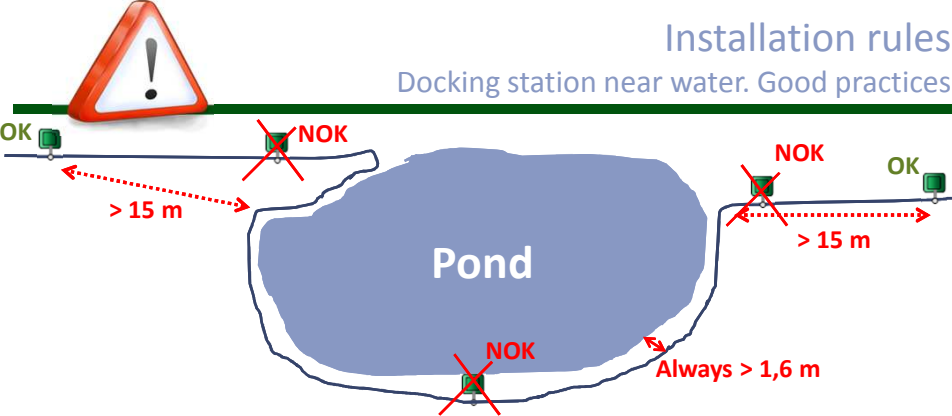


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Installation rules

Docking station near water. Good practices



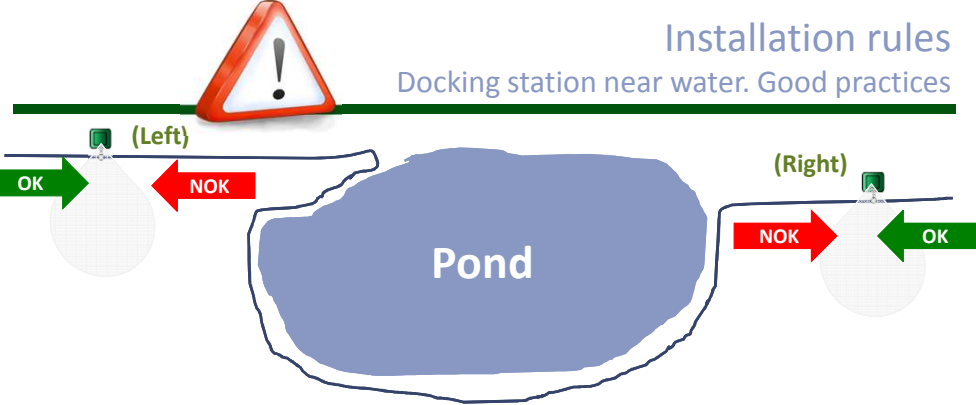
The pond concentrates electromagnetic signal and “attracts” the robot: it is a major risk! To avoid any incident next to water (swimming pool, pond, creek, stream, river):

- **Take an additional 1 m reserve between the wire and the hazardous area:** if the ground is sloppy towards the water, or slippery, or can turn to be wet or flooded, take additional appropriate reserve. When not feasible, put a barrier (ex: an alignment of protection poles)
- **Locate the docking station at least 15 m from any hazardous zone** (edge of the pond, unprotected sloppy/slippy/wet/flooded area) next to the pond
- Method to return to the docking station: [see next slides](#)

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Installation rules

Docking station near water. Good practices



General rules to program the return to the docking station in presence of water nearby:

- **Select direction** (clockwise or counter clockwise) **keeping robot away from the water on its way back to the docking station**
- **Prefer “S” shape return to “U” shape return**

In the above example:

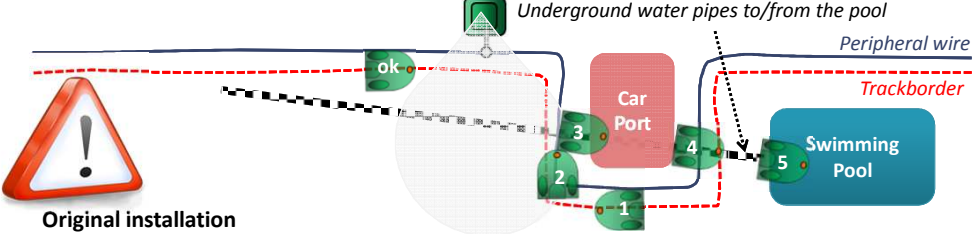
- (Left) docking station: clockwise return, “S” or “U” but preferably “S”
- (Right) docking station: counter clockwise return, “S” or “U” but preferably “S”

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Installation rules

Docking station near swimming pool. Story of an incident



Original installation

- Docking station located in a right position (clearance to the pool > 15 m)
- Return choice: clockwise or counter clockwise return, “S” shape
- Everything has been ok for months. One day, the Parcmow went into the swimming pool

Explanation of the incident

- The PM is back to the station (1). It hears station sonar and goes on the wire (2). At the crossing between the wire and the underground water pipes canal, it interprets such canal as the wire, and follows it up on more than 20 meters down to the pool (4) and (5)

Solution

- Return choice: clockwise only. In such configuration, no confusion between wire and water canal is possible in the station sonar area. There has been no problem since that change

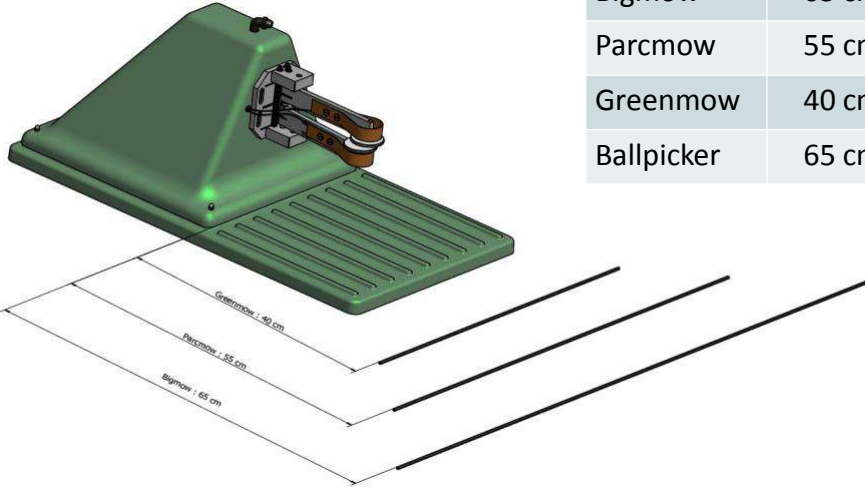


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Installation rules

Position of the docking station on the peripheral wire



Bigmow	65 cm
Parcmow	55 cm
Greenmow	40 cm
Ballpicker	65 cm



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Installation rules

Position of the docking station on pavement

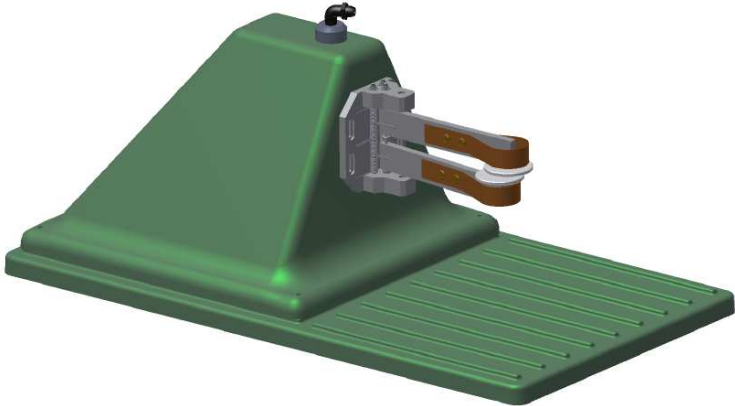


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Installation rules

The docking station “2012”



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Installation rules

Check angle station arm – robot and height



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Belrobotics

Leader in the automatic maintenance of large grounds

3	Appendices
A.	Docking station as from 2012
B.	Battery technology and energy management

ENERGY

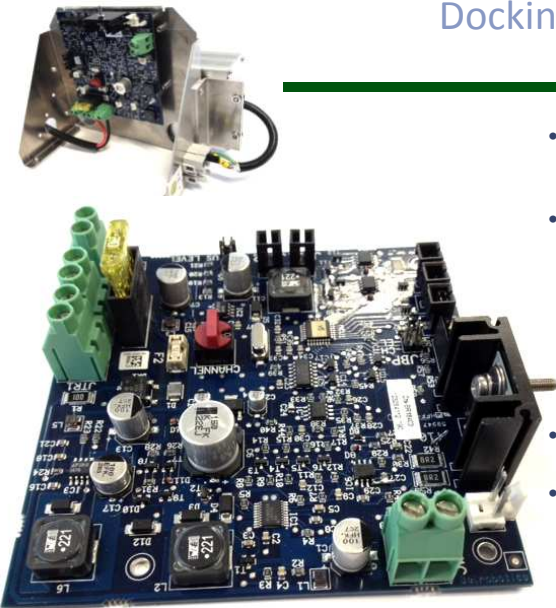
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Docking stations as from 2012

Major features and benefits



- Wire signal strength is automatically adapted to the wire length (min. 200 m up to max. 1.200 m)
- A panel-mount pilot LED indicates
 - Blinking green – normal mode
 - Blinking red – boundary wire has been cut or is too long (usually > 1200m)
 - Continuous red – failure of the docking station's electronic card or wire is too short (usually < 200m)
 - No colour – the station is not connected to an electricity supply
- Automatic reset system in case of power/wire disconnection
- Built-in protection against minor and moderate over-voltages

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Docking stations as from 2012

Not compatible with “old” signal version

- A robot based on “old” signal does not work with a docking station featuring “new” signal
- A robot featuring “new” signal does not work with a docking station based on “old signal”
- Transforming an “old signal” robot and station into a “new signal” configuration is not recommended
- It is although feasible, at a cost:
 - In the docking station:
 - The existing (green) electronic board must be replaced by a new (blue) card Version 4.5 or higher
 - The existing (open) sonar should be replaced by a (waterproof) sonar
 - In the robot:
 - The mainboard (green) must be replaced by a new one (blue) Version 4.0 or higher
 - The coil card (green) must be replaced by a new one (blue) Version 4.0 or higher
 - The software must be updated accordingly

BELROBOTICS THE GRASS MASTERS 

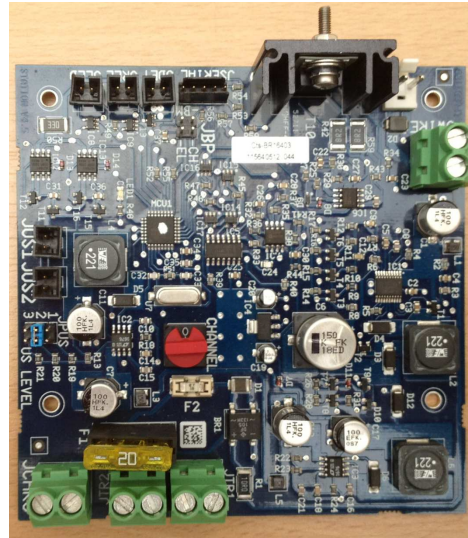
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Docking stations as from 2012

Connections and selections

- JTR1/JTR2 : Supply (AC or DC)
- JCHRG : 30 V contact arm
- JWIRE : peripheral wire
- JUS1/JUS2 : 1 or 2 (*) sonar(s)
- JLED : pilot LED
- JDET : presence detection (*)
- JREL : relay connection (*)
- JSERIAL : PC interface for updates
- CHANNEL : channel selection (6)
- JPUS : sonar range (3 ranges)
- JBP : station type (mower or BP)
- F1 : 20 A fuse (mains)
- F2 : 1 A fuse (electronic board)

(*) *Optional*



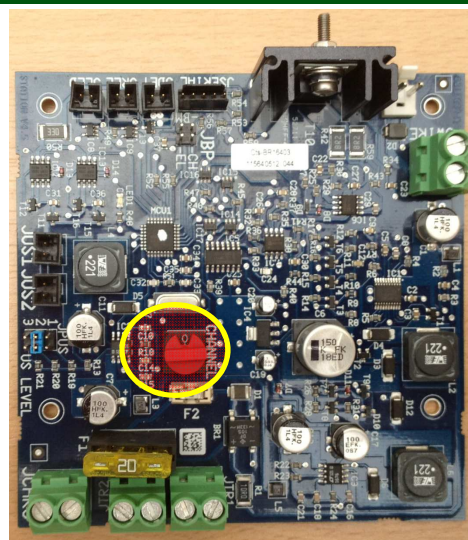
Docking stations as from 2012

Selection of channel

The channel is selected by a rotating switch

- ✓ Factory setting: 0
- ✓ Available: 0, 1, 2, 3, 4, 5, 9*
- ✓ **Disregard channel 2 in vicinity of Belrobotics machines using "old" signal**
- ✓ 9 indicates a "charging only" docking station that emits no signal (second station)

Make sure Parameter P08 on the robot is adjusted to the selected channel number (factory setting: 0). If not, robot will issue a "NO SIGNAL" alarm



Docking stations as from 2012

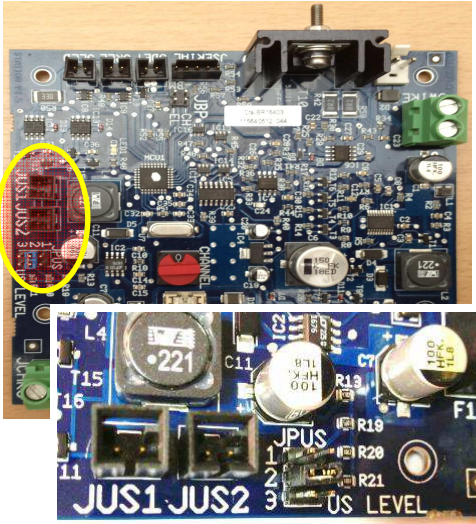
Selection of sonar range (JUS jumper)

The sonar range is selected by the JUS jumper

- ✓ Position 1: short range (~ 5 m)
- ✓ Position 2: mid range (~ 7 m) – factory setting
- ✓ Position 3: long range (~ 10 m)

When a second sonar is used (ex: for docking stations in closed shelters), both sonars operate with the same range

When used with a open sonar, always select Position 1. Higher positions would damage an open sonar



Docking stations as from 2012

Applications of a second sonar



Closed shelters protecting the docking station

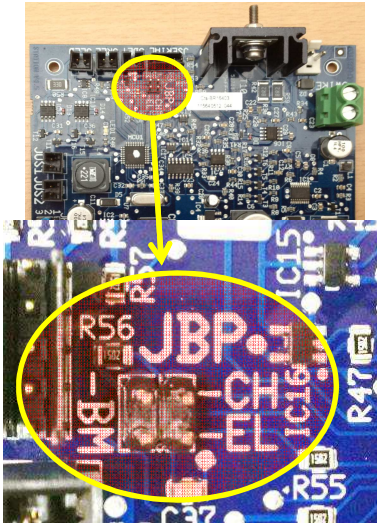


Docking stations as from 2012

Selection of docking station type (JBP jumper)

The docking station type is selected by the JBP jumper

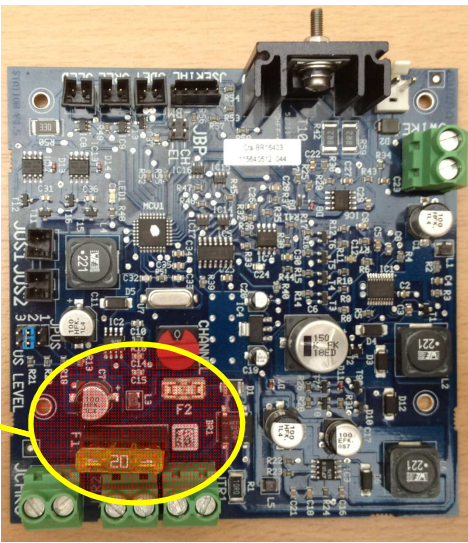
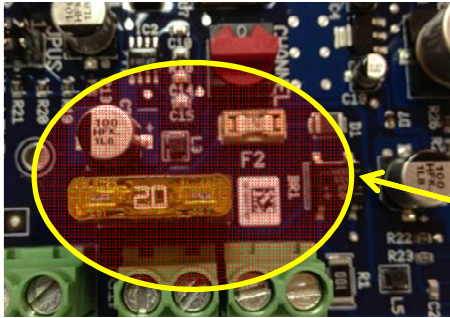
- ✓ Position BM: the station is for a mower (BM, PM or GM). This is the factory setting
- ✓ Position CH: the station is used for the Ballpicker as a “charging station only”
- ✓ Position EL: the station is used with a Ballpicker and is a combined “charging and offloading” station



Docking stations as from 2012

Fuses

- F1 : 20 A fuse (mains)
- F2 : 1 A fuse (electronic board)



Battery technology and energy management

Batteries technology overview

Chemistry characteristics (theoretical)

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THE GRASS MASTERS

	Ni-MH	Ni-Cd	Li-Co	Li-FePO4
Energy density [Wh/kg]	Up to 90	Up to 60	Up to 160	Up to 110
Life-time [cycles] @ 80%	Up to 500	>500	>500	>2000
Overcharge tolerance	Low	Good	None	None
Self-discharge/month	30%	15%	5%	1%
Operating temperature during discharge [° C]	-20 to 50	-40 to 50	-20 to 55	-30 to 60
Typical battery cost	+20%	Ref.	+40%	+55%
Safety	Good	Good	Poor	Good

Li-Ion technologies

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THE GRASS MASTERS

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Battery technology and energy management

Batteries technology overview

Lithium-Ion technology

Li-Ion compared to Ni-MH and Ni-Cd :

✓ Higher energy density

✓ Longer lifetime

✓ Lower self-discharge

Year	Li-ion	Ni-MH	Ni-Cd
1991	0	0	1500
1992	0	0	1800
1993	0	0	2000
1994	0	0	2200
1995	0	0	2500
1996	0	0	2800
1997	0	0	3000
1998	0	0	3200
1999	0	0	3500
2000	0	0	3800
2001	0	0	4000
2002	0	0	4200
2003	0	0	4500
2004	0	0	4800
2005	0	0	5000
2006	0	0	5200
2007	0	0	5500
2008F	0	0	5800

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Battery technology and energy management

Batteries technology overview

Lithium-Cobalt technology

- Most common lithium-ion charge batteries in everyday life (laptops, cell phones, tablets) : **Lithium-Cobalt**
- What about Lithium-Cobalt ?
 - Highest energy density
 - ... but existing risk of **safety issues** !



Battery technology and energy management

Batteries technology overview

Lithium-Cobalt technology

**** Chicago Tribune – Wanted Battery 2.0 (23 January 2013)**

“(...) Tens of thousands of laptop batteries have been subject to product recalls due to the risk of fire.

The Chevrolet Volt electric car got a black eye when its battery ignited after a crash test in 2011.

A cargo of lithium-ion batteries brought down a 747 jumbo jet operated by shipping company UPS in 2010. The two pilots aboard were killed. (...)”



Problems linked to the 787 Dreamliner's lithium-ion batteries

Battery technology and energy management

Batteries technology overview

Lithium-Cobalt technology

**** Canadian – Boeing 787 Dreamliner Lithium Ion Batteries Based on Cobalt Not Manganese (22 January 2013)**

"(...) Green Car Report states lithium ion batteries are a family of products having very different performance characteristics resulting from incorporating specific alloying metals into the battery chemistry. Lithium plus manganese or/and nickel (or other metals) typically carry less energy per volume than lithium plus cobalt, but are widely viewed as less susceptible to overheating. The battery chemistry utilized by the Dreamliner was Lithium Cobalt Dioxide (LiCoO₂); similar to that used in laptop computers and cell phones.(...)"

Battery technology and energy management

Batteries technology overview

Lithium-Phosphate technology

Belrobotics uses Nanophosphate® Lithium Iron Phosphate

- Based on LiFePO₄ technology (LFP)
 - ✓ A longer **life-time**: typically 3 to 4 times longer
 - ✓ A **safer** behaviour, thanks to its chemical stability
 - ✓ The battery can operate at higher **temperatures**
 - ✓ It is easily **recyclable** with limited environmental hazards
- Based on nanotechnology
 - ✓ Better **power** performances and efficiency

Battery technology and energy management

Belrobotics Battery Pack

Belrobotics LFP Battery Packs :

8SXP configuration :

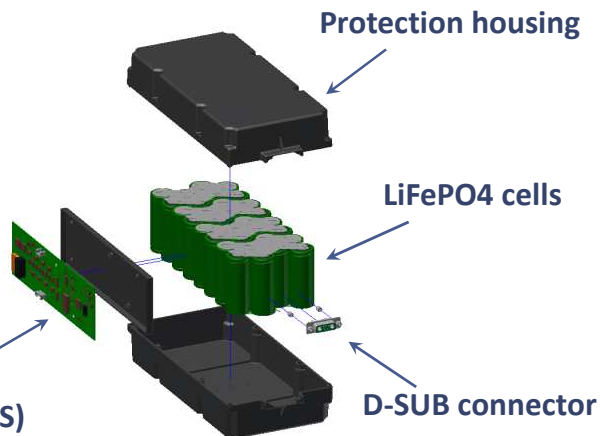
S = in series

P = in parallel

○ Pack **8S4P** : 26,4V/10Ah

○ Pack **8S6P** : 26,4V/15Ah

Proprietary Battery Management System (BMS)



Battery technology and energy management

Belrobotics Battery Pack

Proprietary Battery Management System (BMS)

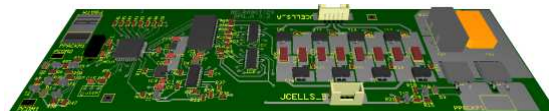
Management of cells in series to maximise the pack lifetime

Battery management

- ✓ Measure of each group of cells in parallel
- ✓ Cells balancing
- ✓ Measure of pack temperature
- ✓ Usage statistics (readable by Belrobotics only)

Battery protection

- ✓ Overcharge protection
- ✓ Short-circuit protection



Battery technology and energy management

Batteries cycling

What happens during a cycle ?

Charge curve

1. Constant Current (CC)

all the time

2. Balancing

3. No Constant Voltage (CV)

Discharge curve

A. End of charge

B. Go to station

C. Stop cutting heads

D. (22 V): Discharged

Charge/Discharge cycle after 4000 cycles

Discharge Voltage

Charge Voltage

29

28

27

26

25

24

23

100

80

60

40

20

0

Battery voltage [V]

Battery Capacity [%]

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Battery technology and energy management

Belrobotics Battery Pack

UN Transportation Certificate (UN/DOT 38.3)

➤ UN Transportation Testing ensures safety of lithium batteries for shipment

➤ A Battery Management System is mandatory to pass these tests

CERTIFICATE / REPORT NO.: BU-2012-000295-UN

UN No. / Shipping name:

UN 3480 LITHIUM ION BATTERY
UN 3481 LITHIUM ION BATTERY
packed with equipment / contained in equipment

Certified Product:

Accumulator - Rechargeable LI-ION

Model Designation:

8S4P ANR26650M1B (26.4V/10.0Ah)

Article Number:

16583-1

Certificate Holder:

Belrobotics s.a.
Avenue Lavoisier 16b · B-1300 Wavre · Belgium

PERFORMED TESTS

RESULTS

38.3.4.1 Test 1: Altitude Simulation

passed

38.3.4.2 Test 2: Thermal Test

passed

38.3.4.3 Test 3: Vibration

passed

38.3.4.4 Test 4: Shock

passed

38.3.4.5 Test 5: External Short Circuit

passed

38.3.4.6 Test 6: Impact

not required for battery packs

38.3.4.7 Test 7: Overcharge

passed

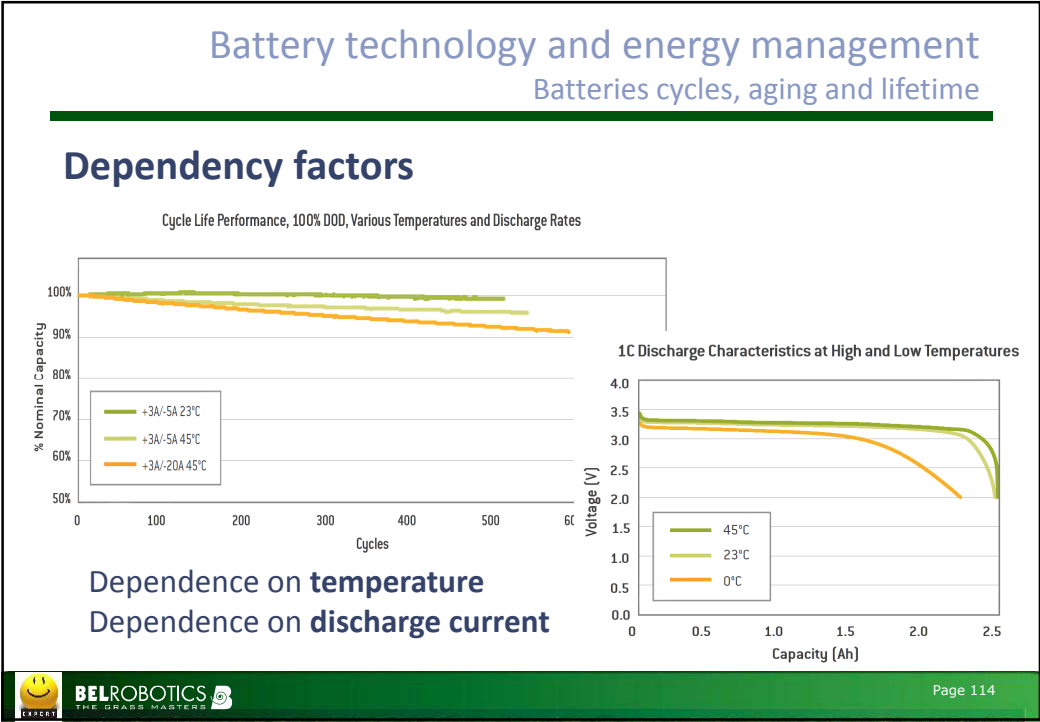
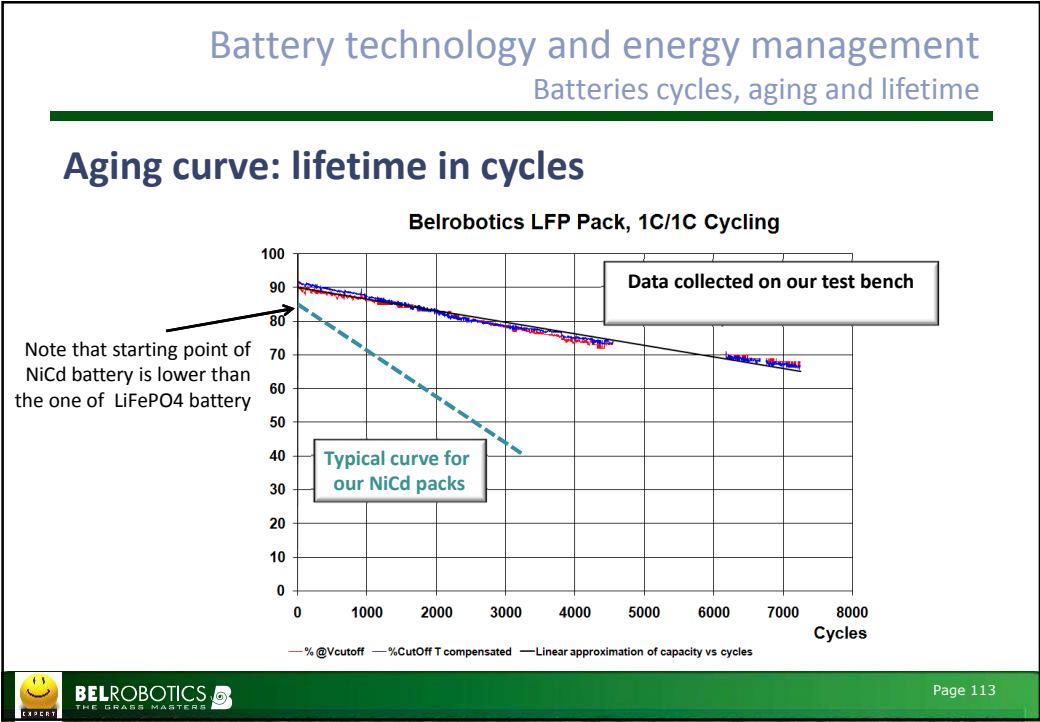
38.3.4.8 Test 8: Forced-Discharge

not required for battery packs

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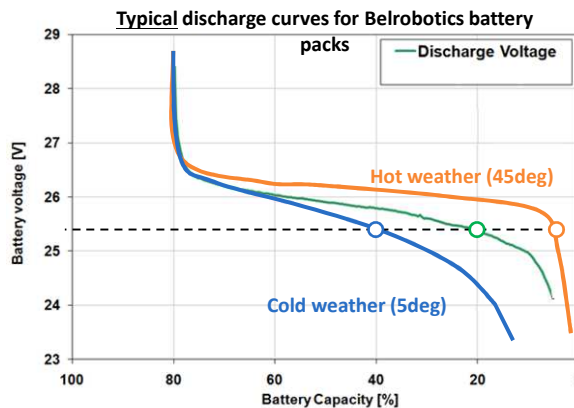
Battery technology and energy management

Voltage commands return to the docking station

Energy left to come back to the station ?

It is difficult to accurately control **when** the robot will come back to the station :

- **Temperature** makes it difficult to determine remaining capacity (see curves)
- **Ageing** influences total capacity



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THE GRASS MASTERS

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Battery technology and energy management

Best practices to avoid damaging the LiFePO4 batteries

- Do not take battery through **deep discharge** (voltage below 18V). This protection against deep discharge is managed by the main board of the robot. Hence:
- **Do not** connect any other device to the batteries
- **Do not** disconnect the battery from the main board
- **Always charge** the battery controlled by the main board, using
 - either an adapted Belrobotics docking station;
 - or the adapted Belrobotics charging system.

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THE GRASS MASTERS

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Battery technology and energy management

Impact of higher charge currents

Daily working time .vs. battery capacity

✓ Increasing charge current provides **marginal gains**

Bigmow : Ich = 10A et C =15Ah				
Cap.	C	→ 2C	→ 4C	→ 8C
h/day	12h40	13h35	14h05	14h20
Gain	/	+7%	+3%	+1%

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THE GRASS MASTERS

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Battery technology and energy management

Optional larger battery packs

When to use larger batteries ?

✓ **Longer cycles** (schedule constraints, complex lawn layout)
✓ **Unusual robot power** usage (grass, slopes, speed, etc.)

	BIGMOW	PARCMOW	GREENMOW
Standard capacity	15 Ah	10 Ah	10 Ah
Optional capacity	24 Ah	15 or 24 Ah	-
Commercial differentiation opportunity			

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THE GRASS MASTERS

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Battery technology and energy management

Charging with DC supply



Battery technology and energy management

Charging with DC supply

Technical features

- ✓ **Input** : universal AC input (110-230 V, 50/60 Hz)
- ✓ **Output** : 32V DC
- ✓ **Charge current** : 10A DC
- ✓ **Energy conversion efficiency** : 95%
- ✓ **IP65** design for outdoor application
- ✓ **Cooling** by free air convection



Battery technology and energy management

Charging with DC supply

Current control (DC) vs voltage control (AC)

- ✓ Independent of external parameters :
 - Main supply
 - Resistors tolerances
 - Contact/cable resistances

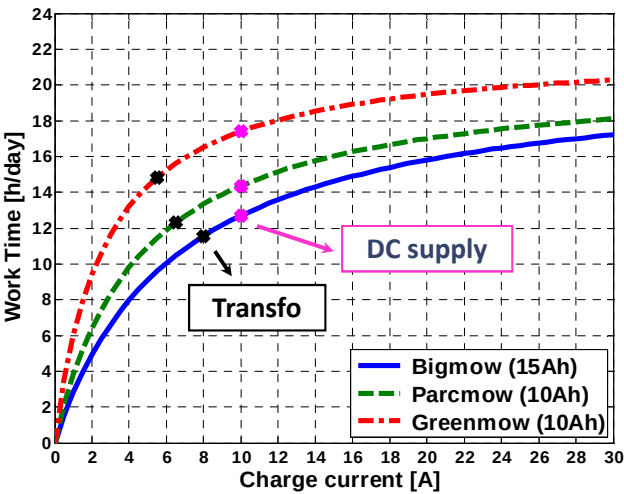
Better protection

- ✓ Against :
 - Overvoltage
 - Short-circuit (automatically resettable)
 - Over-temperature (automatically resettable)



Battery technology and energy management

Charging with DC supply



Battery technology and energy management

Charging with DC supply

12% to 17% capacity increase

✓ DC vs AC supply

➤ Bigmow: + 12%

➤ Parcmow: + 15%

➤ Greenmow: + 17%

When is it useful ?

✓ Reach higher peak capacity: football pitch in May/June

✓ Maintain mowing capacity despite restricted time operation

✓ Reach out to larger areas

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THE GRASS MASTERS

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Battery technology and energy management

Great improvement in mowing capacity

	NiCd battery (till 2011)			LiFePO4 AC generation (2012 onwards)				LiFePO4 DC generation (2013 onwards)				
	Ah	Wrk	Chg	Ah	Wrk	Chg	Gain	Ah	Wrk	Chg	Gain	Total gain
Bigmow	15	90'	90'	15	100'	90'	+5%	15	100'	70'	+12%	+18%
Parcmow	10	90'	75'	10	120'	75'	+13%	10	120'	50'	+15%	+29%
Greenmow	5	50'	50'	10	180'	90'	+33%	10	180'	50'	+17%	+57%
Ballpicker	To be done											

Gains are estimated by comparing (work time)/(work time + charge time) ratios. These figures were confirmed by actual experience on Belrobotics test field. However:

• Actual gains on the field may differ from these figures, as operation schedule and environment may lead to sub-optimal results in comparison with the above

• LiFePO4 batteries feature better in warm temperature and they age much slower than NiCd batteries. We expect the gains compared with NiCd generation increase with lifetime of the equipment

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Battery technology and energy management

High efficiency

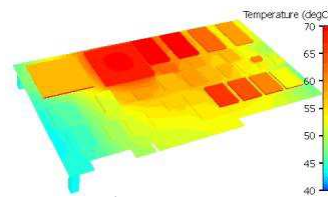
95% Efficiency

- Lower effective charge current (DC) for equivalent mean current (AC)
- No more charge resistors (50 W dissipation)
- Total energy savings ~20%, meaning higher performances with reduced energy bill or equivalent performances with inferior energy bill



Reduced thermal stress

- Lower effective charge current (DC) for equivalent mean-current
- Rectifier bridge
- Cables crimping and connections
- Machine more tolerant to higher ambient t° (Italy, Spain, etc.)

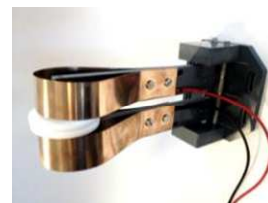


Battery technology and energy management

Charging with DC supply

Compatibility

- ✓ Only for Model 2013 onwards
- ✓ Specific stations with polarised connections



What if AC/DC docking station/robot are mixed up?

- ✓ DC robot on AC station:
 - Either safety fuse in the docking station blows out,
 - or the robot toggles between “fast charge” and “supply outage” state
- ✓ AC robot on DC station: nothing happens. The robot does not “feel” the docking station
- ✓ Mixed combinations do not work but are safe

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