

# **Marvelmind Indoor Navigation System**

## **Operating manual**

v2018\_01\_11

[www.marvelmind.com](http://www.marvelmind.com)

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# 1. Version changes

## **V2017\_12\_29**

- SW features paragraph updates
- General updates
- Sending path to robot
- Radio frequency band switch in latest Dashboard version
- Sending path to robot
- Paired beacons feature description
- Submap feature help video
- Different hedgehog colors in the Dashboard
- FAQ updates

## **V2017\_11\_01**

- Added Sensors settings
- Added Dashboard features
- FAQ
- Fresh Dashboard screenshots
- General updates

## **V2017\_09\_08**

- Added estimation of accuracy of distances measurement
- Added Raw inertial sensors data
- Added Communication of Pixhawk with Marvelmind mobile beacon
- Added Optimal settings for stationary beacons in small and big rooms
- Added Optimal settings for noisy environment

## **V2017\_07\_20**

- Cleaned up description and some corrections were added
- Description of HW v4.5 removed from this manual and given in the previous version of the manual, which can be found here:  
[http://www.marvelmind.com/pics/marvelmind\\_navigation\\_system\\_manual\\_HW\\_v4.5.pdf](http://www.marvelmind.com/pics/marvelmind_navigation_system_manual_HW_v4.5.pdf)
- Description of HW v4.9 added
- Introduced plastic housing for beacons and modem
- Introduced 915MHz variant for the US market (HW v4.9 only)
- General updates and description improvements
- Submaps added
- Description of Dashboard buttons
- HEX and DFU firmware general updates + new links
- Obtaining raw data from inertial sensors
- Settings to get correction north direction

## **V2016\_05\_21:**

- Detailed description of HW v4.5 added (5-sensor beacon)
- New Dashboard with multiple submaps introduced
- Some less relevant older HW versions descriptions are removed
- General updates and description improvements

## 2. Executive summary

Marvelmind Indoor Navigation System is an off-the-shelf indoor navigation system designed to provide precise ( $\pm 2\text{cm}$ ) location data to autonomous robots, vehicles (AGV), and copters. It also used to track other objects that the mobile beacon installed on, for example, virtual reality (VR) systems, helmets for construction workers or miners, etc.

The navigation system based on stationary ultrasonic beacons which united by radio interface in a license-free band. The location where a mobile beacon installed is calculated based on the propagation delay of an ultrasonic signal (Time-Of-Flight or TOF) to a set of stationary ultrasonic beacons using trilateration.

The stationary beacons form the map automatically. No manual entering of coordinates or distance measurement is required. If the stationary beacons not moved, the map built only once and the system is then ready to function after 7–10 seconds after the modem powered



Key requirements proper system functionality

- For 3D (X, Y, Z) tracking - An unobstructed sight by a mobile beacon of three or more stationary beacons simultaneously
- For 2D (X, Y) tracking - An unobstructed sight by a mobile beacon of two stationary or more stationary beacons simultaneously

Distance to the nearest 2 or 3 beacons – not more than 30 meters

## Key capabilities:

Parameter	Technical Specifications
Distance between beacons	Reach up to 50 meters in lab conditions. Recommended distance is 30 meters (Transducer4 looking straight at each other and other transducers are off)
Coverage area	<ul style="list-style-type: none"> <li>- Reach up to 1000 m<sup>2</sup> with the Starter Set configurations</li> <li>- Coverage for larger territories is similar to cellular networks</li> </ul>
Location precision	<ul style="list-style-type: none"> <li>- Absolute: 1–3% of the distance to the beacons</li> <li>- Differential precision: <b>±2 cm</b></li> </ul>
Location update rate	<ul style="list-style-type: none"> <li>- 0.5–45Hz</li> <li>- Can be set manually</li> <li>- Depends on the distance between the mobile and stationary beacons (shorter distance—higher update rate)</li> <li>- Depends on the number of mobile beacons (update rate of 25Hz for 1 mobile beacon, 25Hz/2 for 2 mobile beacons, and 25Hz/3 for 3 mobile beacons)</li> <li>- Depends on the radio interface profile (500kbps vs. 38kbps)</li> <li>- Slightly depends on the number of stationary beacons—different than for mobile beacons</li> </ul>
Power supply	Internal: LiPol battery 1000mAh <ul style="list-style-type: none"> <li>- Battery lifetime depends on usage</li> <li>- Stationary beacon with 16Hz update rate =&gt; up to 72h (tested).</li> <li>- Stationary beacon with 1Hz update rate =&gt; ~72h*16 =&gt; 1 month</li> <li>- Mobile beacon with 8Hz update rate – 12h (tested)</li> </ul>
	External: micro USB – recommended for permanent use
Weight	Mobile beacon from starter set: <ul style="list-style-type: none"> <li>- 59 grams (including battery 1000mAh and housing and antenna 50mm)</li> <li>- 27 grams (bare board w/o battery)</li> </ul>
Beacon size	Size: 55x55x33 mm (with 50mm antenna: 55x55x65mm)

## 3. Basics of the system

### 3.1 What's in the box

Starter Set:

- 4 x Stationary beacons
- 1 x Mobile beacon (aka "hedgehog")

1 x Modem/Router

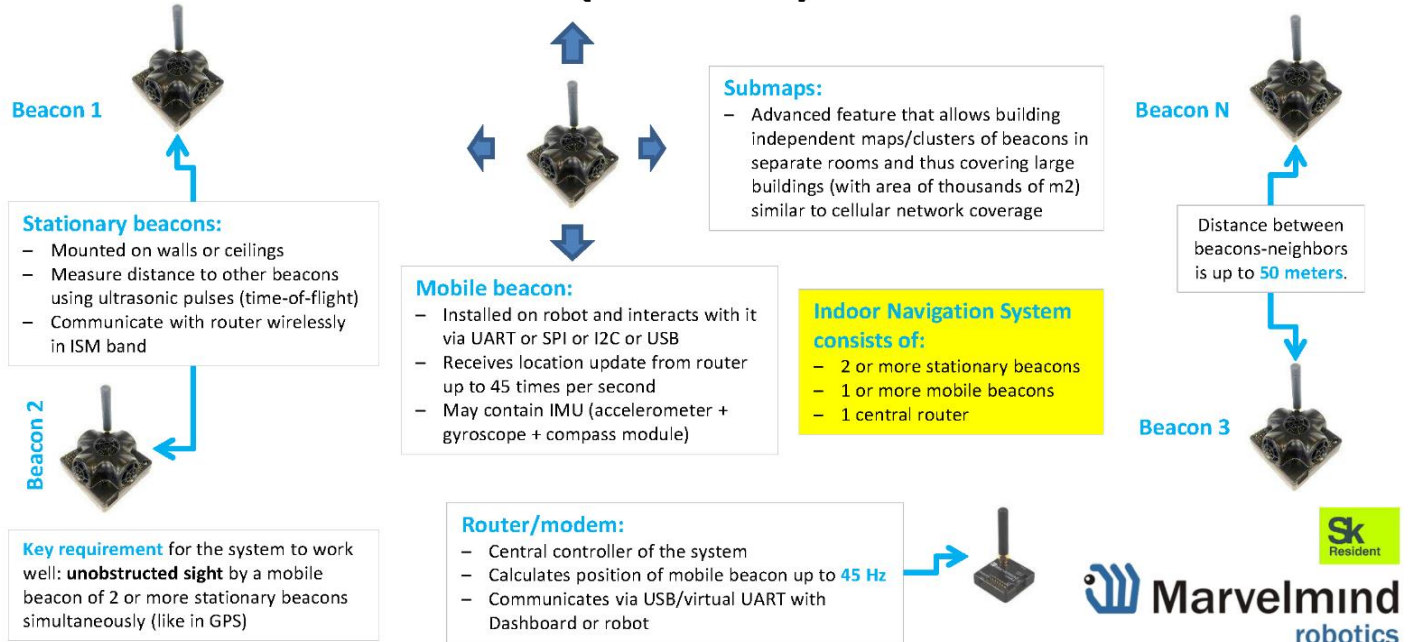
\* Starter set includes beacons without IMU. Exact appearance may vary depending on the hardware version. Characteristics are the same or better unless specifically noted



## 3.2 Indoor Navigation System architecture

Marvelmind Indoor Navigation System provides high-precision ( $\pm 2$  cm) indoor coordinates for autonomous robots and systems ("indoor GPS"). A brief description of the key elements of the system given on the scheme below

# Indoor "GPS" ( $\pm 2$ cm) – architecture





### 3.3 Indoor “GPS” System close-up and internal view



## 4. System elements

### 4.1 Stationary beacons

- Should be mounted on walls and ceilings—above the robot and with ultrasonic sensors facing down—to provide the most robust unobstructed ultrasonic signal coverage to the robot. However, for automatic landing and indoor navigation of copters, for example, it is recommended to install mobile beacon horizontally downwards looking on the belly of the copter.
- The position of the beacons and the angles of the positions should be chosen in such a way that maximum ultrasonic signal coverage is provided for the maximum territory. Proper ultrasonic coverage is the utmost important element for the system to function effectively
- Stationary beacons send out and receive ultrasound when the map is being formed. They only receive the ultrasound once the map is formed and frozen
- Stationary beacons have no exterior differences with mobile beacons
- Inertial measurement unit (IMU) not installed on the stationary beacons
- The mobile and stationary beacons can be easily interchangeably by selecting the [option](#) (except for IMU) in the Dashboard
- There are 433MHz and 915MHz versions available. A proprietary radio protocol is used for communication and synchronization. Other ISM bands are available upon request as well
- Stationary beacon with full-size 165mm antenna (for 433 MHz)
  - \* Full-size 165 mm antenna is optional



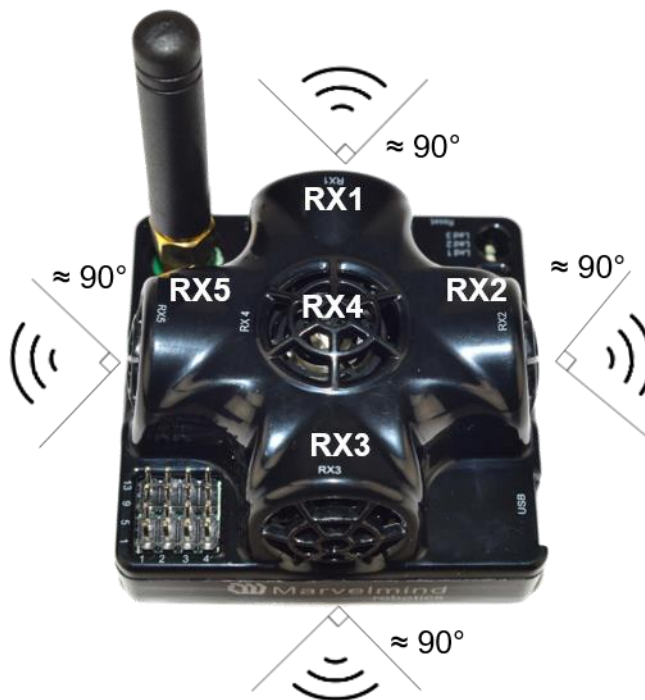
## 4.2 Mobile beacon (“hedgehog”)

- The mobile and stationary beacons can be easily interchanged by selecting the [option](#) in the Dashboard
- The mobile beacons designed placed on a robotic vehicle, copter/drone, AGV, or helmet to trace its location. Formally speaking, location of the mobile beacon is traced—not the robot itself. Since the sizes and the location of the central point of the mobile beacon and the robot are different, the difference taken into account in the robot’s software (SW).
- It’s recommended to place the mobile beacon horizontally to provide optimal ultrasonic coverage in the upper hemisphere.
- Its sensors must not cover with anything that can reduce the strength of ultrasonic signal. For example, the system won’t normally work if one puts the mobile beacon in a plastic box
- The beacon’s coordinates are updated according to the rate set on the Dashboard.
- The system may contain one or several mobile beacons. Current implementation relies on a time-division multiple access approach. Thus, if two mobile beacons are activated they share the same system bandwidth. It means that, if the 16 Hz update rate is selected and there are 2 mobile beacons in the system, each beacon’s location will be updated with the rate of  $16\text{Hz}/2 \sim 8\text{Hz}$ . If there are 3 mobile beacons  $\Rightarrow 16\text{Hz}/3 \sim 5\text{Hz}$ , etc. Future SW implementation may contain different solution that will improve update rates in setups with multiple mobile beacons
- Location data is obtained either from the “hedgehog” via USB (virtual UART), UART, SPI, or from the modem/router via USB (virtual UART). More information on interfaces can be found [here](#)
- Data from the beacon sent in a streaming format identical to that of GPS (NMEA 0183)
- There are 433MHz and 915MHz versions available. Proprietary radio protocol is used for communication and synchronization
- The “hedgehog” has been successfully integrated with Windows PC, Linux machines, Raspberry Pi, Arduino boards, Intel boards, etc.:



### 4.3 Ultrasonic coverage

Each of the sensors on the beacons has  $\approx 90^\circ$  of ultrasonic coverage



## 4.4 Modem/router

- Modem is the central controller of the system. It must be powered at all time when the Navigation System is working. It recommended that an active USB hub used for that purpose or even a regular cellular phone USB power supply. A USB power bank also can be used
- The modem is also used to set up the system, monitor it, and interact with the Dashboard
- It can be placed anywhere within radio coverage for permanent radio connection with all beacons—usually in the radius of up to 100 meters with antennas from the Starter Set
- Radio coverage further extended to a few hundred meters by using a lower bitrate of 38kbps and full-size (165mm for a 433MHz band) antennas, which been tested up to 400 m in ideal conditions
- There are 433MHz and 915MHz versions available
- A proprietary radio protocol used for communication and synchronization



## 4.5 Charging beacons and other details

- The Beacon has 5 sensors (transducers): RX1, RX2, RX3, RX4, and RX5
- Charging occurs automatically every time a USB charger is attached to the board. LED 1 is active and lights red
- It takes 1–2 hours to fully charge the board's battery
- If you plan using a charger for permanent powering of the beacon, make sure that the power source is not noisy (+5V is not noisy). The performance can be monitored by going to



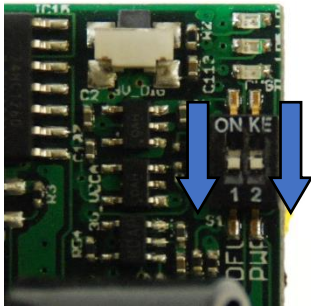
**Dashboard => View => Oscilloscope.**

Read the paragraph [Using Oscilloscope](#)

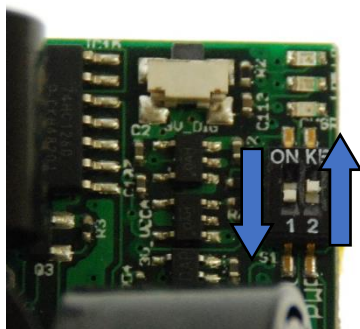
- When the board is charged and turned on, LED 2 will blink every few seconds, if to press RESET button and modem is active. If modem is not active or works on a different radio channel, the beacon automatically goes into sleep mode after 1 minute

## 4.6 DIP switch modes

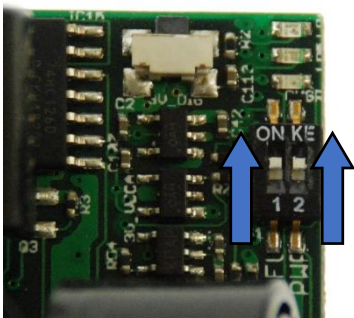
- 1) **Power = OFF, DFU = OFF:** Charging is possible; beacon disconnected from internal battery. This mode recommended if you want to keep the battery fully charged for a long time and to store the beacon on the shelf (



- 2) **Power = ON, DFU = OFF (pictured below):** Normal working mode for the beacon. The beacon fully powered and will wake up every a few seconds to monitor radio signals from the modem. Power consumption is still minimal if the beacon sleeps; the battery can last for many weeks or months. It is recommended the beacon be kept in this mode and the DIP switch not be touched at all unless you plan to store the beacon on the shelf. If that's the case, then mode 1 is recommended



- 3) **Power = ON, DFU = ON:** DFU programming mode. It is used for the initial SW uploading or when the HEX SW cannot be uploaded from the Dashboard



## 5. Setting up the system

### 5.1 First setup of your device

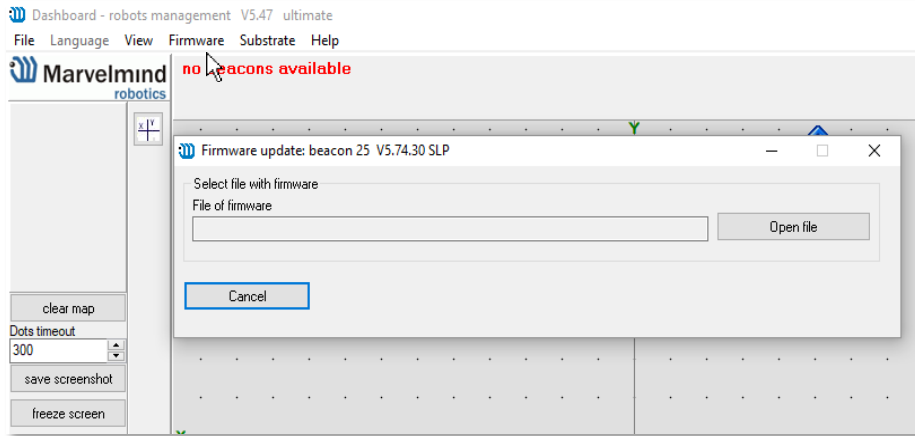
- The steps below describe the very first time you set up of the system.
- Unpack the system. Watch the help video: <https://youtu.be/IyXB3UXHdeQ>  
Note that the video is shot for the previous hardware (HW) version (4.5)
- Check that your boards charged; see that all switches on the beacons are in the correct position (**Power = ON**; **DFU = OFF**). See the paragraph [DIP switch modes](#)
- Press the **RESET** button on each beacon. If LED 2 is not blinking, it means your board turned off or discharged. Check the position of the DIP switch again or charge the beacon via USB



## 5.2 HEX programming

- After charging boards, download the latest stable SW package from [https://marvelmind.com/pics/marvelmind\\_SW\\_2017\\_11\\_15.zip](https://marvelmind.com/pics/marvelmind_SW_2017_11_15.zip)
- Run the Dashboard and update the SW for all beacons and modem using

**Dashboard => Firmware => Choose the file => Program**



- If you see the message **“Not found modem connection to computer through USB”** in the Dashboard, it usually means that the driver is not installed. To install the driver, download it with link at top and run the installation file, then click on the link under and install the driver
- Ensure that:
  - (a) You are programming the modem’s SW to the modem and the beacon’s SW to the beacon;
  - (b) You are using SW for 4.9, if you have HW v4.9; and
- You have the SW from the same SW pack, i.e., the Dashboard SW, modem SW, and beacon SW must be from the same SW pack. Don't mix SW releases

## 5.3 DFU Programming

DFU programming or SW uploading used when HEX SW uploading in the Dashboard cannot be used. For example, when you are updating from a very old SW version or when the SW includes major changes to the system, the only possible way to update the SW will be via DFU programming

After the DFU SW upgrade, futures SW upgrades can be done in a regular manner via the Dashboard

To start programming, move the beacon's DIP switch to the DFU programming mode, as described in the paragraph on [DIP switch modes](#).

Download the latest SW package, unzip it, and select the proper version of the SW for your HW and for your frequency variant. Remember that for DFU programming, you should use DFU SW (DfuSe), not Dashboard.

Download DfuSe v 3.04:

<http://www.marvelmind.com/downloads/Software.zip>.

Here you will find different versions of DfuSe. v3.0.3 or v3.0.5, whichever works the best for your Windows.

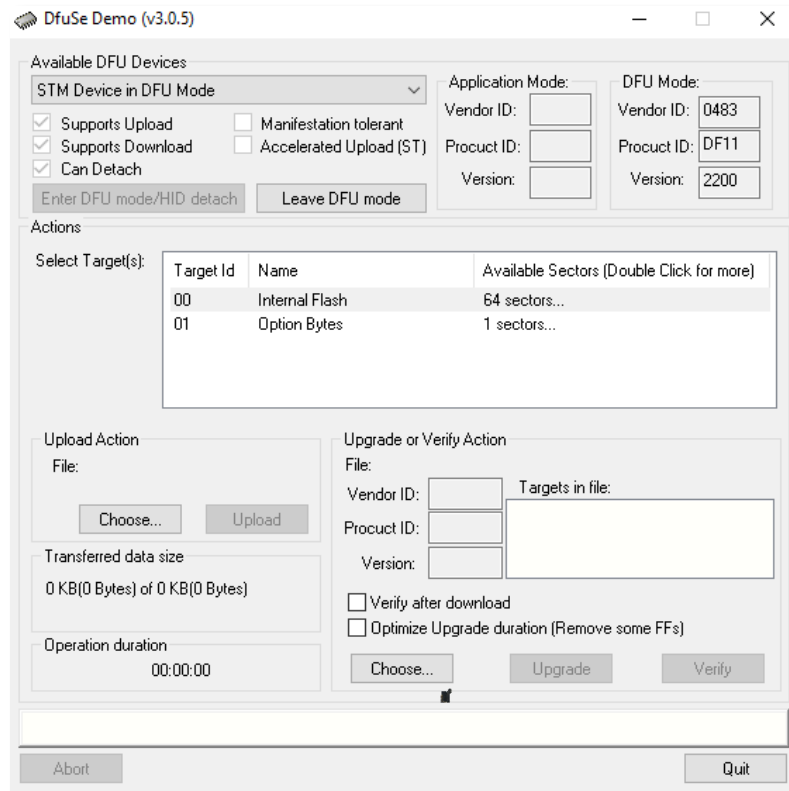
[http://www.marvelmind.com/downloads/DFU/DfuSe\\_Demo\\_V3.0.5\\_Setup.exe](http://www.marvelmind.com/downloads/DFU/DfuSe_Demo_V3.0.5_Setup.exe) - v3.0.5

Download the latest SW package. It includes DFU driver (file) for the beacon:

[https://marvelmind.com/pics/marvelmind\\_SW\\_2017\\_11\\_15.zip](https://marvelmind.com/pics/marvelmind_SW_2017_11_15.zip)

- Put DIP switch into **Power = ON, DFU = ON**
- Connect the beacon via USB to your PC
- Run DfuSe before starting the Dashboard
- Press the **RESET** button on your beacon
- In the upper left corner of the DfuSe program, you will see a device connected in the DFU mode

- Choose the DFU driver (file) for the beacon



- Click the **UPGRADE** button
- After a couple of seconds, the DFU will be uploaded to the beacon. Make sure it actually takes 1–3 seconds and does not happen immediately. Otherwise, the SW has not really uploaded. If the DFU appears to upload immediately, check the "Choose" button you used or change the version of DfuSe SW you selected.
- Move the DIP switch into **Power = ON, DFU = OFF**
- Start the Dashboard and press the **RESET** button on the beacon.
- Check SW on the beacon afterwards
- Everything should be OK with SW now. DFU programming is complete

Follow the same scenario for the modem:

Here is the [link](#) for the modem DFU programming. The steps are similar to those for beacon DFU programming

- After uploading DFU driver by DfuSe short circuit holes temporarily as shown on the picture (for v4.9) press **UPGRADE** button in the DfuSe program
- After a couple of seconds, the DFU will be uploaded to the modem. Make sure it actually takes 1-3 seconds and does not happen immediately. Otherwise, the SW has not really uploaded. If the DFU appears to upload immediately, check the "Choose" button you used or change the version of DfuSe SW to a different one
- Disconnect the short circuit

- Start the Dashboard and press **RESET** button



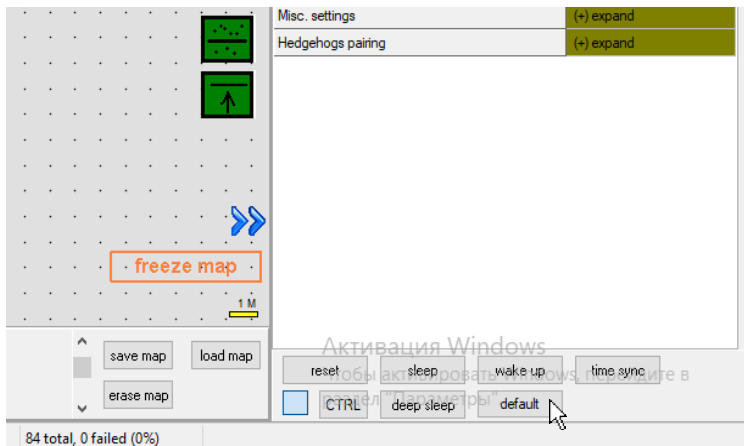
If you experience difficulties in DFU programming, please check and do the following:

- Change your operation system (from Windows 10 to Windows 7 or vice versa).
- Install a different DfuSe version (whichever works best with your Windows)

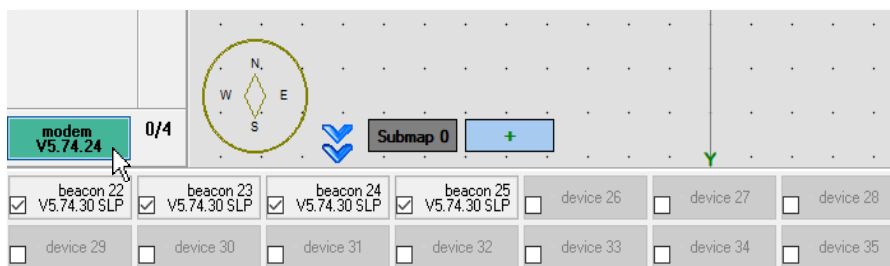
## 5.4 Setup the Dashboard SW

If you've uploaded the latest firmware for all of the boards you can start to activate the system

- While the beacon and modem are connected to the Dashboard, click the **DEFAULT** button on the Dashboard to upload the default settings

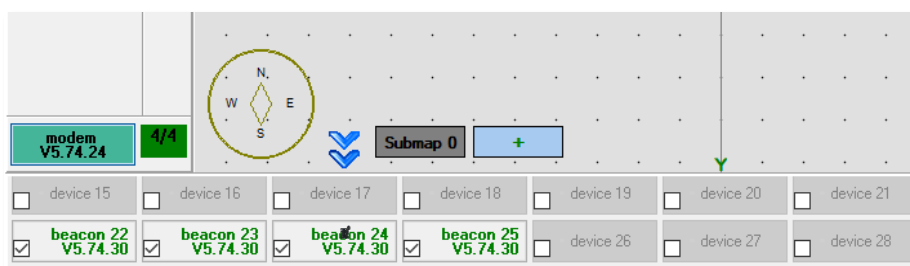


- Write down the beacon's address for future use or change the address at your convenience as shown [here](#)
- Press the **RESET** button on your beacons and modem after programming.
- After programming devices with the latest software, the modem and beacons are ready for use
- Place the stationary beacons on the walls vertically in a way that will provide optimal ultrasonic coverage. It is recommended that you start with a simple 4m x6m room and place the stationary beacons on the opposite walls at a height of 1.85m (default). After familiarizing yourself with the system more complex configurations can be made. The help video can be found [here](#).
- Connect the modem/router via USB to a Windows PC with the Dashboard installed
- Run the Dashboard. In the left corner of the Dashboard, the modem should show as connected

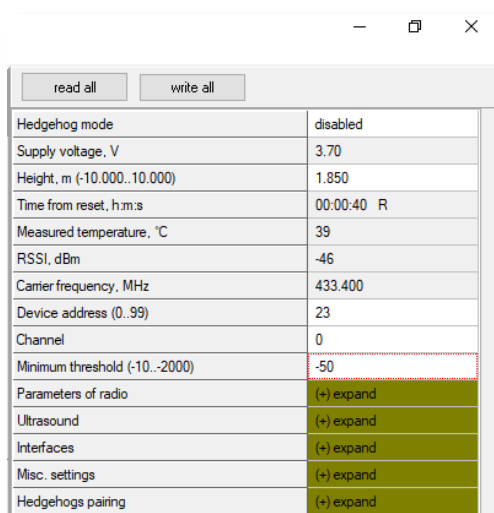


- Wake up all the beacons by clicking on the buttons in the Dashboard on the panel

- It may take up to 8 seconds for the beacons to wake up

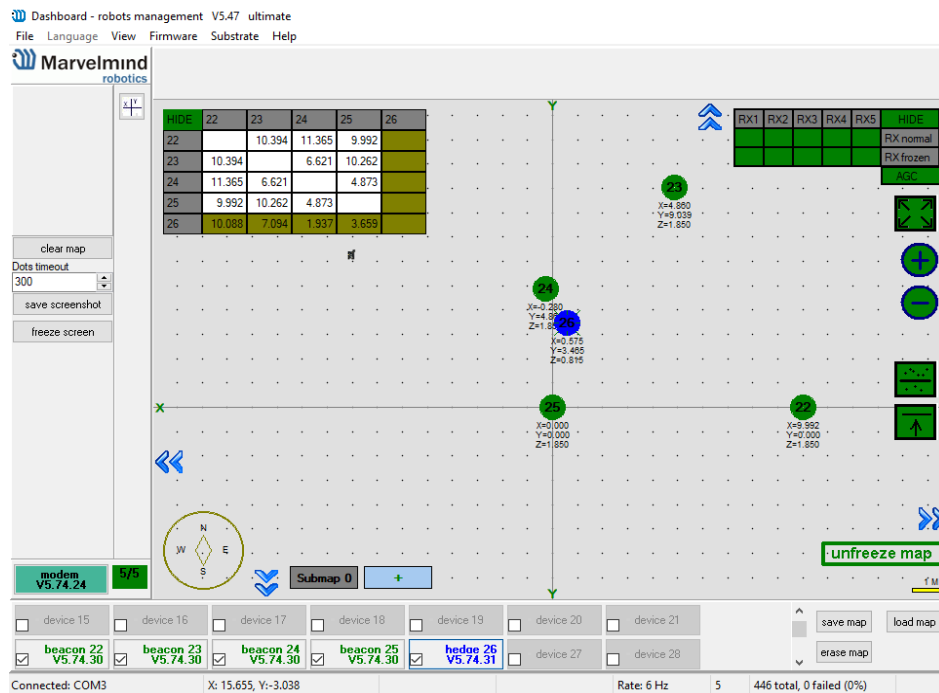


- If the modem is not active and is not powered, the beacons will go into sleep mode automatically after 1 minute
- The system may run the frequency search, if it is the very first time you're waking up the beacons. If this step does not work, disconnect the modem and connect that beacon again via USB. Press the DEFAULT button in the Dashboard and read all the buttons to make sure that the radio settings are really the default ones
- Compare the radio settings on the modem and the radio settings on the beacon. They must be the same
- Now you can check the height position of the beacons, RSSI, radio channel, threshold, etc. on the panel on the right corner of the Dashboard



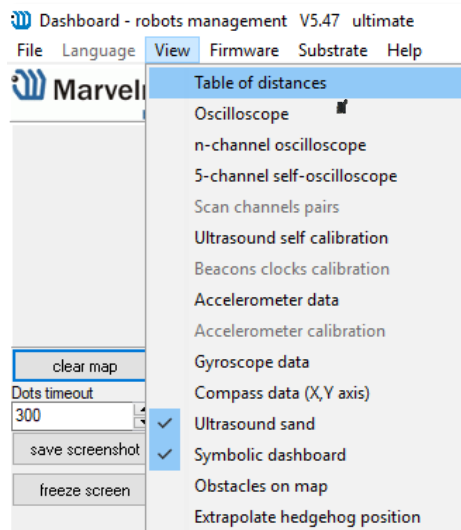
- It is possible to manage 30 beacons simultaneously. In current version one modem supports 30 beacons. If you do not see some of your connected beacons on the map, you may need to scroll to find their addresses
- Double click on the device both to put it into sleep mode and to wake it up
- The map will form and zoom in automatically

- If the map does not form well, check the table of distances in the left corner of the Dashboard. The cells must be colored in white; it means the distances between stationary beacons are measured correctly



- If you see in the table some empty cells or marked **yellow/red**, it is an indication that distances between Some beacons are measured inconsistently or not measured at all. Try to re-position them because usually there is an obstruction of some sort in the between the beacons. It also may be different height of beacons' positon. Reset all these beacons.

Use **View => Table of distances** to monitor the measured distances between beacons



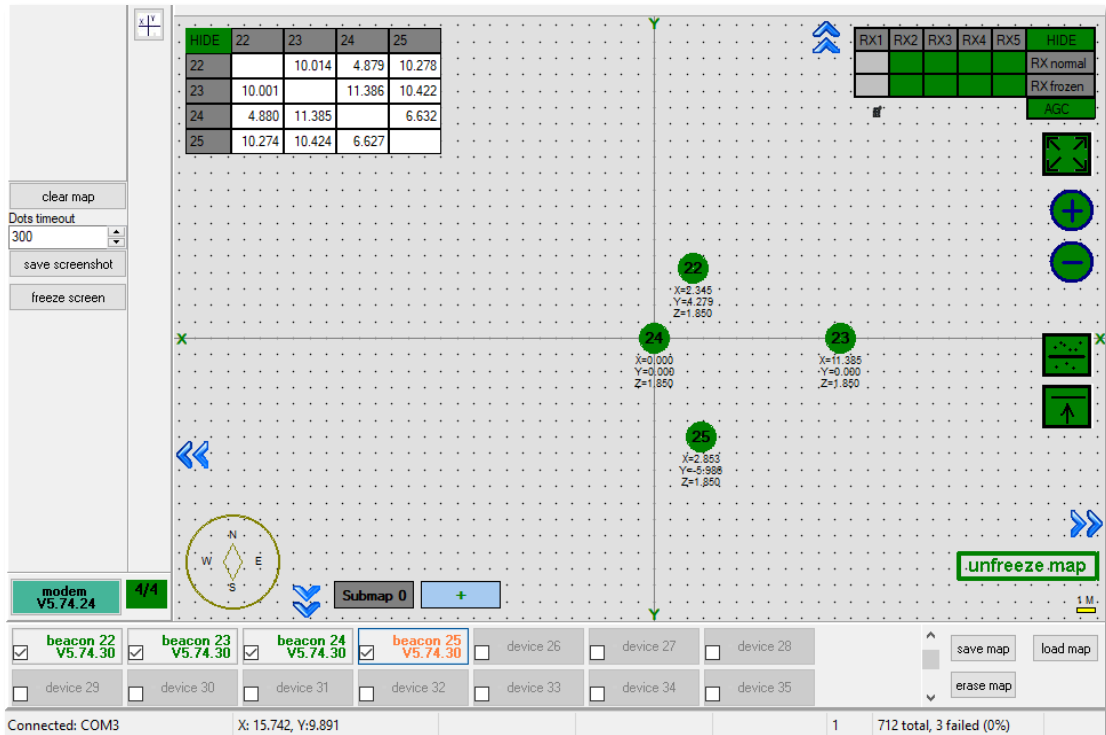
- Freeze the map by clicking the button. Stationary beacons will stop measuring relative distances and will be ready to measure distance from the mobile beacon(s)



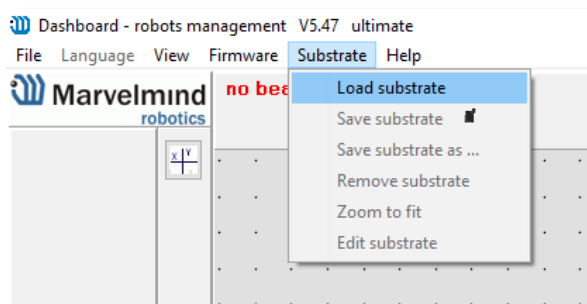
- Turn on and wake up the mobile beacon following the same steps as with the stationary beacon: [https://youtu.be/A4aRsH2-\\_E](https://youtu.be/A4aRsH2-_E)



- If you see on the devices' panel in the Dashboard that the beacon is colored **orange**, it means there are some differences in some of the settings between beacons. For example, some sensors may be off or some ultrasonic or radio settings may be different. You can change the settings for sensors manually by clicking on the panel on the upper right corner of the Dashboard to change the cells from gray to green to turn on sensor. It is recommended that the default settings on all beacons and the modem be used if this is your first time using the system



- After you freeze the map of stationary beacons, wake up the mobile beacon. After it wakes up, it will be traceable in 5-7 seconds
- The system is now fully operational
- In the dashboard, you can upload a picture / map of your room. When the picture is loaded, you can drag the beacons to the points where they are actually located. After dragging two beacons, the picture with beacons will be combined in scale. Use the "Substrate" button on the top toolbar





## 5.5 Dashboard signs, menu and parameters


The main parameters of the connected band are shown on the long panel on the right side of the Dashboard


- Check our [help video](#) for a deeper understanding of the Dashboard menu
- [Here](#) is the detailed explanation of the beacons' settings

### 5.5.1 CEILING and MIRRORING buttons on the Dashboard

- The **MIRRORING** button   allows the map to be display as a mirror reflection

- The **CEILING** button   shows where the mobile beacon is located with respect to the stationary beacons

- When the arrow points up , it means that the mobile beacon is below the stationary beacons

- When the arrow points down , it means that the mobile beacon is above the stationary beacons

### 5.5.2 Radio frequency band and Carrier frequency

When you connect a device to your PC at first time Carrier frequency matches its type

Radio frequency band parameter allows to use different frequency bands and avoid interference as well as channels.

For beacons and modems 433 MHz allowable Radio bands 315 and 433, for beacons and modems 915 MHz allowable Radio bands 868 and 915, but when using antennas at 433 MHz it is possible to use both 315 and 433 MHz

Radio frequency band	915 MHz
Carrier frequency, MHz	919.000

Radio frequency band	868 MHz
Carrier frequency, MHz	869.504

Radio frequency band	433 MHz
Carrier frequency, MHz	433.400

Radio frequency band	315 MHz
Carrier frequency, MHz	315.000

### 5.5.3 Different hedgehog colors in the Dashboard

**Blue** - normal mode and confident tracking

**Orange** - system provides the best location data possible, but confidence is lower, than blue

**Colorless / transparent** - usually, means lost radio packets or no ultrasound coverage

## 5.6 SW feature descriptions

Here we describe the most useful and main features in the Dashboard.

### 5.6.1 Submaps feature

Submaps is a very powerful feature that allows building large maps (full business center, factory, warehouse with total area of 10,000...300,000 or more) based on smaller submaps (30...1000m<sup>2</sup>)

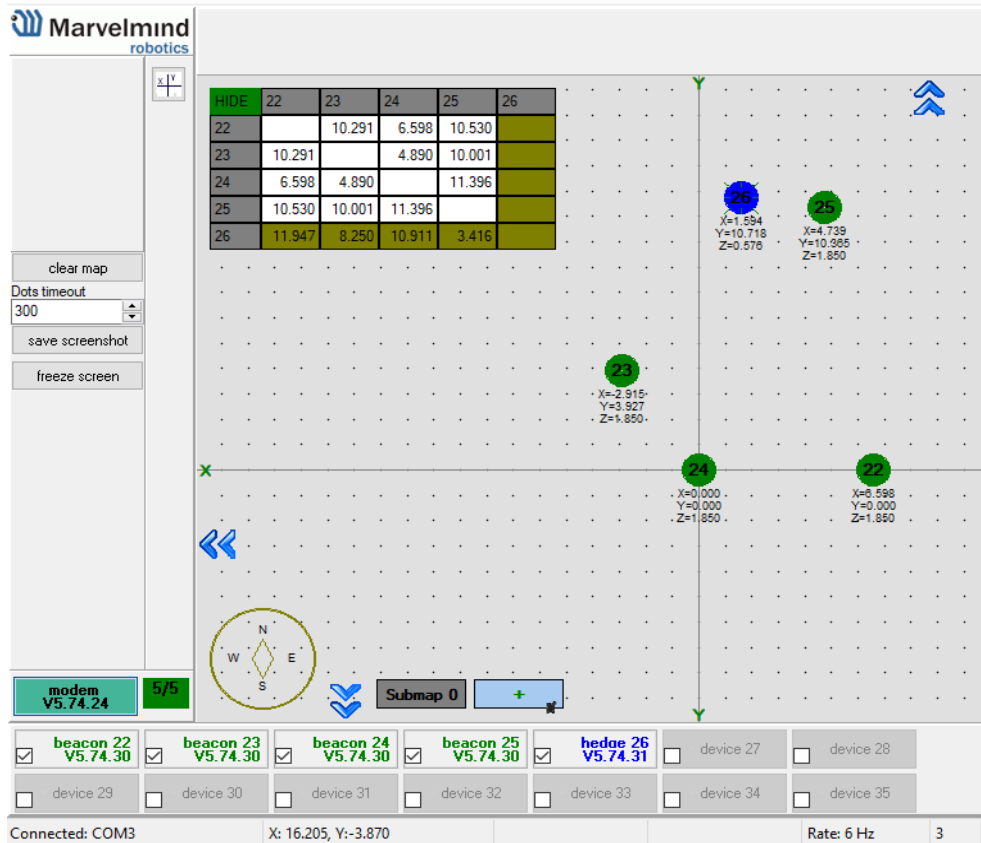
A submap is a part of the map. It includes a subset of used beacons covering part of the navigation area. Current version of Marvelmind system can include up to 10 submap. Please also check our [help video](#).

Follow these steps:

1. Choose the beacons which will be added to certain submap0...submapN
2. Connect the modem and put all the beacons into sleeping mode
3. Click "erase map" button for removing some current settings of beacons and submaps
4. Wake up all the beacons which should be served by submap0
5. Wait a little for map will automatically build. If needed use mirroring function
6. Freeze the map
7. Add the new submap by clicking "+" button. New submap is automatically chosen as active
8. Wake up the beacons which should be served by submap1. By default, all the beacons are served by the last unfrozen submap
9. If the new submap should include beacons which are at the moment served by previous submaps (intersected submaps) click on each beacon, then right-mouse-click=>Add to current submap
10. If the new submap has 1 or 2 common beacons with previous submaps, it will settle as a part of the already built map. Two common beacons give a tight binding. If there is only one common beacon it's possible to drag and drop the submap. If submaps do not have common beacons it is needed to drag and drop the selected submap using the mouse and holding down the CTRL button. Rotation of submap can be executed by using the mouse wheel.
11. Align submaps using M1/M2 parameter
12. Set Service Zones for each submap

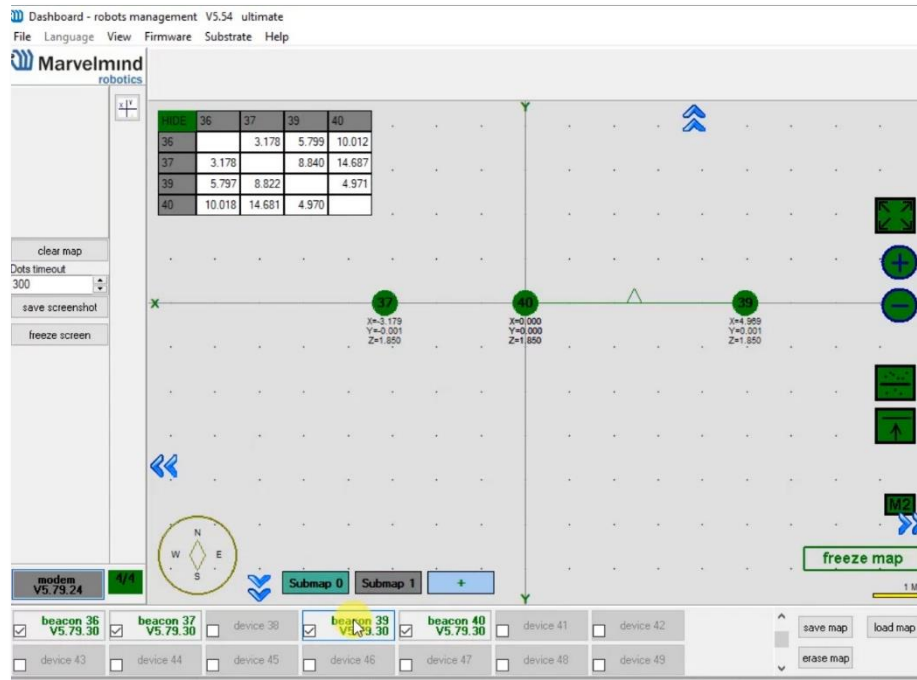
## Starting submaps

- Hedgehogs do not belong to any submap and can move between submap areas. Hedgehogs can be served not by only one submap at the same time. By default, the map consists of single sub-map, Submap0,
- After adding new beacons to the system (waking them up), they appear in the first not frozen submap, or in the Submap0 if all the beacons are frozen

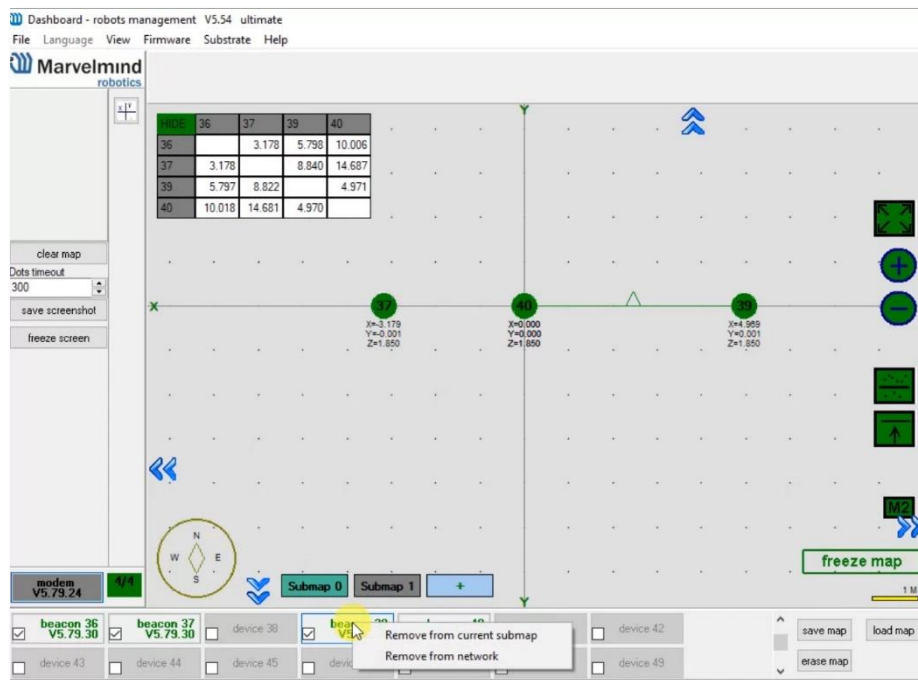


- Pressing the “+” button, add new empty submap to the system.
- Press the button with the submap number (Submap0, Submap1 etc.) - select the corresponding submap
- In this state, if the modem button is pushed, the list of parameters on the right side represents some of the parameters of the selected submap, for example, “Starting beacon trilateration,” “Starting set of beacons,” etc.

- The system after adding beacons to the Submap0, adding new submap and the selection of Submap0

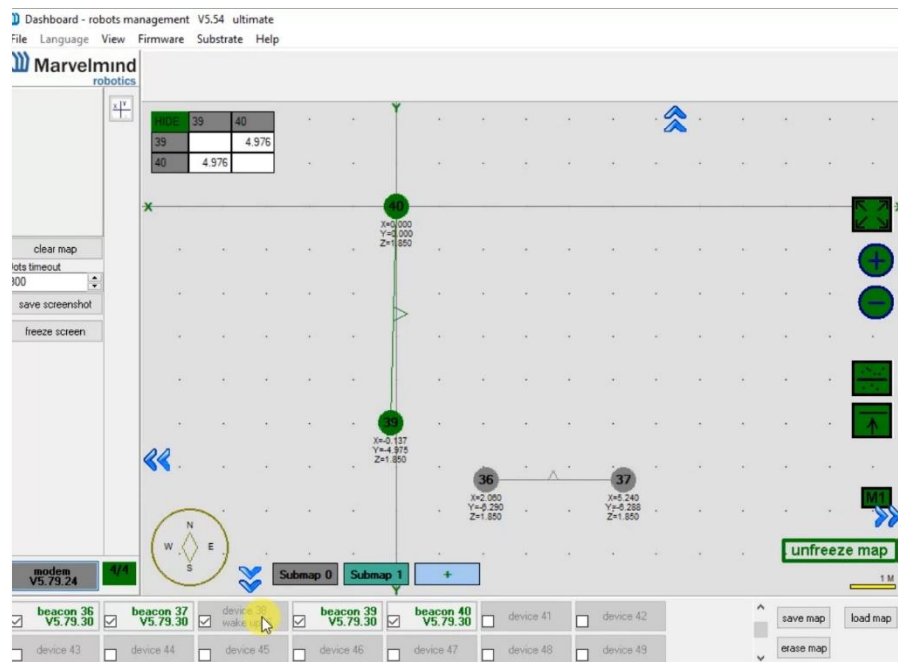


- Now we have 4 beacons, all in Submap0 (it can be seen near the table of distances)



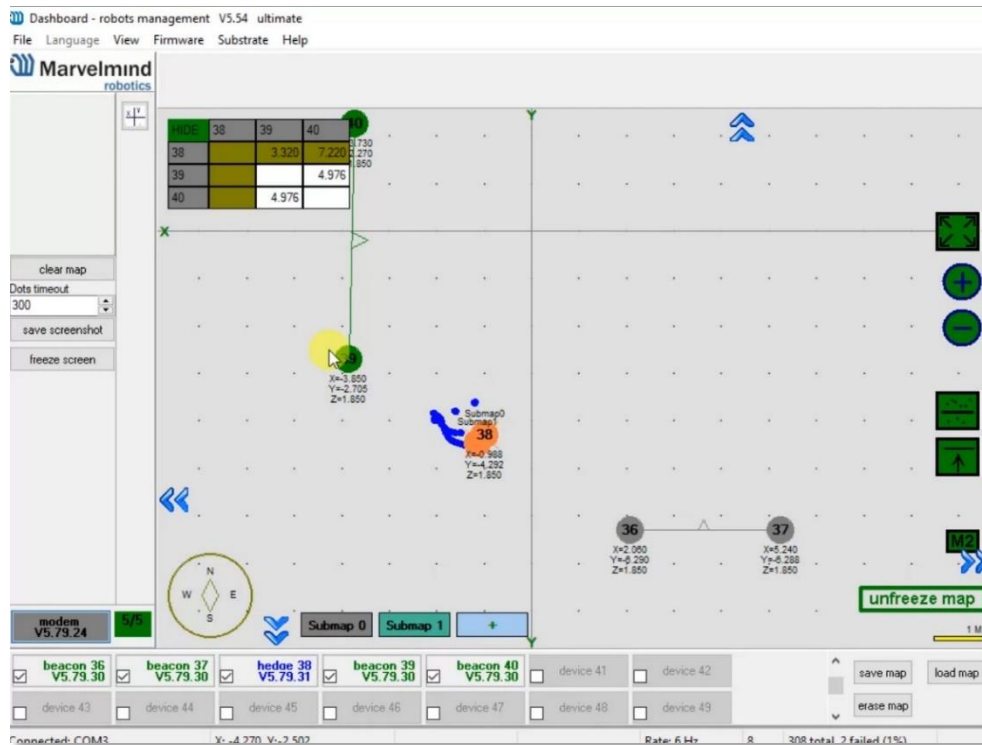
- When the submap selected, the context menu of beacons buttons (available by right clicking the mouse) have the functions of adding and removing the beacons from the submap. In the picture above, we are removing beacon 3 from Submap0.” Then we switch to Submap1 and add this beacon to the submap
- When the submap selected, the beacons that do not belong to the submap are colored **gray**. In the same way, continue with removing beacon 10 from Submap0 and adding it to Submap1

- Now there are two beacons in Submap1, so this submap is built. "Submap 0" is built as well. Now we can freeze both submaps
- If pressing the "freeze map" button when the submap is selected, only the selected submap will be frozen. If pressing the "freeze map" button when the modem button is selected, all submaps will be frozen
- Now we have two good submaps, but they are not correctly located relative to each other. On the right side exist the parameters of shift and rotation for the selected submap; they can be filled in by hands. But a more user friendly way is to drag and drop the selected submap using the mouse and holding down the CTRL button.
- Rotation of submap can be executed by using the mouse wheel. The mirroring button also can be used; it affects only submaps that are selected



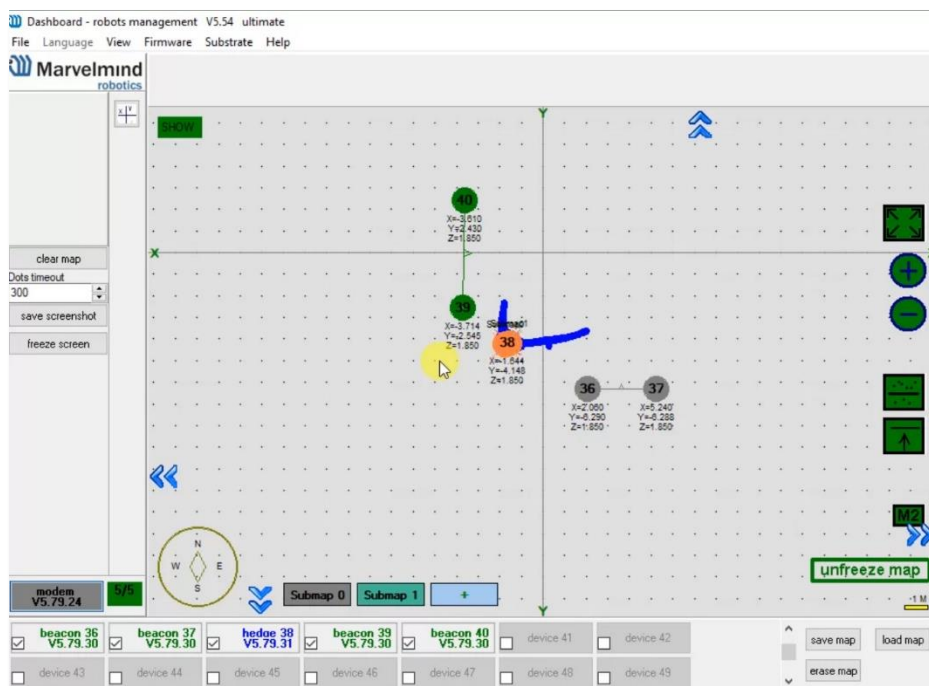
- After some movement, rotation, and mirroring of submaps, we can locate the submaps close to their real relative location
- Now the system is ready to use; we can wake up and track the mobile hedgehog
- In some cases the hedgehog can be lost between the submaps if this area is not covered by any of the submaps.

- Submaps can be removed from system using the context menu of the submap selection button (available with a right mouse click) M1/M2 parameter used for precise superposing submaps which do not have common beacons. So submaps cannot be aligned automatically



To align submaps:

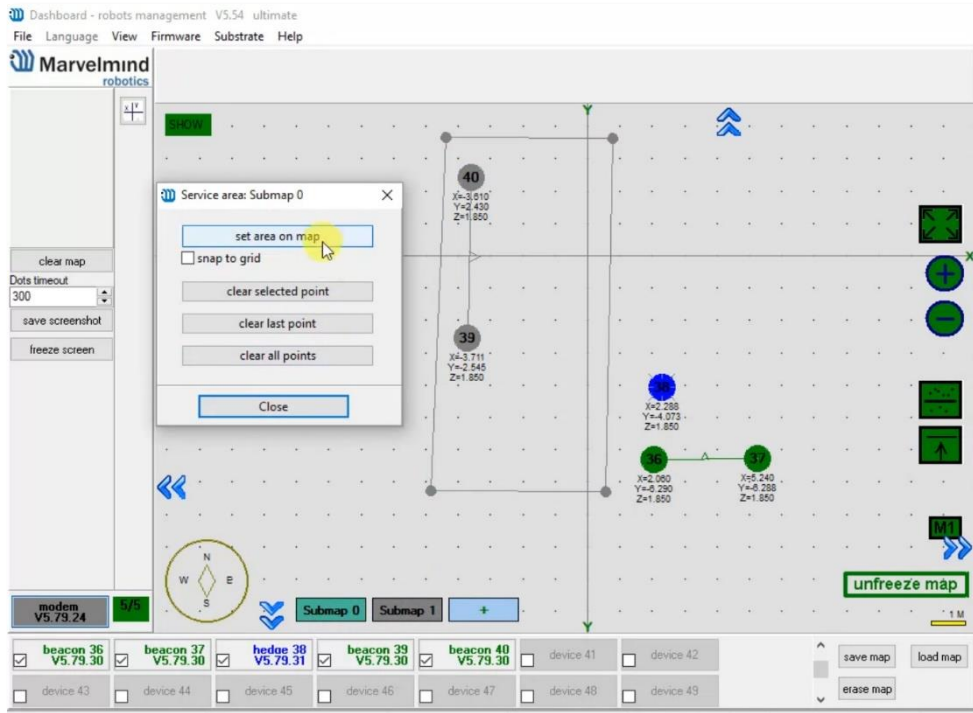
1. Build the system like in previous instruction (1-11)
2. Put M2 in mode on by clicking the icon. Place the hedgehog near the boundary between two submaps. You will see 2 orange hedgehogs blinking, this is how the hedge is seen in two submaps
3. To align submaps correctly (CTRL + scroll/drag) against each other, until the orange mobile beacons are fully overlapped
4. Replace hedgehog to 1 or 2 points and repeat replacing submap for better superposing



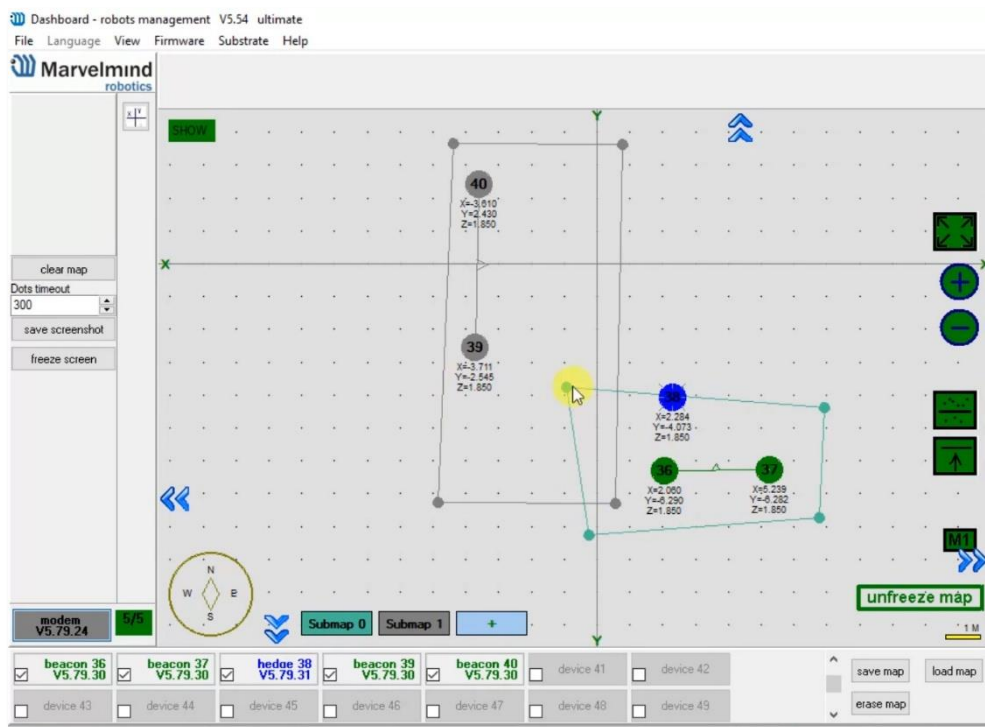


Next step is to set service zones

- Double click on submap icon and choose “Set area on map” in order to tell the system which beacons will serve in which areas and to make the map with submaps far more robust



- Put points around submap, move them to provide service area for current submap. Service areas will cross each other. If hedgehogs get lost between two submaps expand the service area



## 5.6.2 Paired beacons

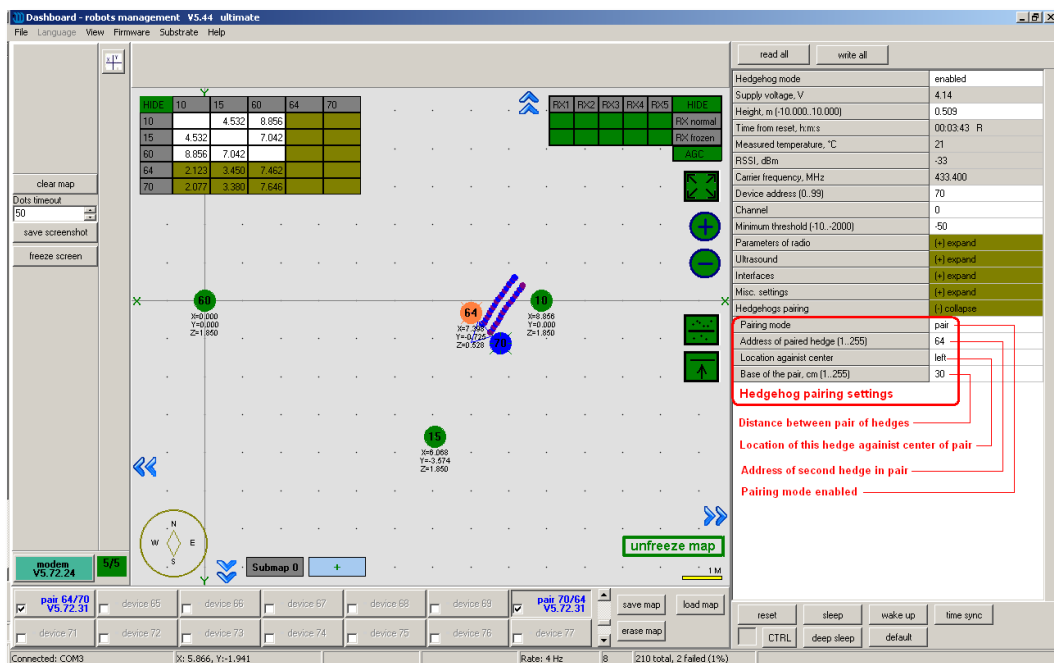
Two hedgehogs can be paired and work together as a single beacon without update rate reduction.

Moreover, each beacon streams out in this mode not only its own location, but direction where the pair is facing. This feature hugely simplifies autonomous driving and flight. Here is updated [protocol](#) with the changes

Please, also check our [help video](#).

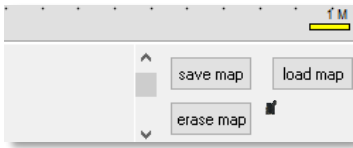
Follow these steps:

1. Wake up stationary beacons and freeze the map
2. Wake up two hedgehogs which were pre-installed on robot/copter/drone
3. Choose one beacon and go to “Pairing mode” parameter and activate
4. Write the “Address of paired beacon”, means number of the beacon, current selected hedgehog is paired with
5. Now choose location against center in parameters relatively the second beacon
6. Go to “Base of the pair” parameter and write actual distance between paired hedgehogs. Do the same for 2<sup>nd</sup> hedgehog



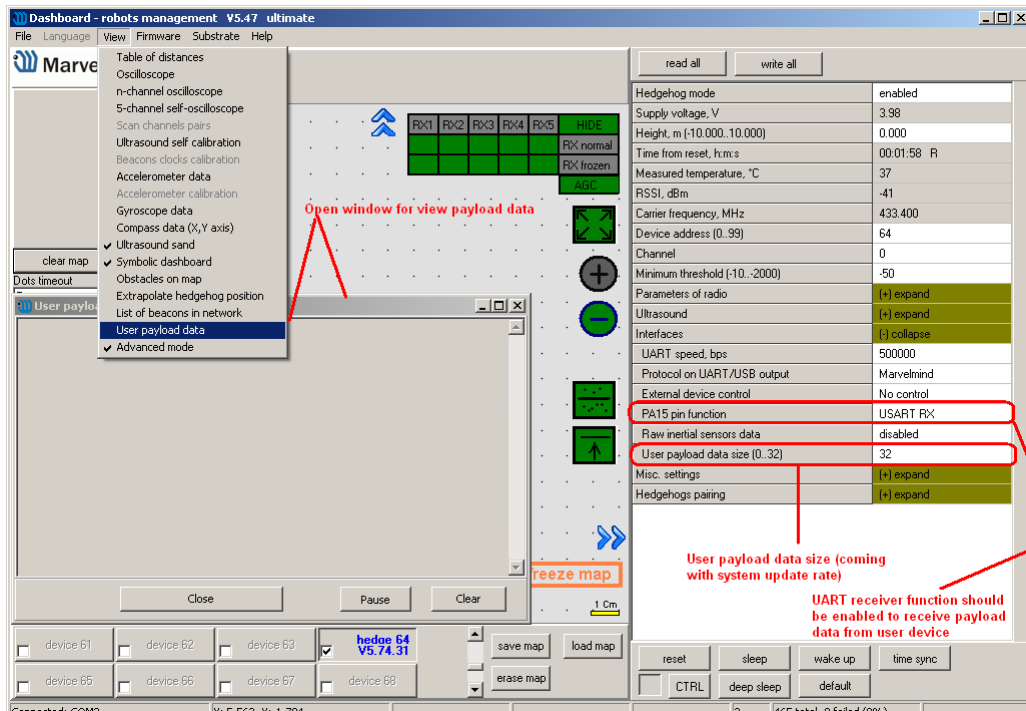
### 5.6.3 Load and save map

Save Map/Load Map feature and buttons are active now. You can build a very complex map with submaps and save all settings for the map, submaps, and all beacons including their ultrasonic gain, triggers, etc.



## 5.6.4 Payload streaming

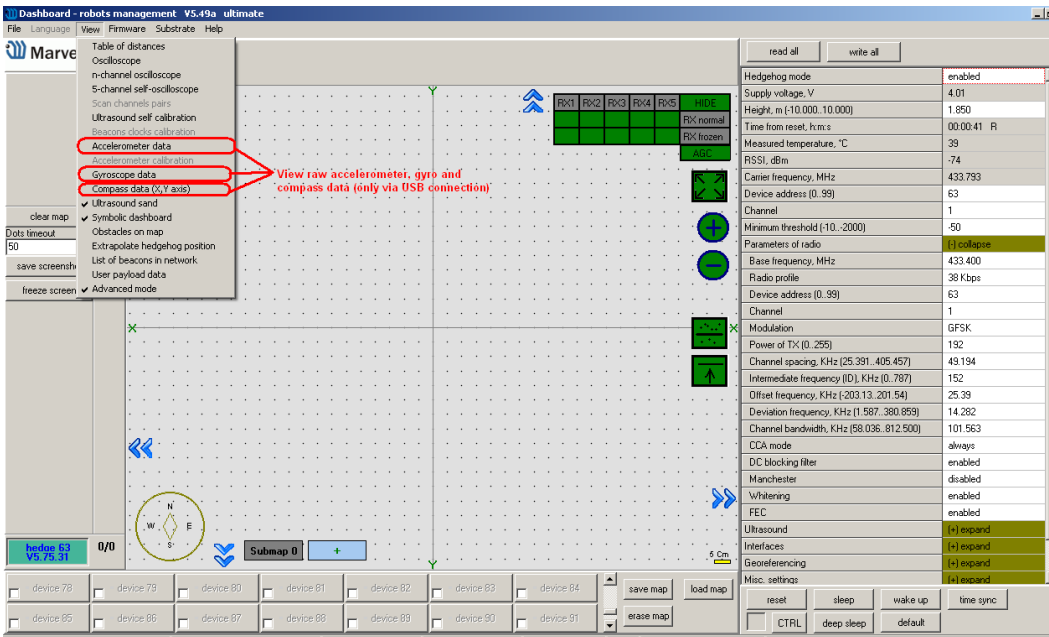
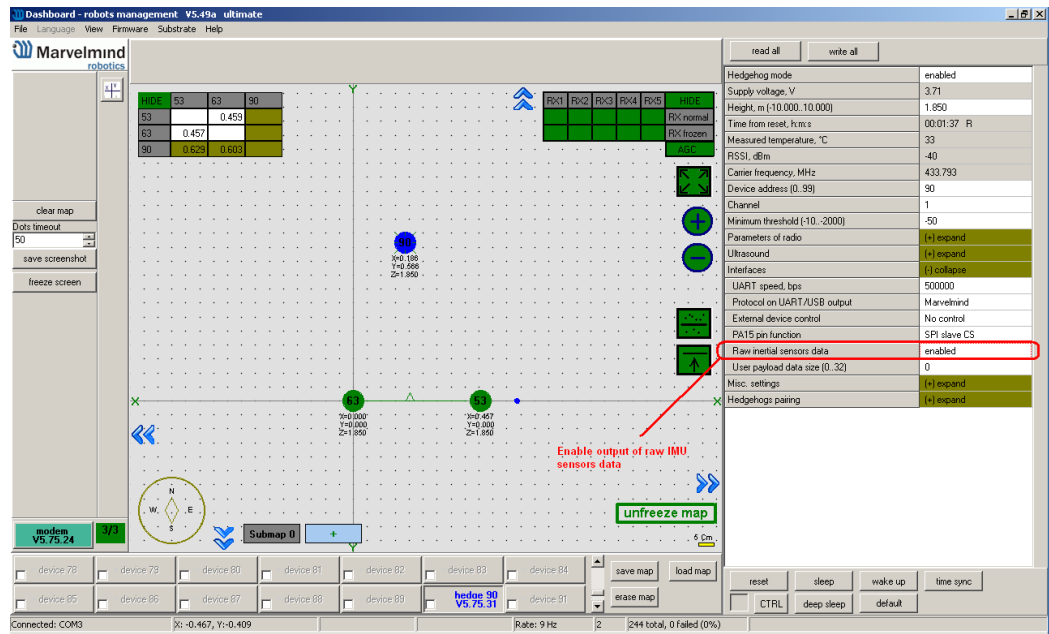
Mobile beacon streaming user payload to modem. See the table with speed vs. payload.



All measurements were made with update rate setting 16 Hz. Real update rate is limited by distance, radio profile and payload data size

System configuration	Radio profile kbps	User payload data per cycle, bytes	Real update rate, Hz	User payload maximum data rate (bytes per second)
2 stationary beacons 3 meters maximum distance	500 (FEC)	0	16	0
		32	16	512
	153 (FEC)	0	16	0
		32	16	512
	38.4 (FEC)	0	9	0
		32	8	256
	38.4 (no FEC)	0	14	0
		32	13	416
4 stationary beacons 11 meters distance (limitation distances auto)	500 (FEC)	0	14	0
		32	14	448
	153 (FEC)	0	12	0
		32	12	384
	38.4 (FEC)	0	6	0
		32	6	192
	38.4 (no FEC)	0	9	0
		32	9	288

### 5.6.5 IMU feature



## 6. Interfaces

Indoor “GPS” system supports many external interfaces that can feed measured location data to an external system (robot, copter, VR, etc.).

There are two different ways to obtain the mobile beacons’ location data from the system

1. From the mobile beacons
  - Each mobile beacon knows its own position and does not know the positions of the other mobile beacons
2. From modem/router
  - Knows position of every mobile beacon in the system

Data from the mobile beacons and from the modem can be obtained at the same time, if necessary

A list of the supported interfaces is shown below.

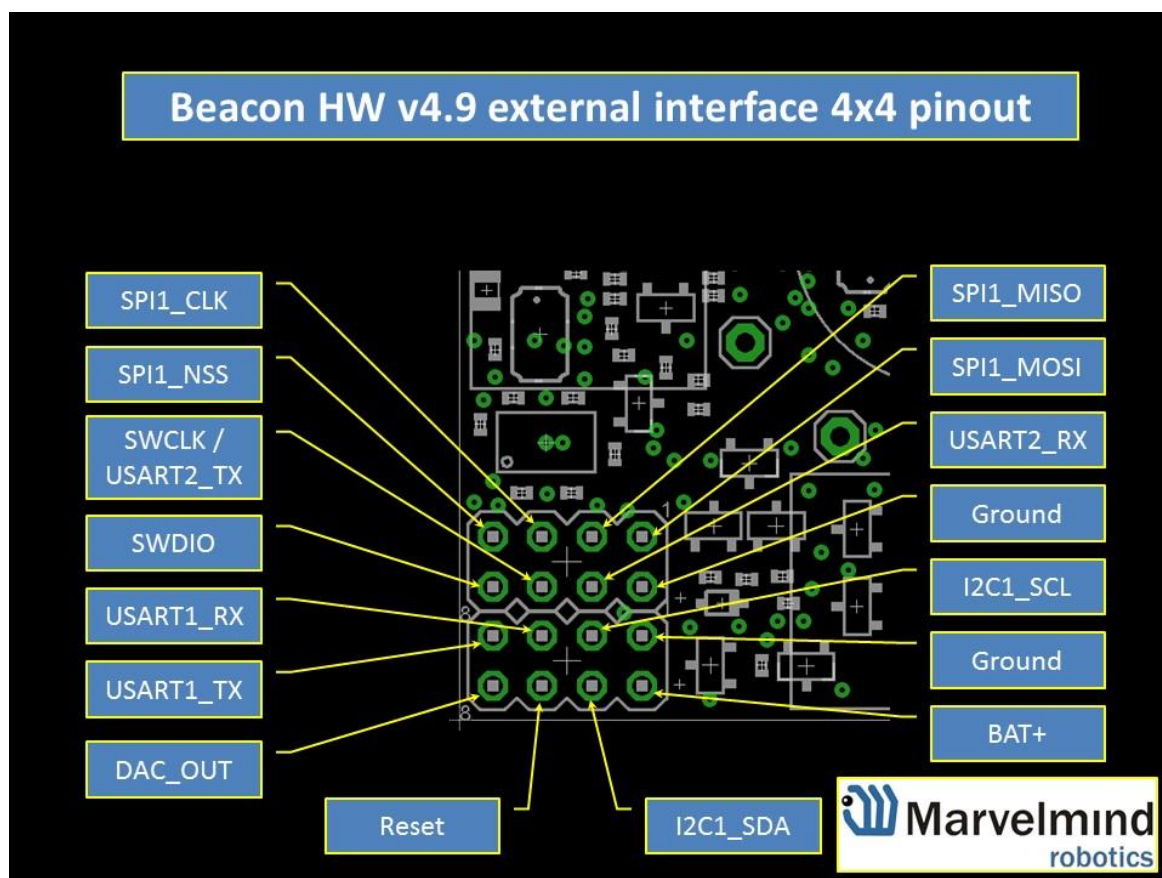
More information on the interfaces can be found here:

<http://marvelmind.com/#Interfaces>

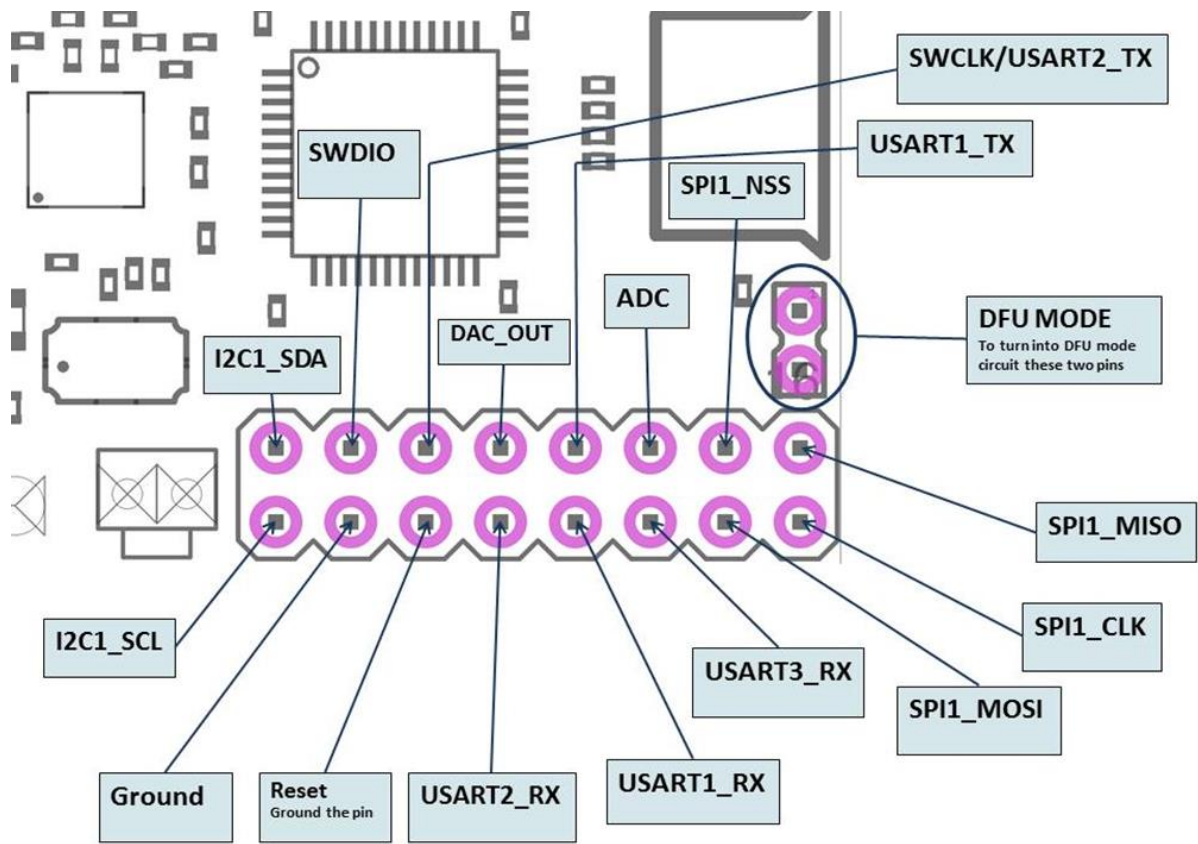
## Supported interfaces

- |  |   |   |
|--|---|---|
| <ul style="list-style-type: none"><li>• <b>Mobile beacon:</b><ul style="list-style-type: none"><li>– UART</li><li>– SPI</li><li>– Virtual UART via USB</li><li>– NMEA</li></ul></li><li>• <b>Modem:</b><ul style="list-style-type: none"><li>– UART</li><li>– SPI</li><li>– Virtual UART via USB</li></ul></li></ul> | <ul style="list-style-type: none"><li>• <b>Integrated with:</b><ul style="list-style-type: none"><li>– Windows (PC &amp; tablets)</li><li>– Linux</li><li>– Mac OS</li><li>– Android (beacon)</li><li>– ROS (beacon)</li><li>– Raspberry (beacon)</li><li>– Arduino (beacon)</li><li>– PixHawk (beacon)</li></ul></li></ul> | <ul style="list-style-type: none"><li>• <b>Sample code:</b><ul style="list-style-type: none"><li>– C</li><li>– Python</li></ul></li></ul> |
|--|---|---|

## 6.1 Beacon HW v4.9 external interface 4x4 pinout top view



6.2 Modem HW v4.9 external interface pinout top view





## 7. Advanced system settings and optimization

Start using advanced settings only when you know what you are doing

If you ran into troubles, connect the beacon or modem to the PC via USB and use the **DEFAULT** button. It will upload “factory settings” to the board while keeping the device address untracked

Carrier frequency, MHz	433.400
Device address (0..99)	1
Channel	0
Parameters of radio	(+) expand
Interfaces	(+) expand
Georeferencing	(+) expand
Limitation distances	auto
Service areas visible	enabled
Service areas active	enabled
Submap X shift, m (-100.00..100.00)	0.00
Submap Y shift, m (-100.00..100.00)	0.00
Submap rotation, degrees (-360.00..360.00)	0.00

Активация Windows

область уведомлений

CTRL

sleep

deep sleep

wake up

time sync

default

### 7.1 How to place beacons

#### Avoid placing beacons on long sound-conducting objects

This is a very rare but may happen in some special circumstances.

The best practice is to place beacons (stationary and mobile) in places that would not result in the transfer of ultrasound energy from the beacon's board/case directly to the place it is attached via a medium other than air. For example, solid attachment of a beacon to a long horizontal metal tube may result in the following:

- Sound emitted from the beacon propagates directly to the metal tube.
- Propagation losses inside metal are much smaller than in the air. Moreover, the tube may act as a low-loss waveguide.
- If the tube is solid enough and long enough, there may be a weird effect where the receiving beacon receives the signal sooner than expected, i.e., sooner than the distance divided by the speed of sound in air. That happens because the speed of sound in metal is much higher than the speed of sound in the air. The ultrasound signal may even look stronger than the real signal propagated through the air due to the lower amount of losses of ultrasonic in metal than in the air
- It is good practice to place beacons on something relatively soft or something that does not conduct sound

**Place beacons in a way that provides the proper ultrasonic coverage. It must be one beacon in the line of sight of minimum 2 beacons. Try to locate them under ceilings to avoid shadows, walls etc.**

- Optimal settings for stationary beacons in small and big rooms

Use 30–50 ultrasonic pulses for larger places and the default 5 pulses for smaller places.

- Optimal settings for noisy environment

There are several ways to reduce impact:

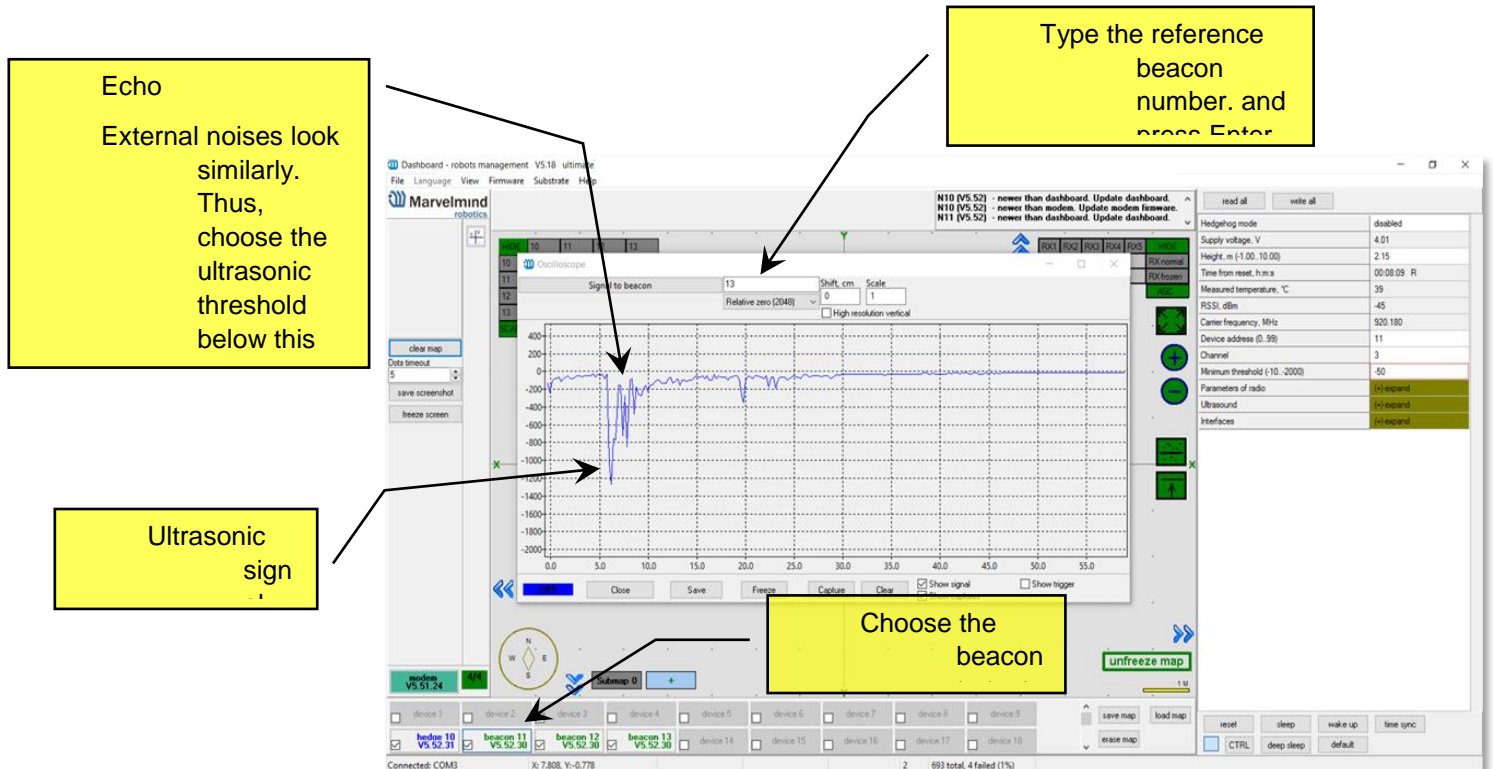
Mobile beacons can be placed very close to the source of noise without harm, but stationary beacons should be placed further from the noise because they are receiving the ultrasound, whereas the mobile beacon is emitting the ultrasound

## 7.2 Using Oscilloscope

Monitor ultrasonic signal from one beacon to another

Use **Dashboard => View => Oscilloscope** to monitor ultrasonic signals from one beacon to another.

It is a very powerful tool, because it gives also information on the background noise, level of the signal, echo, etc. With this tool, it is easy to set up the proper ultrasonic threshold on the Dashboard



## 7.3 Proper ultrasonic signal detection

When external noise is high:

- Identify the source. Usual suspects:
- Ultrasonic-based volume or movement detection alarm systems
- Other robots using ultrasonic
- Parktronic
- Sources of very strong white or impulse noise (air guns, air press, cutters, vacuum cleaner, etc.)
- Rotors of drones/copters

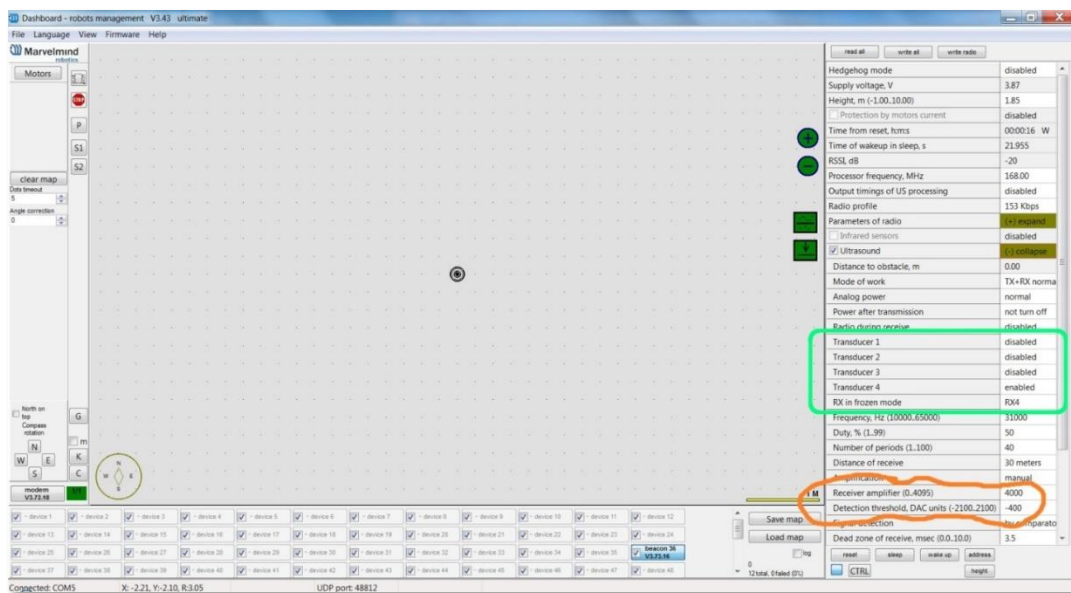
Marvelmind Indoor Navigation System uses proprietary 31kHz frequency for ultrasonic signal and employs additional filtering to combat external noise. This also makes the system rather immune against the “usual suspects.” However, if the external noise is too strong, its source is too close, or it’s emitting a strong signal on frequencies close to 31kHz or white noise, the system functionality can be affected.

The best things to do in this case are to (1) identify the beacons that are affected. Usually, they are those that are the closest to the source of noise; (2) manually reduce the gain of the affected stationary beacons so that the signal from the mobile beacon would have a 1000–1800 amplitude. That would give the best signal-to-noise ratio. Don’t make the gain too high. The noise will be amplified, but the desired signal will be saturated and signal-to-noise ratio will be poor.

The gain settings may be very non-linear. There is almost no change at 4000 to 3000. But around 2500, the gain starts reducing very quickly (1200 – for some HW versions). By setting the gain manually, it is possible to find the optimal gain to obtain the highest signal to noise ratio so the system can work even in very challenging external conditions.

When the map is formed, only the mobile beacon is emitting, whereas stationary beacons are not. Thus, it does not matter how close the mobile beacon is to the source of the noise.

But it matters how close the stationary beacons are to those sources. So select the positions of the stationary beacons accordingly - place them further from the sources of noise



## 7.4 Using hedgehog.log file

The system automatically records all measured positions in the hedgehog.log file that is stored in the same folder as the Dashboard.exe file

The data is written in csv format; each line describes the position of one of the hedgehogs at a certain moment

The line format is described [here](#)

## 7.5 System accuracy evaluation

### 1) Accuracy of distances measurement.

Marvelmind navigation system can measure distances between beacons with accuracy of +/- 2cm if it uses correct ultrasound speed in measurements

The ultrasound speed depends of many factors: temperature of air, pressure, humidity and so on

The main factor is temperature. In temperature range of -20...+50 °C the speed of ultrasound changes on about 0.6 m/ (s\* °C). It gives distance error about  $(0.6 / 340) * 100\% \sim 0.17\% / ^\circ\text{C}$ . So caused by incorrect temperature setting absolute error of distance measurement is 0.17% of real distance between beacons. For example, with distance 30 meters and 5 °C error, this gives  $0.85\% * 30 \sim 0.25$  meters' error. Marvelmind system allows to setup temperature of air in the system settings

### 2) Accuracy of position measurement.

Marvelmind system uses trilateration algorithm to calculate position by distances. The inaccuracy of position calculation is related to inaccuracy of distances measurement and to geometry of relative location of stationary and mobile beacons.

Basic trilateration formulas are given in this article:

<https://en.wikipedia.org/wiki/Trilateration>

As you see, the position of mobile beacons **X**, **Y**, **Z** is calculated from positions of 3 stationary beacons which are set by values of **d**, **i**, **j**. One of the beacons was shifted to (0,0) position to simplify formulas in the article. In formulas for **X**, **Y** we see **d** and **j** in denominators. This means that with low values of **d** and **j** small error of this value can cause large position error.

Please see the picture of the beacons in the article - in more simple words, in means that if one of three beacons is close to line connecting other two beacons, it gives increased inaccuracy of locating mobile beacon.

For example, assume  $d=10$ ,  $i=5$ ,  $j=0.1$ ,  $r_1=7$ ,  $r_2=7$ ,  $r_3=4.8$ .

We get  $x=5$ ,  **$y=2.4375$** ,  $z=4.25$ .

If we suppose that  $j=0.101$  (0.1 cm error), we receive  $x=5$ ,  **$y=-0.06$** ,  $z=4.89$ .

You see very large Y error.

Another example for Z. Assume mobile beacon is relative close to plane of stationary beacons:

$d=8$ ,  $i=4$ ,  $j=6$ ,  $r_1=5.02$ ,  $r_2=5.02$ ,  $r_3=3.01$ .

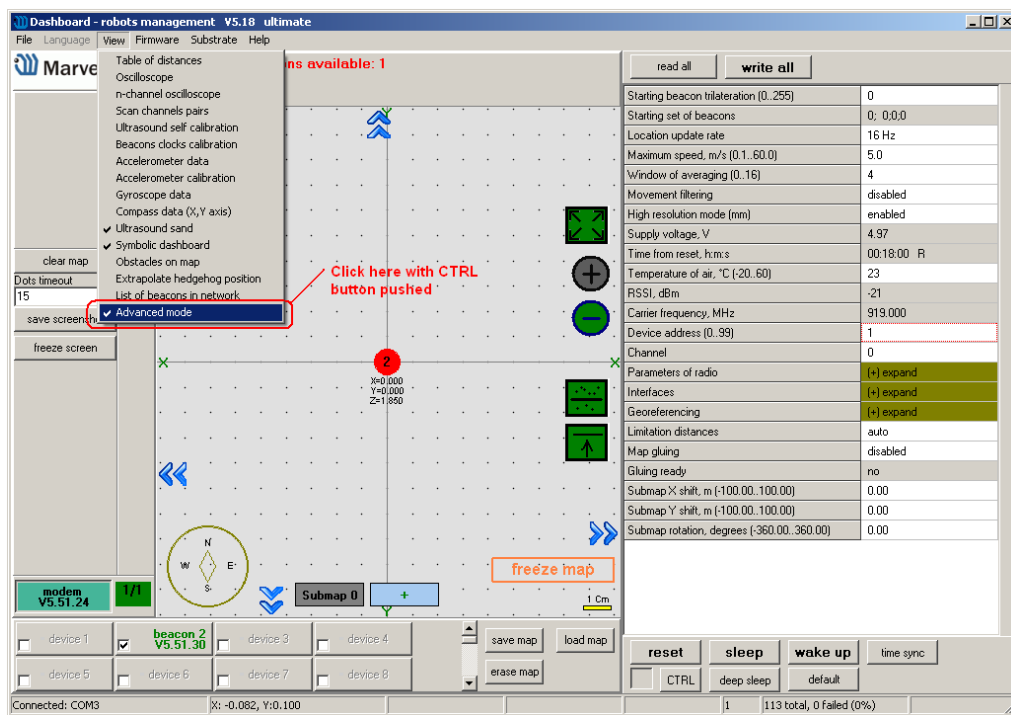
This gives  $X=4$ ,  $Y=3.01169$ ,  $Z=0.36$ .

If we suppose  $r_3=3.0$  (1 cm error), we receive  $X=4$ ,  $Y=3.016$ ,  $Z=0.44$ . Error on Z is about 8 cm.

Also, with  $r_1=5$ ,  $r_2=5$ ,  $r_3=3$ , Z will be 0. As you see, low change of distances causes large change of Z value near the plane

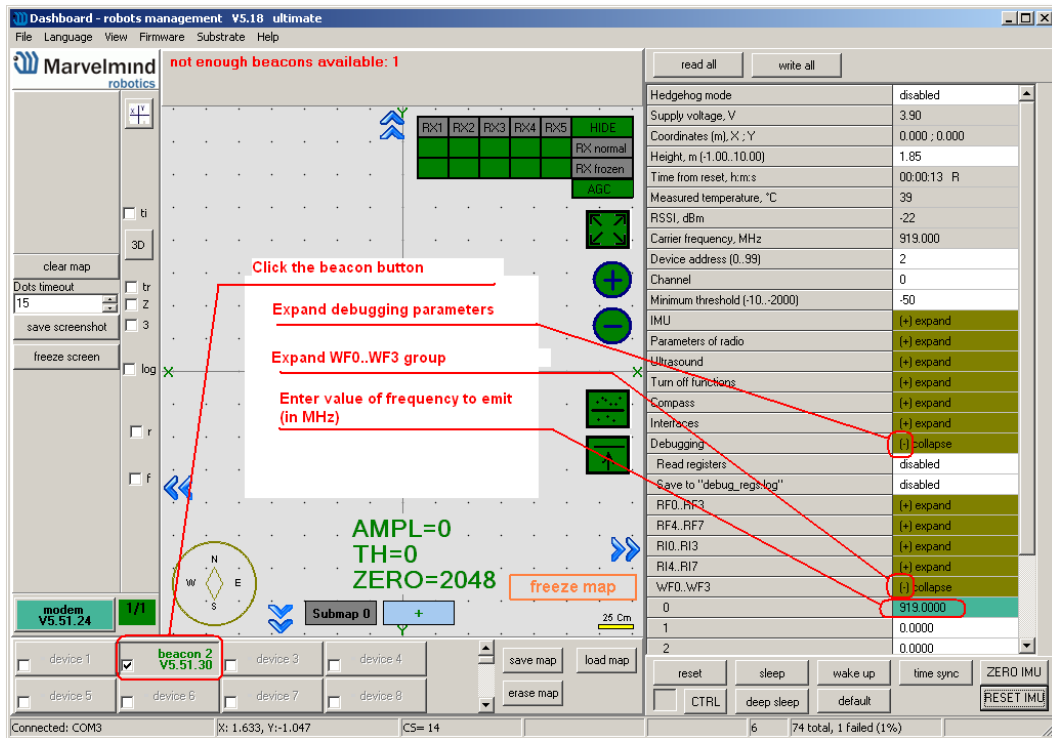
## 7.6 Enable special mode of the Dashboard

To switch the beacon into the mode of emitting constant radio frequency, you need to enable special mode of dashboard with additional functions. Push the CTRL button on keyboard and check the “Advanced mode” checkbox which is shown on screenshot



## 7.7 Force the beacon to emit radio frequency

Click on the button with the beacon on bottom of the window ("beacon 2" in this example) and enter the frequency of emission as shown on following screenshot



After this, the beacon starts permanent emission of selected frequency

Communication with modem will be lost, and after some time the beacon will disappear in dashboard

To return communication with beacon, press hardware reset button on the beacon

After reset, the beacon may restart emission on the same frequency because it was entered in dashboard.

If you need to change frequency of emission, repeat this instruction starting from section 2, or enter another frequency value in window shown on last screenshot and then make the hardware reset of the beacon

## 7.8 Settings to obtain correct north direction

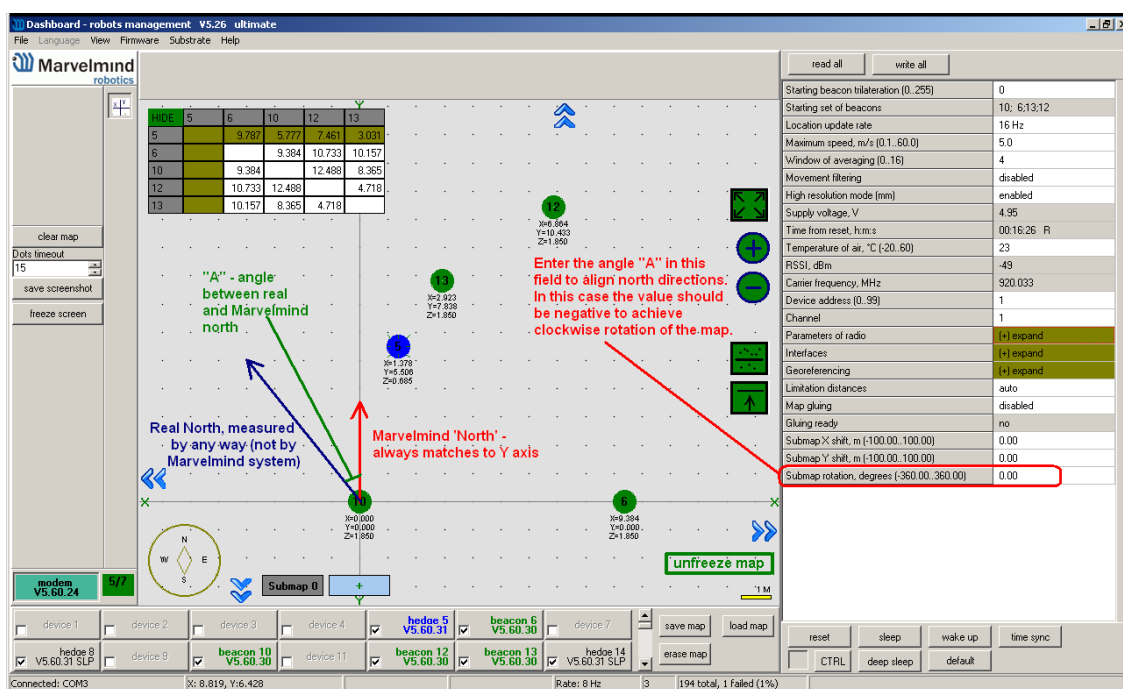
In some cases, it is necessary to obtain a correct north orientation of the map for NMEA output from Marvelmind system. For example, when using a Marvelmind mobile beacon as the navigation data source for Pixhawk installed on a copter, correct north is required for correct yaw control of the copter. The Marvelmind system cannot determine north automatically, so the user should make corrections after building and freezing the map. It can be done in one of two ways:

7. Rotate the Marvelmind map using the dashboard, as shown on the attached screenshot.
8. You can also view the video:  
<https://www.youtube.com/watch?v=AsYXrtg7aVU&feature=youtu.be>

Enter the angle correction (the angle shown on screenshot) on the Pixhawk side from the Mission Planner of APM Planner.

Refer to the parameter "BCN\_ORIENT\_YAW":

[http://ardupilot.org/copter/docs/parameters.html?highlight=bcn\\_orient\\_yaw](http://ardupilot.org/copter/docs/parameters.html?highlight=bcn_orient_yaw)



Beacons may issue raw sensor data. To learn how to obtain this data, please check this protocol:

[https://drive.google.com/open?id=0ByNFYpty-t\\_CRWxSWmhKTkkzVzg](https://drive.google.com/open?id=0ByNFYpty-t_CRWxSWmhKTkkzVzg)

See section **1.3**. The data output comes from UART and the USB (virtual UART) on the mobile beacon.

You can receive the data byte-by-byte and check for the required packet header

See an example here:

[http://www.marvelmind.com/downloads/2017\\_02\\_08\\_C\\_example.zip](http://www.marvelmind.com/downloads/2017_02_08_C_example.zip)

## 7.9 Communication of Pixhawk with Marvelmind mobile beacon

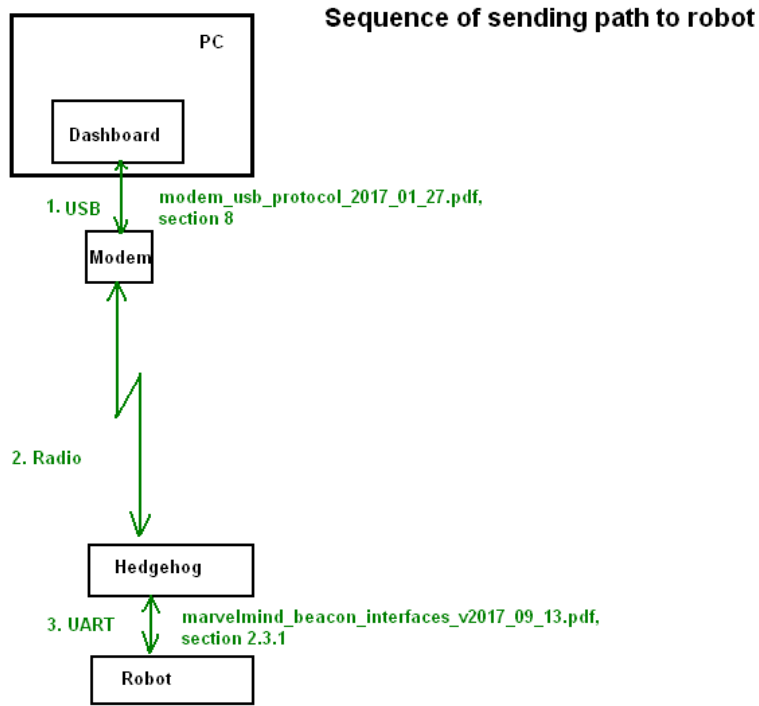
The Marvelmind mobile beacon can be connected to Pixhawk (and to any other hardware or software that inputs GPS according to the NMEA0183 protocol). The mobile beacon can send GPS data via UART and USB (virtual UART) interfaces. For further explanation, please check out this [document](#)



## 7.10 Sending path to robot

1. The dashboard sends request to modem via USB.  
Procedure of sending these requests in dashboard is shown on second screenshot.  
This format of request is described in section 8 of modem protocol:

[https://marvelmind.com/wp-content/uploads/2017/08/modem\\_usb\\_protocol\\_2017\\_01\\_27.pdf](https://marvelmind.com/wp-content/uploads/2017/08/modem_usb_protocol_2017_01_27.pdf)



2. modem transmits data to the hedgehog via radio, using our proprietary protocol



## 7.11 Proper ultrasonic coverage

**The single most important requirement for the system to work well is to have proper ultrasonic coverage**

Each sensor has an ultrasonic beam of ~90 degrees. Outside of that range, the emitting power and sensitivity drops quite rapidly. From the left, right, or back of the ultrasonic sensor, the signal is highly attenuated. Thus, it is crucial to provide proper ultrasonic coverage for the area where the robot will be moving.

- It is also very important to provide proper ultrasonic coverage to the stationary beacons when the map is being formed.

**Mobile beacon (“hedgehog” or “hedge”) is designed to be placed horizontally**

- The mobile beacon has four horizontal and one vertical sensor, each covering its own sector. Together, they cover 360 degrees horizontally and 180 degrees in the upper hemisphere. The lower hemisphere is highly attenuated, so don't expect ultrasonic coverage in that area.

It is advised that the mobile beacon be placed as high as possible on the robot if the stationary beacons are above the mobile beacon. This minimizes shadows from other objects, people, etc.

Dashboard - robots management V5.47 ultimate

File Language View Firmware Substrate Help

Marvelmind robotics

hide	22	23	24	25	26
22		10.262	10.398	6.618	
23	10.262		9.993	4.853	
24	10.398	9.993		11.345	
25	6.618	4.853	11.345		
26	6.991	3.699	3.947	2.003	

clear map  
Dots timeout: 300  
save screenshot  
freeze screen

modem V5.74.24 5/5

Submap 0

beacon 22 V5.74.30  
beacon 23 V5.74.30  
beacon 24 V5.74.30  
beacon 25 V5.74.30  
hedgehog 26 V5.74.31

device 27  
device 28  
device 29  
device 30  
device 31  
device 32  
device 33  
device 34  
device 35

save map  
load map  
erase map

read all  
write all

Hedgehog mode: disabled

Supply voltage, V: 3.70

Height, m (-10.000..10.000): 1.850

Time from reset, h:m:s: 00:05:08 R

Measured temperature, °C: 39

RSSI, dBm: -50

Carrier frequency, MHz: 433.400

Device address (0..99): 25

Channel: 0

Minimum threshold (-10..-2000): -50

Parameters of radio: (-) collapse

Base frequency, MHz: 433.400

Radio profile: 38 Kbps

Device address (0..99): 25

Channel: 0

Modulation: GFSK

Power of TX (0..255): 192

Channel spacing, KHz (25.391..405.457): 49.194

Intermediate frequency (ID), KHz (0..787): 152

Offset frequency, KHz (-203.13..201.54): 0.00

Deviation frequency, KHz (1.587..380.859): 14.282

Channel bandwidth, KHz (58.036..812.500): 101.563

CCA mode: always

DC blocking filter: enabled

Manchester: disabled

Whitening: enabled

reset  
sleep  
wake up  
time sync

CTRL  
deep sleep  
default

- Example of proper positioning of the mobile beacon can be found here:

<https://youtu.be/PFgNPkLGCDk>.

The beacon is placed horizontally and above other objects that can cast a shadow on the stationary beacons

**Keep the radio signal's strength under control**

- The RSSI (Dashboard => right menu) of any beacon/modem must not be higher than -25dBm. Otherwise, the system may malfunction.

It is recommended the distance between the modem and beacons be no less than 0.5–1m. Beacons can be placed as close to each other as needed. If a beacon is extremely close to the modem, disconnect the antenna from the beacon. Monitor the Received Signal Strength Indicator (RSSI). It must be in the range of -25 to -70dBm. An RSSI of less than -70dBm will work too, but packet losses may start occurring. The quality of the radio connection very much depends on external interference as well because the used band is ISM (either 915MHz or 433MHz) and there are numerous co-existing systems

Use 30 - 50 periods (pulses) in settings instead of the default 5. Select:

**Ultrasound settings => Number of periods**

Ultrasound	(-) collapse
Mode of work	TX+RX normal
Analog power in sleep	enabled
Power after transmission	not turn off
Frequency, Hz (100..65000)	31000
Duty, % (1..99)	50
Number of periods (1..100)	5
Amplifier limitation (calibrated)	4000
Amplification	AGC
AGC desired level (-1800..0)	-500
AGC hysteresis (10..2000)	130
AGC step, dB (1..20)	3
Mode of threshold	automatic
Minimum threshold (-10..-2000)	-50

When you have large errors in position estimation (more than a 1m inaccuracy), use the embedded Oscilloscope on **Dashboard => View** to determine which stationary beacon is jammed

Reduce the gain of the ultrasonic manually depending on your system

- Multibyte numbers are transmitted starting from low byte (little endian format)

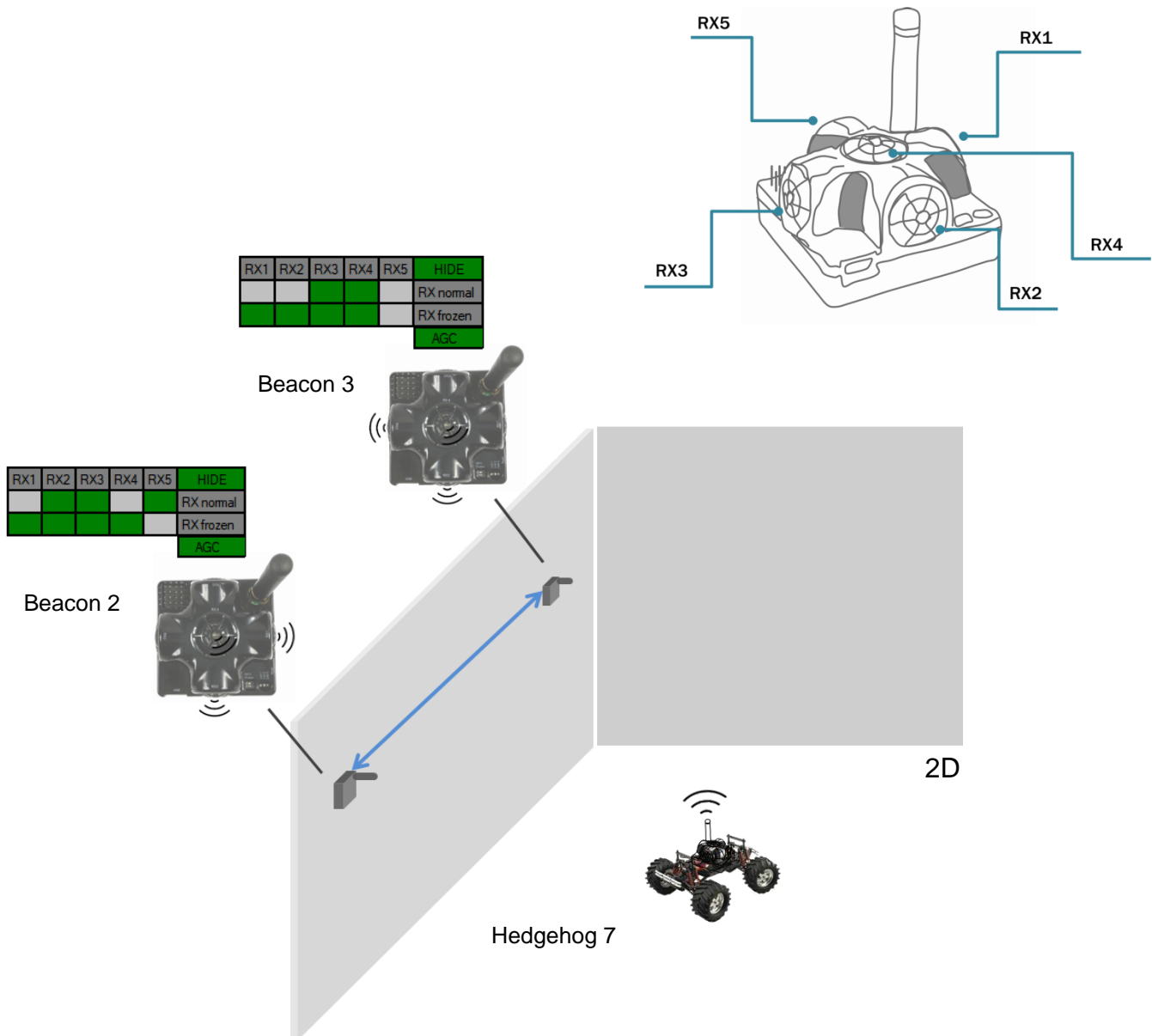
Negative values represented as two's complement

For example:

a 32-bit integer value '-100' is represented as FFFFFFF9C  
(transmitted as sequence 9C, FF, FF, FF in little endian format)

This value is detected as negative by '1' value of MSB  
and converted by subtracting  $2^{32}$ :  $0xFFFFFFFF9C - 0x100000000 = -0x64 = -100$

## 7.12 Sensors settings: example for 2D and mobile beacon



### Beacon 2

RX1 and RX4 emit ultrasound in normal mode for better ultrasonic signal exchange with Beacon 3. In frozen mode RX2 added as working sensor. The rest sensors are turned off. Changing sensors' settings could be found in the panel in the upper right corner of the Dashboard during your beacon is connected to the computer.

### Beacon 3

RX3 and RX4 emit ultrasound in normal mode for better ultrasonic signal exchange with Beacon 2. In frozen mode RX2 added as working sensor. The rest sensors are turned off.

## 7.13 Powering beacons

### Modes of operations

1. Stationary beacons powered from a clean source of +5V USB
  2. Mobile beacon powered from a clean source of +5V USB from a robot
  3. Operations based on internal LiPol 3.7V 1000 mAh cell
- Typical power consumption in deep sleep mode is 50uA, which provides ~2 years of shelf time with a regular 1000mAh battery. The beacon can be woken up from deep sleep only by pressing HW **RESET** button
  - In regular sleep mode, the beacons wake up automatically every 2 seconds for ~20ms to monitor external calls from the modem/router. That causes some additional consumption, but it can still be left for several months in sleep mode
  - Active mode work time directly depends on the location update rate. For example:
    - o With the standard 1000mAh battery and 16Hz update rate, the expected work time will be 97h => 8 days (assuming a 12-hour working day).

With the extended 4300mAh battery and 1Hz location update rate, the expected work time will be ~5800h or 484 days (assuming a 12-hour working day)

Calculated beacon's work time in active mode vs. location update rate

Current cons., mA	Time, ms	Charge, mAh	h	Location update rate, Hz			
				1	4	8	16
23.0	15.0	0.000096	10434783	2899	725	362	181
0.05	12.0	0.000000	6E+09	1666667	416667	208333	104167
42.0	7.0	0.000082	12244898	3401	850	425	213
0.10		0.000000	10000	10000	10000	10000	10000

		Location update rate, Hz				
		1	4	8	16	
		Expected working time				
Standard battery	1000	Hours	1352	376	192	97
		Days	56.3	15.7	8.0	4.0
		1/2-days	112.7	31.3	16.0	8.1
Extended battery	4300	Hours	5814	1618	824	416
		Days	242.2	67.4	34.3	17.3
		1/2-days	484.5	134.8	68.7	34.7

## 8. Frequently Asked Questions

Please check this [forum](#) for more information. Here we will answer the most common questions

### 1 What is the proper way to place the beacons?

The actual distance between beacons must be  $\leq 30$  m. Provide the line of sight from one beacon to minimum two others

### 2 How far can beacons be located from modem?

In the open space the distance from the modem to the beacon can reach several hundred kilometers

### 3 What if hedgehog shown as **orange** circle or **transparent** inside in the Dashboard?

In the open space the distance from the modem to the beacon can reach several hundred kilometers

### 4 What is the obstacle for ultrasound?

The real obstacles for ultrasound are walls (concrete), glass, metal. If you need to cover a multiple-floor territory you can use our Submap feature in which case the tracking will not be interrupted

### 5 How the system works in very low and very high temperatures?

The optimal conditions for the system is 0 °C - 40 °C

### 6 Are beacons resistant to explosions, dust, dirt, water, noise?

- Low-frequency noise (motor noise, industrial equipment) does not interfere with the normal operation of the system
- We now working on IP67 version of beacon. It can work underwater at a depth of one meter up to half an hour. It will be fully resistant to dust, it will have protected housing and sensors

### 7 Is ultrasound harmful for human

We are surrounded by ultrasound impact. For example: parktronic, automatic doors, security alarms. Ultrasound is not harmful as you used to think

### 8 What is the time of delay between positioning the object and respond?

The delay is directly proportional to the update rate. For example, if update rate is 16 Hz delay is 60 ms



## 9 What if losing hedgehog after 0.6 m

By default, the service area for mobile beacons is limited and mobile beacon not positioning far from stationary beacons.

The limit is 1.5x times the maximum distance between the stationary beacons. To expand the service area, please follow the instructions shown in the attached screenshot. Notice that positioning the mobile beacon far from stationary beacons and close to their plane may result in increased positioning error because of bad geometry of measurement

## 9. Contacts

For additional support, please send your questions to [info@marvelmind.com](mailto:info@marvelmind.com)