Marvelmind Indoor Navigation System

Operating Manual

V2015_09_21

Marvelmind robotics

Table of Contents

Marvelmind robotics

1) Executive summary

Marvelmind Indoor Navigation System is off-the-shelf indoor navigation system designed for providing location data to autonomous robots and vehicles, but it can also be used for tracking other objects, where the mobile beacon can be installed.

The system is based on stationary ultrasonic beacons united by radio interface in license-free band. Location of a mobile beacon installed on a robot (vehicle, copter, human) is calculated based on the propagation delay of ultrasonic signal to a set of stationary ultrasonic beacons using trilateration.

Key requirement for the system to function properly is an unobstructed sight by a mobile beacon of three or more stationary beacons simultaneously.

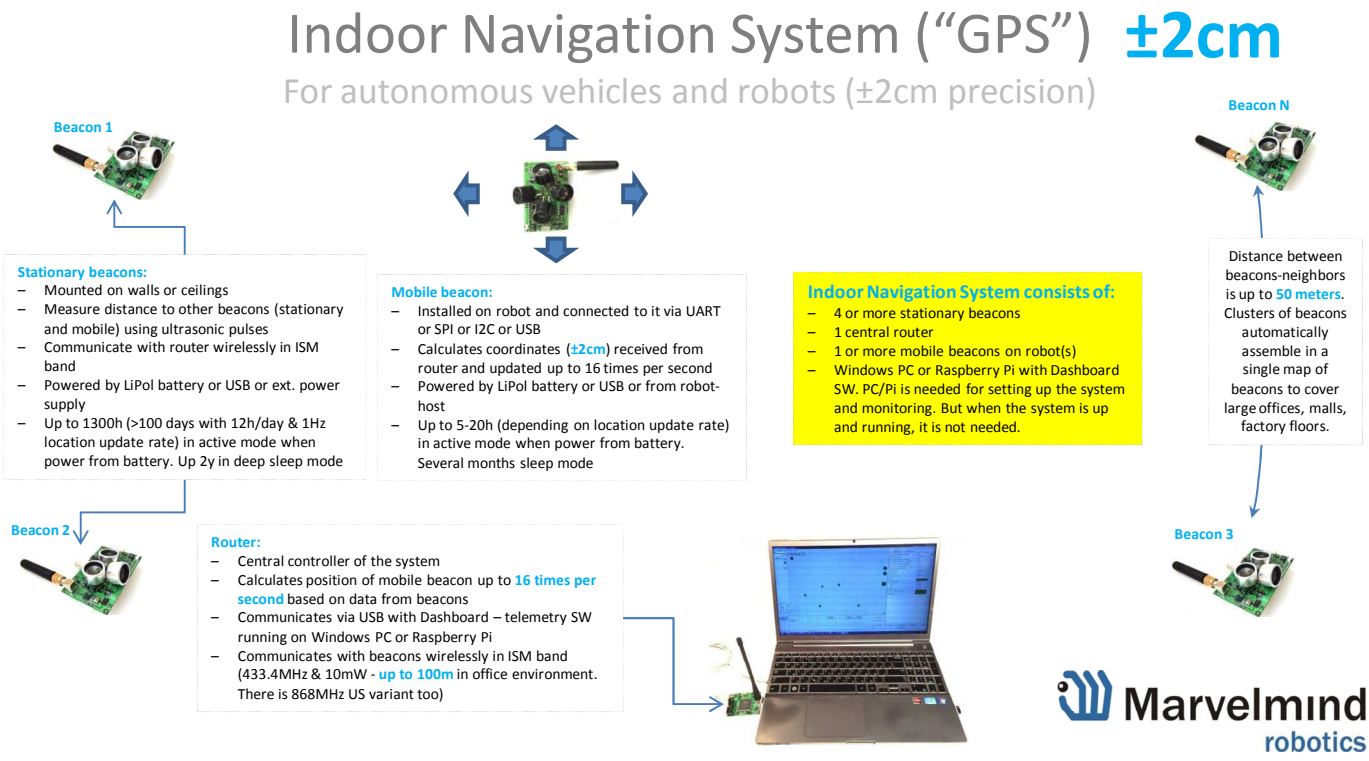
Main capabilities:

- Distance between beacons: up to 50 meters
- Coverage area:
  - up to 1000 m^2 for Starter Set
  - Coverage for larger territories done similar to cellular networks
- Location precision:
  - 1-3% of the distance to the beacons
  - Differential precision: ±2 cm
- Location update rate:
  - 0.5-16 Hz
- Beacons form the navigation system automatically – no manual coordinates measurements or entering required

2) Basics of the system

Marvelmind Indoor Navigation System provides high-precision indoor coordinates for autonomous robots and systems (“indoor GPS”)

Short description of key elements of the system is given on scheme below.



Stationary beacons

- Mounted on walls and ceilings – above the robot – to prove the easiest unobstructed coverage. However, for automatic landing and indoor navigation of copters, for example, it is recommended to place beacons on the floor/ground and install the mobile beacon horizontally downwards looking on the belly of the copter
- Position for the beacons and angles of positioning shall be chosen in such a way that maximum coverage in ultrasonic to be provided for the maximum territory. Proper ultrasonic coverage is utmost important element for the system to function properly
- Stationary beacons emit and receive ultrasound, when the map is being formed. And they only receive the ultrasound, when the map is frozen

Mobile beacon (“hedgehog”)

- The mobile beacons are designed to be placed on the robot to trace its location. Formally speaking, location of the mobile beacon is traced – not the robot itself. Since the sizes and the central point of the mobile beacon and the robot are different, this difference has be taken into account
- The mobile beacon has to be placed horizontally to provide optimal ultrasonic coverage
- Its sensors must not be closed with anything that can reduce the strength of ultrasonic signal
- The beacon’s coordinates are updated according to the rate set in the Dashboard
- System may contain one or more stationary beacons. However, current implementation relies on time division multiple access approach, thus, if two mobile beacons are activated, they share the time. It means that, if 16 Hz update rate is used and there are 2 beacons, each beacon’s location will be update with the rate => 16Hz/2 = 8Hz. If there are 3 mobile beacons => 16Hz/3 = 5.3Hz, etc. Future implementation will contain different solution
- Location data can be obtained from the hedgehog via USB (virtual UART), UART, SPI

Modem/router

- The central controller of the system
- It is used to set the system, monitor it, interact with the Dashboard
- It can be placed anywhere within radio coverage to have permanent radio connection with all beacons
- It must be powered all the time, when the system works. It is recommended to use active USB hub for that purpose

3) What is in the box

Starter Set:

- 4xStationary beacons
- 1xMobile beacon (“hedgehog”)
- 1xModem/Router

* Exact appearance may slightly differ depending on the HW version. Characteristics are kept to same or better

Boxed Set:

- 4xStationary beacons in boxes
- 1xMobile beacon (“hedgehog”) in box
- 1xModem/Router in box

* Exact appearance may slightly differ depending on the HW version. Characteristics are kept to same or better.

** Boxes are 3D printed. The cases provide mechanical protection, but rather limited environmental protection.

4) Technical Specifications

Table: Technical Specifications

Parameter	**Technical Specifications**
Distance between beacons	Up to 50 meters (transducer4 to transducer4 looking straight to each other)
Coverage area	Up to 1000 m^2 for Starter Set configuration. Coverage for larger territories done similar to cellular networks.
Location precision	- Absolute: 1-3% of the distance to the beacons - Differential precision: ±2 cm
Power supply	Internal: LiPol battery 1000mAh;
	External: microUSB
Weight	Stationary beacon: xx grams
	Board + Case1: yy grams
Board size	45x65 mm; Height: 25mm

Table: Power Consumption

- Typical power consumption in deep sleep mode is 50uA that gives ~2y shelf time for regular 1000mAh battery. Beacon can waken up from deep sleep only by pressing HW reset button
- In regular sleep mode the beacons wakes up automatically every 2 seconds for ~20ms to monitor external calls from modem/router. That brings some additional consumption, but still leaves several months in sleep mode
- Active mode work time directly depends on the location update rate. For example:
    - With the standard 1000mAh battery and 16Hz update rate, the expected work time will be 97h => **8 days** (assuming 12h working day)
    - With the extended 4300mAh battery and 1Hz location update rate the expected work time will be ~5800h or **484 days** (assuming 12h working day)

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

				Location update rate, Hz			
Current cons., mA	Time, ms	Charge, mAh	h	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	mAh	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	mAh	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

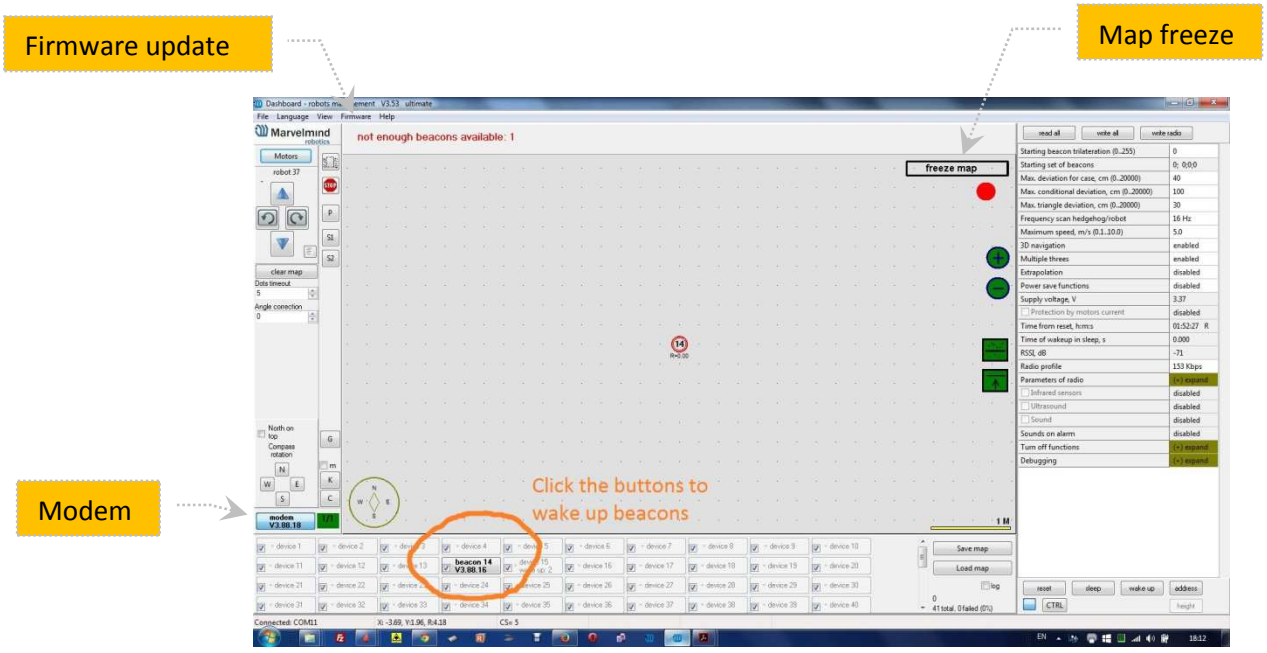
5) Models comparison

Parameter	Starter Set	Boxed Set	Boxed+Holder Set	Outdoor Set
Optimized for	Price	Overall	Overall + performance	Outdoor + performance
Other important characteristics	Unprotected board – use with care	Protecting case against mechanical impact. Limited outdoor protection	Protecting case against mechanical impact. Limited outdoor protection	Average outdoor protection. Transducers rotate independently to provide maximum ultrasonic coverage
Size	Smallest size and weight	Size and weight is about the same as for Starter Set	Larger size due holder of stationary beacons. Mobile beacons and modem are the same as for Boxed Set	Larger and substantially different case Same case for mobile and stationary beacon
Battery	Standard 1000mAh	Standard 1000mAh	Standard 1000mAh	Extended 4300mAh

6) Setting up the system

Basic setup routine:

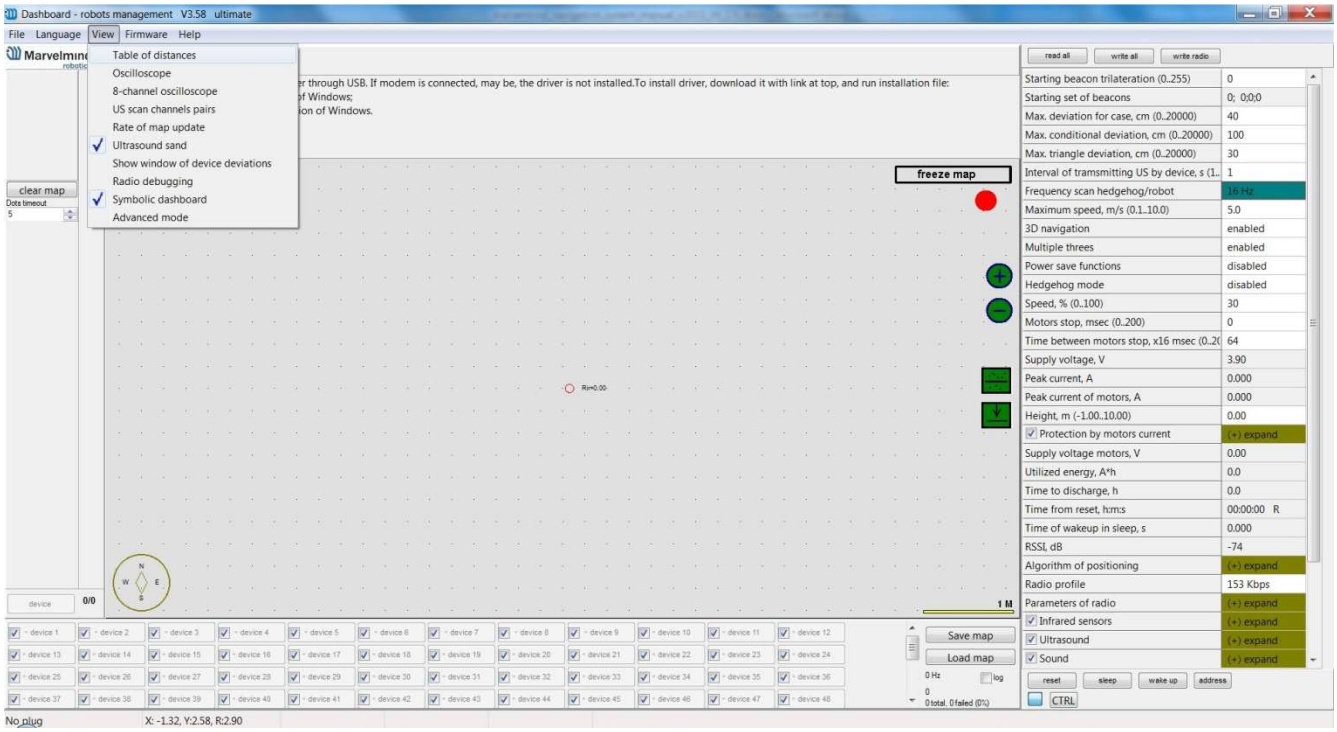
1. Unpack the system. See the video: https://youtu.be/7PsbmP3VP3Y
2. Download and install Dashboard and STM32 driver on your laptop: http://www.marvelmind.com/#Download.
    a. If there are newer SW versions, run the Dashboard and update the SW using **Dashboard** => **Firmware**
3. Check that all switches on beacons are in the right position: http://www.marvelmind.com/pics/power_switch.jpg
4. Place stationary beacons on the walls vertically in such a way that optimal ultrasonic coverage is provided. To start with the system it is recommended to use a simple room of 4x6 meters or so and place the stationary beacons on the opposite walls on 1.85m height (default). After familiarizing with the system far more complex setup can be done
5. Connect the modem/router via USB to the PC with Dashboard installed
6. Run the Dashboard
7. Modem shall appear connected
8. Wake up all beacons by clicking on the buttons in the Dashboard. It takes beacons up to 8 seconds to wake up
9. The map will form automatically
    a. If map does not form, use **View** => **Table of distances** to monitor the measured distances between beacons (See advanced system setting in the following chapter)
10. Freeze the map. Stationary beacons will stop measuring relative distance and will be ready to measure distance from the mobile beacon
11. Turn on and wake up mobile beacon similar to the operations with the stationary beacon.
12. The system now is fully operational



Marvelmind robotics

Advanced system settings and optimization:

1. **Use Dashboard => View => Table of distances** to monitor the distances between beacons



If you see in the table some empty cells or marked yellow or red, it is an indication that distances between some beacons are measured inconsistently or not measured at all. Try to check what the problems with those beacons are. Try to re-position them, because, usually, there is an obstruction of some sort in the between the beacons.

2. Use Dashboard => View => Oscilloscope to monitor ultrasonic signal from one beacon to another. It is very powerful tool, because it gives also information on the background noise, level of the signal, echo. With this tool it is easy to set up the ultrasonic threshold in the Dashboard

Hints on usage:

- Choose the beacon to test
- Type the reference beacon number. And press Enter

3. Choosing proper ultrasonic detection threshold

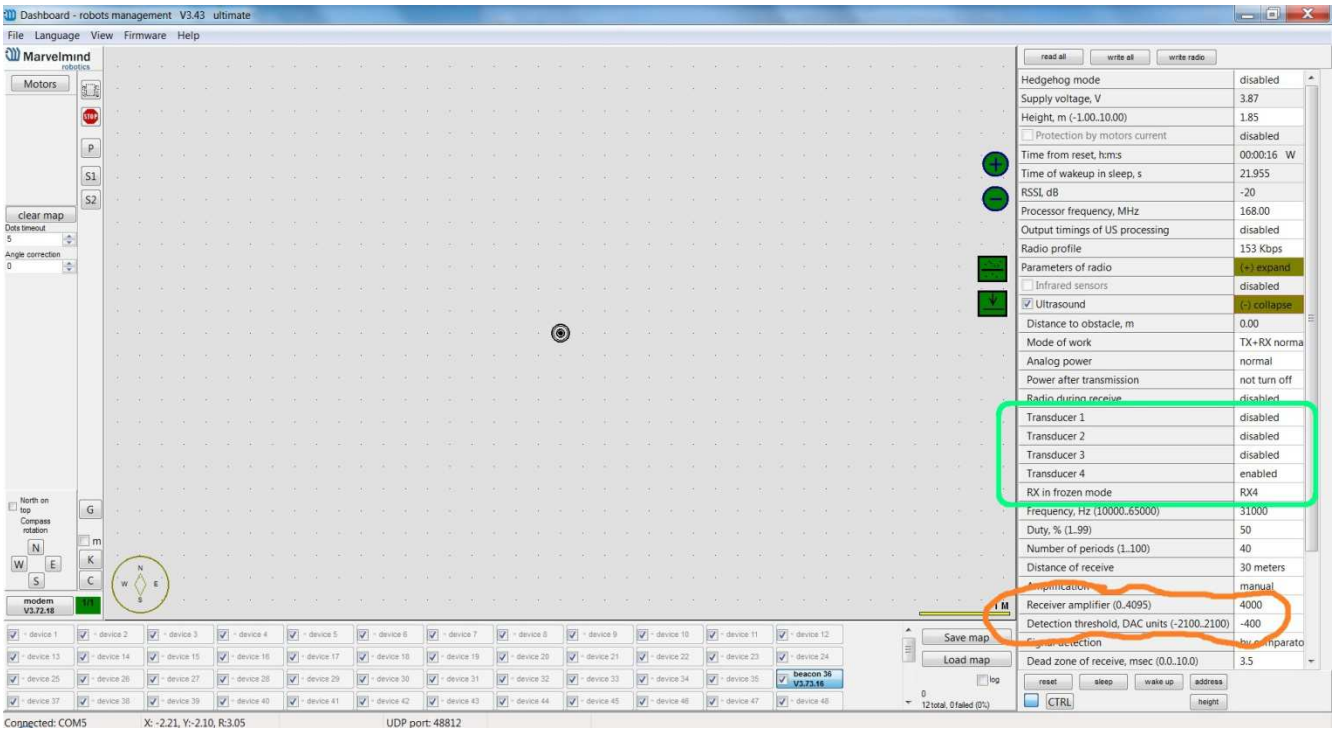
This is important!

Choose the ultrasonic threshold below the external noise, but higher than the minimal expected ultrasonic signal from other beacons or the hedgehog. For the example above: -500 to -2000 would be safe choice. However, as mentioned, the shown noise is not a real external noise, but echo from the previous measurements that will settle to the time of the measurement in the real system, as opposite to the oscilloscope setup. In this configuration the external noise is not visible at all – too low.

When external noise is high:

- Identify the source. Usual suspects:
  - Ultrasonic based volume or movement detecting alarm systems
  - Other robots using ultrasonic
  - Parktronics

    - Sources of very strong white or impulse noise (air guns, air press, cutters, vacuum cleaner, etc.)
- Marvelmind Indoor Navigation System uses proprietary 31kHz frequency for ultrasonic signal and employs additional filtering to combat external noise. And it makes the system rather immune against usual However, if the external noise is too strong, its source is too close, or is emitting strong signal on frequencies close to 31kHz or white noise, the system functionality can be affected
- When map is formed, only mobile beacon is emitting, but stationary beacons are not. Thus, it does not matter how close the mobile beacon is to the source of noise. But it matters how the stationary beacons are close to those sources. So, select the position accordingly
- If noise is still there, one can choose to reduce the gain of the ultrasonic receiver while keeping the level of own ultrasonic signal strong above the noise above the threshold.



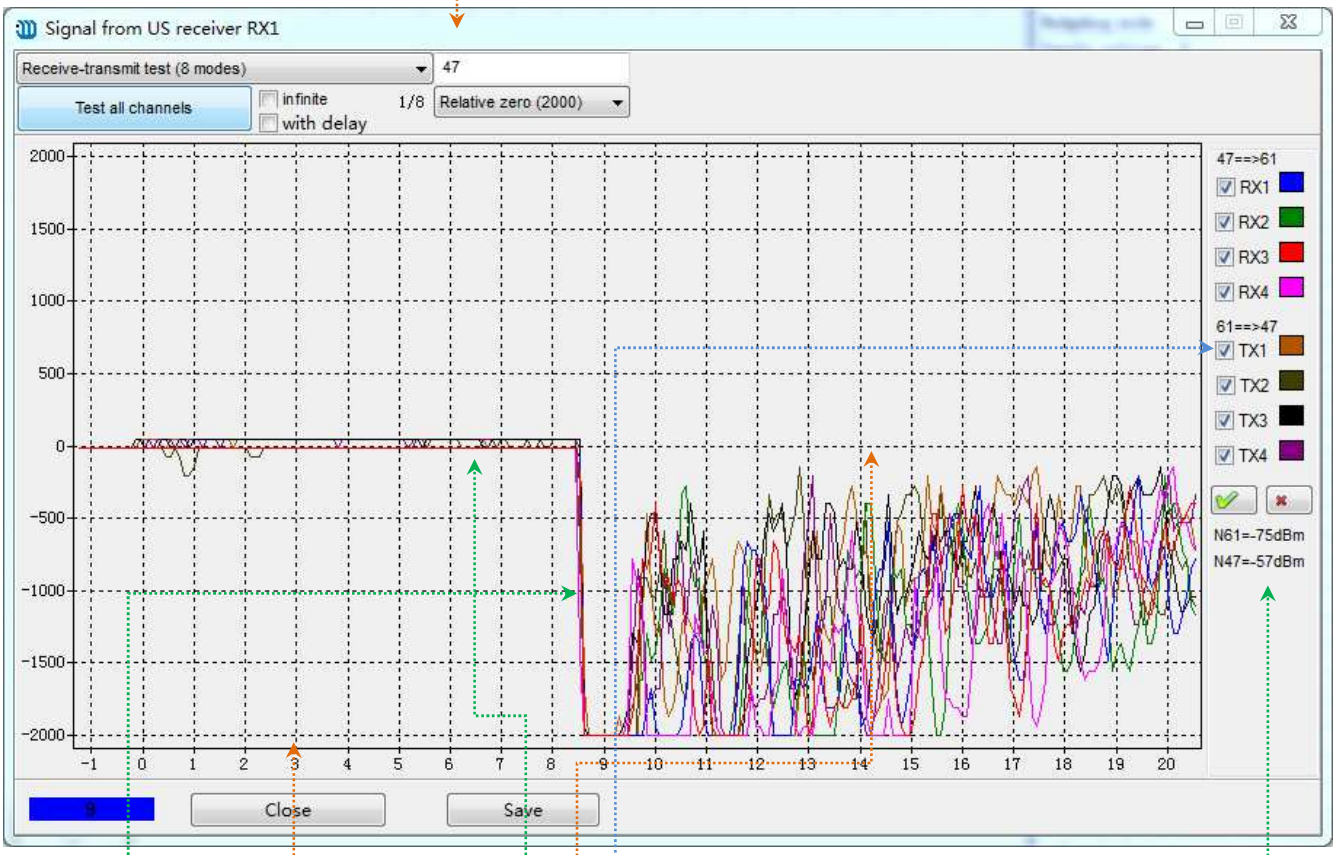
Also right selection of the threshold is the key in such a noisy environment. The gain is very non-linear. 4000 to 3000 – almost no change. But around 2500 the gain starts reducing quickly. Thus, it is possible to find the optimal gain to obtain the highest Signal/Noise ratio. Set the threshold value accordingly

4. Use Dashboard => View => 8-channel oscilloscope for very deep analysis of transducers performance

Hints:

- Choose the reference beacon and press Enter, like with regular Oscilloscope described above

Example of the test result:



- In this example beacon n61 selected and tested against reference beacon n47
- Note that there is nearly no noise
- Front of the signal from different sensors is nearly at one line. The difference is explained by the fact that they are indeed have a distance of a couple of cm from each other
- No full-scale horizontal lines must be. If there are, it means that some sensors either don't receive or do not emit. By ticking the ticks it possible to identify which particular sensors malfunction to easier to trace the source of the problems (wrong setting, mechanical damage, etc.)

7) Important aspects and hints

- **The most important is to provide proper ultrasonic coverage.**

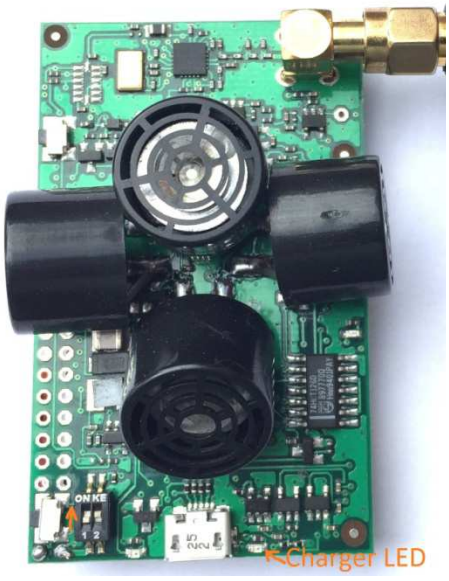
- **Stationary beacons are designed to be placed vertically, antenna on the right, and the beacon above the robot.**
    - In this way they provide the best ultrasonic coverage.
    - Each sensor has an ultrasonic beam of ~90 degrees. Outside of that range the emitting power and sensitivity drops quite rapidly. From the left, right, or back of the sensor the signal is received highly attenuated. Thus, it is crucially important to provide proper ultrasonic coverage for the area where the robot will be moving.
    - Also it is very important to provide proper ultrasonic coverage for other stationary beacons when the map is being formed

- **Mobile beacon ('hedgehog") is designed to be placed horizontally.**
    - Mobile beacon has four sensors each covering its own sector. Together they cover 360 degrees horizontally.
    - It is advised to place the mobile beacon as high as possible, if stationary beacons are above the mobile beacon, to minimize shadows from other objects, people, etc.
    - Example of proper positioning of the mobile beacon: https://youtu.be/PFgNPkLGCDk - the beacon is placed horizontally and above other object can produce shadow to the stationary beacons

- **Keep the distance between beacons and modem more than 1.5m.**
    - RSSI (Dashboard => right menu) of any beacon/modem must not be higher than -25dBm. Otherwise, the system may malfunction (packets lost unnoticeable, etc.)
    - It is also preferred that the distance between beacons is more than 1.5m

- **Start using advanced settings only when you know what you are doing.**
    - If you ran to troubles, use "Set all to default" button.

- **Charging.**
    - Charging is done automatically every time, when the USB charger is attached to the board
    - It takes 1-2h to fully charge the board's battery.
    - After charging is finished the right LED goes dark
    - Make sure that the power switch is ON
    - Otherwise, the battery is fully disconnected and won't be charged
    - For more, see the picture on the right



Deep hints:

- **Avoid placing beacons on long sound conducting objects**
    - This is a very rare case, but may happen in some special circumstances
    - The best practice is to place beacons (stationary and mobile) in such places that would not result in transferring ultrasound energy from the beacon's board/case directly to place it is attached. For example, attaching the beacon to the long horizontal tube may result in the following:
        - Sound emitted from the beacon propagates directly to the metal tube
        - Propagation loses 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 when the receiving beacon receives the signal sooner than expected, i.e sooner than (speed of sound in air / distance). That happens because of speed of sound in metal is much higher than speed of sound in the air and some part of the path the sound travelled in the metal. The ultrasound signal may even look stronger than the real signal propagated through the air due to lower losses of ultrasonic in metal than that in the air
    - It is good to place beacons on something relatively soft or not so sound conductive.

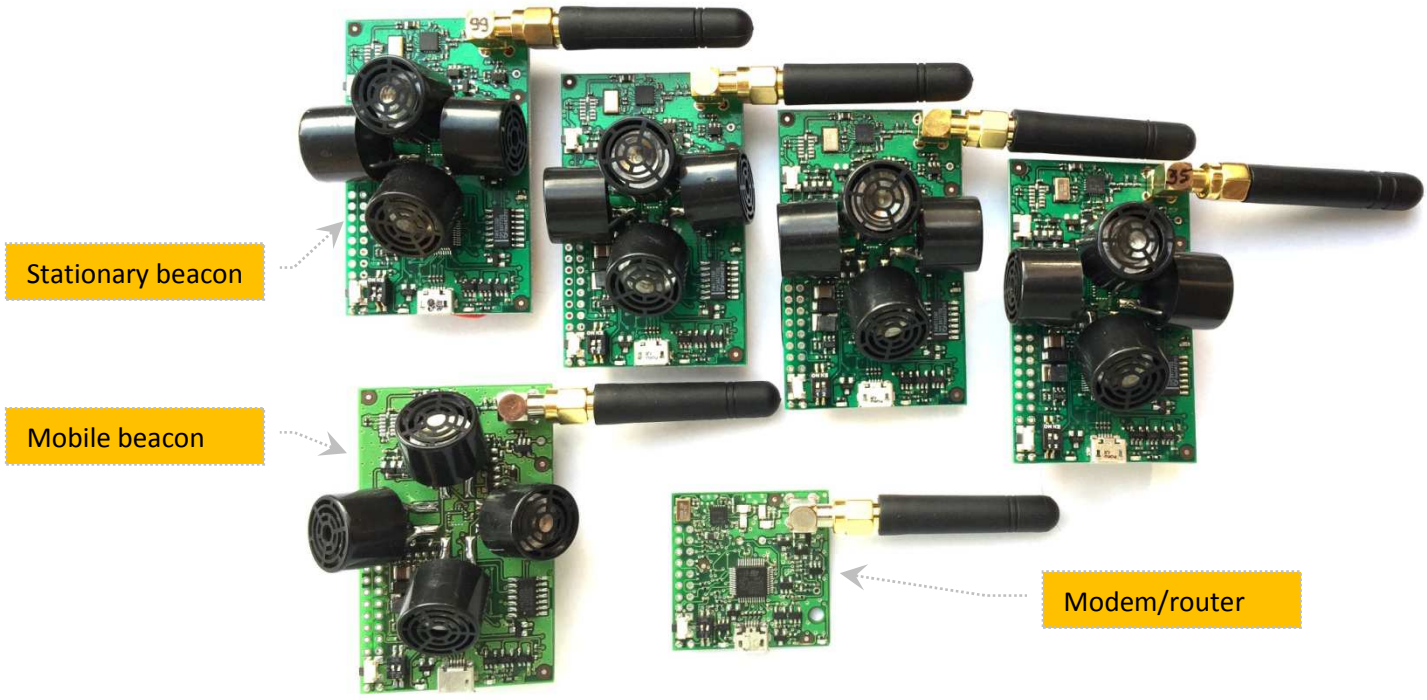
8) Frequently Asked Questions

Support for 3D

- System supports 3D navigation and it is turned on by default

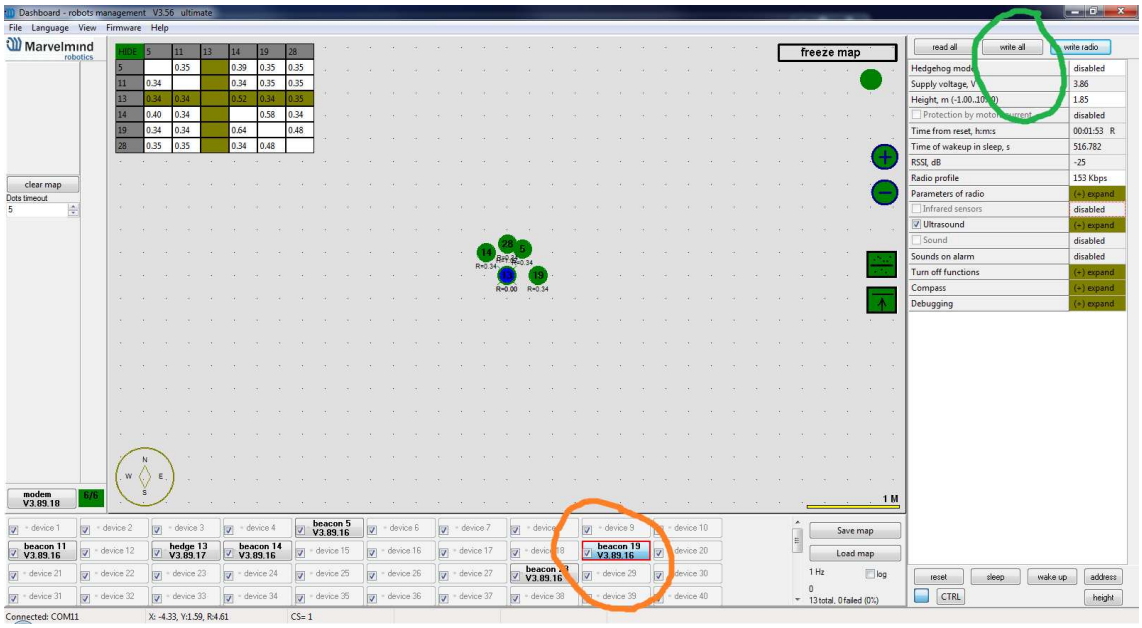
Difference between hedgehog and stationary beacon

- Stationary beacons and mobile beacon (hedgehog) have slight difference in angles of sensors. Mobile beacons are designed to operate horizontally with sensors looking 45 degrees to horizon in 4 directions. With this they provide ~360 horizontal coverage
- Stationary beacons have angles of the sensors optimized vertical placement with the robot lower than the stationary beacon
- Modem/router is the main controller of the system. It may have both sensors and battery, but it is not necessarily for its operation, so it may have none of them
- Mobile beacon and stationary beacons have the same SW. The only difference that one needs to enable hedgehog functionality in the Dashboard for a particular beacon to make mobile. In the supply box mobile beacons are activated as mobile beacons already. For testing purposes it is possible to convert mobile beacon to stationary one and vise versa. However, one needs to remember about the angles of the sensors and optimization for ultrasonic coverage



What does the red color around the beacon tab on the bottom of the Dashboard mean?

– It means that one of the settings of the beacon is different than the rest of the beacons.



If it is done intentionally, for example, for testing purposes or for optimizing the performance, it is OK. But you have not done anything intentionally, please, choose one of “white” beacons, check its settings, and use “CTRL+Write All” to copy-paste all settings from the “white” reference beacon to all other beacons.

9) Contacts

For more support, please, send us your questions to info@marvelmind.com. We will guide and advise you.