User Manual

Beacon HW v4.9

915MHz

Marvelmind Indoor Navigation System
Operating instructions for beacon

V2017_05_02

www.marvelmind.com

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1. Executive summary

Marvelmind Indoor Navigation System is off-the-shelf indoor navigation system designed for providing precise (+-2cm) location data to autonomous robots, vehicles (AGV) and copters. It can also be used for tracking other objects, where the mobile beacon can be installed, for example, in virtual reality (VR) systems.

The navigation 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, VR) is calculated based on the propagation delay of ultrasonic signal (Time-Of-Flight or TOF) 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 - for 3D (X, Y,Z) tracking

- An unobstructed sight by a mobile beacon of two stationary or more stationary beacons simultaneously – for 2D (X,Y) tracking

Key capabilities:

- Distance between neighboring beacons: up to 50 meters. Recommended distance in real-life environment – up to 30m *
- Coverage area:
  - Up to 1000 ㎡ for Starter Set
  - Coverage for larger areas is done similar to cellular networks; can be much larger, than 1000 ㎡ and depends on the radio interface that can be further extended
- Location precision:
  - 1-3% of the distance to the beacons (without calibration)
  - Differential precision: **±2 cm**
- Location update rate:
  - 0.5-45Hz
    - Can be set manually
    - Depends on the distance between mobile beacon and stationary beacons (smaller distance – higher update rate)
    - Depends on the number of beacons
- Beacons form the navigation system automatically – no manual coordinates measurements or entering required (except of height)

        * Sensor 4 to sensor 4 direct line; all other sensors are disabled

Parameter	Technical Specifications
Distance between beacons	Up to 50 meters; Recommended - 30 meters (Transducer4 to Transducer4 looking straight to each other and other transducers are off)
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	Mobile beacon from Starter set: - 55 grams (including battery 1000mAh and housing) - 27 grams (bare board w/o battery)
Beacon size	Size: 55x55x33 mm (with antenna: 55x55x65mm)

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3. Basics of the system

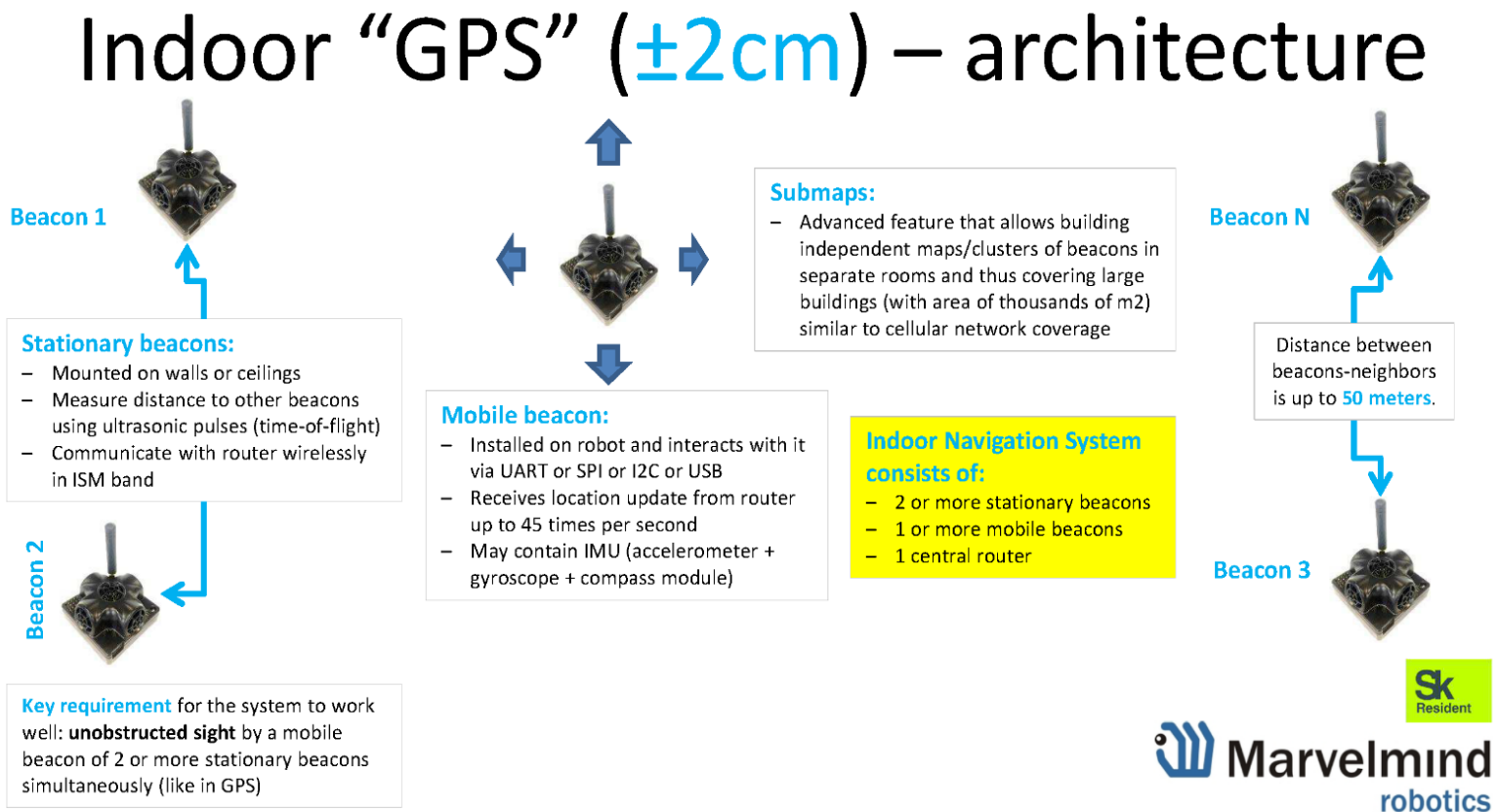## 3.1 What's in the box

Starter Set:

- 4xStationary beacons
- 1xMobile beacon (aka "hedgehog")
- Deleted part

* Exact appearance may wary depending on the Hardware version. Characteristics are kept the same or better unless specially noted

3.2   Indoor GPS architecture

Marvelmind Indoor Navigation System provides high-precision (± 2 cm) indoor coordinates for autonomous robots and systems ("indoor GPS"). Brief description of the key elements of the system is given on scheme below:

Indoor "GPS" (±2cm) – architecture

Beacon 1

Stationary beacons:
- Mounted on walls or ceilings
- Measure distance to other beacons using ultrasonic pulses (time-of-flight)
- Communicate with router wirelessly in ISM band

Beacon 2

Key requirement for the system to work well: **unobstructed sight** by a mobile beacon of 2 or more stationary beacons simultaneously (like in GPS)

Submaps:
- Advanced feature that allows building independent maps/clusters of beacons in separate rooms and thus covering large buildings (with area of thousands of m2) similar to cellular network coverage

Mobile beacon:
- Installed on robot and interacts with it via UART or SPI or I2C or USB
- Receives location update from router up to 45 times per second
- May contain IMU (accelerometer + gyroscope + compass module)

Indoor Navigation System consists of:
- 2 or more stationary beacons
- 1 or more mobile beacons
- 1 central router

Beacon N

Distance between beacons-neighbors is up to **50 meters**.

Beacon 3

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3.3   Indoor GPS – beacon's inside view

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3.4   System elements

3.4.1   Stationary beacons

- Shall be mounted on walls and ceilings – usually, above the robot and ultrasonic sensors facing down – to provide the most robust unobstructed coverage of ultrasonic signal to robot. 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 is provided for the maximum territory. Proper ultrasonic coverage is the utmost important element for the system to function effectively

- Stationary beacons emit and receive ultrasound, when the map is being formed. And they only receive the ultrasound, when the map is formed and frozen

- Stationary beacons have no exterior difference with mobile beacons

- Inertial measurement unit aka IMU is not installed on the stationary beacons

- The mobile and stationary beacons can be easily interchanged by selecting the option (Except IMU) in the Dashboard

- There is 915MHz version available. Proprietary radio protocol is used for communication and synchronization. Other ISM bands are available upon request too

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3.4.2 Mobile beacon ("hedgehog")

- The mobile and stationary beacons can be easily interchanged by selecting the option in the Dashboard

- The mobile beacons are designed to be placed on the robot vehicle or copter/drone or 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 has be taken into account in the robot's SW

- The mobile beacon has to be placed horizontally to provide optimal ultrasonic coverage – upper hemisphere

- 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 mobile beacons. 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 selected and there are 2 mobile beacons in the system, each beacon's location will be updated with the rate of 16Hz/2 ~ 8Hz. If there are 3 mobile beacons => 16Hz/3 ~ 5Hz, etc. Future SW implementation will contain different solution that will improve update rate in the setup with multiple mobile beacons.

- Location data is obtained either from the "hedgehog" via USB (virtual UART), UART, SPI. More on interfaces: http://www.marvelmind.com/#Interfaces

- Data from the beacon is sent in a streaming format identical that of GPS (NMEA 0183)

- There is 915MHz version 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: http://marvelmind.com/pics/supported_interfaces.png

3.4.4 Charging beacons and other details

- The Beacon has 5 sensors (transducers) RX1, RX2, RX3, RX4, RX5

- DIP switch modes:

    1) Power OFF, DFU OFF: charging is possible; beacon is disconnected from power. This mode is recommended, if you want to keep the battery fully charged for many months

    2) Power ON, DFU OFF: normal working mode for beacon. The beacon is fully powered and wakes up every a few seconds. Power consumption is still minimal, if the beacon sleeps and the battery can last for many weeks or a few months. It is recommended to keep the beacon in this mode and to not touch the DIP switch at all, unless you want to store the beacon on the shelf. Then, the mode 1) is better and recommended

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

- Charge your board from USB

- 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

- If you plan using charger for permanent power of the beacon, make sure that it is not noisy. The performance can be monitored by Dashboard => View => Oscilloscope, visit oscilloscope paragraph

- When the board is charged and turned on LED 2 is blinking every few seconds.

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4. Setting up the system

4.1 The very first setup routine of your device

The routine below describes the very first setup of the system. If you have done that already, please, jump to the chapter <u>Using the system after the very first setup</u> below.

4.1.1 Unpack the system. Watch the help video: https://youtu.be/IyXB3UXHdeQ. Note that the video is shot for the previous HW version 4.5

4.1.2 Check that your board is charged; see that all switches on beacons are in the correct position. See paragraph <u>detailed description and charging</u>

4.1.3 If LED is not blinking, it means your board is turned off, please check the position of DIP switch again if everything is okay charge via USB; see appropriate paragraph

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4.2 Setup software (Dashboard)

4.2.1 After charging boards download the **latest stable software package** from http://www.marvelmind.com/#Download

4.2.2 Select the SW version of the portable or distribution and unzip

4.2.3 Then run the **Dashboard** and update the SW using **Dashboard** => **Firmware** => **Choose the file** => **Program**
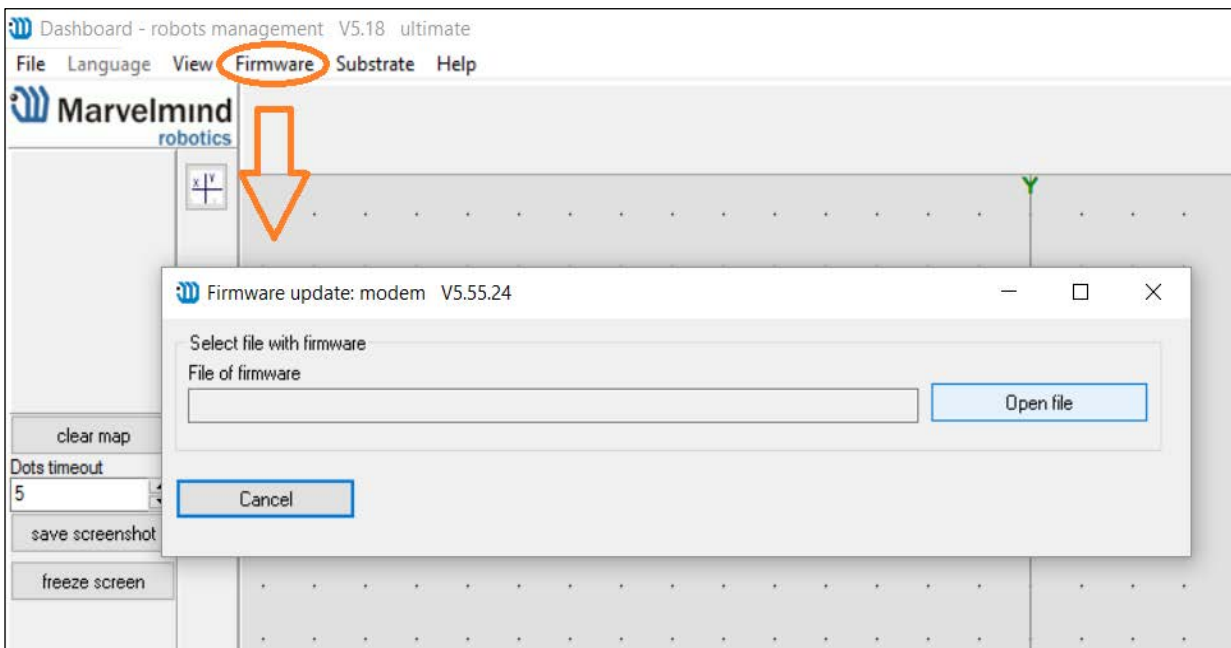
4.2.4 Ensure that you are (a) programming beacon's SW to beacon; (b) you are using SW for 4.9, if you have HW v4.9; (c) you have the SW from the same, i.e. Dashboard SW and beacon SW must be from the same SW pack. Don't mix SW releases

4.2.5 While beacon is connected to the Dashboard, press Default button to upload the default settings

4.2.6 Write down and use later the beacon's address or change the address to your convenience as shown here

4.2.7 Press RESET button on your beacons after programming

4.2.8 After programming devices with the latest software beacons are ready for use.
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 configurations can be done. Here is the help video

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Now you can check the height position of the beacons, RSSI, radio channel, threshold etc. on the panel in the right corner of the Dashboard

Hedgehog mode	disabled
Supply voltage, V	3.67
Height, m (-1.00..10.00)	2.15
Time from reset, h:m:s	00:00:04 R
Measured temperature, °C	39
RSSI, dBm	-49
Carrier frequency, MHz	920.180
Device address (0..99)	13
Channel	3
Minimum threshold (-10..-2000)	-50
Parameters of radio	(+) expand
Ultrasound	(+) expand
Interfaces	(+) expand

4.2.9   Notice, that there are 99 beacon's addresses available. If you don't see some of your connected beacons on the map, scroll it so you will be able to find their addresses
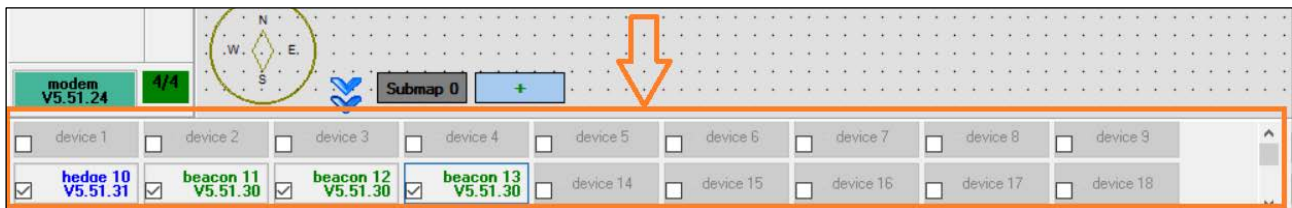
4.2.10 Also double click on the device to go into sleeping mode and double clicking to wake up

4.2.11 The map will form automatically and zoom in automatically

4.2.12 If the map does not form well. Check the Table of distances in the left corner of the Dashboard. Cells must be colored in white; it means the distances between stationary beacons are measured correctly.

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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 check what the problems with
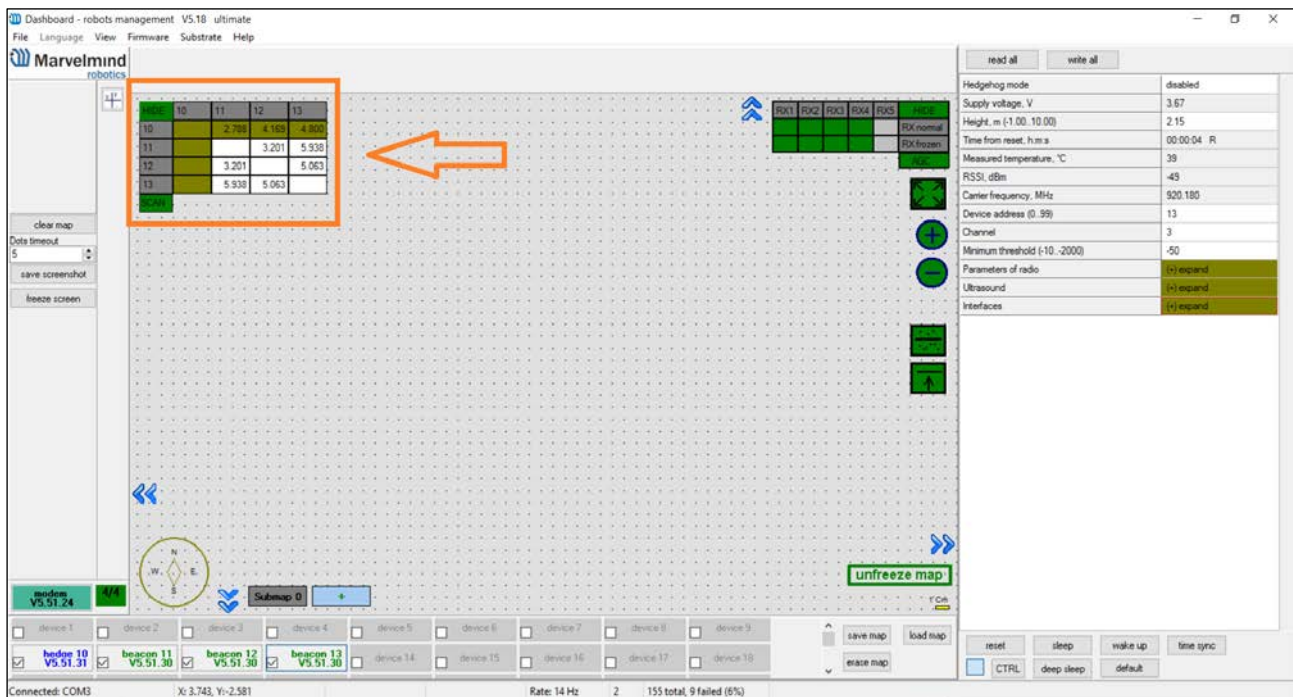
those beacons are. Try to re-position them, because, usually, there is an obstruction of some sort in the between the beacons. Reset them.

Use **View => Table of distances** to monitor the measured distances between beacons
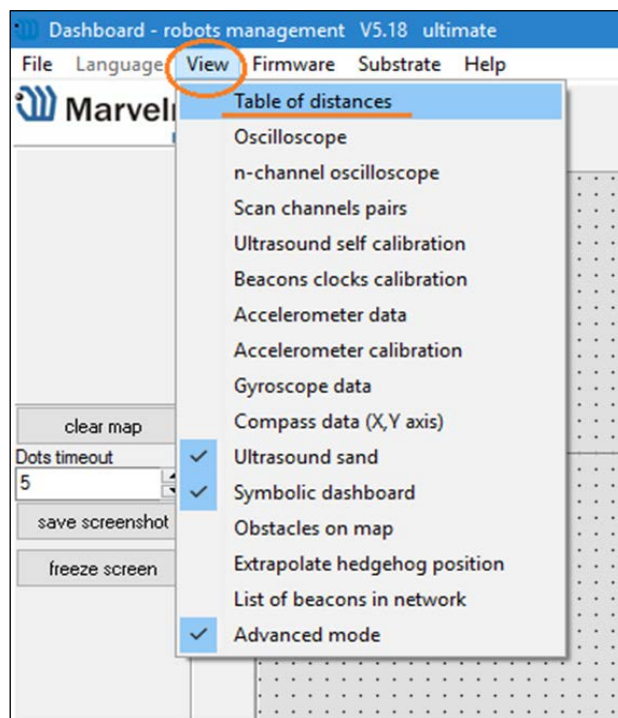
4.2.13   Freeze the map by clicking the button. Stationary beacons will stop measuring relative distances and will be ready to measure distance from the mobile beacon(s)

4.2.14 Turn on and wake up mobile beacon similar to the operations with the stationary beacon: https://youtu.be/A4aRsjH2-_E

4.2.15 If you see on the devices' panel beacon colored **<u>orange</u>** (see pic. #1) it means some settings between beacons are different, for example: some sensors are off or some ultrasonic or radio settings are different. You can change the settings for sensors manually by clicking on the panel in the right corner of the dashboard and make grey cells green to turn on sensor. But for starting, it is very much recommended to use default settings on all beacons

4.2.16 After you froze the map of stationary beacons, wake up the mobile beacon. After it wakes up, it will be traceable in 5-7 seconds

4.2.17 By now, the system must be fully operational
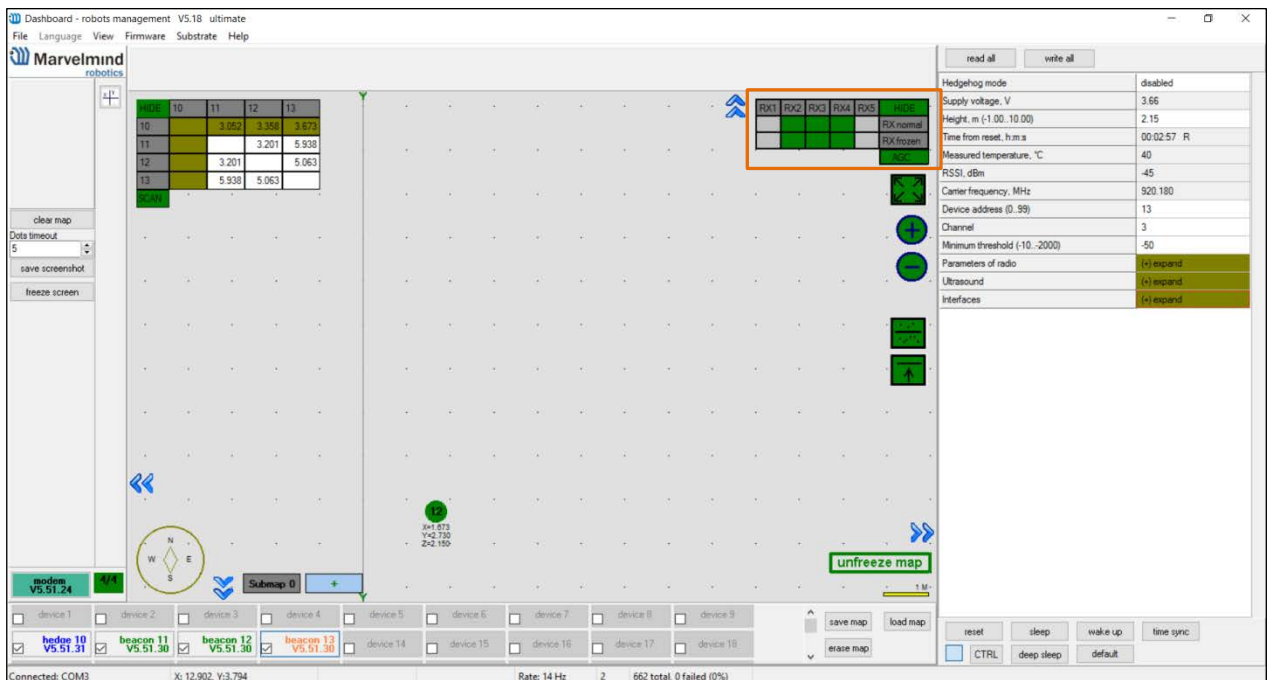
4.3 Using the system after the very first setup

4.3.1 **<u>To be described in another manual</u>**

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5. Interfaces

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

There are two different ways to get mobile beacons' location data from the system:

- From mobile beacons
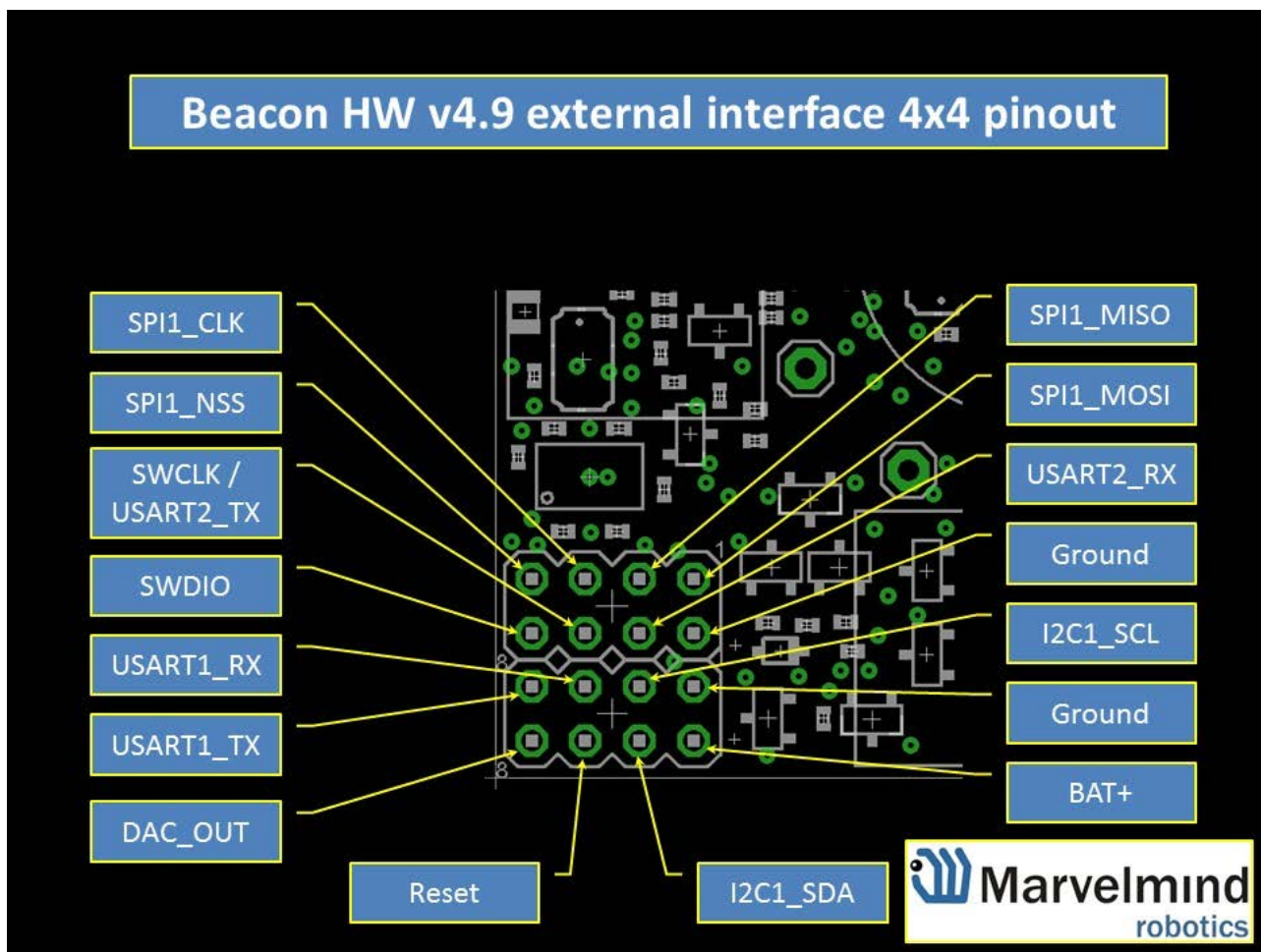   - o Each mobile beacon knows its own position and doesn't know position of other mobile beacons

List of supported interfaces is shown below:

Supported interfaces

- **Mobile beacon:**
    - UART
    - SPI
    - Virtual UART via USB
    - NMEA

- **Integrated with:**
    - Windows (PC & tablets)
    - Linux
    - Mac OS
    - Android (beacon)
    - ROS (beacon)
    - Raspberry (beacon)
    - Arduino (beacon)
    - PixHawk (beacon)

- **Sample code:**
    - C
    - Python

More on the interfaces can be found on the link: http://marvelmind.com/#Interfaces

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5.1 Beacon HW v4.9 external interface 4x4 pinout

Beacon HW v4.9 external interface 4x4 pinout

SPI1_CLK
SPI1_NSS
SWCLK / USART2_TX
SWDIO
USART1_RX
USART1_TX
DAC_OUT

SPI1_MISO
SPI1_MOSI
USART2_RX
Ground
I2C1_SCL
Ground
BAT+

Reset
I2C1_SDA

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6. Advanced system settings and optimization

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

If you ran into troubles, connect beacon to PC via USB and use **Default button**. It uploads "factory settings" to the board while keeping the device address untacked

6.1   Using oscilloscopes

6.1.1   Monitor ultrasonic signal from one beacon to another

Use Dashboard => View => Oscilloscope to monitor ultrasonic signal 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. With this tool it is easy to set up the proper ultrasonic threshold in the Dashboard.

Use this tool to set up the proper ultrasonic threshold in the Dashboard.

Type the reference beacon number. And press Enter

Echo;

External noise looks similarly. Thus, choose the ultrasonic threshold below this value, for example, -500 to -2000

Ultrasonic signal front

Choose the beacon to test

6.1.2 Proper ultrasonic signal detection

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.)
    - Rotors of drones/copters

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 suspects". However, if the external noise is too strong; or its source is too close; or it is emitting strong signal on frequencies close to 31kHz or white noise, the system functionality can be affected.

The best things to do in this case – (1) to identify the beacons that are affected. Usually, they are those, that 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 has 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 are very non-linear. 4000 to 3000 – almost no change. But around 2500 the gain starts reducing very quickly (1200 – for some HW versions). Thus, it is possible to find the optimal gain to obtain the highest Signal/Noise ratio.

When the map is formed, only mobile beacon is emitting, whereas stationary beacons do 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 positions of stationary beacons accordingly – farther from the source of noise.

6.2   Using hedgehog.log file

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

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6.3   Important aspects and hints

The single most important aspect 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 sides of the ultrasonic 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 to other stationary beacons when the map is being formed

Mobile beacon ('hedgehog" or "hedge") is designed to be placed horizontally

- Mobile beacon has four horizontal and on vertical sensors each covering its own sector. Together they cover 360 degrees horizontally and upper hemisphere. Lower hemisphere is highly attenuated, so don't expect ultrasonic coverage in that area

- It is advised to place the mobile beacon as high as possible on the robot, 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 objects that can produce shadow to the stationary beacons

Keep the radio signal's strength under control

- RSSI (Dashboard => right menu) of any beacon must not be higher than -25dBm. Otherwise, the system may malfunction (packets lost unnoticeable, etc.)

- It is recommended to keep the distance between beacons not less than 0.5-1m. Beacons can as close to each other as you need so. If beacons are extremely close from each to each, just disconnect antenna from the beacon. Monitor Received Signal Strength Indicator (RSSI). It must be

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in the range of -25…-70dBm. Lower than -70dBm will work too, but packet losses may start occurring. The quality of radio connection very much depends on the external interference too, because the used band is ISM and there are many systems co-existing.

6.4   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 via other medium 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 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 the distance divided by the speed of sound in air. 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 practice to place beacons on something relatively soft or not so sound conductive

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6.5   Table: Power consumption

Recommended mode of operations:

-   Stationary beacons are powered from a clean source of +5V USB

-   Mobile beacon is powered from a clean source of +5V USB from a robot

-   Operations based on purely own installed batteries is also supported and possible

-   For fully autonomous and easy use and testing, each beacon has its own power LiPol battery

-   Typical power consumption in deep sleep mode is 50uA that gives ~2y shelf time with a regular 1000mAh battery. Beacon can be woken up from deep sleep only by pressing HW reset button

-   In regular sleeping mode the beacons wake up automatically every 2 seconds. 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							

		2.78E-07		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

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6.6 Different colors in the Dashboard menu

To be added in the next Manual release

6.7 Ultrasonic coverage

To be added in the next Manual release

6.8 Submaps

To be added in the next Manual release

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4. Frequently Asked Questions

http://www.marvelmind.com/forum/viewforum.php?f=2

5. Contacts

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

6. FCC Statement

Changes or modifications not expressly approved by the party responsible for compliance could void the user's authority to operate the equipment.

This equipment has been tested and found to comply with the limits for a Class B digital device, pursuant to Part 15 of the FCC Rules. These limits are designed to provide reasonable protection against harmful interference in a residential installation. This equipment generates uses and can radiate radio frequency energy and, if not installed and used in accordance with the instructions, may cause harmful interference to radio communications. However, there is no guarantee that interference will not occur in a particular installation. If this equipment does cause harmful interference to radio or television reception, which can be determined by turning the equipment off and on, the user is encouraged to try to correct the interference by one or more of the following measures:

-- Reorient or relocate the receiving antenna.

-- Increase the separation between the equipment and receiver.

-- Connect the equipment into an outlet on a circuit different from that to which the receiver is connected.

-- Consult the dealer or an experienced radio/TV technician for help

This device complies with part 15 of the FCC rules. Operation is subject to the following two conditions (1)this device may not cause harmful interference, and (2) this device must accept any interference received, including interference that may cause undesired operation.

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