MONALISA 2.0 – Sub activity 3.3

Indoor positioning System: Pilot Development

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Approvals

Prepared by:                      Data: 07/07/2015

V. Gavazov
M. Annese

Verified by:                      Data: 07/07/2015

G. G. Fogazzaro

Approved by:                     Data: 07/07/2015

V. De Val
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## Release History

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<th>Release</th>
<th>Descrizione</th>
<th>Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>00</td>
<td>First release</td>
<td>07/07/2015</td>
</tr>
</tbody>
</table>
3 Scope of the document
Scope of the document is to describe the most important results from the PTS Pilot Development activities and, in particular, it reports the results of the characterization and testing activity performed on People tracking pilot system realized in the EU TNT co-funded project MONALISA 2.0.

4 References

5 Acronyms
CMOS: Complementary MOS technology, semiconductor technology approach utilized to realize Camera chip where pixel are made by Metal-Oxide-Silicon transistors
EM: Electro-Magnetic, referring to Electro-Magnetic waves or fields
HF: High Frequency, it refers to RF frequency in the range of 3 MHz - 30 MHz
LED: Light Emitting Diode, solid state device that emits light when crossed by electrons current
LF: Low Frequency, it refers to RF frequency in the range of 30 kHz - 300 MHz
LIDAR: Laser Imaging Detection and Ranging, metering technique that use a light pulse to measure distances
PTS: People Tracking System, used here as synonym of Indoor Positioning System
RFID: Radio Frequency Identification, identification and tracking systems that use Radio Frequency Electro-Magnetic waves
RSSI: Received Signal Strength Indication, parameter used to deduce the target position from the power of signals received from many RF emitters
RTLS: Real Time Locating System, positioning system that work in real time
SMCS: Safety Monitoring and Control System, Software that manage all safety systems on board of large vessels
TDOA: Time Difference Of Arrival, parameter used to deduce the target position from the time a signal need to reach RF reference receivers
UHF: Ultra High Frequency, it refers to RF frequency in the range of 300 MHz-3 GHz

6 Pilot system & test setup description

6.1 Pilot system Architecture
Martec People tracking System required many technical adaptations of market available technologies in order to be able, at system level, to fulfill all of the requirements that are needed on board of a Vessel [1].
Thus, validation tests performed in laboratory have focused on different system features and on different part of the system. Slightly different test set-up were realized to focus on mentioned specific aspect of Martec People Tracking System features. Before going in detail about the implemented test setup, the general system architecture is depicted and its main components are described.

Using a bottom-up approach, the system is composed by the following items:

1) **RFID TAG**: this device is carried by tracked people. This is an active device, battery powered, that communicate its position to fixed devices, called satellites.

2) **Satellites**: PTS system is composed by various devices, called satellites, fixed at specific position in the vessel rooms. Satellites perform mainly following activities:
   a. communicate with carried TAGS through RF signal, identifying TAG position;
b. transmit data to the upper levels of the system (DCU);
c. execute specific commands from the upper system levels.
d. Many satellites are connected on the same cable (called branch), from which they receive power supply and trough which they transmit collected data. PTS might have more than one branch.

3) **PTS runtime application firmware**: it is a software component installed in the satellite whose purpose is to manage all of the satellites activities (as mentioned in the previous item description) during standard operation time

4) **Data Collection Units (DCU)**: These devices perform following main activities:
   a. provide power supply to the Satellites trough branches cables;
   b. collect data from all of the satellites trough branches cables;
   c. trough branches cables, forward to satellites commands that are coming from upper levels of the system;
   d. forward data collected to upper levels of the system by Ethernet connection.

Data collection units are connected to Satellites trough branches cables. Each branch cable is connected with two DCU, one at each edge. This redundancy is needed to make the system compliant to Safe Return To Port regulation.

5) **Branch**: one cable starting from and ending to a DCU, interconnecting a certain number of Satellites, carrying data from them and providing power supply to them.

6) **PLPData**: it is a software module installed on a PC or on a server at middleware level of the system. It is used during branch configuration to make the startup of the branch assigning unique address to each satellite.

7) **ModbusTcpPts**: it is a software module installed on a PC or on a server at middleware level of the system. It is used during branch configuration once the startup of the branch is terminated. It is used to send the final configuration to the satellite firmware.

8) **TDC (Tracking Data Collector)**: it is a software module installed on a PC or on a server at middleware level of the system. It is used in normal function of the satellite to collect information about satellites status and about tags localization. Collected data are saved in a specific database, in order to be available to the top system application software.

9) **PTSViewer**: it is a software module installed on workstations and on servers at Top level of the system (i.e. application level). This software reports the tracking data to the user in a compact and readable graphic format.

Following picture show software modules architecture in more detail, highlighting modules interaction and mode of operation.
In the next description we refer with the name **Power Line** to the network that supplies power to satellites and that carries data from and to satellites. Power line is thus composed by DCUs, one cable and multiple satellites.

In the laboratory a system composed by two branches was realized, each one of the mentioned branch being utilized to test specific PTS features:

- **Power line test branch (branch 1)**: composed by 29 satellites and 2 DCU, this branch was used for performance test from electrical point of view; this set is aimed to test data transmission owe wired network and power supply (power line performances).
- **RFID tracking test branch (branch 2)**: composed by 8 satellites and 1 DCU, this branch was distributed along the Laboratory in different locals and was used to mainly test wireless RF localization and also for to test correct data interpretation at the Top System.

Next paragraphs describe more in detail the mentioned branches.
6.2 Power line test branch
Tests on Branch 1 are focused on the following key aspects of PTS:

1. Electrical performance, power supply on the branch cable;
2. Data transfer on branch cable performance;
3. Short Circuit detection and immunity;
4. Open Circuit detection and immunity.

Before starting with the description of the above listed items, we will describe some relevant features of such branch configuration.

At the ends of the branch there are 2 DCU which supply power to satellites and perform the power line communication in order to collect information from each satellite and make it available for the Top System. Communication with Top System is performed by DCS using Ethernet 10/100 protocol.

From Figure 2 it is possible to see that thanks to the two DCU, the branch is configured in order to have a redundant power supply:

![Power line system architecture: redundancy on power supply and data collection.](image)

Power line test branch is redundant also in terms of communication capability, as shown in Figure 3:
Figure 3 – Power-line system, data collection units details.

On the Branch there are 29 satellites, a number needed to evaluate multiple devices in a communication event and to verify high power consumption levels. Then the 2 DCU can be connected via Ethernet to different software installed on PC (PLPData, ModbusTcpPts, TDC).

Since in this case the purpose of the setup it is testing electrical and communication behavior on the branch line, the satellites position is not optimized for movements tracking performances evaluation. Satellites are rather placed on a test table as shown in following pictures, using a cable long enough to represent the real onboard scenario.

In order to be as close as possible to a real situation, a very long cable it was used, in particular 30m between DCU Main and the first satellite, 15m between each couple of satellites and 30m between DCU Backup and the last Satellite. Characteristic of the cable are the same as the one used on board the Cruise Vessel used for the Pilot Project. The total cable length used is near 500m, this is a real cable length which can be found on board the cruise vessel.
Figure 4 - Power line lab system test set-up.
6.3 RFID tracking test setup

The purpose of Branch 2 is to test RF localization and top system data acquisition and representation. On other words, the branch configuration is optimized to test:

1. Tag detection performances;
   a. Ability to follow tag which moves under satellites in the branch;
   b. Behavior of a tag when two satellites have cover area overlapped;
   c. Acquisition of 10 tags under the same satellite;
2. Data storage reliability;
3. Data representation effectiveness;
4. Detection of low battery warning from Tag.

![Diagram of RFID tracking test setup]

Figure 5 – Reduced set-up to test tracking performances.

From Figure 18 it is possible to see that the configuration of this branch 2 is simplified respect to branch 1. The system is composed by one single DCU and 8 Satellites. That is because all redundancy tests are performed on branch 1, and because a smaller number of TAGs are needed to check localization reliability. On other words, this configuration is enough to tests tags acquisition and verification. Following pictures show how the readers are installed on Martec Labs trough installation plan and through some photos.
Figure 6 – Lab satellites distribution map.

Figure 7 - Satellite location pictures.

Following picture show People Tracking TAGS utilized during in Lab tests.
In order to check data representation effectiveness on a realistic Man-Machine Interface, we integrated the installed branch on Martec Safety Management System (SMS) emulating a real onboard. The picture below shows a sketch of the Man machine interface used during the test, which has the same look and features that the real version installed on board of Cruise and Navy vessels.

We choose a branch with all satellites in the same deck in order to facilitate observation of tags movements.

![Man machine interface sketch](image)

Figure 8 – Man machine interface replicates the system mounted on the real vessel.

7 Power Line test results

7.1 Power supply test

Power supply tests are mainly aimed to determine with enough accuracy following electrical parameters:

- Voltage drop across powerline cable caused satellites absorption;
Current consumption and voltage drop are important parameters, needed for reliable and optimized real system design. On other words, mentioned electrical parameters are important to design:

- power line cable;
- maximum number of satellite in one branch;
- maximum length of each branch.

### 7.1.1 Test Condition
First measurements campaign was performed with one DCU in following conditions:

1) first stretch of cable incremented to 100m to increase voltage drop, considering very long distance between control cabinet and first satellite;
2) 29 satellites with 15m cable length between each couple of them.
3) System power supply: <50V dc
4) Measurements repetition: 20 times

Second measurements campaign was performed redoing all of the measurements with two DCU (Main and Backup) in order to check the differences.

### 7.1.2 Results

- One DCU test case:

<table>
<thead>
<tr>
<th>Voltage at DCU output</th>
<th>&lt;60Vdc</th>
</tr>
</thead>
<tbody>
<tr>
<td>DCU current consumption</td>
<td>&lt;5A</td>
</tr>
<tr>
<td>Voltage at Last satellite/Voltage at first satellite</td>
<td>0.87</td>
</tr>
</tbody>
</table>
Two DCUs test case:

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Voltage at DCU main output</td>
<td>&lt;60Vdc</td>
</tr>
<tr>
<td>DCU main current consumption</td>
<td>&lt;2.5A</td>
</tr>
<tr>
<td>DCU Bck current consumption</td>
<td>&lt;2.5A</td>
</tr>
<tr>
<td>Lowest Voltage /highest voltage provided to a satellite</td>
<td>0.95</td>
</tr>
</tbody>
</table>

7.1.3 Conclusions

Test results confirm that in the worst case, i.e. only one DCU, last satellite has 13% loss in voltage: there is margin before reaching low voltage supply limit for satellites.
In case of normal branch conditions, results are as expected: very low voltage drop and low current consumption (this last being beneficial to DCU from heating point of view).
7.2 Power-line Communication tests

Communication signal attenuation in the powerline cable is one of the most critical topics in developing powerline application. It is very important to take communication signal attenuation under control to avoid jeopardizing the high data rate allowed by such technology. Communication tests were then performed in worst case condition for attenuation, that means when only one DCU is working and all of the satellites are distributed along the cable.

7.2.1 Test Condition

As mentioned, tests were made in the worst case with only DCU Main and 32 satellites. The DCU interrogates in broadcast all of the satellites which reply in sequence. To monitor the signal attenuation, one oscilloscope was utilized, with probes connected on the power-line at the DCU output/input position, in order to check the reply of all of the satellites distributed along the cable:

1) Only DCU Main connected to the branch;
2) 32 satellites on the branch;
3) Oscilloscope probes connected to the powerline at the DCU output;
4) Cable length;
5) Test repetition: 20 Times.

7.2.2 Results
As mentioned in previous paragraph, this test check the attenuation of power-line cable measuring the signal amplitude of the reply message from satellites and DCU, at the DCU input/output points on the power-line. Figures below show amplitude signals emitted by the first and the 29th satellite during one repetition of the test. The received signal must be above 100mV to be considered good enough to guarantee proper communication.

**Test Performed**
- Satellites reply signal measurement.

**Test description**
- Reply signal from satellites must be above 100mV at the DCU in/out point.

**Results**
- 20 iteration all passed
7.2.3 Conclusions

Performed tests demonstrate that in a realistic conditions of cable length (500m) and satellites number (32), communication on power-line is working properly with high operative margin.

Communication over PTS powerline performances are suitable for the cable length and the satellites number required by a realistic onboard application scenario.
7.3 Short Circuit and open Circuit tolerance

To be compliant with Safe return to Port regulation, all of the satellites are equipped with an active system for monitoring and recovering short circuit and open circuit events on the power line cable. Figure below sketch the short/open circuit detection architecture.

![Diagram](image)

**Figure 11 – Power-line short circuit test.**

The system was tested in order to verify its robusteness versus sigle point of faillure, i.e. single open/short event on the powerline. When a short circuit occur, one part of the branch is powered from and communicate to DCU Main and a the other one powered form and communicate to DCU Backup.
7.3.1 Test Condition

For short/open circuit test, complete branch was used, with DCU Main, DCU Backup and 29 satellites. Using TDC software, which collect and save branch status information during the test, and PTSViewer which read information from database and allows observing status of satellites on PC.

![Diagram of test setup](image)

**Figure 12**– Power-line short and open circuit test set-up.

The PTS Viewer software show the status of each satellite on the branch, as reported in figure below.

![Table of satellite status](image)

**Figure 13** – Satellite status when no open or short circuit event is reported.

In normal condition all satellites on the branch have status indication equal to zero, this means that there are not warnings on the branch.
Test conditions are reported here below:

1) DCU Main and BCU Backup are connected to the branch;
2) 29 satellites on the branch;
3) PTSViewer and TDC software loaded on monitoring PC;
4) Monitoring PC connected with DCUs through LAN network;
5) Test repetition: 20 times for short; 20 times for open.
7.3.2 Results

Short Circuit tests

When short circuit occurs, branch is divided into two parts, one is powered from and communicates with DCU Main, the other one is powered from and communicates with DCU Backup. On PTS viewer such a situation is represented as follow:

![Figure 14 – Short circuit location.](image)

It is possible to observe that the short circuit is between satellite 10 and satellite 11.

In the table here below tests results are reported.

<table>
<thead>
<tr>
<th>Test Performed</th>
<th>Test description</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Short circuit position detection</td>
<td>Verify that it is possible to locate the short circuit position in the branch</td>
<td>20 iteration all passed</td>
</tr>
<tr>
<td>Short circuit: branch split</td>
<td>Verify that all of the satellites are reachable trough either DCU main or DCU Bck</td>
<td>20 iteration all passed</td>
</tr>
</tbody>
</table>

Open Circuit tests
When open circuit occurs, branch is divided into two parts, one is powered from and communicates with DCU Main, the other one is powered from and communicates with DCU Backup. On PTS viewer such a situation is represented as follow:

![Figure 15 - Open circuit location.](image)

It is possible to observe that the open circuit is between satellite 10 and satellite 11.

In the table here below tests results are reported.

<table>
<thead>
<tr>
<th>Test Performed</th>
<th>Test description</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Open circuit position detection</td>
<td>Verify that it is possible to locate the open circuit position in the branch</td>
<td>20 iteration all passed</td>
</tr>
<tr>
<td>Open circuit: branch split</td>
<td>Verify that all of the satellites are reachable trough either DCU main or DCU Bck</td>
<td>20 iteration all passed</td>
</tr>
</tbody>
</table>

### 7.3.3 Conclusion
In conclusion this test demonstrates that the system is well structured and a single failure on the branch, short circuit or open wire, does not introduce system performances degradation.

Short circuit or open circuit do not introduce degradation on the PTS functionalities.
8 RFID tracking tests
As previously mentioned, RFID tracking test bench (Branch 2) was used to:
1) test wireless communication between satellites and TAG;
2) test the localization mechanism that is based on such wireless communication;
3) check data propagation up to the storage database.

The storage database is populated and encapsulated by TDC software module, whereas PTSViewer application is utilized to visualize test results on a ship deck representation.

Tests made on the pilot system are listed here below:

- Moving tags tracking accuracy and reliability;
- Detection of low Tag battery warning;
- TAG anti collision system efficacy: capability of a single satellite to locate multiple TAGs at the same time;
- Neighbors satellites mutual interference during localization processes.

8.1 Single Tag movements tracking test
To check moving TAGs tracking capabilities, a person carrying a PTS TAG was walking on a pre-defined path, trough all of the satellites detection area, at a speed up to 2m/s, with detecting area of each satellite ranging from 2m to 5m. The path
was designed such that the position sequence of each satellite has the same order of the satellite ID. Many iteration of such exercise were performed at different speed, and the results are here below summarized.

<table>
<thead>
<tr>
<th>Test Performed</th>
<th>Test description</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Walk on pre defined path wearing PTS tag</td>
<td>A person carrying a PTS tag follows a predefined path in the lab, passing in sequence through the detection areas of all of installed satellites. Walking speed up to 2m/s. PTS system generated data are recorded and inspected through “PTSViewer” PC application.</td>
<td>100 iteration no errors</td>
</tr>
</tbody>
</table>

Figure 17 shows a typical record of tracking man walking at low speed. The reported table shows the readout of the tracked TAG. It is possible to appreciate that all of the satellites numbered from 1 to 9 (field “Sat_ID”) are detecting the tag passage in the correct sequence (see the detection time in the field “Time_Stamp”).

![Figure 17 – Tag movement tracking test.](image)

### 8.1.1 Conclusion

In conclusion this test demonstrates that the system is able to track with high accuracy a walking person having a speed up to 2m/s.

PTS tracking reliability and accuracy are compliant with the requirements.
8.2 Low battery warning test

Low battery warning is an important indication from tags which inform that the battery is going out of charge. Since the alarm arise first time, few more day of charge are still guaranteed, giving the operator enough time to detect and solve the problem.

To check that feature, some tag were equipped with batteries intentionally depleted and the low charge monitoring tool was checked to verify that it is able to capture the situation.

As example in Figure 18 reports TAG monitor output when tags having ID 51 and 144 (field “Tag_ID”) were equipped with depleted batteries. The entry associated with such Tags become red and the field “Status” assumes the value “Allarm” which means that battery status is under the predefined voltage.

![Figure 18 – Tag low battery test.](image)

8.2.1 Conclusion

In conclusion this test demonstrates that the system robust against Tags batteries depletion.

Developed People Tracking System is able to alert when Tags batteries are running out of charge.
8.3 Multiple tag detection: collision tests

In RFID systems, one key topic to test is the probability of collision (disturbance) of signals sent from multiple Tags that are in communication with the same reader (here satellite) at the same time. The Tags cross-disturbance (i.e. collision) during communication with the same satellite is directly related to the readout speed in crowded situation. For our system, anti-collision requirements are not critical because the detection are of each satellite is limited (roughly 5m²) and then it cannot accommodate many people. Furthermore, in traffic jam scenario, travelling speed of each tag is much below the 2m/s utilized for single Tag tracking test.

<table>
<thead>
<tr>
<th>Test Performed</th>
<th>Test description</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moving up to 10 Tags in the detection area of one satellite.</td>
<td>10 Tags were moved under the same satellite. Tags detection speed was recorded</td>
<td>100 iteration, all Tags detected within 3 seconds</td>
</tr>
</tbody>
</table>

![Image of RFID tag detection](image)

Figure 19 – Multiple Tag detection by single satellite.

8.3.1 Conclusion

In conclusion this test demonstrates that the system robust against crowding events.

Developed People Tracking System is able to detect in 3 seconds people density of 2 people/mm².
8.4 Neighbors satellites mutual interference

Each satellite has its own detection area and a good system design procedure requires that two adjacent detection areas should have a minimized overlap, to avoid the Tags in the overlap region jumping from one satellite to the other. In a real world it is very difficult to avoid detection area overlapping, because often this would imply lack of coverage and then reduction of reliability.

The developed system avoid this problem allowing minimal overlap without generating tracking erratic data. That was achieved with a special algorithm that allows to assign a Tag to one and only one satellite also in situation where more detection areas are overlapping.

The mentioned algorithm was tested with the following procedure.

<table>
<thead>
<tr>
<th>Test Performed</th>
<th>Test description</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moving 1 Tags in the detection area of two</td>
<td>10 Tags were moved under the same satellite. Tags</td>
<td>100 iteration, all Tags detected</td>
</tr>
<tr>
<td>satellite (overlap region.).</td>
<td>detection speed was recorded</td>
<td>within 3 seconds</td>
</tr>
</tbody>
</table>

![Figure 20 – Satellite detection areas overlap scenario.](image)

The mentioned algorithm was tested with the following procedure.

<table>
<thead>
<tr>
<th>Test Performed</th>
<th>Test description</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tracking behavior in overlapped detection</td>
<td>Moving 1 Tags in the detection area of two satellites (overlap area).</td>
<td>100 iterations, the tag was always correctly assigned just to one satellite.</td>
</tr>
<tr>
<td>areas.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

8.4.1 Conclusion

In conclusion this test demonstrates that the system is robust against satellite detection area overlap.
Developed People Tracking System allows minimal overlap in satellites detection area without showing erratic data.
9 People tracking pilot system lab characterization test results: conclusions

All of the performed tests showed expected positive results, confirming the ability of the realized system to meet desired requirements. The table here below reports pilot system requirements (REF [1]) compared with tests results.

<table>
<thead>
<tr>
<th>Requirements</th>
<th>Test results</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>PTS characteristics</strong></td>
<td><strong>Requirement for pilot application</strong></td>
</tr>
<tr>
<td>Precision</td>
<td>5m or better</td>
</tr>
<tr>
<td>Speed</td>
<td>Below 3 m/s</td>
</tr>
<tr>
<td>Localization reliability</td>
<td>99,9% at system level</td>
</tr>
<tr>
<td></td>
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<td></td>
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<td></td>
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<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>SRtP</td>
<td>Single point of failure tolerant</td>
</tr>
<tr>
<td>Failure detectability</td>
<td>Real time monitoring of each point of detection</td>
</tr>
</tbody>
</table>

Tests and characterization activities showed that the realized People Tracking pilot System is compliant with all of the requirements.
39 partners from 10 countries
taking maritime transport into the digital age

By designing and demonstrating innovative use of ICT solutions
MONALISA 2.0 will provide the route to improved

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