siar

sewer **i**nspection **a**utonomous **r**obot

D28.2 - Multi-Media Report on Phase I Experiments

SIAR Consortium

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ECHORD

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1. Introduction

This report summarizes the work that has been performed by the partners during the 6 months of phase 1. During this 6 month period the partners have made different studies, designs and experiments that lead to the solution that is now presented in the deliverables “D28.1 - Detailed Robot Design” and “D28.2 - Multi-Media Report on Phase I Experiments”. Evaluation of some robotic components were made in Seville through the use of an existing RaposaNG platform. Meanwhile, a six-wheeled robot platform prototype was designed and built for the experiments and evaluation of sensors, communications and locomotion in Barcelona’s test-bed scenario.

This report ends with a small collection of multimedia material in order to show the advances of the SIAR project during Phase I. As detailed in the Progress Report, the SIAR team has developed a number of experiments for testing and validation of the basic technologies required by the robot: robot platform, sensors, communications and basic navigation algorithms as odometry and mapping.

In addition, the SIAR team started with the dissemination of the project, getting in contact with companies and public bodies to present the project. This report includes TV report in a Spanish regional television (Canal Sur).

All the videos related with this report are located in the following public web-repository:
https://drive.google.com/open?id=0B-bCskQGnkviakszdFdrTEJNOGM

2. Phase I: M01-M06 Chronological Events

January 1, 2016. Project official start.

The SIAR team started the definition of the requirements of the sewer inspection robotic system. IDM prepared a RaposaNG robot platform and shipped it to its Seville partners. The Consortium started their studies and evaluation of the sensors, actuators and processing system, based on the existing RaposaNG (see Figure 1).

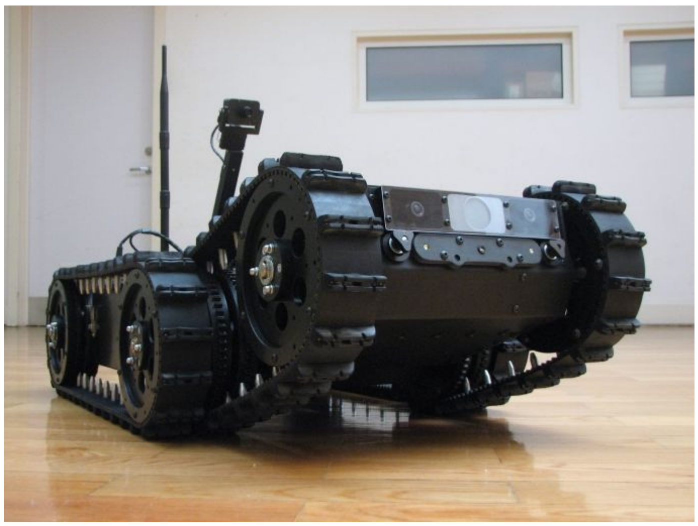

Figure 1. RaposaNG platform

Two NUC computers, RGBD cameras and wireless transducers were bought and installed in the RaposaNG platform. The ROS drivers for controlling the RaposaNG platform and for sensor data gathering were developed. In the next weeks, communication, mapping and navigation tests were performed using the developed algorithms and programs.

Sampling systems for the gases, liquids and solids were studied and some commercial solutions fulfilling the requirements were identified.

A hardware architecture design, as well as an initial software architecture, were outlined.

February 17, 2016. Kick-off meeting at Barcelona.

The SIAR Consortium was represented in this kick-off meeting by: Paulo Alvito (IDM), Fernando Caballero (USE), Luis Merino and David Alejo (UPO). This m

Figure 2. Visit to the sewer during the kick-off meeting.

After the kick-off meeting and after an evaluation of scenario based on the collected videos and images, it became clear to the team that a tracked solution based on RaposaNG would have many difficulties to deal with this specific environment. Hence, IDM team started the study of other robotic kinematic configurations that could be more suitable for the proposed sewer scenario.

This study took us to a six-wheeled robot configuration, based on six independent motor actuators, depicted in Figure 3.

Figure 3. Six-wheeled configuration.

To test the viability of the proposed configuration, a six-wheeled robot prototype was designed and produced, largely through the use of existing machinery, materials and components. Figure 4 depicts the prototype design.

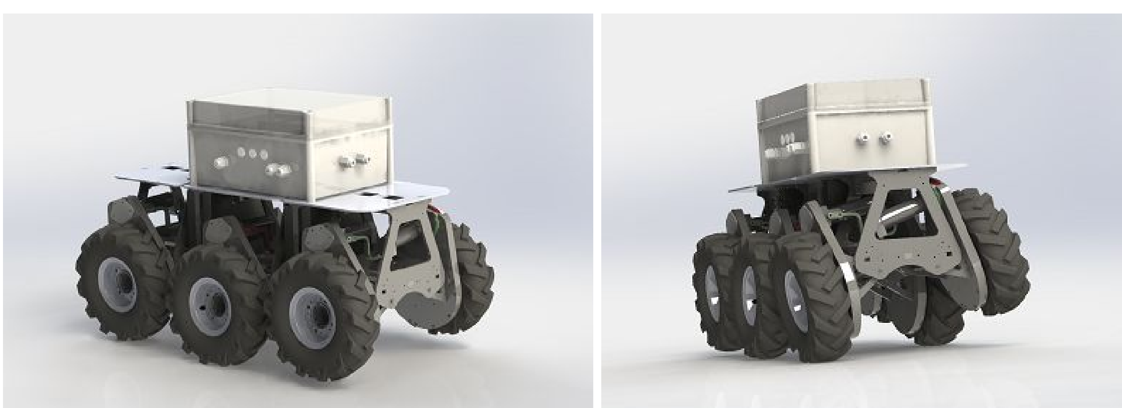

Figure 4. SIAR 1st prototype design.

This IP67 prototype included six 90W DC motors with gearbox and encoders, two motor controllers boards, bearings and POM plastic materials. It was also included an IP67 plastic box in the top to encase all the electronics and payload devices.

The platform was assembled and tested over outdoor terrain through the use of a remote controller (see Figure 5).

Figure 5. SIAR first prototype tests.

Meanwhile, the UPO team was working on the ROS driver to control the new platform. Furthermore, they were designing the sensor payload for low-cost 3D perception. Different iterations of the configuration of the cameras have been analyzed and tested in local experiments. Figure 6 shows some of the iterations.

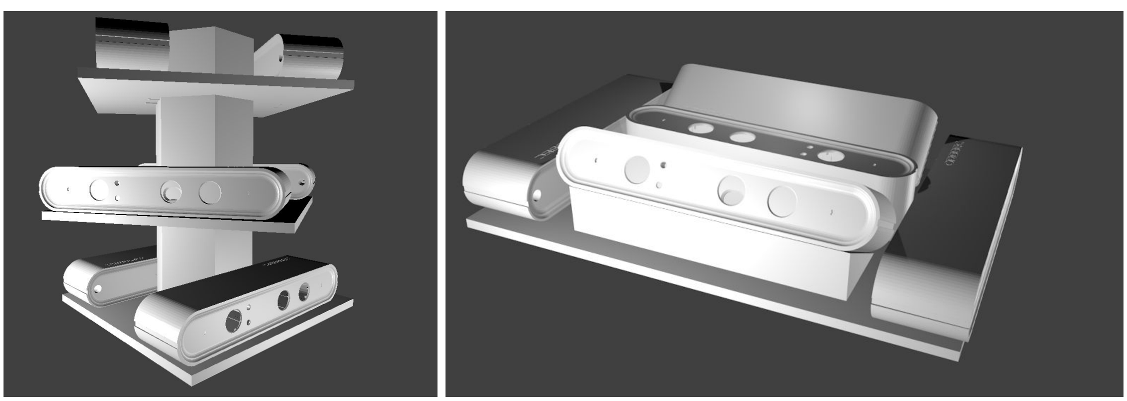

Figure 6. Multi-RGBD camera system for 3D perception. Left: one of the tested configurations.
Right: configuration for the final design

A ROS driver for multi-camera capturing was also developed and tested with the RaposaNG robot.

USE designed the communication system to be employed, using ad-hoc networks. Besides the TCP-based ROS communication, a ROS package was also developed for ROS messages serialization through RS-232, so that radio modems can be used, and UDP, for lightweight communication channels through this network.

Feb, 2016. Local teleoperation and data gathering experiments at UPO premises.

Presences from SIAR consortium: Fernando Caballero (USE), Luis Merino and David Alejo (UPO).

Since mid-February, not having access to actual sewers, different experiments were carried out in the maintenance underground corridors of the UPO main buildings, which include up to 500 meter-long corridors (see Fig. 7) without communication infrastructures.

Figure 7. UPO's underground corridors where the tests were carried out.

The initial experiments were aimed to test the ROS driver of the platform, and the sensor gathering capabilities (telemetry, 3D information, etc) as depicted in Figure 8.

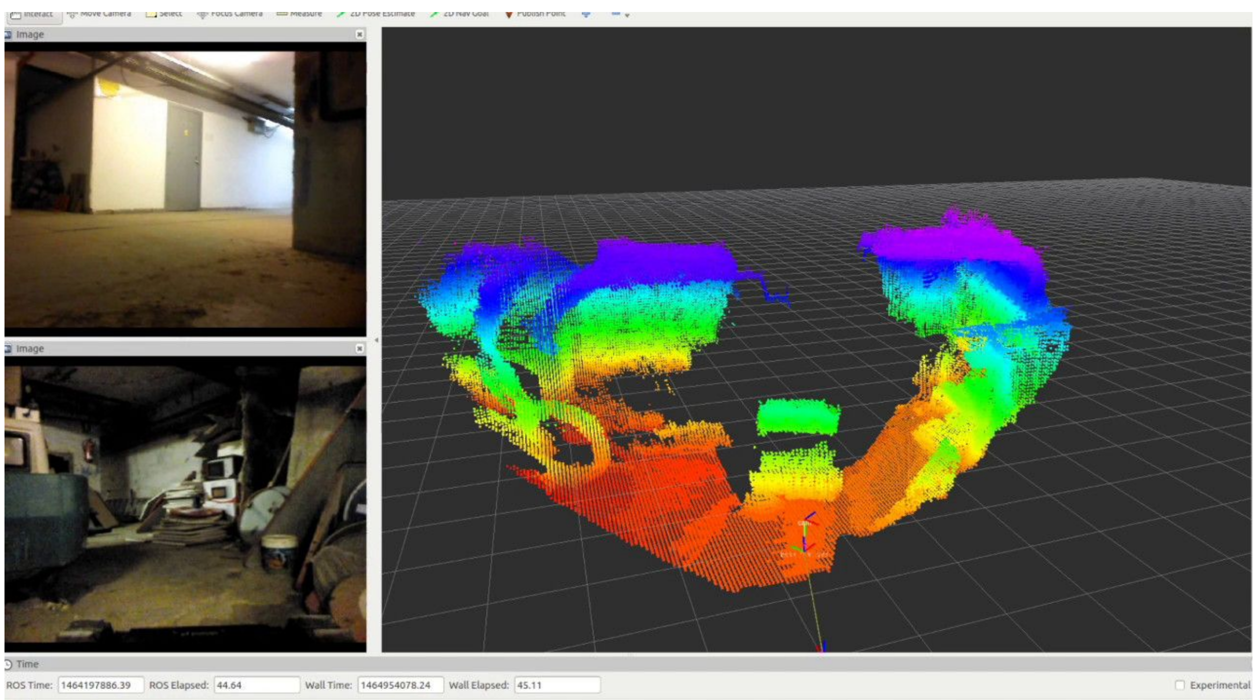

Figure 8. Teleoperation experiment, and 3D data gathering.

April 26-27, 2016. SIAR 1st visit for on-site experiments.

Carlos Marques (IDM), Fernando Caballero (USE) and David Alejo (UPO), went to Barcelona for some on-site experiments with the prototype solution (see Figure 9). Just before this 1st series of experiments at Barcelona, all the elements that were being tested in the RaposaNG were installed in the new prototype and the ROS drivers to control the new platform were developed and used to control the robot. David Alejo (UPO) moved to Lisbon on April 19-20 to help in this integration.

Figure 9. SIAR first prototype sewer experiments.

Performed experiments:

- Evaluation of the performance of the prototype kinematics in the sewer system;
- Evaluation of the communications between the robot and the control console;
- Collection of data with the installed RGBD cameras;

It terms of locomotion, this 1st visit for experiments showed that the width of platform was not adequate to run over the 400 mm sewer gully and consequently it was decided to change the width of the platform from 480 mm to 560 mm.

A new motor board controller, able to control 6 motors at the same time, was also developed, increasing the speed of communication between the navigation computer and the motors.

After evaluating the new control system, new ROS drivers to control the board were developed and used to control the robot with the PC.

Meanwhile, the RGBD data, odometry and IMU data collected in the 1st visit for experiments was used to create a map of the main sewer collector under the Passeig de Sant Joan (see Figure 10).

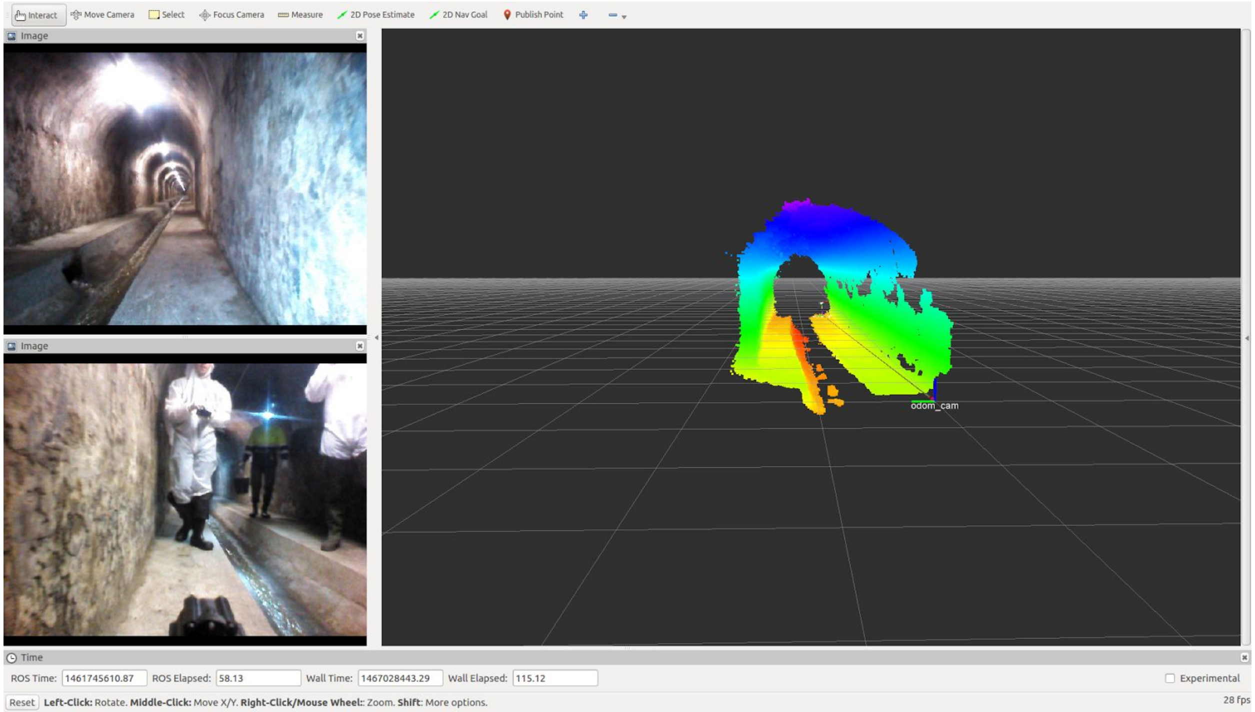

Figure 10. 3D map of the sewer galley under Passeig de Sant Joan.

April 28, 2016. Meeting with Department of Infrastructures and Sanitation from the Lisbon City Hall.

Paulo Alvito (IDM) presented the SIAR project to the Department of Infrastructures and Sanitation from the Lisbon City Hall. He also collected information about the main concerns of the City regarding the inspection of its sewer network. The City Hall has demonstrated its interest in following the evolution of the project and in hosting some local experiments. A support letter from the Lisbon Municipality is included in Annex 1.

April-June, 2016. Communications and Teleoperation Experiments, local UPO premises.

Persons from SIAR consortium: Fernando Caballero (USE), Luis Merino and David Alejo (UPO).

Since April, and in addition to the experiments in the sewers, several further experiments were carried out in the campus of UPO regarding communications and remote teleoperation, using several repeaters and the RaposaNG platform (see Figure 11).

In these experiments, an evaluation of the main characteristics of the envisaged solution has been carried out, by performing experiments with different number of repeaters and distances.

Figure 11. Communication experiments: the robot and one of the repeaters.

Figure 12 shows two configurations of the experiments that were carried out at UPO’s premises. The results are described in detail in deliverable D1.1.

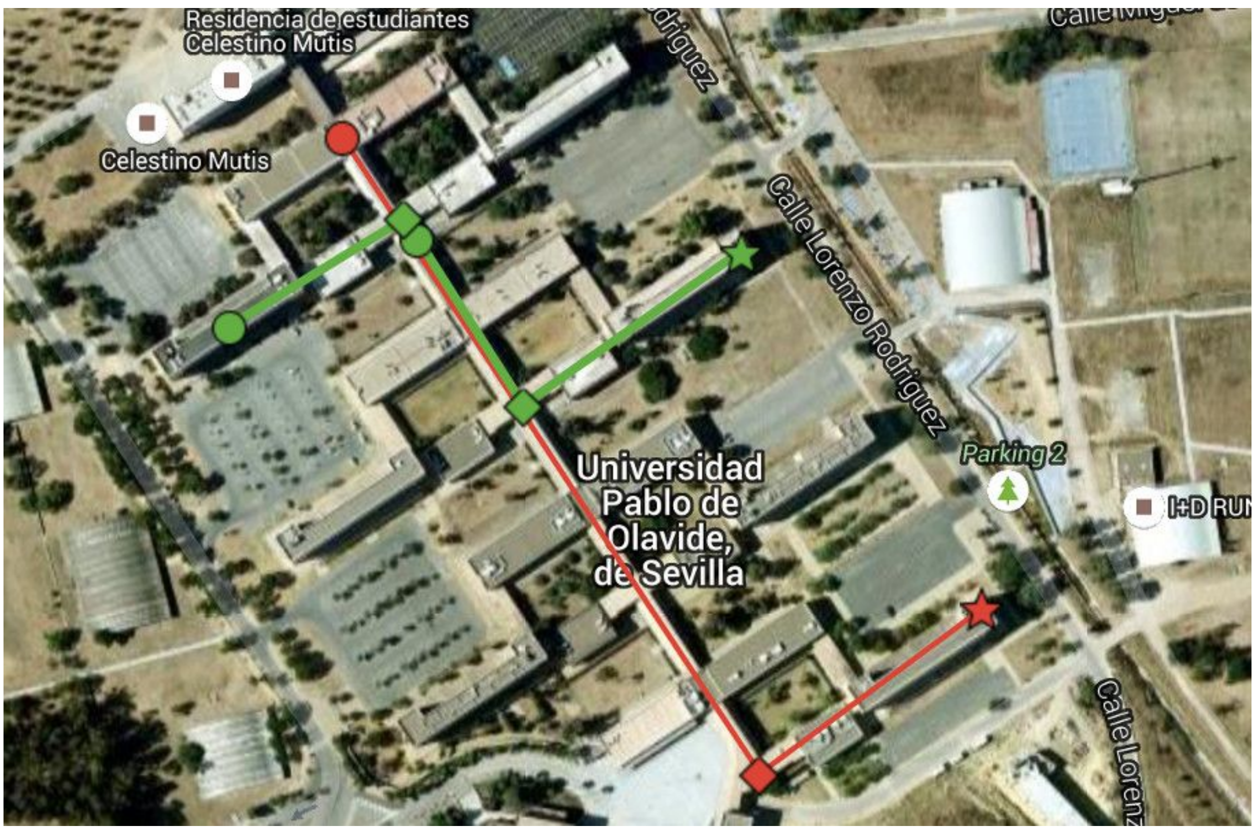

Figure 12. Communication experiments. Red: experiment with one repeater; the first leg is 330 m long, while the second is 120 m. Green: experiment with two repeaters; each leg is approximately 100 m long.

May 25, 2016. Dissemination: Canal Sur documentary about SIAR.

Persons from SIAR consortium: Fernando Caballero (USE), David Alejo and Luis Merino (UPO).

Even at this stage of the project, the consortium has performed some dissemination tasks. As a result, on May 25 a team of the TV show “EnRed”, from the regional public broadcasting station RTVA (with an average audience of 500.000 persons). The documentary was aired on June 14th, 2016 and it can be accessed through the following link:

http://www.canalsur.es/television/programas/enred/detalle/320.html?video=879385

Figure 13. SIAR in the EnRed TV show.

June 7-8, 2016. SIAR 2nd visit for on-site experiments.

Carlos Marques (IDM), Fernando Caballero (USE) and David Alejo (UPO) went to Barcelona for a second round of on-site experiments (see Figure 14).

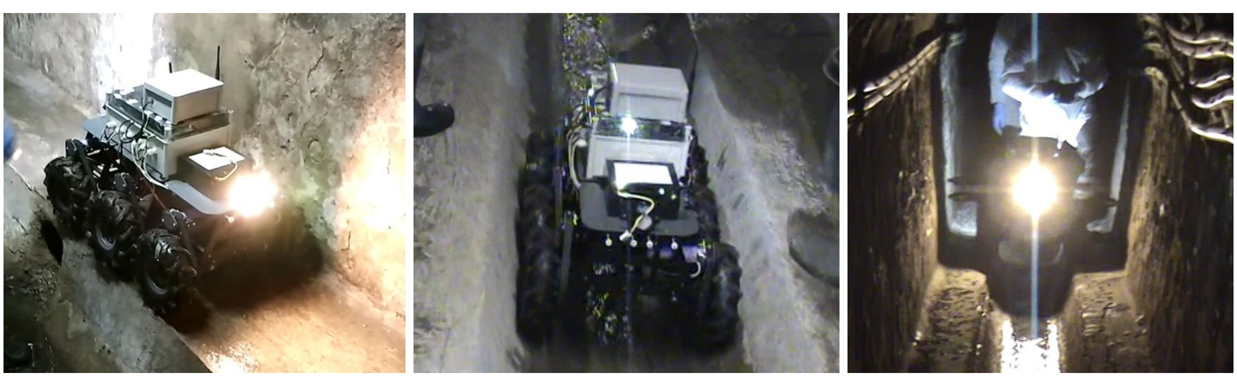

Figure 14. SIAR second round of experiments.

Performed experiments:

- Evaluation of the locomotion performance of the kinematics with increased width of the platform;
- Remote control the platform in different sections of the sewer system;
- Evaluation of the communications between the robot and the control console;
- Tele-operation of the robot inside the sewer network using the communication repeaters to increase the communication distance;
- Collection of data with the installed RGBD cameras.

The 2nd visit for experiments was important to test the mobility of the prototype robot inside the sewer, to test communications, to collect data to create a 3D map of the sewer network and allowed the team to have a better understanding of the main issues that can affect the robotic inspection.

During these experiments it was also possible to see that the new width of the platform was too big for some sections of the main sewer passage at Passeig de Sant Joan. Based on the 1st visit evaluation and on these 2nd one, it was decided that the robot must be able to change automatically the width between the wheels to be able to adjust to the different sections of the sewer network. These observations were reflected on the design of the proposed solution. A new solution was designed that makes use of 3 linear motors that are able to change the width of the robot between a minimum of 460 mm and a maximum of 666 mm (see Figure 15).

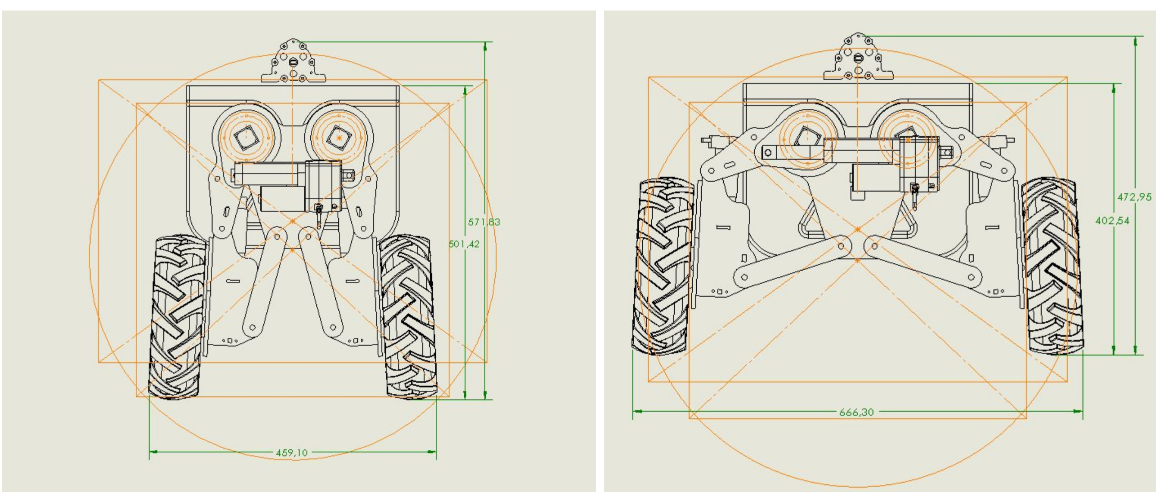

Figure 15. SIAR robot 460 mm and 666 mm widths.

The experiments with the repeaters and their possible use in the final solution implies the inclusion of a robotic arm to deploy and retrieve the wireless repeaters, which has been included in the final design of the solution (see Figure 15).

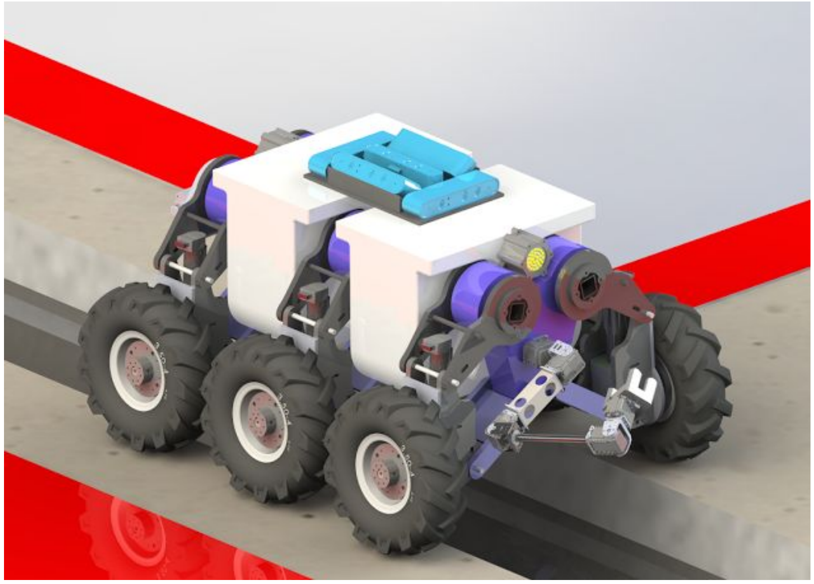

Figure 15. SIAR design with inclusion of a robotic arm.

A new electronic hardware system was developed to measure the battery current consumption and to determine the level of discharge and remaining operation time of the robot batteries.

June 21, 2016. SIAR 3rd visit for on-site experiments.

Fernando Caballero (USE) and David Alejo (UPO) went to Barcelona for a quick round of on-site communication experiments using more than one repeater.

June, 2016. IDM meeting with Vodafone Portugal.

In June, Paulo Alvito from IDM hosted a meeting with representatives from Vodafone Portugal and presented the SIAR project. They have expressed their interest in the project and in testing one of their wireless communications technologies on the SIAR robot. Their expression of interested is in Annex 1.

July 6-7, 2016. Phase I Evaluation.

The SIAR Consortium will be represented in Phase I evaluation experiments by: Paulo Alvito and Carlos Marques (IDM); Fernando Caballero (USE); Luis Merino and David Alejo (UPO).

Phase I evaluation system setup includes:

- SIAR robot prototype;
- 3 wifi repeaters;
- Remote controller;
- Control console.

Tests to be performed during the evaluation:

- Viability of the robotic solution mobility in the sewer network conditions;
- Communications suitability in underground sewage system network;
- Autonomy versus mobility of the robotic solution.

3. Phase I: Task Execution Evaluation

For the Phase I, M01-M06 period time, two tasks were defined on the SIAR proposal: the Robot platform specification and design (Task 1); and the proof of concept with the RaposaNG (Task 2).

The following subsections evaluate their execution and any deviation from the original proposal.

3.1. Task 1: Robot platform specification and design

Task 1 DoW (from the SIAR proposal) is presented in Table 1.

Task 1: Robot platform specification and design [M01-M06]		
Participant	**Role**	**PMs**
IDM	Task leader. Specification and design of the robot platform (mechanics, power, electronics architecture)	4
USE	Contribution to the design of the communication system. Testing and validation of sensors for localization.	0.5
UPO	Testing and validation of sensors for robot navigation and sewer monitoring.	1
Objectives: Robot platform and sensors specification and design based on the project requirements; Communication system specification and design; Individual sensor tests.		
Description of work and contribution of individual participants: Meet the public body at Barcelona to: discuss and refine the requirements; visit the real sewer environment. All the partners will contribute for the specification of the robot kinematics and communication systems which have been identified has two critical issues. Main sensors required for robot navigation and sewer inspection analyzed in detail and tested: low-cost IMU, 2D LIDAR, RGBD sensors, pan&tilt unit and sensors for environmental sampling. Individual tests will be used to check the approaches.		

Table 1. Task 1 description from the SIAR proposal

The execution of Task 1 started with the study of the requirements for the sewer inspection robot system. The required sampling sensors and actuators were defined and some commercial systems for sampling and inspection were identified. At the same time the sensors for the autonomous navigation, mapping and localization the robot in the sewers were selected and acquired.

A six-wheeled kinematic configuration was identified to be a better choice of kinematics to move inside a sewer system than a tracked robot with flippers. A prototype with the selected kinematic configuration was developed, assembled and used to test the locomotion, communications and collect data with the selected sensors for localization and navigation.

The final mechanical solution has been designed in different integrations based on the feedback from the on-site experiments. The robot electronics were designed, which includes the robot power architecture, the low-level and high-level communication architectures

A low-cost system for 3D perception has been designed using 5 RGBD cameras, able to capture 3D information around the robot. This information will be used for enhanced odometry, map building and sewer serviceability inspection. An initial proof of concept version has been tested in local experiments and in the sewer.

The communication system is aimed to remove tether or other devices that may hamper the mobility of the robot. Thus, the communications between the robot and the control station is based on the deployment of repeaters. During this period, a first proof of concept has been integrated and tested in local experiments and in the sewers at Barcelona.

Finally, the software architecture has been designed, and an initial version integrated into the platform, using ROS, including a simple teleoperation stations, allowing to control the robot at distance, gather all sensorial data and create local maps.

This task contributed to deliverable “D1.1 - Detailed Robot Design” which is now being delivered together with this progress report.

A “Economic Viability Study” based on the proposed solution is also being delivered together with this report.

Task 1 execution: 100%
Partners PMs: IDM 4,5; USE 0,5; UPO 1
Note: partner IDM required more 0,5PM than planned for this task.

3.2. Task 2: Proof of concept with RaposaNG

Task 2 DoW is presented in Table 2.

Task 2: Proof of concept with RaposaNG [M03-M06]		
Participant	**Role**	**PMs**
IDM	Customization of RaposaNG for proof of concept demo.	1
USE	Contributions to sensor software integration and testing.	1
UPO	Task leader. SW&HW integration for proof of concept tests.	1
Objectives: Preliminary testing of the designed systems over an existing robot platform.		
Description of work and contribution of individual participants: Preliminary tests and validation of critical subsystems of the design, namely: robot kinematics; sensor payload; and communication system. This will lead to a Critical Design Review, including a proof of concept over an existing RaposaNG in a realistic scenario (partners will procure one). The following tests are envisaged: sensors tests (the sensor payload selected in task 1 will be tested in month 4); the proof of concept of the communication system will be tested at month 5; proof of concept test at month		

6. The proof of concept test constitutes Milestone 1, and it includes the evaluation of main critical features of the design, namely: teleoperation of the platform over the communication system; and reception of images and scanning data over the communication system.

Table 2. Task 2 description from the SIAR proposal.

The execution progress of this task is quite evident in this work progress report. The team decided to anticipate Task 2 to M01 to start evaluating the navigation sensors with RaposaNG robot as soon as possible.

After the kick-off meeting that included a visit to the sewer system, became evident that the RaposaNG platform did not have an adequate locomotion system for the proposed sewer scenario. This led to the design and construction of six wheel platform prototype to be used for the on-site experiments and for the final evaluation in July 2016.

Three on-site visits for experiments in sewers of Barcelona were performed to study, identify and evaluate the performance of different robot systems.

The selected payload sensors were integrated on the robot and used in the 2 visits for experiments the sewers of Barcelona.

In the last visit the team was able to:

- Remote control the platform in different sections of the sewer system;
- Evaluate the communications between the robot and the control console;
- Tele-operate the robot inside the sewer network using the communication repeaters to increase the communication distance;
- Collect data with the installed RGBD cameras;

An additional short visit was used to test the communication system with a larger number of repeaters.

This task has contributed to deliverable “MMR1 - Multi-media report on Phase I experiments” which is now being delivered together with this progress report.

Task 2 execution: 100%
Partners PMs: IDM 1; USE **1.3**; UPO **1.5**
Note: partners UPO and USE required more effort than planned for this task, including local experiments and additional visits to the sewers.

3.3. List of Milestones

Phase I included only one milestone: “Full system design: demonstration of major critical features to be developed, including risk analysis, timeline for the entire project”.

Means of verification: “RaposaNG based Lab. Platform. Ability to: tele-operate SIAR through communication system; send images and scanning data.”

This milestone has been **fully achieved** with the deliver of D1.1 and with the different experiments that were performed during the period and reported in MMR1.

For Phase I the RaposaNG has been used by partners UPO and USE for local tests in Seville. The SIAR team decided to build a new prototype with different kinematics to better address the locomotion requirements in the sewer system of Barcelona.

4. Financial Execution

For the Phase I, M01-M06, the executed effort for IDM, was 5,50 PMs divided as follows:

- 2,61 PMs level one, with a cost of 9.335€;
- 2,89 PMs level two, with a cost of 6.412€.

Total effort costs executed for IDM is 15.747€.

The total costs for travel are 2.698€, in which are included the kick-off meeting in Barcelona held on the 17th of February; two meetings for tests and partners integration, in Barcelona, held from 26th to 27th April, and from 7th to 8th June, and also the airfare and accommodation costs for the next meeting in July. For this last trip we estimate an extra cost of 350€ for e.g.meals, local transportation, etc.

Considering that, the robotic platform used, was considerably changed from the initially planned, the initial budget for consumables, was not enough to cover all the costs. Therefore, the total costs for consumables are 4.797€.

The transport of the robotic platform, twice to Barcelona and back to Lisbon, had a cost of 554€. The estimated cost for the transport of the platform in July is an extra 280€.

In conclusion, we present the following table costs, for IDMind, Phase M01-M06:

IDM	PMs	Total costs
Costs per Month for Level 1	2,61	9 335
Costs per Month for Level 2	2,89	6 412
Travel expenses		2 698
Consumables		4 797
Other Direct Costs		554
Direct Costs		23 796
Indirect Costs		11 399
Total RTD Costs		35 195

Extra direct costs estimated: 630€

For the Phase I, M01-M06, the estimated executed effort for UPO, was 2,50 PMs divided as follows:

- 1,0 PMs level one, with a cost of 4.224€;
- 1,5 PMs level two, with a cost of 3.150€.

Total effort costs executed for UPO is 7.374€.

The estimated total costs for travel are 3.508,50€, in which are included the kick-off meeting in Barcelona held on the 17th of February; three meetings for tests and partners integration, in Barcelona, held from 26th to 27th April, from 7th to 8th June, on 21th of June, and also the airfare and accommodation costs for the next meeting in July; and one trip to Lisbon for equipment integration and testing

In conclusion, we present the following estimated table costs, for UPO, Phase M01-M06:

UPO	PMs	Total costs
Costs per Month for Level 1	1,0	4224,00
Costs per Month for Level 2	1,50	3150,00
Travel expenses		3508,50
Consumables		0
Other Direct Costs		0
Direct Costs		10882,50
Indirect Costs		6529,50
Total RTD Costs		17412,00

For the Phase I, M01-M06, the estimated executed effort for USE was 1,80 PMs with a cost of 3.850,50€:

Total effort costs executed for USE is 6.930,90€.

The estimated total costs for travel are 2.482,00€, in which are included the kick-off meeting in Barcelona held on the 17th of February; three meetings for tests and partners integration, in Barcelona, held from 26th to 27th April, from 7th to 8th June, on 21th of June, and also the airfare and accommodation costs for the next meeting in July.

In conclusion, we present the following estimated table costs, for USE, Phase M01-M06:

USE	PMs	Total costs
Costs per Month	1,8	6930,90
Travel expenses		2482,50
Consumables		0
Other Direct Costs		0
Direct Costs		9413,40
Indirect Costs		5648,04
Total RTD Costs		15061,44

5. Videos

5.1. Video: basement_UPO

This video shows the SIAR robot teleoperation during the experiments in March 2016 for sensor and communications testing. These tests were carried out in the UPO's basement. The robot was teleoperated during the experiment and all the sensors captured to build a map as shown in the video. Figure 1 shows some photos of the environment and the robot.

Figure 1. RaposaNG in the experiments at the UPO basement

5.2. Videos: platform_preliminar_test_1 and plaform_preliminar_test_2

The first mobility tests of the SIAR platform are shown in these videos at IDM facilities (Lisbon). In the experiments the platform is driven over different types of ground and over different obstacles. It can be seen how the robot stays stable even when dealing with large obstacles.

5.3. Video: television_siar_short

Clip of video extracted from a SIAR report at Spanish public regional television (Canal Sur). The project is presented to the general media in a TV show focused on technological advances and trends. Canal Sur is the biggest public television in the region of Andalusia (South of Spain), a region with more than 8 millions inhabitants.

5.4. Videos: sewer_sant_joan_in and sewer_sant_joan_out

These videos show part of the experiments carried out in Barcelona in April 2016. Many sub-systems were tested in these experiments: locomotion, odometry, drivers, cameras and software. The video sewer_sant_joan_in shows the 3D map building process while the robot moves along the Sant Joan sewer.

The video sewer_sant_joan_out shows the same clip but gathered from an external camera, so that we can observe the robot. Figure 2 shows some photos of the experiment.

Figure 2. First field experiments at Barcelona

5.5. Videos: sewer_valencia and sewer_valencia_defects

These videos show the 3D reconstruction of the Valencia Street sewer during the field experiments in june. The first video shows part of the sewer reconstruction. The sewer_valencia_defects video shows a part in which some structural defects can be seen in the visual image and also in the 3D reconstruction. Figure 3 shows some details of 3D maps.

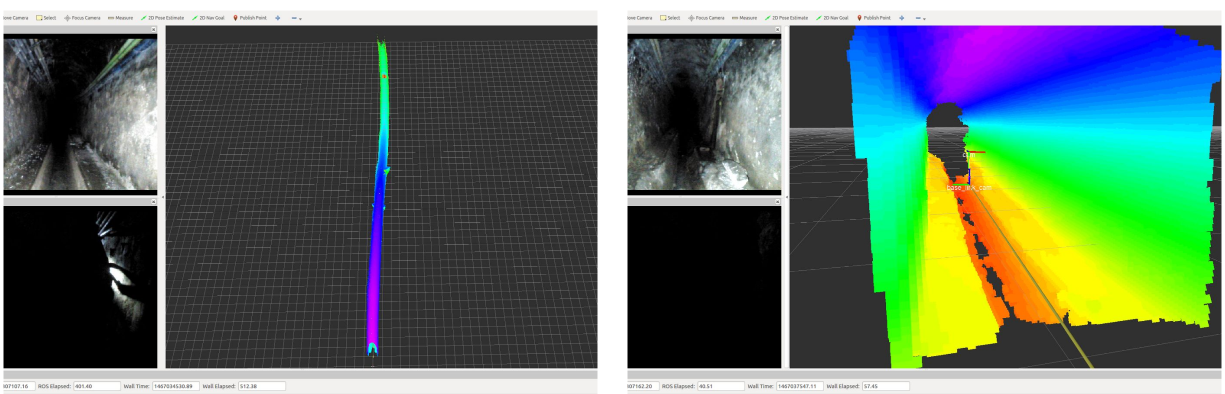

Figure 3. Left: Section of 45 meters of sewer. Right: Structural defect in the image and also in the 3D map

5.6. Videos: mobility_sant_joan, mobility_valencia and mobility_bailen

These videos shows the SIAR platform navigating in Sant Joan, Valencia and Bailen streets. Specially interesting is the video at Sant Joan, where the robot is driven in the middle of the sewer.

Figure 4. SIAR robot navigating in Valencia Street sewer

Annex 1. Support Letters.

CÂMARA MUNICIPAL DE LISBOA
DIRECÇÃO MUNICIPAL DE PROJECTOS E OBRAS
DEPARTAMENTO DE INFRAESTRUTURAS, VIA PÚBLICA E SANEAMENTO

To:
Project coordinator Echord Plus Plus - SIAR

Lisbon, 17th June 2016

Concerning: Support letter for ECHORD Plus Plus Project - SIAR

Dear Project Coordinator,

On behalf of the Lisbon Municipality I, Maria da Assunção Vaz Alves Reboredo, would like to confirm my support and interest in the Echord Plus Plus project SIAR (Sewer Inspection Autonomous Robot).
It is of my knowledge that the project goal is to develop a fully autonomous ground robot able to autonomously navigate and inspect the sewage system with a minimal human intervention, and with the possibility of manually controlling the vehicle or the sensor payload when required.
It is a part of the vision and strategy of the Lisbon Municipality to increase innovation and creativity in the city, and to support major international projects, that can facilitate citizens' everyday life.
We would also be happy, if invited, to follow the developments of the SIAR project and to provide our feedback as a potential end user of the Robot.
I am looking forward to our future cooperation.

Sincerely yours,

Assunção Alves, Departement Director

Rua Dom Luis de Sousa lotes B1 a B8, 1070-326 Lisboa - Tel +352 288 171 601 - e-mail dmpo.dcmivp.dcivps@cm-lisboa.pt

Subject: Project SIAR (Sewer Inspection Autonomous Robot)
From: Carvalho, Patrícia, Vodafone Portugal <patricia.carvalho@vodafone.com>
Date: 30-06-2016 12:49
To: "palvito@idmind.pt" <palvito@idmind.pt>
CC: Carvalhosa, Ricardo José, Vodafone Portugal <Ricardo.Carvalhosa@vodafone.com>, Tomé, João Gonçalo Boléo, Vodafone Portugal <goncalo.tome@vodafone.com>, "Pacheco, Tiago Manuel, Vodafone Portugal" <Tiago.Pacheco@vodafone.com>, Magalhães, Nuno Miguel Pedroso, Vodafone Portugal <Nuno.Magalhaes@vodafone.com>

Dear Project Coordinator Paulo Alvito,

On behalf of Vodafone Global Enterprise I, Patrícia Carvalho, would like to confirm my interest in the Echord Plus Plus project SIAR (Sewer Inspection Autonomous Robot).

It is of my knowledge that the project goal is to develop a fully autonomous ground robot able to autonomously navigate and inspect the sewage system with a minimal human intervention, in which the team intends to study different wireless communication technologies.

It is a part of the vision and strategy of Vodafone to increase innovation and, as in this case, follow major international projects, that can facilitate citizens' everyday life through connectivity.

We would also be happy, if invited, to follow the developments of the SIAR project and to potentially contribute with our own knowledge regarding wireless communication technologies.

I am looking forward to our future cooperation.

Sincerely yours,

Patrícia Carvalho
Sales Country Manager Portugal - Vodafone Global Enterprise
Enterprises Business Unit – Vodafone Portugal
Mobile: + 351 911 965 871
Email: patricia.carvalho@vodafone.com