siar

sewer inspection autonomous robot

D28.10 - Serviceability Inspection

SIAR Consortium

IDMind (IDM), PT

Universidad de Sevilla (USE), ES

Universidad Pablo de Olavide (UPO), ES

ECHORD

Table Of Contents

1. Introduction

Serviceability inspection refers to the ability of the robot to determine whether the sewer is working properly or not. In particular, a sewer is considered to be in service if the sediments on the floor are below certain levels, if the water is flowing correctly or there is no water accumulated in the sewer.

This document describes the approach developed in SIAR for serviceability inspection with the robot. The approach involves a module that is able to generate potential serviceability alarms automatically and in real-time, by analyzing online the data provided by the sensors onboard the robot. These alarms are geo-referenced by using the localization system of the robot, and can be further analyzed by the operators. The approach also considers operational procedures to plan the serviceability inspection mission, and to debrief the results.

The document first describes the approach for automatic defect inspection in Section 2. Then, Section 3 presents the operational procedures for each area that was proposed to be inspected. Then, Section 4 shows the results obtained in the inspection tests carried out in Barcelona. The document also includes further advances in the monitoring of the sewers (Section 5), and finalizes with conclusions.

2. Advances in Automatic Serviceability Detection

In Phase II we already included a preliminary version of a system for the automatic detection of potential defects, even though the associated KPIs were planned for Phase III. In this phase, we have focused first on the analysis of the serviceability according to the requirements as indicated in the Challenge Brief.

2.1 Overview

Regarding the “Serviceability Reduction Alarm”, the Challenge Brief [ECHORD++, 2014] mentions:

“On the basis of the scanning or the video made, the robot has to compare the obtained data with the available information of the sewers (mainly type and section) and identify where the sewer serviceability has been reduced. The operator should receive a “pop-up” alarm that indicates the location of the obstruction and helps to decide if the robot has to make an extra specific snapshot or video.”

The proposed system follows this strategy. The robot is able to automatically recognize the section type which is traversing by using the 3D scanning data. It does this by comparing these data with the known section types in a database. It could also use information from the GIS and the localization of the robot [Alejo et al, 2017] to determine the section, but currently it employs this automatic detection.

Then, once the section type is determined, the system needs to focus on the gutter/bucket, the sill and the curbs to determine potential serviceability reductions, according to the guidelines in the Challenge Brief. The system measures the deviation of the recorded 3D data from the ideal situation of the gutter and curbs to raise alarms. A noise reduction and temporal consistency filters are finally applied to discard false alarms.

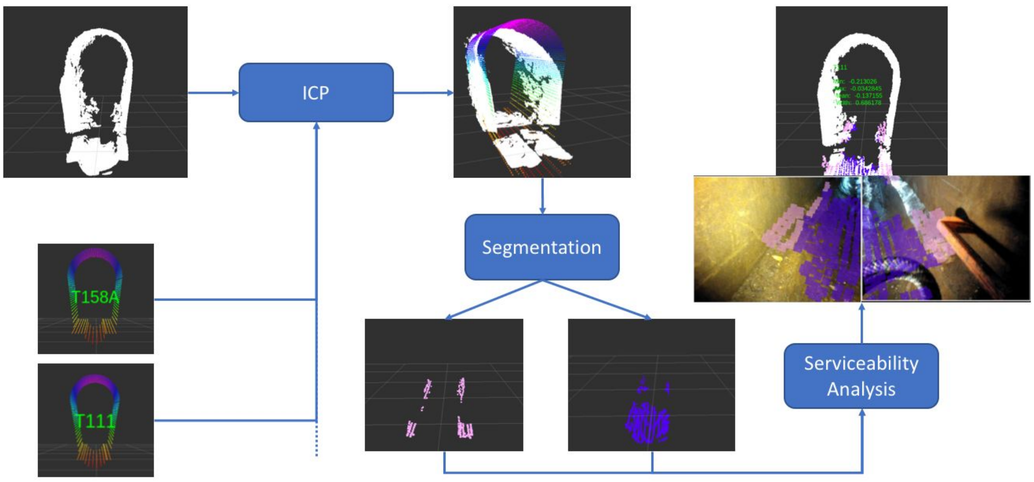

Figure 2.1: Main processing pipeline. ICP is used to estimate (and align) the current section type by comparing the 3D data (in white) with virtual models from the database. Then, the parts related to serviceability (curb and gutter, sill, etc) are segmented from the input point cloud. These parts are analyzed to estimate potential serviceability alarms.

Figure 2.1 summarizes the processing pipeline. The next sections detail these steps.

2.2 Automatic detection of sewer type

The first step in the processing pipeline is the detection of the sewer type. The objective is, given the 3D input from the sensors of the robot, to determine the most likely section type from the set of possible section types.

The robot stores a database of 3D virtual models of the different section types, according to the drawings of the different sections as provided (see Figs. 2.2 and 2.3). These virtual models also contain labels for the different parts of the sewer: gutter, curbs, walls and roof.

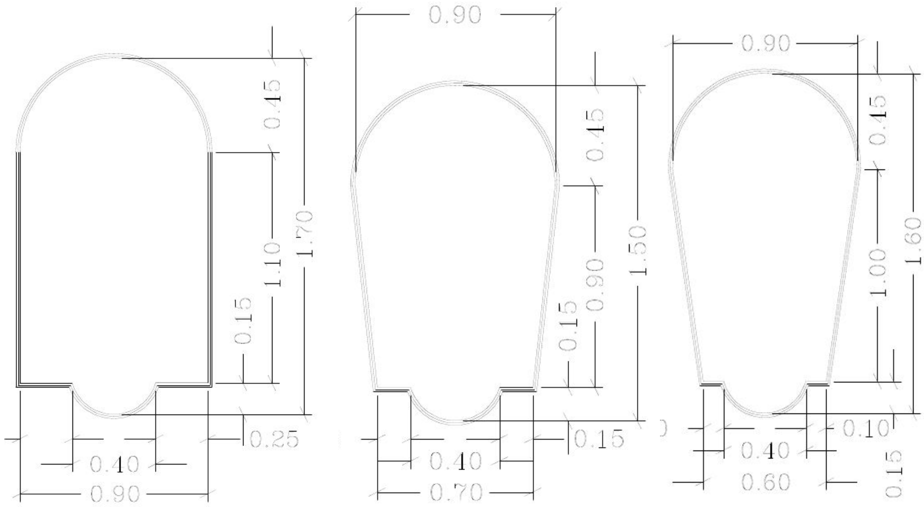

Figure 2.2: Different definitions of section types. Left: T135B. Center: T108. Right: T111

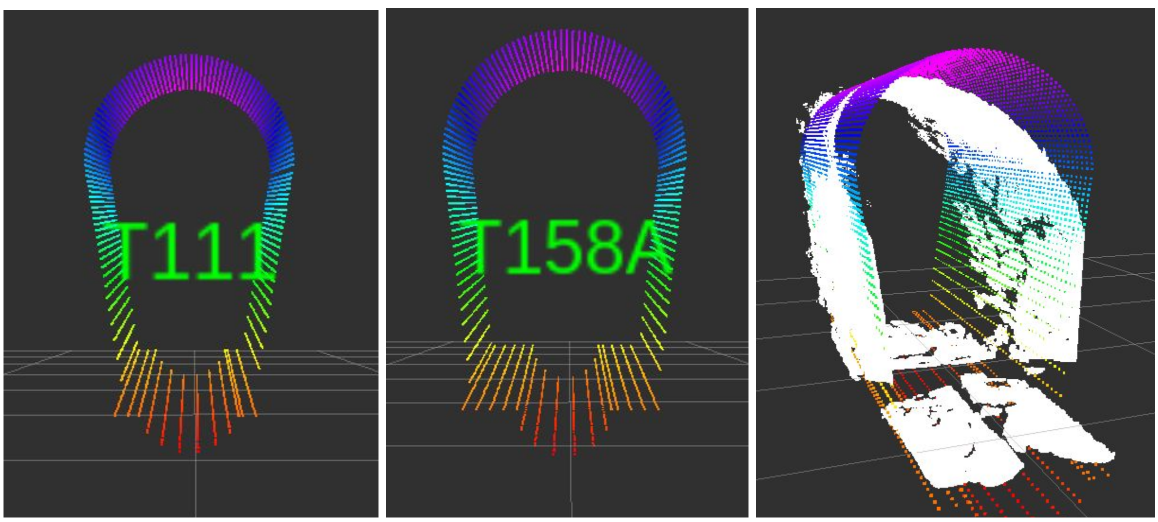

Figure 2.3: Left and center: Virtual ideal 3D models for section types T111 and T158A. Right: the current 3D data (white) is aligned using ICP to all the models in the database searching for the one that best fit the data.

The procedure to determine the section type is based on the Iterative Closest Point [Besl and McKay, 1992] algorithm. The current sensor data is matched, using ICP, to the different virtual models of the sections (see Fig. 2.3, right). To initialize ICP, the virtual model is created approximately aligned to the optical camera that provides the 3D data. The section types are ranked according to the residual of the alignment between the real data and the virtual model. The section with the lowest residual is selected as the current section type.

2.3 Segmentation of sewer elements

As an additional result of the alignment described in the previous section, the current point cloud is segmented into the different parts of the sewer; that is, each 3D point is classified as either gutter, curbs, walls or roof. Each point of the cloud is labeled according to the label of the closest point in the virtual 3D model of the sewer. Figure 2.4 shows the results of the segmentation.

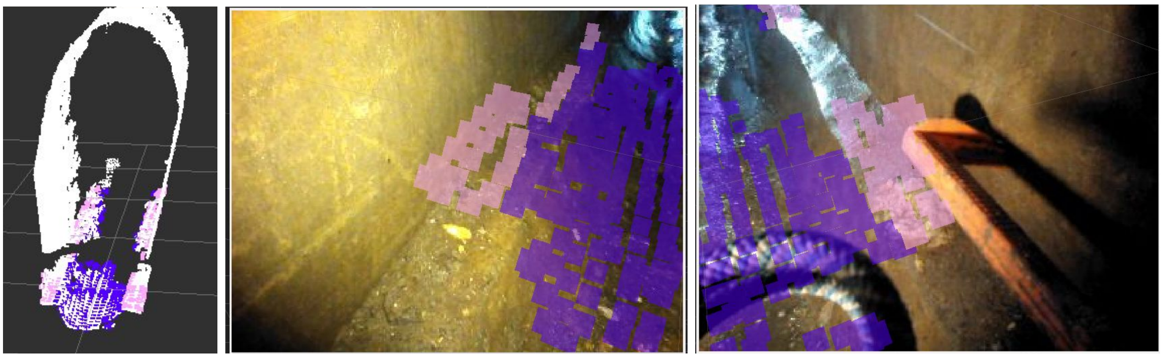

Figure 2.4: Point-cloud segmentation. After the alignment with the section, the points are segmented according to the different parts of the sewer. Left: points segmented as gutter (purple) and as curb (pink). Center and right: the points projected back on the frontal left and right cameras of the robot.

2.4 Serviceability analysis

Once the 3D data input has been aligned with respect to the section type and segmented into different parts, the serviceability analysis is carried out.

First, only the parts corresponding to the gutter, curbs and sill are considered in such analysis.

Then, on one hand, the method extracts those points that separate from the model further than a minimum distance, as these points may indicate deviations from the ideal section model, and thus a potential serviceability problem.

At the same time, the absolute maximum, minimum and mean height of the 3D points segmented as points of the gutter is computed. This way it is possible to estimate if the gutter could be blocked by comparing with the ideal minimum, maximum and mean height of the gutter. The same is carried out with the curb.

As a result, potential alarms are generated (see Fig. 2.5). A temporal consistency filter is employed to filter out false alarms due to brief misreadings or misalignments of the sensor data.

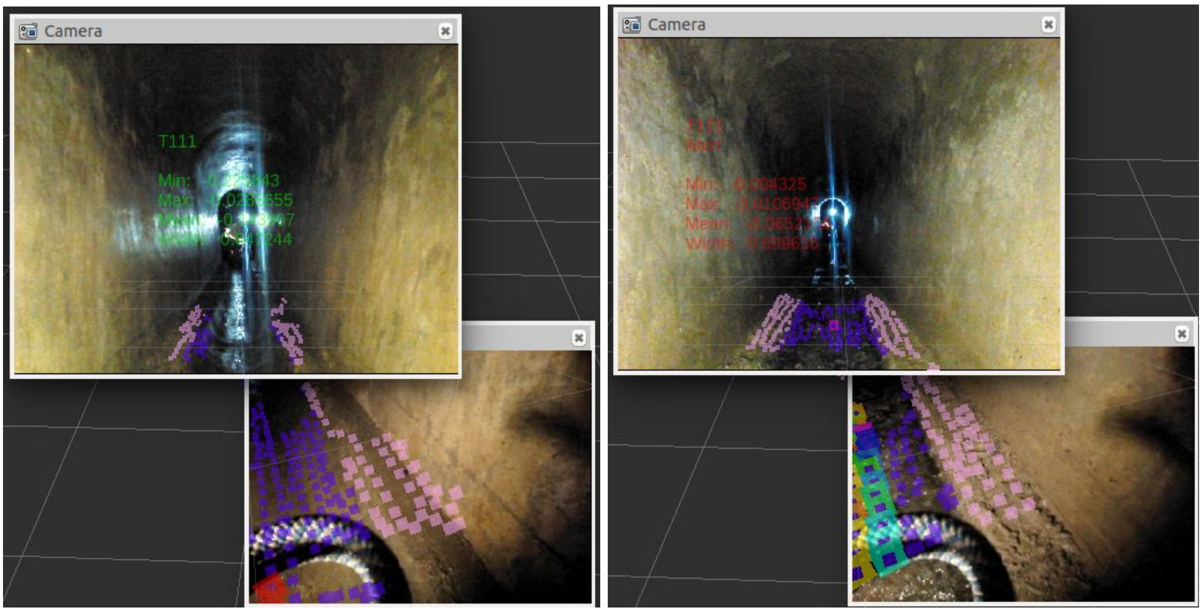

Figure 2.5: Left: the serviceability of the gallery is correct. The frontal and down right cameras are shown (there is a down left camera that is not shown for clarity). In green, the absolute values for the height of the gutter are displayed in the frontal image for the operator. In purple and pink, the 3D points corresponding to the gutter and curb respectively. Right: serviceability alarm. The values are displayed in red. Many of the 3D points in the down-right camera (marked as colored points) are detected as departing from the ideal section (the gutter is blocked by debris).

3. Operational procedure

In this section, we detail the operational procedure followed in the different scenarios we have been experimenting between April and July 2018 for performing serviceability inspection.

The most crucial part of the inspection plans for our platform is the selection of manholes for robot and repeaters deployment. To this end, we have used the following procedure:

1. First we have to select the fork or curve in which the communications base station will be deployed. To this end, a fork or curve close to the center of the inspection area will be selected. This method assures good communications in all inspection directions into the sewer.
2. Then, a manhole near the selected fork or curve will be used to deploy the robot and the communications base station. Note that the ground control station computer will be connected to the communications base station by cable.
3. Finally, the repeaters are positioned in manholes in the vicinity of some forks to provide the desired track with wireless network coverage.

When the plan is executed, we first deploy the communication device of the base station and the SIAR platform through the same manhole. Next, the repeaters have to be deployed in the selected manholes. Then, we perform a connectivity from the base station to guarantee that all nodes are accessible and that the quality of the link is fair enough. If the connectivity is not satisfactory, we deploy additional repeaters wherever needed.

Once the deployment has been carried out and checked, SIAR can start the inspection. The following formula can be applied to estimate the inspection time of a linear segment:

$$t = \frac{2L}{0,5\,(v_i+v_b)} \simeq 10L \qquad (1)$$

where L is the length of the track, v_i is the inspection velocity (approximately 0,15 m/s) and v_b is the velocity when returning from the track (approximately 0,4 m/s). The expression can be approximated to just ten times the length to be inspected (L), this assumes that the velocity to perform the track in both directions is 0,2 m/s.

We will describe now the inspection plans obtained with the aforementioned method.

3.1 Inspection plan Virrei Amat Square

Figure 3.1 represents the inspection plan generated for Virrei Amat Square. The following points detail the plan for the inspection of the Virrei Amat Square area.

1. **Robot deployment.** The idea is to deploy the robot in the central manhole of the area to be inspected. The communication device will be installed in the closest fork.

This will allow to control the robot with direct communication in most of the tracks. The deployment time is estimated to be 20-30 minutes.

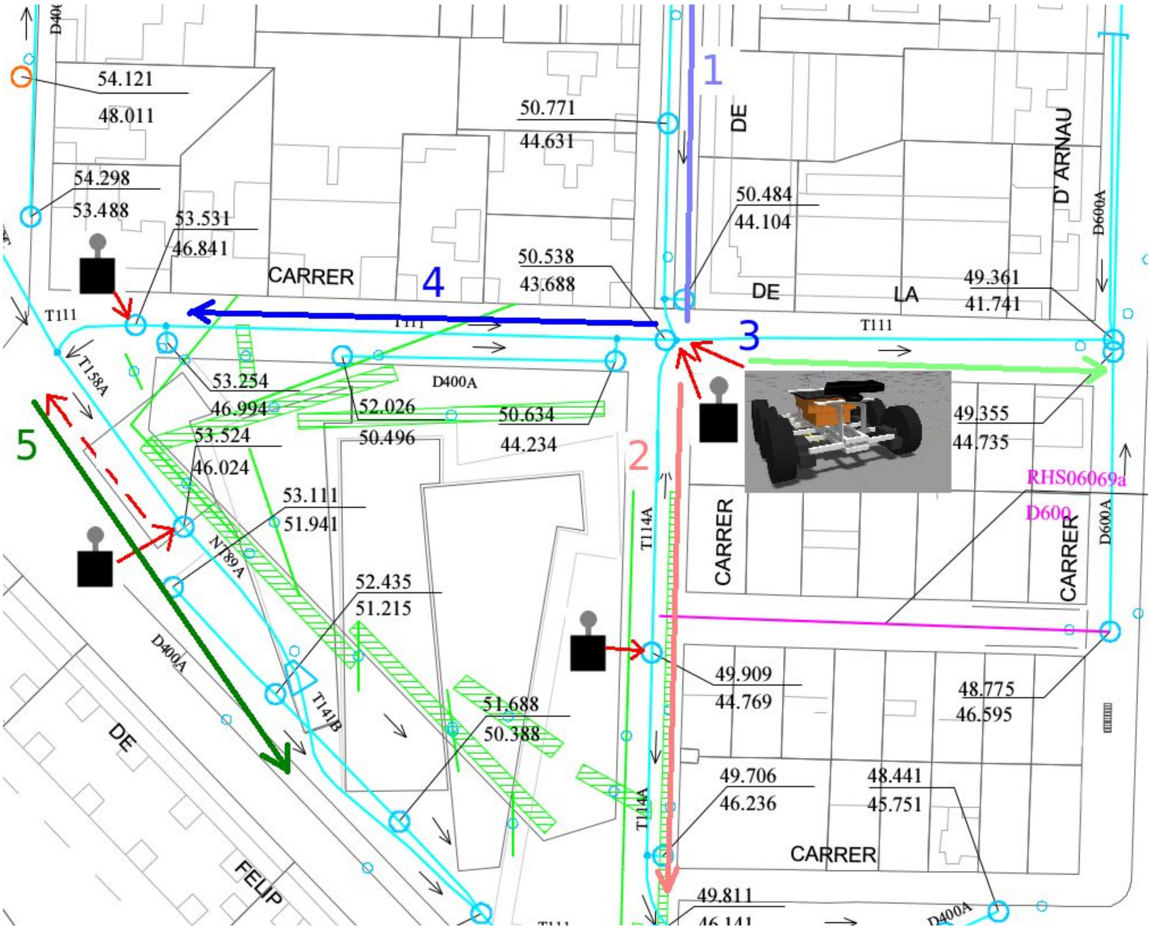

Figure 3.1: Inspection plan for Virrei Amat Area.

2. **Repeater deployment.** Once the robot and the communication equipment of the base station have been deployed, the operators should leave the sewer and deploy the repeaters in the locations signalized in Figure 3.1. The operator at the base station should then confirm the connectivity with each one of the deployed repeaters. The time for deploying the repeaters is about 10 minutes for each repeater. This should be further reduced with the use of the new self-deployable devices described in D28.9, section 3.

3. **Connectivity checks.** Then, the connectivity with the robot and the deployed repeaters should be checked in the base station.

4. **Sewer inspection.** The setup has finished and the operator is able to perform the inspection plan as described in Figure 3.1. This figure has some lines with numbers that define the order in which the different sections will be visited. The expended time to inspect a section depends on the length of the track, the type of section to be visited and the number of defects found during the inspection. An estimation of this time can be obtained by using Eq. (1).

a. Track 1. The section type is T114A, the robot was commanded to proceed with a width of 65 cm, which prevents the platform to fall inside the gutter. It has a length of about 70m. Expected inspection time: 15 minutes.
b. Track 2. Same section. Length: 90m. Expected inspection time: 20 minutes.
c. Track 3. Section T111, commanded width: 60 cm. Length: 70 m. Expected inspection time: 15 minutes.
d. Track 4. Same section. Length: 100 m. Expected inspection time: 22,5 minutes.
e. Track 5. Sections T158A, NT189, T114B. The robot is commanded to have maximum width (71 cm). Length: 80 m. Expected inspection time: 20 minutes.

5. **Robot retrieval and cleaning.** The robot should be retrieved from the same manhole where it was deployed. Once the robot is deployed, it should be cleaned with sprayed water. In the meantime, the other operators can collect the deployed repeaters. The estimated time to perform this operation is about 30 minutes.

3.2 Inspection Plan in Sol de Baix area

As specified in the actions for Phase III, one week before the Challenge two inspection areas were proposed as candidates for the Serviceability inspection Demo. Therefore, our team designed one possible inspection plan for each proposed area. The idea was to check the types of galleries to be inspected, the possible challenges regarding the mobility of the platform and the points for placement of the communication devices.

Figure 3.2 represents the inspection plan for the Sol de Baix area. The area presents less variations of the section type when compared to the Virrei Amat area. In addition, the sections are wider, which will probably make it less difficult for the SIAR platform to navigate in this area.

The inspection in this case can be done by always exploring the gallery without going backwards, because of the inspection area is a ring. In this way, the expected inspection time is reduced. The inspection area can be divided in 4 tracks with a length of more than 100 m each. The total track has a length of more than 700m. Our estimation is that the area can be inspected in less than two hours, once the robot is deployed. The complete procedure could be finished in three hours, by adding the preparation and retrieval times that have been described in Section 3.1.

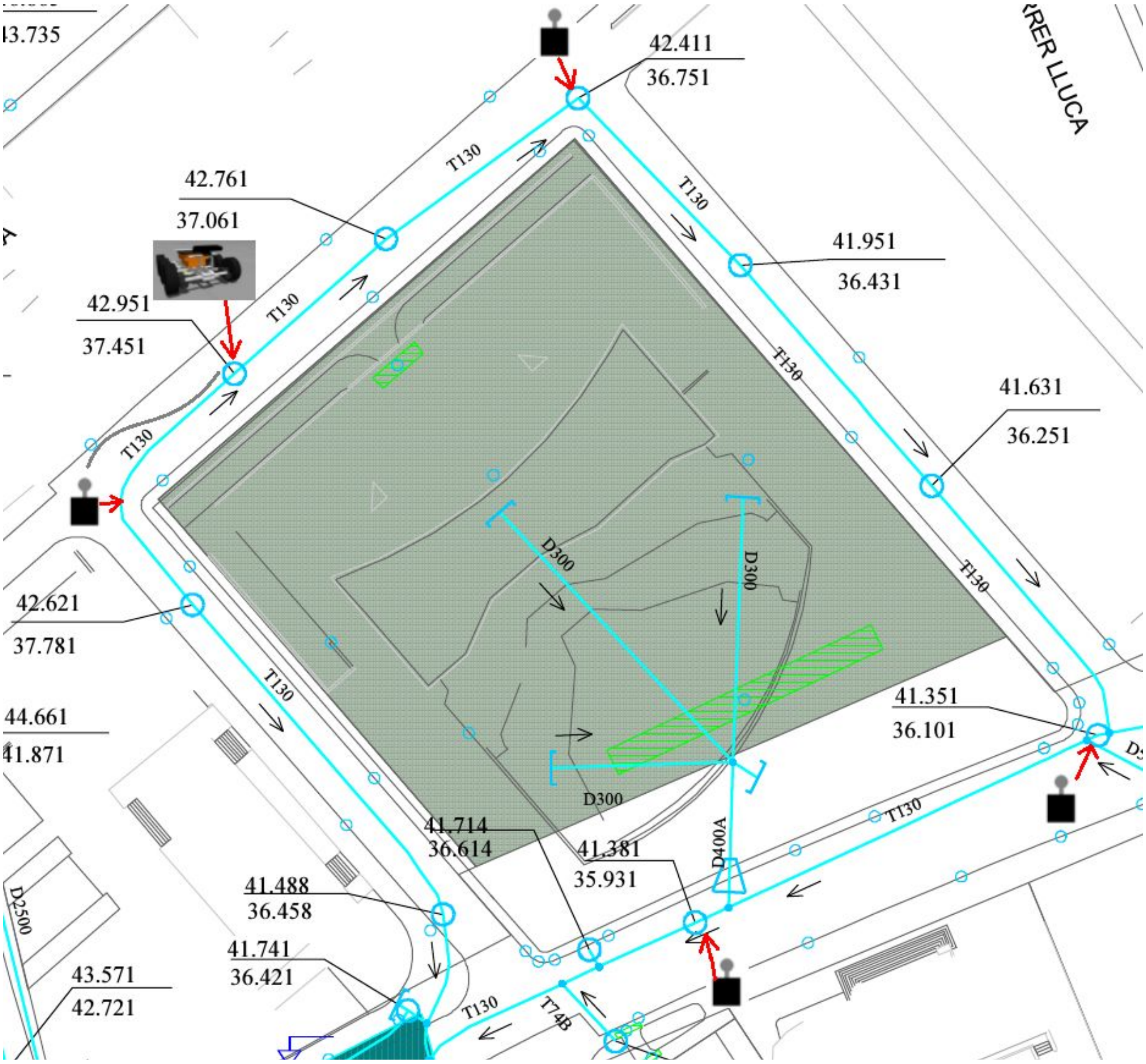

Figure 3.2: Generated inspection plan for the Sol de Baix area.

3.3 Inspection Plan in Creu de Pedralbes area

In this section we present the inspection plan to an additional area. This area was visited three times, twice with robots, during the april-june period, 2018, and was proposed by BCASA personnel following a request of our consortium to make an experiment in an environment not known *a priori,* as a preparation for the Serviceability demo of July, 2018.

Figure 3.3 represents the proposed setup for the environment of Creu de Pedralbes area. As usual, the idea is to first deploy the communication devices and then to make some connectivity tests. The repeater of the base station should be installed at the fork close to the manhole where the platform will be deployed. The other should be installed in the defined manhole.

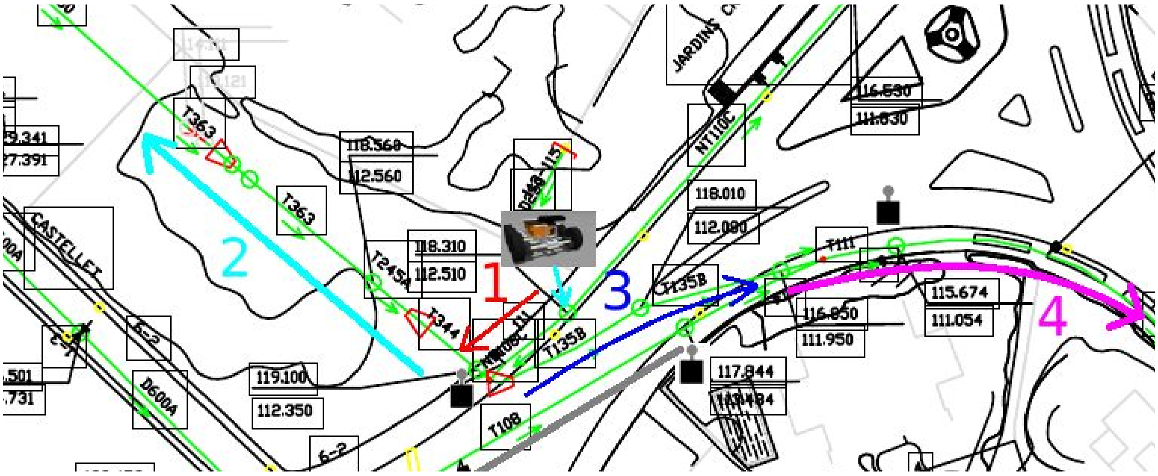

Figure 3.3: Inspection plan for Creu de Pedralbes area.

1. **Robot deployment.** The communication system of the base station and the robot are deployed through the manhole pointed by the cyan arrow (see Figure 3.3). The communication system is placed in the nearby fork. The time to deploy the robot is about 20-30 minutes.
2. **Repeater deployment.** The repeaters are disposed in the remaining manholes. The deployment time is about 10 minutes for each repeater. This time will be reduced with the new self-deployable devices.
3. **Connectivity checks.** At the base station, the operator confirms the connectivity with all the deployed repeaters. If not, further repeaters should be deployed in the surrounding manholes. The time to check the connectivity should take less than 10 minutes, as long as no further repeaters are needed.
4. **Sewer inspection.** Once the robot is deployed and the connectivity is checked, the robot is commanded to perform the inspection as planned. In this case, we divided the track into the following parts.
    a. Track 1. The section type is NT108C, the robot is commanded to proceed with minimum width (61 cm), which prevents the platform to fall inside the gutter. It has a length of about 10 m. Expected inspection time: 3 minutes.
    b. Track 2. Sections T344, T245A, T363. Length: 25m. Expected inspection time: 7 minutes.
    c. Track 3. Section T135B, maximum width: 71 cm. Length: 25 m. Expected inspection time: 7 minutes.
    d. Track 4. Section T111, commanded width: 60 cm. Length: 50 m. Expected inspection time: 15 minutes.
    e. Track 5. Section T108. Commanded width: 65 cm. Length: 50 m. Expected inspection time: 15 minutes.
5. **Robot retrieval and cleaning.** The robot should be collected from the same manhole where it was deployed. Once the robot is collected, it should be cleaned with sprayed water. In the meantime, the other operators can collect the deployed repeaters. The estimated time to perform this operation is about 30 minutes.

4. Experimental results on serviceability inspection

In recent months we performed several visits to Barcelona to meet with the end-users (BCASA) to discuss the requirements of the inspection tasks (both serviceability and structural) and to perform serviceability inspection in different scenarios. Following these meetings we implemented the previous methods and operational procedures, that were deployed in the real robot.

In the following section, we present the outcome of serviceability inspection results obtained during the demonstration carried out in the Virrei Amat Square on the 4th of July, 2018.

4.1 2018/07/04: Serviceability inspection in Virrei Amat Square

On the 4th of July, 2018, the serviceability inspection demonstration was performed in the Virrei Amat square. During the experiment, more than 400m of sewer galleries were inspected and up to 13 serviceability defects were automatically detected and localized by the platform using the method described in Section 2. As indicated in the Challenge Brief, the system automatically raises alarms so that the operator can confirm them by inspecting further the data provided by the robot. This can be done online (as during this inspection), but also offline by processing the data recorded by the robot.

It is worth to mention that the proposed algorithm for automatic serviceability assessment has a number of parameters that are adjustable by the operator to favor a more sensitive detection (which can generate more false alarms) or a more conservative detection (with less false alarms). These parameters were adjusted to a sensitive case for this inspection.

Besides this, the algorithm is still under development, and currently the algorithm assumes that the galleries follow a straight line. Therefore, it may raise false alarms when the gallery is curved. We are developing an extension of the algorithm to generalize it to curved galleries, but it was not available for the demo. Therefore, in the current version, the algorithm should be deactivated whenever traversing curved galleries to reduce the false alarms.

Figure 4.1 represents the raw report as generated by our detection algorithm. Note that the number of defects is 26 instead of 13. The explanation is simple: our detection algorithm currently raises one alarm whenever a serviceability loss is detected and another when the serviceability goes back to normality.

As a summary, our algorithm detected two main zones where there are very noticeable defects where human intervention would be needed for cleaning purposes. The first zone corresponds to Serviceability defects from 6 to 9 (see Figure 4.1) that were found in the second inspected section (see Figure 3.1). Then, other defects were found at the end of section 4. In these cases the serviceability was reduced in a great extent or even there were accumulated dirt that prevented the water to flow in these areas. The other defects were punctual or were due to false alerts. As a last remark, please note that all the alarms generated by our module are listed here with no exception. In the process, only four false alarms were generated in a track of more than 400m. Therefore, our algorithm can be used as an aid to the operator as was requested in [Echord++, 2014]. For each alert, a video can be found. Please refer to Appendix I for more details on the available multimedia data.

Figure 4.1: Automatically generated serviceability report for Virrei Amat area. The yellow spots show the location of the manholes. The red spots indicate the generated alerts.

We will now detail the contents of each alert. For each alert we provide the GPS coordinates, time, distance to the closest manhole and code of such manhole for both, the beginning and the end of the potential problem.

4.1.1 Alert 1: Serviceability defects 0 and 1

Figure 4.2 represents a snapshot of the defects related to Alert 1. In this case, minor defects can be found: two little stones in the gutter and some defects in the rightmost curb. This is most probably a false alarm.

Begins:

Approximate Location: 41.4296813316248º N, 2.17636363515367º E

Distance to closest manhole: 13.5 m. Closest manhole: MH 30.

Local Time: Wednesday, 4 July 2018 9:57:28

Ends:

Approximate Location: 41.4297028120515º N, 2.1763668305947º E

Distance to closest manhole: 11.3 m. Closest manhole: MH 30.

Local Time: Wednesday, 4 July 2018 9:57:48

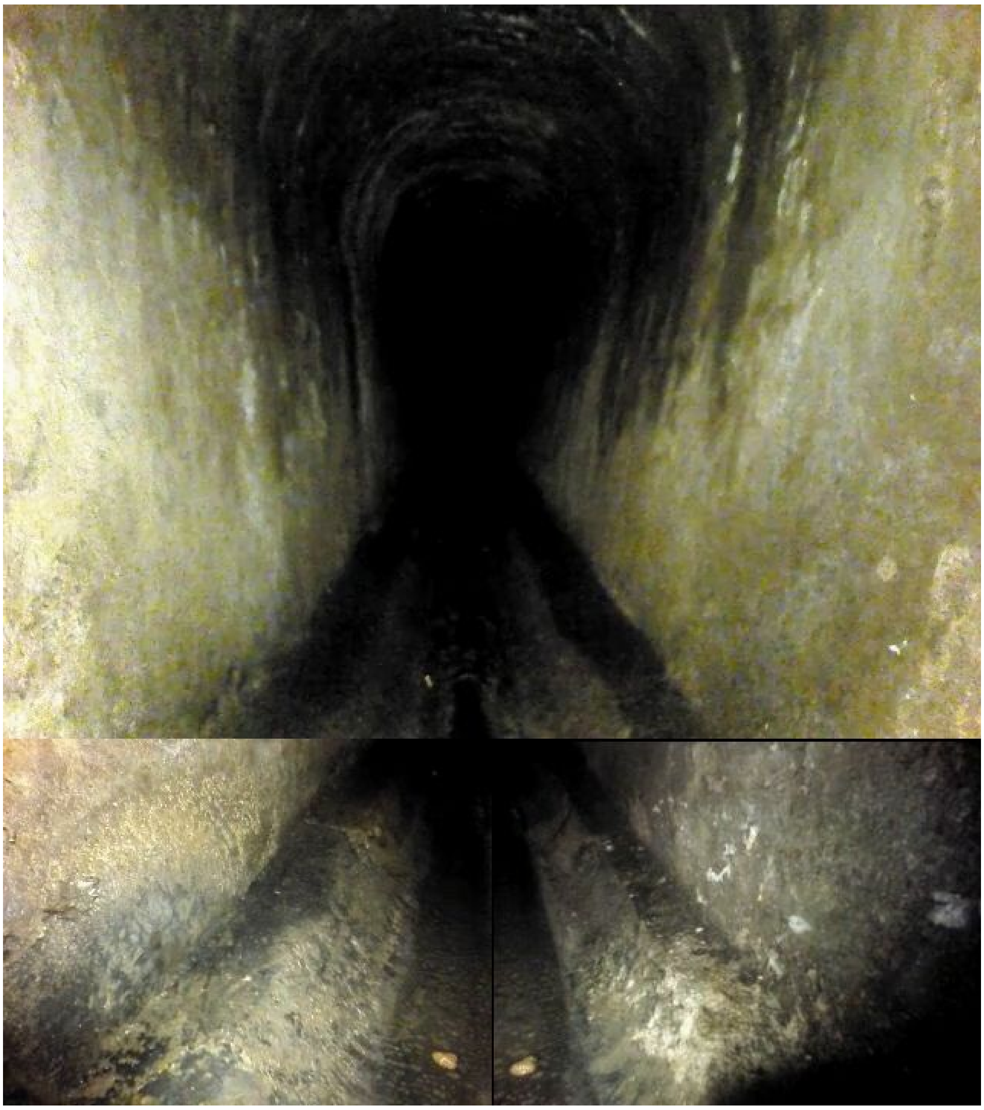

Figure 4.2: Composed snapshot of three frontal cameras in Alert 1. Two small stones on the gutter and defects in the rightmost curb can be found.

4.1.2 Alert 2: Serviceability defects 2 and 3

Figure 4.3 represents a snapshot of the defects related to Alert 2. In this case there are noticeable sediments on the gutter and in the leftmost curb.

Begins:

Approximate Location: 41.429958926848º N, 2.17637205319557º E

Distance to closest manhole: 17.2 m. Closest manhole: MH 30.

Local Time: Wednesday, 4 July 2018 10:03:07

Ends:

Approximate Location: 41.4299643553128º N, 2.17637281140011º E

Distance to closest manhole: 17.6 m. Closest manhole: MH 30.

Local Time: Wednesday, 4 July 2018 10:03:12

Figure 4.3: Composed snapshot of three frontal cameras in Alert 2.

4.1.3 Alert 3: Serviceability defects 4 and 5

Figure 4.4 represents a snapshot of the defects related to Alert 3. In this case, minor sediments can be found in the gutter. The defects seem not to be enough to compromise the serviceability of the gutter. This can be considered as a false alarm.

Begins:

Approximate Location: 41.4301522399199º N, 2.17638514914928º E

Distance to closest manhole: 17.62 m. Closest manhole: MH 29.

Local Time: Wednesday, 4 July 2018 10:05:49

Ends:

Approximate Location: 41.4301528232937º N, 2.17638529289864º E

Distance to closest manhole: 17.52 m. Closest manhole: MH 29.

Local Time: Wednesday, 4 July 2018 10:05:54

Figure 4.4: Composed snapshot of three frontal cameras in Alert 3.

4.1.4. Alert 4: Serviceability defects 6 and 7.

Figure 4.5 represents a snapshot of the defects related to Alert 4. In this case, sediments are accumulated in the gutter and prevent the water from flowing.

Begins:

Approximate Location: 41.4293970987477º N, 2.17634594066756º E

Distance to closest manhole: 10.5 m. Closest manhole: MH 31.

Local Time: Wednesday, 4 July 2018 10:32:44

Ends:

Approximate Location: 41.429392140929º N, 2.17634534044302º E

Distance to closest manhole: 10.8 m. Closest manhole: MH 31.

Local Time: Wednesday, 4 July 2018 10:32:48

Figure 4.5: Composed snapshot of three rear cameras in Alert 4.

4.1.5. Alert 5: Serviceability defects 8 and 9.

Figure 4.6 represents a snapshot of the defects related to Alert 5. In this case, sediments are accumulated in the gutter and prevent the water from flowing. The accumulated water at the end of the serviceability defect can be found in the video (see Appendix I). This alarm is quite close to Alarm 4 and they can be considered as the same problem.

Begins:

Approximate Location: 41.4293735996281º N, 2.17634463508326º E

Distance to closest manhole: 12.8 m. Closest manhole: MH 31.

Local Time: Wednesday, 4 July 2018 10:33:02

Ends:

Approximate Location: 41.4293330666559º N, 2.176344141824º E

Distance to closest manhole: 16.7 m. Closest manhole: MH 31.

Local Time: Wednesday, 4 July 2018 10:33:22

Figure 4.6: Composed snapshot of three rear cameras in Alert 5.

4.1.6. Alert 6: Serviceability defects 10 and 11.

Figure 4.7 represents a snapshot of the defects related to Alert 6. Some minor defects can be found in the gutter and both curbs.

Begins:

Approximate Location: 41.429501709881º N, 2.17650713824641º E

Distance to closest manhole: 11.0 m. Closest manhole: MH 31.

Local Time: Wednesday, 4 July 2018 10:59:17

Ends:

Approximate Location: 41.4295018072204º N, 2.17651488048804º E

Distance to closest manhole: 11.6 m. Closest manhole: MH 31.

Local Time: Wednesday, 4 July 2018 10:59:22

Figure 4.7: Composed snapshot of three rear cameras in Alert 6.

4.1.7 Alert 7: Serviceability defects 12 and 13.

Figure 4.8 represents a snapshot of the defects related to Alert 7. In this case, it is clearly a false alarm that was raised because of the presence of a curved gallery, as the current detector assumes a straight gallery.

Begins:

Approximate Location: 41.4295015786844º N, 2.17714225693918º E

Distance to closest manhole: 5.2 m. Closest manhole: MH 69.

Local Time: Wednesday, 4 July 2018 11:04:03

Ends:

Approximate Location: 41.4295015786844º N, 2.17714225693918º E

Distance to closest manhole: 5.2 m. Closest manhole: MH 69.

Local Time: Wednesday, 4 July 2018 11:04:15

Figure 4.8: Composed snapshot of three frontal cameras in Alert 7.

4.1.8 Alert 8: Serviceability defects 14 and 15.

Figure 4.9 represents a snapshot of the defects related to Alert 8. In this case, a reduction of the serviceability can be found at the gutter.

Begins:

Approximate Location: 41.4295272581086º N, 2.17541256490674º E

Distance to closest manhole: 3.1 m. Closest manhole: MH 15.

Local Time: Wednesday, 4 July 2018 11:15:21

Ends:

Approximate Location: 41.4295263437485º N, 2.17542350186291º E

Distance to closest manhole: 3.1m. Closest manhole: MH 15.

Local Time: Wednesday, 4 July 2018 11:15:41

Figure 4.9: Composed snapshot of three frontal cameras in Alert 8.

4.1.9 Alert 9: Serviceability defects 16 and 17.

Figure 4.10 represents a snapshot of the defects related to Alert 9. This alert relates to the same problem as Alert 8.

Begins:

Approximate Location: 41.4295262118865º N, 2.1754122053897º E

Distance to closest manhole: 3.2 m. Closest manhole: MH 15.

Local Time: Wednesday, 4 July 2018 11:16:00

Ends:

Approximate Location: 41.429525911519º N, 2.1754118872776º E

Distance to closest manhole: 3.3 m. Closest manhole: MH 15.

Local Time: Wednesday, 4 July 2018 11:17:20

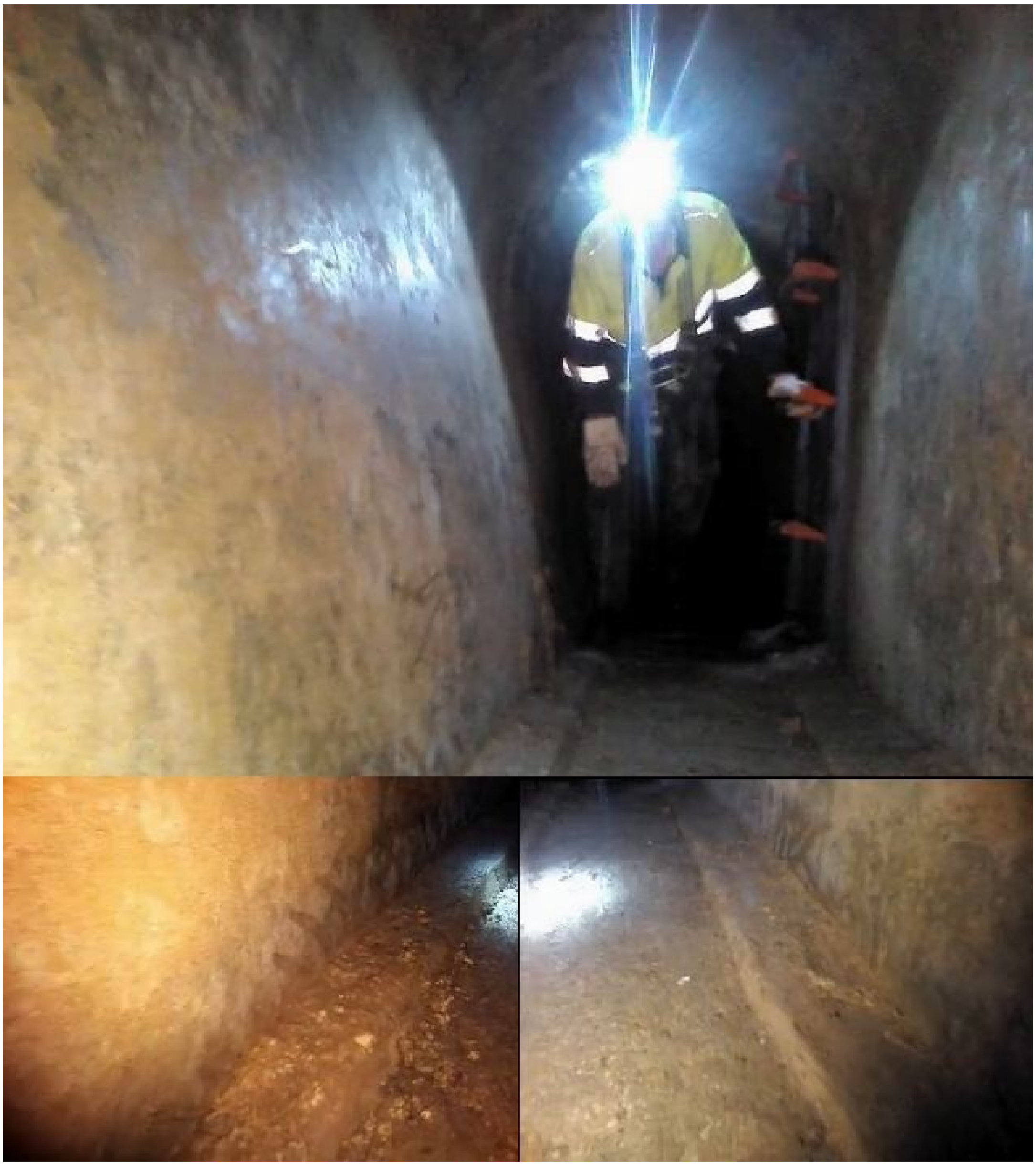

Figure 4.10: Composed snapshot of three frontal cameras in Alert 9.

4.1.10 Alert 10: Serviceability defects 19 and 20.

Figure 4.11 represents a snapshot of the defects related to Alert 10. In this case a noticeable sediment over the rightmost curb can be found. Also, some sediments can be detected at the gutter.

Begins:

Approximate Location: 41.4292350362057º N, 2.17547497772877º E

Distance to closest manhole: 1.0 m. Closest manhole: MH 35.

Local Time: Wednesday, 4 July 2018 11:53:32

Ends:

Approximate Location: 41.4292333432361º N, 2.17547687095216º E

Distance to closest manhole: 1.5 m. Closest manhole: MH 35.

Local Time: Wednesday, 4 July 2018 11:54:04

Figure 4.11: Composed snapshot of three frontal cameras in Alert 10.

4.1.11 Alert 11: Serviceability defects 21 and 22.

Figure 4.12 represents a snapshot of the defects related to Alert 11. This alert is the same as Alert 10, but seen in another point of view (with the rear cameras). Therefore, they can be merged together.

Begins:

Approximate Location: 41.4292087645207º N, 2.175506324146º E

Distance to closest manhole: 5.3 m. Closest manhole: MH 35.

Local Time: Wednesday, 4 July 2018 11:56:21

Ends:

Approximate Location: 41.4290971683706º N, 2.175629689723º E

Distance to closest manhole: 9.4 m. Closest manhole: MH 37.

Local Time:Wednesday, 4 July 2018 11:58:07

Figure 4.12: Composed snapshot of three rear cameras in Alert 11.

4.1.12 Alert 12: Serviceability defects 23 and 24.

Figure 4.13 represents a snapshot of the defects related to Alert 12. Some minor sediments can be found in the gutter.

Begins:

Approximate Location: 41.4290243774084º N, 2.17567339421793º E

Distance to closest manhole: 3.5 m. Closest manhole: MH 37.

Local Time: Wednesday, 4 July 2018 12:01:31

Ends:

Approximate Location: 41.4290243420483, 2.17567338852683º E

Distance to closest manhole: 3.5 m. Closest manhole: MH 37.

Local Time: Wednesday, 4 July 2018 12:01:38

Figure 4.13: Composed snapshot of three frontal cameras in Alert 12.

4.1.13 Alert 13: Serviceability defects 25 and 26.

Figure 4.14 represents a snapshot of the defects related to Alert 13. A medium sized stone can be found in the rightmost curb. However, this is most probably a false alarm.

Begins:

Approximate Location: 41.4289540074062º N, 2.17570635021486º E

Distance to closest manhole: 8.8 m. Closest manhole: MH 37.

Local Time: Wednesday, 4 July 2018 12:03:19

Ends:

Approximate Location: 41.4289296464584º N, 2.17572062885186º E

Distance to closest manhole: 11.7 m. Closest manhole: MH 37.

Local Time: Wednesday, 4 July 2018 12:04:12

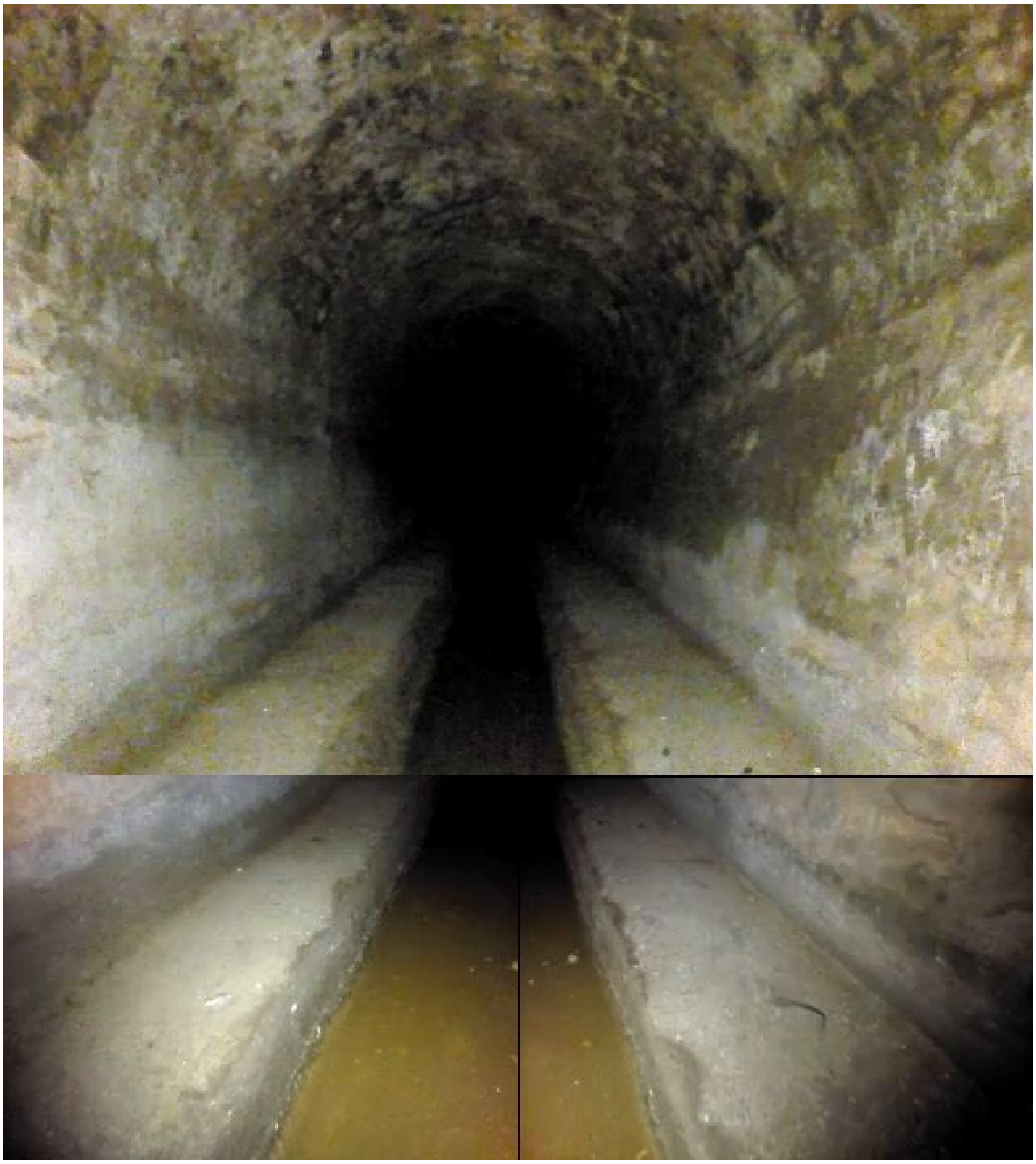

Figure 4.14: Composed snapshot of three frontal cameras in Alert 13.

5. Other advances

5.1 Gas Sensors

The GAS sensors of Figure 5.1 have been integrated into the SIAR systems and first results have been obtained in field experiments.

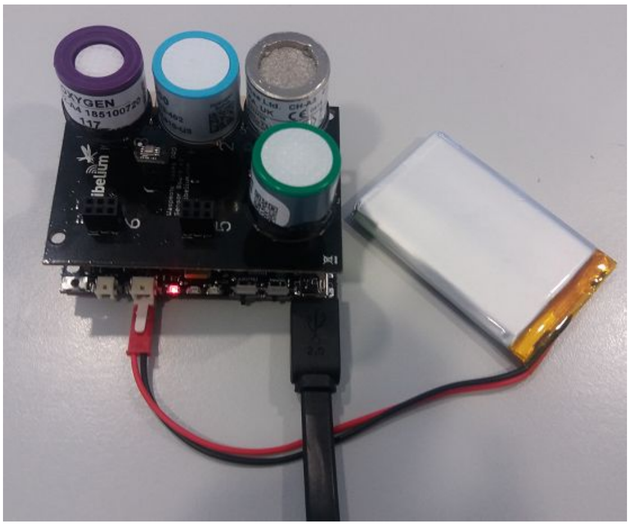

Figure 5.1: Waspmote Pro OEM gas system

The sensor can measure the following gases:

- Molecular Oxygen (O_2) Gas Sensor [Calibrated]. It will provide the percentage of oxygen on the environment with an accuracy as good as ±0.1% (ideal conditions). It will give an alarm if the percentage drops under 19.5% or if it rises above 23.5%.
- Carbon Monoxide (CO) Gas Sensor for High concentrations [Calibrated]. It will provide the ppm of the CO concentration with an accuracy as good as ±1 ppm (ideal conditions). It will give an alarm if the ppm are above 50 ppm.
- Hydrogen Sulfide (H_2S) Gas Sensors [Calibrated]. It will provide the ppm of H_2S concentration with an accuracy as good as ±0.1 ppm (ideal conditions). It will give an alarm if the ppm are above 5ppm.
- Methane (CH_4) and Combustible gases sensor [Calibrated]. It will provide a measure of LEL methane percentage with an accuracy as good as ±0.15% LEL (ideal conditions). It will give an alarm if the percentage is above 50%.

The system also includes temperature (ºC), humidity (% RH) and pressure (Pa) sensors that will be used to increase the accuracy of the gas sensors. Figure 5.2 shows a datalogin from the sensors. In addition to the gas sensors information previously described, it is also possible to determine the inclination of the board, using an 3-axis accelerometer, the voltage and power level of the battery.

```
+++++++++++++++++++++++++++++++++
Acceleration X: -16 | X angle: -0.9167715072
Acceleration Y: -87 | Y angle: -4.9910416603
Acceleration Z: 1000 | Z angle: 90.0000000000
Battery Level: 85 % | Battery (Volts): 4.0840001106 V
Gas O2 concentration: 20.7667961120 Vol. % - O2 Alarm: OFF
Gas H2S concentration: 0.5267459869 ppm - H2S Alarm: OFF
Gas CO concentration: 0.4259382247 ppm -  CO Alarm: OFF
Gas CH4 concentration: 0.0000000000 % LEL - CH4 Alarm: OFF
Temperature: 25.8799991607 Celsius degrees
RH: 47.8994140625 %
Pressure: 99022.8593750000 Pa
***************************************
```

Figure 5.2: SIAR gas sensors datalogin example

Figure 5.3 depicts some plots of the gas sensors obtained by the robot at the sewers of Virrei Amat Square in Barcelona. They were obtained during the Serviceability demo on July 4, 2018. The values of the concentrations of the different gases, humidity and pressure are presented as a function of the location of the robot. The values were obtained when the SIAR robot inspected the Track 1 of the Virrei Amat area.

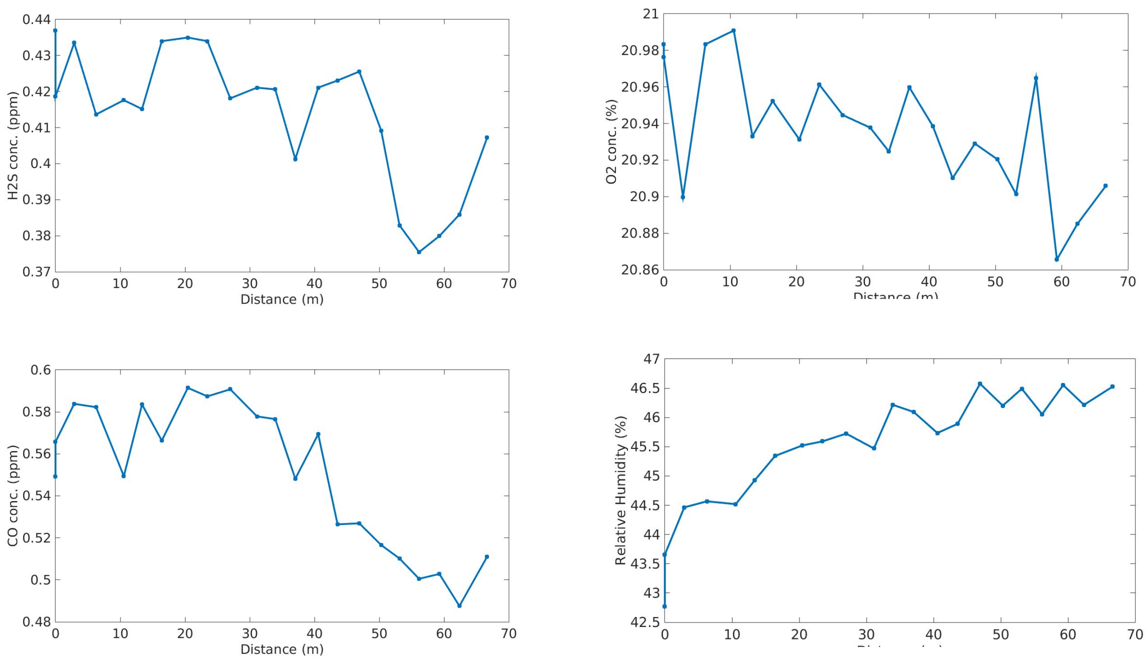

Figura 5.3: From left to right and up to down, concentrations of H_2S, O_2, CO and relative humidity as functions of the traveled distance in Track 1 of Virrei Amat area.

5.2 GUI development

During Phase III we are developing and experimentally testing a new teleoperation GUI. This GUI has been designed according to the specifications obtained during the visit of the 12th of April, 2018 and during the Serviceability Demonstration. Currently the Base Station is able to provide to the user, in real time, information related with the Serviceability Analysis module (see Section 2). Moreover, the operator has the option of hiding or showing some outputs of the module as desired. Also, the operator has now the information of the three front cameras available, which was requested to confirm the alerts obtained by the Serviceability Analysis module.

In the remaining period of Phase III the GUI will be exhaustively tested in the field experiments by BCASA personnel. This experience will allow to fine-tune the GUI and adapt it to the needs of the operators.

The current version of the GUI includes the following features:

- All the functionalities are now compiled into a standalone application which has been designed to be user friendly.
- Two different modes of operation: exploration; and mission execution & planning
  - The exploration mode has a new design that allows the operator to have localization, real-time images, depth information and SIAR prioceptive information at the same time (see Figure 5.4).
  - In the mission execution mode the operator can easily get information about the alerts found during the experiment (see Figure 5.5).
- In addition, the content of the GUI is customizable by the user and new modes can be saved to further adapt to the needs of each operator.

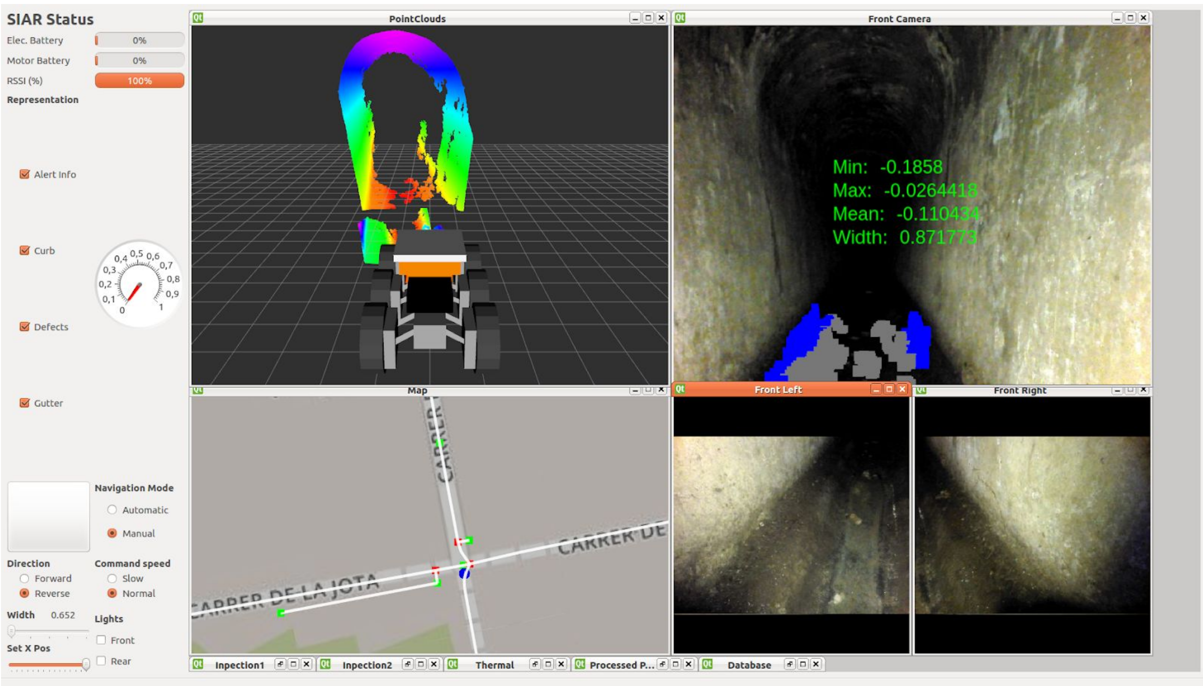

Figure 5.4: Exploration view of the developed base station.

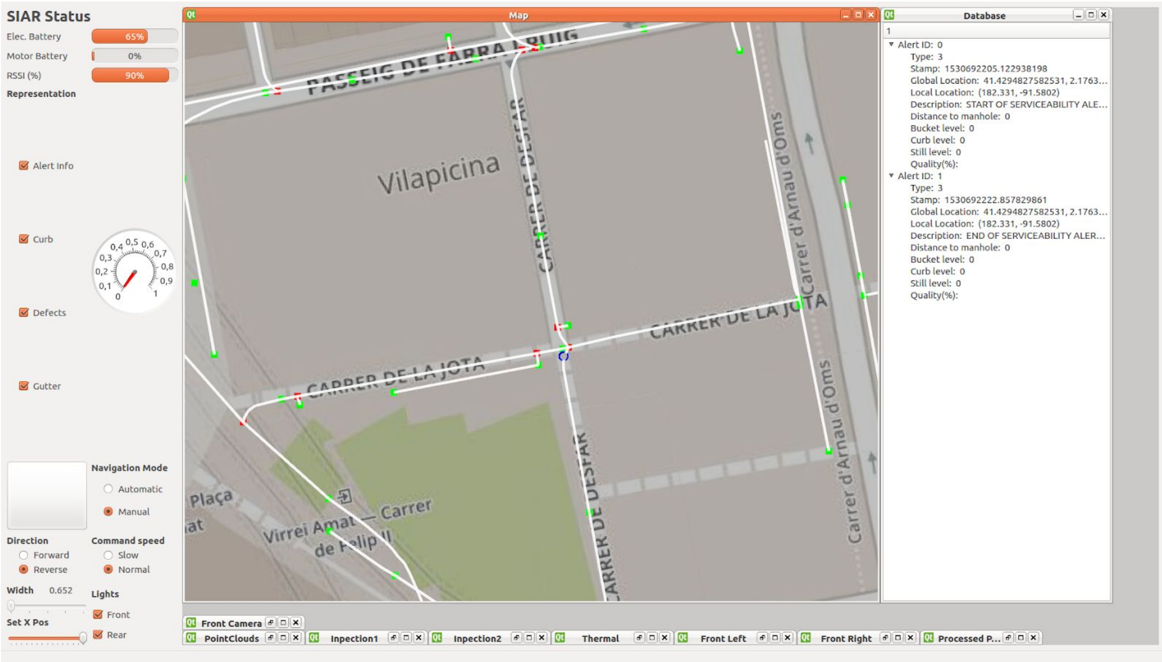

Figure 5.5: Mission execution view of the developed base station.

6. Conclusions

This document presented the serviceability analysis tools developed by the SIAR team. These tools permanently analyze the gutter and the curb searching for elements that might compromise the correct flow of water. This detection is performed online, and the resulting detections are shown to the operator immediately, which allows to allocate more resources to validate the defect or just gathering more information of interest.

The document also showed the results of the serviceability tests performed in Barcelona on July 2018. The experiments have shown that, while there is still some room for improvement, the proposed methods are accurate enough and with relatively small number of false alarms. Detailed information about each detection is presented in the document: closest manhole to the defect, time of the detection and images.

This deliverable also presented some advances made in the integration of the gas sensing suit and the ground control station. They were also tested online during the experiments of July 2018.

Next months will be devoted to finish and improve the integration of the different tools developed for sewer inspection in Phase III. Additionally, the new robot hardware frame will be tested and integrated into the SIAR software framework. Several experiments will be performed in Barcelona to evaluate the improvements in robot navigation, the new robot hardware frame and its new components, and the new repeater system.

References

[Alejo et al, 2017] David Alejo, Fernando Caballero, and Luis Merino. RGBD-based Robot Localization in Sewer Networks. In Proc. of IEEE/RSJ International Conference on Intelligent Robots and Systems, IROS, pp. 4070–4076, 2017.

[Besl and McKay, 1992] P. J. Besl and N. D. McKay, "A method for registration of 3-D shapes," in *IEEE Transactions on Pattern Analysis and Machine Intelligence*, vol. 14, no. 2, pp. 239-256, Feb. 1992. doi: 10.1109/34.121791

[ECHORD++, 2014] ECHORD++. "Utility infrastructures and condition monitoring for sewer network. Robots for the inspection and the clearance of the sewer network in cities", Internal Report, 2014

Appendix I: Video files attached to this report

Next lines list a set of videos attached to this report. They are videos of the cameras mounted in the robot during the serviceability tests carried out in July 2018:

- alert_1.mp4: Video containing the visual images of the robot camera for the Alert number 1.
- alert_2.mp4: Video containing the visual images of the robot camera for the Alert number 2.
- alert_3.mp4: Video containing the visual images of the robot camera for the Alert number 3.
- alert_4.mp4: Video containing the visual images of the robot camera for the Alert number 4.
- alert_5.mp4: Video containing the visual images of the robot camera for the Alert number 5.
- alert_6.mp4: Video containing the visual images of the robot camera for the Alert number 6.
- alert_7.mp4: Video containing the visual images of the robot camera for the Alert number 7.
- alert_8.mp4: Video containing the visual images of the robot camera for the Alert number 8.
- alert_9.mp4: Video containing the visual images of the robot camera for the Alert number 9.
- alert_10.mp4: Video containing the visual images of the robot camera for the Alert number 10.
- alert_11.mp4: Video containing the visual images of the robot camera for the Alert number 11.
- alert_12.mp4: Video containing the visual images of the robot camera for the Alert number 12.
- alert_13.mp4: Video containing the visual images of the robot camera for the Alert number 13.