Publishable summary

1.1 Summary description of project context and objectives

ROBO-SPECT concept is steaming from the latest developments in robotics, advanced fields of computer vision and sensors that have opened the floor for automated robotic solutions, exploitable in the near to medium term in the field of inspection of the civil infrastructure in general and transportation tunnel infrastructure. Tunnel infrastructure is ageing urgently requiring inspection and assessment while nowadays inspection is mostly performed through tunnel wide visual observations by inspectors. This process is slow, labour intensive, expensive, subjective and often requiring lane shutdown during inspection at a time of limited budgets and inspector resources and heightened requirements for safety and maximum tunnel uptime.

ROBO-SPECT, adapts and integrates recent research results in intelligent control in robotics, computer vision (tailored with semi-supervised and active continuous learning and sensing) in an innovative, integrated, robotic system that automatically scans the intrados for potential defects on the surface and detects and measures radial deformation in the cross-section, distance between parallel cracks, cracks and open joints that impact tunnel stability, with mm accuracies. This permits, in one pass, both the inspection and structural assessment of tunnels. Intelligent control and robotics tools are interwoven to set an automatic robotic arm manipulation and an autonomous vehicle navigation so as to minimize humans' interaction. This way, the structural condition and safety of a tunnel is assessed automatically, reliably and speedily.

The robotic solution currently being developed consists of a robotic vehicle equipped with a large crane (able to reach high tunnel diameters and move in rail or road ground) and a robotic manipulator at its end with high moving accuracy. This crane is further equipped with a high resolution multi-view camera system able to detect tunnel anomalies (corrosion, delamination, calcium leakages, opening joints and other surface defects that could affect the tunnel structural integrity) and direct the robotic arm towards the defects to take more precise measurements using ultrasonic fiber-optic sensors with accuracies of up to 0.1mm. The results of the measurements are fed into a structural assessment tool that calculates the internal forces and external loads applied on every point of the lining cross-section and the local and global safety factor at the time of the inspection, the structural reliability and probability of local or global failure at the lining cross-section at the time of the inspection, the evolution of material damage assessed by algorithms corrected with inspection results and finally the probability of structural failure in the future.

Actual data sets and real tunnels will be used for training data collection as well as the final system validation and benchmarking. The consortium includes (or is associated to) major operators in the fields of tunnels such as the London Underground (UK), Parisian Metro (France), infrastructure of tunnels of VSH (Switzerland), and three road tunnels of the Egnatia Motorway (Greece

1.2 Description of the work performed since the beginning of the project and main results achieved so far

The work in ROBO-SPECT started with an analysis of the state of the art and technological benchmarking of the existing technologies and methodologies for tunnel structural inspection and assessment in order to direct and adapt the ROBO-SPECT solution (WP1). At the same time the project end-users defined ten separate scenarios that the project will be validated (and benchmarked) during the related stage towards the end of the project. The end-user requirements were also extracted via interviews and questionnaires collection from the end-users but also several iterations in order to comply with the robotics nature of the project as well as it contractual obligations. The identification of standards, best practises and recommendations followed concluding all the above work (tasks1.1-1.4) to the deliverable D1.1. The tasks 1.5 and 1.6 focused on the analysis of the extracted and consolidated end-user requirements as well as available methodologies and resulted into the deliverable D1.2 that includes the final system software and hardware specifications. The creation of an external user group ensured and aimed the requirements validation. What followed the WP1 requirements and specifications activities was the initiation of the actual technical WPs focusing on the technical project developments.

The work in **WP2** included the design of the first prototype to be assembled including the intelligent global controller of the robot. The WP2 work for the period concluded with the completion of the low level drivers of the robotic arm the laboratory tests to evaluate the basic capabilities of the robotic arm. This work was reported in D2.1.1 – "Extended Length Mobile Robotic System Prototype for Tunnel Inspection" that includes all details regarding the different components, the inspection procedure and the modes of operation.

WP3 work focuses on the application of the computer vision algorithms in detecting cracks and surface deterioration from the tunnels internal surface. WP3 started with the definition of the training set to be used for the machine learning detection algorithms and the type of data needed for the annotation process and their relative data collection (initial set), annotation and categorisation of real world images from tunnels in Greece (Malakassi & Metsovo). This task was completed simulating the real-world process and conditions that will be encountered by the robotic system at real tunnels. A set of local visual descriptors for tunnel inspection purposes in conjunction with an initial set of machine learning algorithms for visual detection of tunnel artifacts have been developed and evaluated on the available set of tunnel images. Deliverable 3.1 ("Initial algorithms for detecting tunnels cracks and other defects through the use of Visual Descriptors") has been submitted including information on the initial set of visual detection algorithms for tunnel defects.

WP4 activities have also progressed following the project schedule of the measuring devices design and implementation. The design of the fiber-optic ultrasonic sensor has concluded and this has led to the fabrication of the first prototypes development. System assembly, prototype testing and specifications of the final prototypes have also been executed and reported in deliverable D4.1.1 (Prototype of sensor system suited for measuring the width and depth of cracks tested in the laboratory). The report contains details on the first-generation prototype of ROBINSPECT sensor system for the measurement of crack width and depth on tunnel lining, assembled in laboratory environment for early tests. In the system, both commercial piezo-ceramic sensors and custom fiber-optic sensors for ultrasounds have been utilized.

Structural Assessment activities have also started following the structure of **WP5**. The activities have started from the task on Deterministic, Time-Dependent, Materials' Degradation of the Tunnel Lining that has developed the relevant methodology as described in deliverable D5.1.1. At the same time the studies on deterministic assessment of the structural condition and safety of the tunnel lining (during inspection) focused on the methodology development based on which the structural condition of the concrete lining, in cast-in-place and segmental tunnels, locally and globally, can be assessed exclusively based on measurements from the tunnel intrados. The methodology on the prediction of the probabilistic, time-dependent, structural condition has also has been devised aiding the assessment of the future, probabilistic, structural condition of the lining, both locally and globally. The development of the structural assessment tool (SAT) has started with the definitions of the data flows and integration matters between the robotic system and itself.

WP7 preliminary activities started during the last months of the reporting period (year 1) actually activating the WP activities earlier. This was done in order to have a better input to WP2-WP5 on the field tests where the validation will take place. For the moment only the particular case of EOAE tunnels has been investigated whereas the other sites will be investigated in the next period.

Dissemination and exploitation activities have been running in the framework of **WP8** and following the project schedule. A large number of public articles has been disseminated. A special session for ROBO-SPECT has been arranged at the forthcoming WTC 2015 conference (22-28 May 2015). ROBO-SPECT has been presented through research publications into two conferences (2014 IEEE International Symposium on Robotic and Sensor Environments and ISARC 2014 International Symposium on Automatics and Robotics in Construction). The project website has been developed and associated with the project twitter and linkedin tools that have also been activated. A group of external experts has been established to communicate with similar project participants and the two period WP8 deliverables (8.1,8.2) have been submitted including the documentation of the project website and dissemination plan (incl. use of foreground (draft)).

Consortium management activities (**WP9**) have ensured the smooth project execution in management, financial and technical levels through the active involvement of the project coordinator, financial manager, technical manager and quality manager. The project plenary meetings have been organised together with the project steering committee meetings whenever required. Reporting/administrative processes have been precisely followed by the coordinator.

1.3 Expected final results and their potential impact and use (including socio-economic impact and wider societal implications of the project so far)

ROBO-SPECT Expected Final Results	Socio-Economic Impact / Societal implications
1. An automated intelligent robotic system for inspection and structural assessment of transportation tunnels	○ Stimulation of innovation in robotics in the EU ○ Quicker and more enhanced visual inspection of tunnels with reduced tunnels' down-time ○ Reduced costs for tunnels' inspection ○ Safer operation of transportation tunnels with reduced and more targeted inspections ○ Improved conditions for tunnel assessment ○ Increased competitiveness of tunnel inspection industry by speedy and reliable inspections ○ Increased passengers' safety via safer tunnels
2. A computer vision system for tunnel inspection and assessment of the structural condition able to detect structural defects	○ Extended state-of-the-art computer vision schemes for extraction of reliable, robust and precise 3D measurements in tunnels ○ Applied recent advances in active continuous learning to tunnel inspection mechanisms ○ Incorporated recent SoA on semi-supervised learning schemes towards tunnel anomalies

3. Methodologies for visual data collection	○ Enhanced methodologies towards the computer vision society ○ Non-intrusive and quick structural assessment methodologies for tunnel inspection
4. Extended 3D reconstruction tools able to detect tunnel's cracks	○ Precise defects detection in tunnels imposing quicker tunnel assessment and safer tunnels ○ More reliable and speedy tunnel inspection
5. A new tunnel evaluation framework to extract local knowledge, being able to incorporate social knowledge from other civil engineers, process data from diverse sources, compensate erroneous decisions, improve control mechanisms for robots	○ Assessment of tunnels' structural condition and stability with reduced costs ○ Aided tunnel managers' decision on intervention strategy also reducing costs ○ Reduced evaluation time and more efficient maintenance planning ○ More reliable and speedy tunnel evaluation
6. A sensor system embeddable to the robotic system described in (1) measuring crack widths and depths or joint openings (0.1mm)	○ More precise, quicker and cheaper tunnel cracks detection and classification
7. A quantitative structural assessment tool that based on the robotic system input will automatically assess the structural condition and stability of tunnels	○ Assessment of tunnels' structural condition and stability ○ Aided tunnel managers' decision on intervention strategy
8. A tested, validated and benchmarked system including the above	○ Accelerate transition of scientific/technical research results into proof of concept exploitable technology, prototypes and IPRs ○ Closer to the market research output

1.4 ROBO-SPECT public websites and info points

In the framework of operation of ROBO-SPECT, a public website and various social groups have been created including linkedin and twitter tools. Project dissemination through internet is considered as a means that can increase the project impact as well as serve as a valuable tool to communicate project results and outputs towards the relevant audiences.

- Project website: www.robo-spect.eu,
- LinkedIn Tool: link
- Twitter Tool: link

1.5 The ROBO-SPECT Consortium and Contact Details

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