ROBO-SPECT

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Plan for the use of the foreground (Final)

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ABBREVIATION	DESCRIPTION
GCS	Ground Control Station
IAARC	International Association for Automation and Robotics in Construction
IST	Information Society Technologies
ITA	International Tunnelling and underground Association
SWOT	Strengths Weaknesses Opportunity Threats
TRL	Technology Readiness Level

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1. EXECUTIVE SUMMARY

This document is the Final Exploitation Plan within the ROBO-SPECT project as an outcome of the WP8 activities and in continuation of the previous deliverable D8.2.

The exploitation plan describes the approach defined by the consortium to exploit the results of the project. It comprises the following sections:

- Business case, first in the core domain of ROBO-SPECT and then in adjacent domains;
- Identification of the foreground, both at consortium level and at partner level;
- Roadmap towards industrialisation;
- Business models;
- Exploitation strategy, both at consortium level and at partners levels.

2. INTRODUCTION

The report is the final plan for the use of foreground as defined during the project execution. This document, was updated during the project duration based on the exploitation plan that was defined during the project first stages. The overall technology readiness level (TRL) of ROBO-SPECT system at the end of the project can be defined 5 to 6.

The exploitation plan (plan for the use of the foreground) of ROBO-SPECT describes the approach defined by the consortium to exploit the results of the project. The final exploitation plan is structured in the following way:

- Business case, first in the core domain of ROBO-SPECT and then in adjacent domains;
- Identification of the foreground, both at consortium level and at partner level;
- Roadmap towards industrialisation;
- Business models;
- Exploitation strategy, both at consortium level and at partners levels.

2.1 Introduction

The technology readiness level (TRL) of ROBO-SPECT system at the end of the project was initially around 6, at system level. This meant that the industrialisation effort to reach a product should not have been so huge. However, the feed-backs from the development and integration phases allowed a better vision of the detailed maturity levels at component level. In addition, the real modularity and customisation capabilities have been proposed by the end-users and assessed technically. In particular, the robot itself needs to correspond to the end-users requirements and constraints and is not likely to be the same for road tunnels inspection where the height is 11 m than in metro tunnels where the height is less than 3 m. The robot platform is off the shelf, but the installation of ROBO-SPECT system needs a substantial effort of adaptation to each platform. Also, the navigation in the tunnel will depend on the type of traffic, road, track, channel, which will necessitate different undercarriages.

The system cannot fully be a turnkey system as the performances will highly depend on the type of tunnel and the environmental conditions, in particular the texture and the lighting conditions. In addition, in many tunnel cases the walls are seldom naked and some parts may be covered with cables, cabinets, displays, panels, etc. So the system has to be set-up with an important volume of initial data (to generate a state zero) and calibrated (to reduce the number or false alarms). For the situation assessment part, the system is also a "learning system" as the historical data will greatly enhance the quality of the assessment.

The targeted market is mainly the domain of tunnels inspection. However, it can be extended to the inspection of other types of infrastructures, especially if hazards can be a threat for inspectors (weakened structures, chemical threats, sewers, drainage tunnels etc.)..

2.2 Business Case

2.2.1 Market Orders of magnitude

The market that is targeted by ROBO-SPECT solutions encompasses any type of transportation tunnels and underground works of engineering (concrete). Taking the example of France, we have:

- Railways tunnels: 1855 active tunnels,
- Motorways tunnels: ca 12500,

- Paris metro: 200km in underground.

Taking an average length of 100 m per tunnel, that gives an order of magnitude of between 1500 and 2000 km of tunnels in France. Let's then take a basis of 100 000km accessible in the world.
For motorways tunnels, studies (French transport ministry) have computed that for simple tunnels an average of 3 permanent technicians per km were needed (beside intervention teams). This number can reach 6 to 9 for complex long bi-directional tunnels in the Alps (cross-border tunnels with heavy traffic). Taking the lower range of salaries, it will therefore reach a magnitude of 200 k€ per km/per annum. And it only encompasses salaries. This makes a global accessible market in the order of magnitude of 30 billion euros per year.
If we stay on the very modest side, we can expect to address 1 per cent of the market. That makes 300 M€ per year which is a big market for ROBO-SPECT solution and clearly a valid business case.

For the cost of ROBO-SPECT solution, at this stage of the project, the Rough Order of Magnitude can be computed in the following way (integrating the cost of software development): to develop ROBO-SPECT system, the budget is 4.77 M€, not considering the cost of the background. If we consider the development part in it (including WP1 to WP7 in that), that is around 4M. With EC funding, the consortium investment would be 1.4M that we want to be paid off with a batch of 100 robots. We assume 10k per robot. The purchase cost of the robot should integrate the material costs of robot and arm, the sensors, GCS and coms solution. I would be 40k (to be confirmed). So, we have a purchase cost of 50k. Considering an amortisation plan of 3 years, it makes roughly 20k per year including the maintenance. An inspection will need 3 to 4 hours as an average (including the time to bring, install and remove the system) with 2 persons, so we consider 4 hours per 100m.
The cost of an inspection of 100 m of tunnel will be in the vicinity of 150 euros with ROBO-SPECT solution, which makes it particularly attractive and warrants a quick return on investment (ROI).

2.2.2 Global Market Overview

The global market is therefore in a ROM of 30 B€. The repartition on the continents is of course not homogeneous as it depends on the density of the transportation networks (Western Europe and Asia and US). The interest of ROBO-SPECT solution also highly depends on the level of salaries (as for all automation assets). Countries with low salaries might be less interested in procuring robots. Finally, it also depends on the local laws that define the frequency and depth of the inspections.
So, the countries where ROBO-SPECT solution will be more easily marketable are Western Europe, the US and Japan. In the second rank will come the countries where the salaries are increasing regularly (BRIC).

2.2.3 European Market Overview

For the specific European Market, the main interesting areas are:

- Large cities (metros, buried roads and underground facilities),
- Mountainous areas (especially the Alps arch and several smaller areas with lower mountains/hills),

The customers will therefore essentially be road/motorways networks operators; railway operators and metro operators. The preliminary studies performed with the project end-users show that there is a great interest in ROBO-SPECT solution, especially if the system can be operated without long closure of service in the facilities.

Nowadays and worldwide, there are around 250 companies into the development, manufacturing, sales and distribution of service robot systems and relevant modules. There is a large data base of companies that is now expanding. Today about 300 product ideas exist including demonstrators, prototypes and products in service robotics for almost any kind of (physical) tasks. These service robot types are systematized into a service robot classification scheme which has been under development since the year 1999.

It is widely known that Europe has developed a worldwide successful robotics market and industry, focusing mainly in industrial robotics and currently hold up to a 30% of the market share. The industrial sector is strongly relevant to ROBO-SPECT aiming a TRL (technology readiness level) of 6-7 (following some demonstration and piloting activities) whereas industrial robots form an essential part of Europe's industrial manufacturing sector. The table that follows indicates the annual sales figures in industrial robotics per region of origin as included in the European Robotics Coordination Action - Market survey on European Service Robots [2].

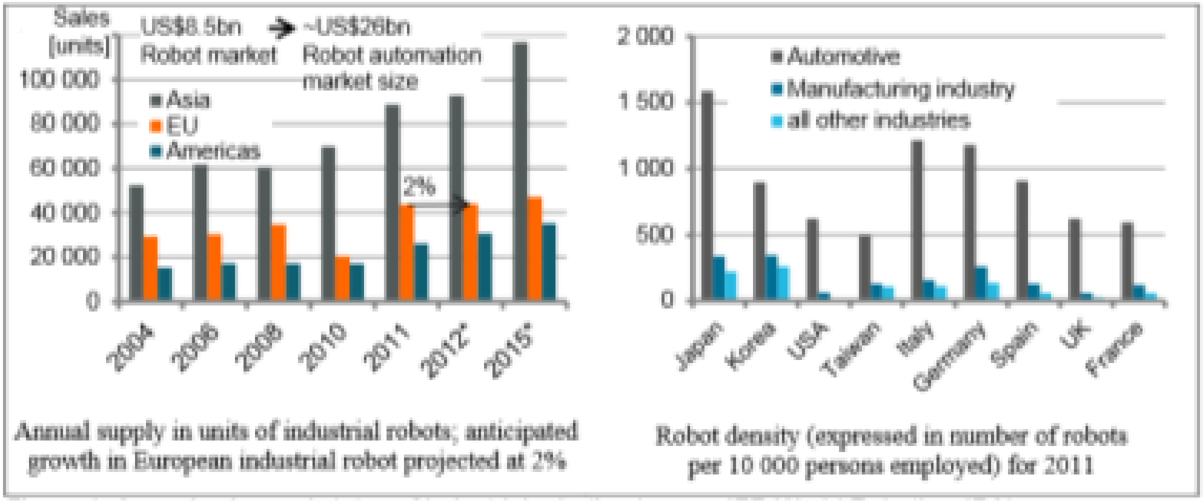

Fig 1: Annual Sales and status of industrial robotics (source: IFR World Robotics, IPA)

2.2.4 Adjacent domains

If ROBO-SPECT system is optimised for the search and identification of anomalies/cracks in tunnels with concrete lining, it could also be used for other types of inspections (bridges, buildings, etc.) provided some modifications/adaptations are made to the sensors and/or the system processing. It enlarges the system use cases by a huge factor compared to the relatively low cost of the modifications. At first glance, the sensor configuration could be very similar, the detection algorithms should also be re-useable. The major modifications could come from the structural assessment studies as the material and structures will be different.

Table 1. ROBO-SPECT Benefits to specific sectors

	Factors	Potential Benefits per sector	
		Actor	**Benefit**
Benefits	Fast and reliable Inspection and assessment of existing tunnels	Inspection industry Tunnel operators	Quicker Inspections, Decreased traffic disruption
	Improved working conditions for the Inspectors	Tunnel operators	Safer tunnels
	Optimized frequency of inspections	Tunnel operators	Quicker Inspections, Decreased traffic disruption
	Documenting the inspection Findings	Tunnel operators, construction companies	Quicker Inspections, Improved databases
	Identifying a particular defect	Tunnel operators, construction companies, Maintenance teams	Assessing the overall condition of the liner, more reliable inspections, Improved databases
	Identifying severity of defect	Tunnel operators,	Assessing the overall

		construction companies. Maintenance teams	condition of the liner, more reliable inspections, Improved databases
	Automated non-destructive inspection techniques	Robotic industry, Tunnel operators, construction companies, Maintenance teams	Creation of new markets for robots through technology transfer
	Knowledge transfer through a large number of dissemination events	Robotic industry, Tunnel operators	Knowledge exchange and Transfer

2.3 ROBO-SPECT expected changes

ROBO-SPECT system has been designed to replace the technicians for terrain inspections. One ROBO-SPECT system, if industrialised, could inspect 1 km per day, which makes a certain number of persons that can be replaced by the robot. Of course, operators and maintenance costs have to be taken into account.
Speed is also a major issue because inspection might necessitate the closure of a lane which might create traffic jam.
The use of a ROBO-SPECT system shall induce important cost savings for the main end-users considered in the project (motorways operator and metro tunnel operator).

2.4 Feed-back from end-users

The system was presented in detail during several conferences, special sessions and ROBO-SPECT events, the preliminary trials in VSH and during the final trials in Metsovo (Greece) in July 2016. The project gathered an important set of comments and additional requirements.
An important axis is the extension to other types of linings as the concrete linings are not the most numerous. This necessitates of course other types of sensors and other algorithms for the status assessment.
All the end-users have asked for the capability to be able to take the control of the robot at any time of the mission (with the capability to orient the cameras and other sensors). The impact of this request is to add video cameras installed on the robot in addition to the cameras of computer vision. It also means that the fully autonomous mission of the robot does not correspond to the real concept of operation of the end-users for this type of product. The GCS has therefore an essential role and must be carefully designed to warrant smooth transitions between the automatic mode and the (semi) piloted mode. This should also include the upgrade and configuration of some extra safety systems on-board to guarantee the safe operation of the robotic system being manually (and possible remotely) controlled by the operator(s).
As regards the robotic platform itself, the assessment of the end-users was:

- Too slow and lacking the capability to operate on uneven terrains/rubbles (Egnatia Odos),
- The speed can be acceptable if all actions are performed simultaneously – that is in the same mission - (detection, measurements and structural assessment (Egnatia Odos)
- The platform is not adapted (too big and too slow) for most railway tunnels. The system concept is however good and should be developed further to be more independent from the hardware (users).

The synthesis of the end-users can be summarised by:

- The concept of combining all the inspection actions in one system is good,
- The concept of operations needs to be reviewed and enhanced (in particular as regards the set of data needed for the system (initial/previous states, 3D maps, environmental data, etc.).
- The robotic platform chosen for the prototype is not adapted and needs to be replaced by something that is smaller, less complex mechanically, more flexible and more modular.

- Particularly for the case of rail tunnels, a large size robotic system would dramatically reduce the available inspection time due to the system having to be transported on the inspection point (on rails), perform the inspection and return in a very small time slot (usually 01:30-04:30am).
- Full automated positioning of the sensors by the robotic arm would need further testing to improve accuracy and might need to be replaced by a semi-automatic method using video cameras for precise positioning.
- The system should be adaptable for other platforms (eg trucks).
- The integration performed in the GCS is adequate and operationally viable.
- Attention is to be put on the local communications capabilities. The solution implemented in Metsovo tunnel was successful because the consortium could access the fiber-optic supporting the SCADA via a secure connection, but all the tunnels might not be equipped with accessible communication solutions. This might bring other communication options on-board such as TETRA or other similar (but this would drastically limit the transmission bandwidth).

3. IDENTIFICATION OF THE FOREGROUND

The Foreground of ROBO-SPECT will essentially be the integrated robot system, composed of:

- **The robotic platform itself and its navigation system,**
- **The articulated arm integrating the sensors (cameras, laser and ultrasound) and its control unit,**
- **The computer vision system,**
- **The 3D laser system,**
- **The robot Ground Control Station,**
- **The structural assessment system.**

It therefore comprises the following full system

Full system:

- With or without the control room module
- Extensions to other sensors
- Adaptation of communications

These components are connected by COTS communication solutions which will not be considered as foreground. Since the system is being developed for a specific purpose which is to detect anomalies in concrete tunnels with high performances, the integration of all the components is very tight and it would be difficult to extract separate components to market them separately. However, the robot and the sensors could be used separately as building blocks of other systems.

The marketable packages are:

Module Name	Description	Developer and Owner
Autonomous robotic vehicle with robotic crane	This system includes the robotic vehicle with the following hardware components and capabilities: - Robotic vehicle and crane; - Mapping of the tunnel area based on visual SLAM (laser system and beacons); - Robotic vehicle automatic navigation and waypoints' following; - Motorised and sensorised joints; - Power (inverter), battery systems and control (processing) units; - Onboard wifi based connectivity.	ROB
High precision robotic arm	This module includes the hardware and software components as defined below: - Mitsubishi pa-10 high precision robotic arm; - Algorithms and laser scanning system for collision avoidance and trajectory estimation to localise ultrasonic sensor on the wall for crack measurements; - Software platform for manual positioning of the ultrasonic sensor on crack position	UC3M
Computer Vision System (hardware)	The computer vision system includes the hardware developed and assembled by ICCS: - 4x PointGrey-Grasshopper GS3-U3-91S6C-C (machine vision cameras); - 1 led light; - Pan & Tilt Mechanism for their control and direction (developed by ROB); - Processing PCs for data extrapolation and processing.	ICCS
Crack and Defects Annotated	This includes the data annotated data-sets for crack and defect detections as collected from the Tunnels of Metsovo, Malakasi A, Malakasi B and the Metsovo Drainage tunnels (Egnatia Motorway) and the VSH Haggerbach test	ICCS, ENPC, EOAE, VSH

Material	tunnels (VSH)	
Computer Vision System – crack detection algorithms	This includes the software algorithms as developed by ICCS for crack detection in tunnel linings: - Machine learning detection algorithms; - Extracting appropriate feature vectors; - CNN annotations.	ICCS
Computer Vision System – defect detection algorithms	The defect detection system includes the following: - Visual detection algorithms; - Deep learning features; - Semi-supervised learning and defect segmentation.	ENPC
Computer Vision System – 3D stereo algorithms	The stereo algorithms developed by ICCS consist of the following: - Extraction of XYZ coordinates of the crack; - Local 3D reconstruction for the structural assessment tool (visual inspection) ; - Estimation of the orientation and position of the crack; - Estimation of the crack length for choosing whether to measure a crack with ultra-sonic sensors, or not; - A perpendicular section to the tunnel lining for the estimation of tunnel deformations.	ICCS
3D Laser Scanning System – configuration and setup	This includes the COTS hardware and the developed configuration software for tunnel deformations estimation: - Faro Focus 3D X 130 (OTS); - Algorithms for automated triggering of the laser scanner; - Conversion of the results for the DSS tool (structural assessment)	ICCS
Ultra-sonic sensor	The ultrasonic sensor and software as developed by CNR consist of the following: - Final prototype of ROBO-SPECT sensor system for the measurement of crack width and depth on the tunnel lining; - Methodology and algorithms for crack width measurement with a tip contact sensor.	CNR
Ground Control Station	The Ground Control Station user interface and communication hardware includes the following: - GCS user interface that monitors constantly the robot mission; - Results exploitation and user annotation; - WIFI-type data link.	ADS
Structural Assessment Software - Algorithms	This includes the structural assessment software algorithms that have been developed jointly by DBA and TECNIC including the following: - Deterministic time-dependent degradation of the tunnel lining; - Deterministic assessment of the structural condition and safety of the tunnel; - Prediction of the probabilistic time-dependent structural reliability and probability of structural failure.	DBA, TECNIC
Structural Assessment Software – UI and Consolidated Software	The Structural Assessment User interface tool developed by RISA includes the following capabilities: - 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; - The probability of local or global failure in the future (for tunnels where the external loading on the lining has reached a stable value).	RISA

For this final exploitation plan, each partner defined what was their foreground and their background. From this definition, the partners and the consortium can define the conditions of commercial exploitation of the foreground, including where relevant the associated conditions to use the background of some partners that can be embedded in the system.

Due to the intrinsic nature of the robotic system and its specialisation, the exploitation strategy should have mainly focussed on marketing the whole system, either to sell it as a turnkey solution or, if the end-users prefer this alternate solution, to propose it in operator/service mode.

At the current status of development of the system, the following bottlenecks exist:

1. **The robot itself**: As previously mentioned, the robot might be adapted to the inspection of road tunnels, but it is too big for metro tunnels and many railways tunnels. It is also too complex mechanically and as a result much too slow for the end-users. That implies that the ROBO-SPECT system should largely be independent from the robot platform as the customer might prefer other COTS platform or ask for the installation of the system on their own platform (wagons, trucks, etc.).
2. **The robotic arm**: at the current stage, the robotic arm is still at low TRL and further testing is needed.
3. The robotic partner in charge of the platform (ROB) is not willing to exploit ROBO-SPECT results industrially.
4. The robotic partner in charge of the Integrated Global Controller (IGC) and of the robotic arm (UC3M) is not willing to exploit the ROBO-SPECT results commercially.

4. EXPLOITATION PLAN

4.1 Roadmap

The roadmap defines the steps after the project to reach marketable solutions ("industrialisation plan"). The actual steps that will be investigated towards the development of the project exploitation plan are described for the whole consortium (consortium exploitation) and for the partners (individual exploitation).

The ROBO-SPECT industrialisation road map addresses both the technical and nontechnical roadblocks. It will contain road mapping towards obtaining the required standardisations, for providing to the ROBO-SPECT robotic system additional functionalities (e.g., for the inspection and assessment of the functional behaviour of concrete tunnel linings), additional coverage of tunnel lining materials (e.g., metallic segmental linings), implementation in different platforms depending on the topology and activity in the tunnel/roads and additional markets (e.g., sewer tunnels), development of processes that are more trustworthy in the difficult tunnel conditions, improved adaptability of the various types of carriers, ad-hoc wireless communications to support the robot operation, better cost/benefit or price/performance ratios and an assessment of the time dependent evolution of the involved technologies while the above are happening. Similar projections and measures in road mapping are developed for components of the proposed robotic system (e.g., the computer vision system with minor modifications can be made appropriate for the inspection of concrete structures such as bridges or nuclear plants or for quality control in the manufacturing of precast concrete elements).

4.2 ROBO-SPECT Exploitation target group

The ROBO-SPECT target group has identified a series of potential target groups that ROBO-SPECT has approached towards the final year of the project execution and plans to approach in the future. This includes State, federal and local highway or rail agencies involved in tunnel design, inspection and maintenance operations, as well as consultancy companies involved in tunnel inspection or tunnel inspection management and leadership or operation. It is expected that this will affect all (tunnel) project phases including feasibility, design, authority and public, tender as well as construction and operation and maintenance [4].

The operational framework of ROBO-SPECT has been identified to range inside the various types of tunnels and applications (depending on usage):

- TBM bored
- Immersed
- Cut and Cover
- Rock and SCL

The above include of course applications that the ROBO-SPECT project is directed and are limited to the cast-in-place reinforced concrete linings or precast segments as well as cast in situ. The following table describes the deterioration categories:

Table 2. ROBO-SPECT Deterioration Matrix

Deterioration Category	Seriousness
Progressive corrosion of steel reinforcement bars through continuous water seepage or repeated cycles of humidity and dryness. Rust and fluid is detected on the surface of the concrete	The seriousness can be minor at this stage before this situation becomes one that requires urgent measures
Cracks have been generated within the concrete as a result of corrosion of the steel reinforcement bars. An increase of rust fluid and swelling in the vicinity of the cracks is detected	If swelling is identified in the vicinity of cracks, there is the possibility that exfoliation has occurred
Falling of concrete debris as a result of expansion of rust due to corrosion of the steel reinforcement bars	This is a situation that is close to becoming an urgent one

Progressive corrosion of the steel reinforcement bars that are exposed (phenomenon that occurs at the cross section of steel reinforcing bars)	The rate of corrosion of the steel reinforcement bars accelerates. If it is left unattended, there is every possibility that the situation will develop into an urgent one
Calcium leaching (efflorescence) due to aggressive groundwater moving from the extrados to the intrados of the lining. It produces white deposits on the surface	It increases the porosity, and, consequently, the permeability of the concrete lining. This process reduces both the stiffness and the strength of concrete

The above include various types of tunnels including rail or road tunnels in big cities (TBM type), long tunnels under highlands (TBM type), tunnels at river or other water obstacles and crossed tunnels (immersed), shallow tunnels more for rural areas (surface type) (cut and cover tunnels) and finally tunnels with irregular cross-sections and other peculiar characteristics (rock and SCL type).

Potential end-users as contacted by the project consortium include the following:

- Egnatia Motorway (Greece)
- London Underground (UK)
- SITAF/TEKNOSITAF (France)
- Parisian Metro (France)
- London Thames Link (UK)
- London Cross Rail (UK)
- CH2M Hill (UK)
- Eurotunnel
- HS2 (UK)
- Aegean Motorway S.A. (Greece)
- Attiko Metro (Greece)
- Nea Odos (Greece)
- Attiki Odos (Greece)
- Olympia Odos (Greece)
- NETIVEI (Israel)

4.2.1 Optimisation of maintenance strategies of tunnels

It is also expected that ROBO-SPECT will significantly contribute to the optimisation strategies of tunnels that is currently operated manually. ROBO-SPECT will contribute to systematic condition assessment by thorough and structured tunnel examinations. Furthermore, when industrially available, ROBO-SPECT system/technologies would in most cases be integrated in the overall safety system of the operator that manages the infrastructure (metro, tunnels, bridge, etc.). The data and information gathered by ROBO-SPECT system could thus be merged with other data gathered by other sensors/subsystems to enrich the safety monitoring. In the other way round, provided additional processes are implemented, the ROBO-SPECT platform could combine crack detection with the detection of other phenomena/abnormal situations that could be a threat for the persons/goods (electrical installation, safety devices, foreign objects, etc.).

4.3 Market need towards the ROBO-SPECT solution

ROBO-SPECT stems from the need for an automated inspection of highway, railway and metro tunnels as a potential new market for the emerging service robot sector for several reasons including:

- need for speedy inspections: Inspection cannot take place when vehicles are using the tunnel and closing of some or all lanes for inspection can create traffic jams that in some cases have significant social and financial cost.
- limited and decreasing labour force for tunnel inspection and assessment at a time when a significant fraction of the tunnel length is in need of inspection. Much of the tunnel infrastructure was constructed more than half a century ago and there is a wide spread evidence of deterioration. The facts that little is known about the long-term structural performance of tunnels and that inadequate

tunnel structural safety can have grave consequences for a very large number of people (e.g., a metro line in a large city may transport 60,000 passengers/hour) make the need for inspection more pressing.
- working conditions for tunnel inspectors are unhealthy and unsafe.
- current employable technologies for tunnel inspection range from visual inspection that is slow, expensive and subjective, to the deployment of instruments for the more in depth assessment of sections of concern that is slow and expensive.
- currently there is no organised and structured way of data collection, reporting and cross-reference in a database system that can be used to compare current and previous tunnel conditions and measurements. It is therefore very difficult for the inspection teams to keep records and make evolution comparisons.

4.4 Consortium exploitation plan

The 3 possible axes have been identified to exploit the system as viable options:

1. Direct system procurement,
2. Operator contract,
3. Service contract.

Direct system procurement

This option is the most interesting as it can be supported by a simpler commercial organisation and the return on investment can be quicker. The model is based on a "turnkey solution" but, as explained previously, the system will need be customisable for other tunnel cases than those already tested:

- To be integrated in the organisation of the customer. This aspect mainly concern the customisation of the GCS and the Control room modules plus the communication solutions between robot, GCS and Control room,
- Slight customisation of the robotic navigation and positioning might be needed together with slight configuration of the visual crack and defect detection algorithms. This will have to do with
- The customer choice for the robotic platform (option to be studied more in details when the system is really integrated as the impact on the navigation module, on the Intelligent General Controller (IGC) and the sensor integration might be important and not commercially viable.

Two main aspects have also to be taken into consideration:

- There might be need to train properly operators and technical support team. So the organisation in charge of the system sales shall also be able to propose this training.
- The system needs to be configured and calibrated. In addition, the 3D modelling of the tunnel and the first state ("initial status") need to be established. This should be done between the customer and the seller as a system set-up activity and would include construction data, previous measurements and tunnel testing results of the past.

So, if this option is finally chosen, the commercial entity should be in a position to provide the support services in addition to the turnkey system procurement.

Operator contract

In this option, the entity in charge of the exploitation of the system will develop a rolling stock of systems that will be proposed for rent. In the majority of cases, system configuration and operator training will be compulsory as in the previous option.

The viability of this option highly depends on the flexibility of the industrial solution to be adapted on the various tunnel types and to the customer procedures. The return on investment for this option will also be much longer as the investment in developing the stock is bigger and the cash flow is spread on a longer period.

Service contract

This business model option is similar to the previous, with the difference that the system operators and support are provided by the commercial entity. This solution is easier for the customer but is by definition more expensive as it includes specialised staff personal cost (both for the system operation and for the expertise related to anomaly detections and structural assessment. Also, the service should not be one shot given the fact that a good knowledge of the tunnel history is a pre-requisite to achieve good results.

It is also possible that a combination of these models should be advisable to address a majority of customers that are different in size and in inspection procedures.

4.4.1 Individual exploitation plans

ROBO-SPECT Individual Exploitation Plan [ICCS]

Relevance of the project in the strategy of the entity

ICCS as a research institute has applied recent research on computer vision, image processing and analysis to (i) identify cracks and other defects on tunnels internal surface, (ii) create precise 3D models of the tunnel surface and (iii) incorporate the user in the loop. The computer vision team of ICCS is planning to extend research in image processing and machine learning algorithms developed in ROBO-SPECT in a multi fold attitude having clearly defined the significance, innovation and actual approach of the developed technologies. This is absolutely in line with the ICCS strategy in further exploiting research project results into applied domain such as this of tunnel inspection but also extending to all fields of visual inspection in a huge span of applications such as tunnels, bridges, sewers, nuclear plants, oil and gas platform as well as underwater inspections of critical infrastructures.

The ICCS business model spans into three distinct but interconnected pillars such as those of research, teaching and partnership. Apart from basic research that takes place in the institute, there is a strong activity into teaching of the research outcomes through firm links with the National Technical University of Athens. At the same time, ICCS collaborates a lot with research and business communities where the outcomes of ROBO-SPECT are expected to be exploited.

Exploitation strategy

As an academic partner, the Institute of Communication and Computer Systems (ICCS) being strongly linked with the National Technical University of Athens (NTUA) Greece intends to use the ROBO-SPECT results towards academic, research as well as dissemination purposes. ICCS will focus in improving research innovation on the tunnel visual inspection in general being in close cooperation with various stakeholders in the EU region. Inside ROBO-SPECT, ICCS has demonstrated the usage of computer vision and machine learning algorithms and technologies towards visual inspection of transportation tunnels.

ICCS will has provided technical support and will continue doing so in the implementation of visual inspection of tunnels through direct cooperation with the project end-users (Egnatia Highway and London Underground) but experience gained through contacts with other major end-users (London rail, SITAF, Aegean Motorway etc).

The ICCS exploitation strategy includes the following:

- Exploit ROBO-SPECT computer vision results and outcomes into the worldwide scientific community through paper and demonstration. In particular, during the world-wide ISPRS 2016 congress held in Prague Czech Republic, ICCS will present work about the ROBO-SPECT platform and will take place in meetings with the International Federation of Surveying Engineering (FIG) in order to disseminate the results to civil and survey engineer society. An official letter from the FIG is attached naming specific the importance of ROBO-SPECT project.
- Promote the developed methodologies inside the tunnel inspection industry as innovation into structural inspection. ICCS in corporation with civil engineer groups of NTUA.
- Highlight the results and benefits of the developed algorithms to wider public and academic society
- Extend research and increase TRL level of existing algorithms in the application of tunnel inspection

- Extend current research outcomes to other application fields such as critical structures' monitoring and inspection (bridges, civil buildings, nuclear plants, manufacturing precast concrete, water sewage systems etc.)
- Increase interest of National Tunnelling Societies/ Associations and the National Technological Platforms in Construction, the National Associations in Automation and Robotics and the National Associations in Image Processing/Pattern Recognition/Machine Vision about the ROBO-SPECT results.
- Incorporate the results to American Robotic groups and Civil Engineers. Examples include the inclusion of Prof. George Bebis in the advisory board of Robo Spect.

The target groups of the computer vision algorithms have been identified as follows:

- Transportation tunnels' (rail and road) owners
- Transportation tunnels' operators
- Inspectors of transportation tunnels (internal and external)
- Research institutes focusing on computer vision algorithms
- Other pre-casted concrete infrastructures' inspection entities

Background

ICCS has established during the recent years strong research in computer vision, image analysis and processing and machine learning. Some of the background knowledge of ICCS is

- Low –level image processing methods exploiting color and texture mainly using filters
- High level sematic processing on the use of semantics and ontologies
- Neural networks processing including classification and learning
- 3D reconstruction from images with accuracy less than 10mm
- 3D reconstructions from point clouds of laser scanners
- Relevance feedback schemes and incorporation of the user in the loop of the decision process for bid data application scenarios
- Image analysis in structure engineering methods such as detection of defects into piles of bridges

Identification of the foreground

ICCS was developed methods for

- Crack detection in tunnels using only visual data. The detection is performed under high noisy conditions in terms of appearance of other objects, watering, etc.
- The introduction of deep convolution neural networks for refining the cracks and discriminate them from other defects in tunnels
- Development of precise 3D models as for the tunnel surface.
- Development of relevance feedback schemes that automatically improve system performance taking the user into the loop.
- Effort for integrating these systems with the robotic system.

Planned roadmap for exploitation

The ICCS roadmap for ROBO-SPECT exploitation strategy is totally inlined with the ROBO-SPECT concept for exploitation and the project consortium agreement. This includes a series of steps and business activities to ensure that the project results and outcomes are thoroughly exploited during and after the project duration as follows:

- **Involving stakeholders from early stages:**
  This includes the early involvement of major stakeholders into the project activities from the beginning of the project (participation to end-user requirements extraction), during the project execution (through workshops participation to events etc) and the final project stages (final project workshop, special sessions' organisation etc). Stakeholders range inside various application domains such as those of computer vision and sensors (eg University of Cambridge, University of Nevada), robotics (eg Heron robotics, EU Robotics, University Jaume I), tunnelling industry and road operators (eg SITAF, Attiko metro, Aegean Motorway, London Rail, London Crossrail, London Underground) as well as site surveyors and structural engineers (eg EPPO, SANEF, CETU).

- **Obtaining stakeholders' views via workshops and questionnaires:**
  All ROBO-SPECT identified stakeholders have been invited in the internal workshop of ROBO-SPECT (at the project mid-integration stage) that took place at the premises of CH2M Hill (in London, UK). During this workshop, the project concept and first results were presented followed by fruitful discussions directly with the potential system operators where feedback was collected that created a re-evaluation of the end-user requirements and system specifications. This was the ROBO-SPECT consortium has focused its activities into building a system following actual and precise industrial requirements.
- **Organisation/Participation to workshops:**
  Several workshops have been attended by the ICCS personnel in the concept of computer vision, 3D vision and machine learning. Several special sessions have been organised where concepts and research matters in the field of computer vision and visual tunnel inspection were heavily discussed amongst research institutes and industrial parties.
- **University teaching and academic degree thesis/PhD:**
  The ICCS team, having firm links with the National Technical University of Athens and the laboratory of Microwave and Fiber Optics (MFOL) has created and followed a series of under/post-graduate and PhD thesis for the University students directly aligned to the project outcomes and concept.
  The project results was disseminated in the under graduate course Photogrammetry II of the NTUA. In that course students was learnt about the significance of 3D modelling especially in case of infrastructure and civil protection.
  In addition, a detailed awareness of the results was announced to the master program course "Multimedia". The post graduate students was aware of the advantages of computer vision and image analysis in protection safety and security of civil infrastructures.
  ICCS in cooperation with the Technical University of Crete (TUC) in Chania was disseminated the results of the project into the master program of this university.
  Finally, ICCS has participated in the researcher night of Marie Curie Actions disseminated the results to the wide public and seeking for exploitation of the knowledge obtained.
- **Regular communications and active involvement:**
  The ICCS team has been in direct communication with the project end-users (internal and external) as well as other stakeholders related to the fields of computer vision, image processing and machine learning in various stages of the project and before important deliverables and milestones. This has included several teleconferences that have lead developments in the required industrial direction.
- **Sustaining project results:**
  This has included production of internal reports, recommendations and continuous feedback to/from stakeholders towards the sustainability opportunities of the undergoing research.
- **Follow-on Research:**
  Follow-on research of the ROBO-SPECT outcomes has been guaranteed through engagements in further research before implementation is ready. This has been feasibly through participation into new research projects and/or strongly liaising with existing ones. This includes the projects of INACHUS (FP7-SEC), ZONESEC (FP7-SEC), SENSKIN (H2020-ICT), EVACUTE (FP7-SEC) and other that the ICCS team participates/coordinates. It is well expected also that the aforementioned research in ROBO-SPECT will also be applied, extended and enhanced in further research projects and research topics.

ROBO-SPECT Individual Exploitation Plan [ADS]

Relevance of the project in the strategy of the entity

ADS have studied for the last ten years the market of critical infrastructure protection (and thus inspection). This activity that was initially an opportunity for the use of UAVs in civilian domain integrated progressively other types of unmanned platforms, robots and surface vessels. In particular, the protection of ports which is an interesting domain for ADS calls for a combination of airborne, terrestrial, surfave and sub-surface assets. ADS don't want to produce the unmanned systems (except for UAVs), but can integrate them in the end-users systems if relevant. The integration of sub-systems in a large system requires a good knowledge of the sub-system by the integrator.

The robotic from another side is a major domain of interest for AIRBUS planes (and helicopters in a lesser extent) as the assembly chain of the aircraft are more and more automated and necessitate reinforced controls.
One of the major product line of ADS is DEOINT that proposes the integration of surveillance, Intelligence, observation platforms (manned and unmanned) into a ground system (through a generic Ground Station) to produce substantiated reports adapted to the needs of the end-users. In that sense, ROBO6SPECT is an invaluable experience to integrate ground robots in the system.

Exploitation strategy

ADS wijj capitalize on the GCS developed for the project (including the communication solutions) to integrate it in the portfolio of GEOINT products.

Being a space and aeronautics company, ADS are not planning to develop ground robots. But as the ground robots can be integrated in the system portfolio of the company or in the inspection systems of the assembly line of aircraft, they are valuable assets. The systems developed by ADS having generally a long lifetime (20+ years) and the quality of service being guaranteed in the contracts, ADS cannot have a strategy of buying the robot off-the-shelf as any minor procurement. There is a need for a long term association with a robot provider that can be trusted. The strategy of ADS will therefore be to search for one of several robotic partners that meet the conditions of quality, durability and costs. As demonstrated during the project, the system should be as much as possible independent from the hardware components (the choice of the robot depends on the infrastructure to be monitored and the hardware components become quickly obsolete).

Regarding the multi-platform ground control station adapted during the project by ADS, the maturity is such that it can be integrated as such in the portfolio. Beside the specificities of future platforms that needs to be taken into account for the statuses, all the other messages (platform<->GCS) are standardized and do not request big modifications.

Background

ADS brought to the project existing components of the Ground Control Station (GCS). The embedded tools used to customize the GCS and adapt it to the tunnel and robot were also used (3D graphic tools).

Identification of the foreground

The foreground developed during the project mainly lies in the connection with the robot (mission preparation, IGC, components and sensors). The mission monitoring and exploitation modules have been developed by ADS from existing components with an operational support from EOAE.

Planned roadmap for exploitation

The components of the GCS developed during the project are directly integrable in the portfolio (they are above TRL7). Any use on concrete market systems would require adaptations of the connectors to the specific robots chosen by the customer and adaptation of the tunnel/infrastructure model. The work needed to integrate the components into operational systems is therefore a customization work and not an industrialization effort.

ROBO-SPECT Individual Exploitation Plan [UC3M]

Relevance of the project in the strategy of the entity

Participation in the project follows the UC3M trajectory collaborating in the latest advances in robotic technology. In this particular case, UC3M stands out in the field of robotics in construction in general and in the robotic inspection in particular with collaborations in projects such as ManuBuild, I3CON, FutureHome and TunConstruct. The particular characteristics of this project, requiring advanced robotic control and design, provides the perfect environment to apply and improve the latest developments in robotic control, simulation and/or automation in which the UC3M RoboticsLab is expert.

Exploitation strategy

- **Results sustained internally**
  UC3M followed the strategy of using the mainstream online channels and social networks such as Twitter or LinkedIn for project visibility and dissemination since the start of the project. Additionally, several national spanish press media have been informed during the project development and articles were written about the project. The results of the project will be presented in several internal meetings and the knowledge acquired will be used to propose graduate and post-graduate final projects in the area.

- **Promotion to workshop**
  UC3M also provides the project with reputation with dedicated contributions on relevant research journals such as Automation in Construction, ISARC among international conferences and workshops such as RoboCity2030. UC3M will continue to use the developed robotic advances of the project in national and international workshops, conferences, symposiums and publications in relevant journals and other outstanding media.

- **Continuation of research**
  The research carried out inside the ROBOSPECT project will be used in future projects related with automation in construction and inspection, robotic arm control and 3D environment reconstruction for arm planning. Part of the experience acquired by UC3M is being used on the EU project STAMS currently under development. STAMS project aims to develop inspection modules dedicated to periodic measurements and the continuous monitoring of flooded mine shafts (coalmines). UC3M will continue to work with ROBOSPECT consortium partners in future projects related with the automation and control of robotic equipment.

- **Future Projects**
  UC3M will continue to exploit the technology developed and the experience acquired during the project in future investigations to increase the TRL of the system and creating new project proposals to take advantage of the advances and milestones reached during the ROBOSPECT project.

Background

UC3M demonstrated robotic inspection proficiency with participation in projects such as the TunConstruct project. The TunConstruct project was part of the European Commission 6th Framework Program (FP6), and was conducted by 41 partners from 11 European countries. The main objective of the TunConstruct project was to reduce the cost and time of construction of underground infrastructure, promoting the sustainability of our environment and the safety of people during the phases of construction and use of services and infrastructure. In order to contribute to the general objective of the project, several different engineering applications were developed. One of these proposals where UC3M’s labour was prominent and success was demonstrated involved the development of a robotic system capable of performing inspection and maintenance in concrete tunnels.

Identification of the foreground

During the development of the ROBO-SPECT project, the design and setup of the tunnel inspection robot was achieved and demonstrated in an operational environment (European Commission (EC) TRL 7). The created system leads the state of the art in autonomous robotic inspection, with no other similar systems on the road. The following details a number of the characteristics of the system developed during the project:

- Intelligent Global Controller (IGC) to manage communications and processes between each of the ROBO-SPECT subsystems (vision, ultrasonic, navigation, crane movement, robotic arm, mission management, etc…).
- Protocol for communications between every component.
- Algorithms for fast and precise positioning for US sensor with a redundant robotic arm manipulator on the tip of the system. Precision was tested and validated during integration meetings with demonstrated 5 mm repetitivity in the precise location of the ultrasonic sensors on the crack.
- Collision free trajectory generation for every robotic component through 3D laser environment reconstruction using Octomap backgrounds.
- Integration of contact sensors attached to the ultrasonic frame, development of dedicated electronic card for sensor data acquisition and communication with IGC.
- Shared software component synergy (ROS module common resources).
- Cross-platform Shared folder structure (Windows & SAMBA protocol).
- Robotic arm teleoperation module for manual positioning of the ultrasonic sensors.

Planned roadmap for exploitation

As an academic institution, UC3M cannot directly commercially exploit commercial products. The roadmap for commercial exploitation is through technological transfer in the form of patents, where UC3M files for patents on the robotic system and/or specific design issues/solutions. These patents are posteriorly licenced for commercial exploitation. Further exploitation includes the academic education and further research purposes.

ROBO-SPECT Individual Exploitation Plan [CNR]

Relevance of the project in the strategy of the entity

CNR motivations in participating to ROBO-SPECT were related to a general interest in the research institute about ultrasonic device and system technology and, more generally, devices for structural monitoring. In a previous project, indeed, the CNR group taking part in ROBO-SPECT had developed sensor for tunnel structural monitoring (Underground M3, Eurocores Program). Moreover, some previous experience was present about ultrasonic technology, particularly on the optical-acoustical devices that were proposed also in ROBO-SPECT for crack width measurements.

Exploitation strategy

The results achieved within ROBO-SPECT will be exploited by protecting the intellectual property generated by the project foreground and using it for technology transfer of the technology to commercial partners. Some follow-up development to increase the TRL of the system developed in ROBO-SPECT by CNR and use it as a standalone system for crack depth and width measurement is foreseen after the end of the project.

Background

Relevant background for ROBO-SPECT at CNR was a previous know-how about ultrasonic sensors and actuators and sensors for structural monitoring, particularly strain sensors.

Identification of the foreground

In the project, CNR has developed an automatic sensor system that can be used to measure the depth and width of surface opening cracks in concrete. The system was developed to work on the arm of a robot, but could be in principle utilized also as a standalone system by a human operator. The TRL reached within the project is 5 (system successfully tested in real application conditions).

Planned roadmap for exploitation

CNR cannot directly exploit the foreground of the project on a commercial ground, because it is a non-profit publicly funded research organization. Consequently the exploitation route will follow the way of technology transfer of the foreground to industrial partners that can be interested in increasing the TRL of the system developed in the project and commercializing it. Among the possible partners, companies already producing ultrasound systems for structural monitoring, such as PULSONIC, will be contacted first.
Possible steps of such exploitation roadmap will be:

- Development of a new version of the system for standalone use by operating some modifications of the prototype tested in the project.
- Development of a massive production method for the system, exploiting outsourced fabrication facilities

Transfer of the know-how about the engineered system to an industrial partner for commercialization in which CNR will receive royalties on sales

ROBO-SPECT Individual Exploitation Plan [ROBOTNIK]

Relevance of the project in the strategy of the entity

Robotnik is a company offering robotic solutions to many different applications. ROBO-SPECT focuses on the development of an innovative, integrated, robotic system that automatically scans the intrados of a tunnel, which is completely in line with the solutions offered by the company.

Exploitation strategy

Robotnik has gained great experience during the project development, not only from the mechanical side (adapting the crane to the needs of the project) but also from the software side. An important reverse engineering effort has been made, which adds value in future similar cases

Important knowledge has been gathered about automating hydraulic circuits and electrical vehicles. A general view of the appropriate sensor, transducers and controllers is also a good comeback.
Developing algorithms for the localization and navigation of big 4 wheels automated vehicles inside tunnels will be for sure an important know-how. The outcomes can be used for the navigation of indoor electrical vehicles.
Also there is very little precedent on working with the kinematics of such big and complex cranes. The coding has been done with special focus in portability/scalability for future implementations of this kind of cranes.
Finally, communications and interfaces inside the robot but also with modular components of Robospect will be kept in mind in future developments.

Apart from the robotic vehicle itself, the outcomes aforementioned will be used in future products and services offered by the company.

Background

Robotnik started its activity in 2002 and is currently a leading company in the European service robotics market. The company objective can be defined in one sentence: **the development of mobile robotics products and services**. Products include mobile robot platforms and mobile manipulators, while services are based on mobile service robotics applications like inspection, cleaning or logistics.
Specific knowledge gained in recent inspection tunnels projects has been of relevance dealing with not only localization and navigation aspects but also with the use/addition of the needed sensors and interfaces.
Electrical vehicles automation done in the past have also some similarities with the automation of the vehicle itself.

Identification of the foreground

ROBOTNIK was responsible for the development of the robotic vehicle, the research and development of the guiding and controlling algorithms that are executed in the robot CPU, and to program the robot localization, navigation and planning according to the supervised autonomous measurement. Next is the list with the main developments in which Robotnik has taken part:

- Obstacle avoidance and SLAM algorithms for autonomous navigation.
- Sensorization and installation of custom actuators in order to automate an existent vehicle.
- Development of low level controls for the mentioned actuators.
- Inner modules to manage communications and translate IGC commands to actual processes in the robot operation
- Kinematics needed for the automated movement of a heavy 10 m crane
- Control algorithms for positioning the crane tip with the cameras in the target position.
- Collision free trajectory generation for the automated crane through 3D laser environment reconstruction using Octomap backgrounds.
- Design, manufacture, control and integration of the automated Pan&Tilt Vision System .
- Shared software component synergy (ROS module common resources).
- Mission Planner software for mission creation and robot state monitor with maps and images of the processes.

Planned roadmap for exploitation

Since 2005, Robotnik has manufactured mainly R&D mobile platforms, professional service mobile robots and logistic robots. In all cases we are producing our own design, usually refined in two or three redesign cycles.
This will be the strategy in the ROBO-SPECT case. After obtaining a real product (mainly autonomous vehicle with obstacle avoidance and SLAM navigation) it will be further refined and redesigned to fulfil the needs of a future real tunnel inspection application.

ROBO-SPECT Individual Exploitation Plan [RISA]

Relevance of the project in the strategy of the entity

RISA is a well-established SME whose activities going back to 1990. It offers its clients full service including complete system analysis with the necessary software, special software adaptation, mathematical and statistical methods development and supply and installation of the accompanying hardware and software.

RISA management expects a strong future need for risk analyses, information systems and decision analysis/support Tools in civil engineering works. Accordingly, the company has been a partner in eight EC funded projects on probabilistic structural reliability and/or decision support for the civil infrastructure (bridges, tunnels, buildings, pipes).
In these projects RISA was in charge of the assessment of the time-dependent, probabilistic, structural reliability and/or decision analysis/support.

Moreover, RISA management anticipates that the know-how, technological expertise and scientific visibility gained through this project will lead to new successful collaborations with both existing and new customers and partners in the area of services and Structural assessment applications.

Exploitation strategy

The main exploitation strategy is to create partnerships with deterministic Structural assessment software vendors to create bundles or packages with our structural reliability module and decision support tool.

Background

RISA has established throughout the recent years a high level of expertise in structural reliability, Decision Support Systems, data acquisition and System Integration.

Identification of the foreground

RISA has built an integrated software package that can provide a detailed assessment of the structural condition of the tunnel exclusively based on robotic measurements.
This tool estimates:

• 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.
• The probability of local or global failure in the future (for tunnels where the external loading on the lining has reached a stable value).

The entire system has been successfully tested in real conditions thus attaining a TRL of 6.

Planned roadmap for exploitation

RISA's roadmap for the ROBO-SPECT exploitation strategy is totally in line with the ROBO-SPECT concept for exploitation and the project consortium agreement. This includes a series of steps and business activities to ensure that the project results and outcomes are thoroughly exploited during and after the project duration as follows:
Regular communications and active involvement:
The RISA team has been in direct communication with the project end-users (internal and external) as well as other stakeholders related to the fields of structural Assessment, Infrastructure management in various stages of the project and before important deliverables and milestones. This has included several teleconferences that have lead developments in the required industrial direction.
Follow-on Research:
Follow-on research of the ROBO-SPECT outcomes has been guaranteed through engagements in further research before implementation is ready. This has been feasibly through participation into new research projects SENSKIN (H2020-ICT), and AEROBI (H2020-ICT). It is well expected also that the aforementioned research in ROBO-SPECT will also be applied, extended and enhanced in further research projects and research topics.

ROBO-SPECT Individual Exploitation Plan [DBA]

Relevance of the project in the strategy of the entity

D. Bairaktaris & Associates Ltd (DBA) of Athens, Greece – an SME – is a 55 year old civil engineering firm specializing in the design of complex structures. In the past it has participated in research projects such as TUNNELING, SEWAGE, MONICO, MEMSON with special interest in the creation and development of Structural Assessment Modules based on measurements mainly from strain gauges and accelerometers.

Through the participation in the ROBO-SPECT project the knowledge and experience acquired from the previous projects has been expanded by incorporating in the Structural Assessment Module (SAM) the measurements of cracks and elastic displacements. The S.A.M. can also be used to make an assessment of the structural condition of tunnels based on measurements of cracks and elastic displacements that are acquired through conventional measurement methods and manually input apart from the robot measurements. The S.A.M. produces the internal forces developed at the locations of visible cracks, the external soil pressures and the internal forces along the perimeter of the final permanent lining as well as the locations and size of potential cracks along the external invisible face of the lining.

The analysis methodology presented in ROBO-SPECT is based on the original analytical formulation of more accurate fundamental laws of tensile strains – concrete deformations and bond-slip between concrete and steel reinforcement bars resulting from the processing of the published results of the most recent relevant laboratory tests.

Planned roadmap for exploitation

The ROBO-SPECT system can be made available in the following forms:

Through the lease of the system (both the hardware and the software) for either isolated or long-term periodical tunnel inspections.
By selling a complete system to a user to use in either a single tunnel or multiple locations depending on the requirements and needs.
By developing and selling a lighter ceiling-suspended sensor carrier system moving along a rail and with wireless communication to the data base and PCCDN tool along with the software as permanent monitoring equipment of a single tunnel.

ROBO-SPECT Individual Exploitation Plan [TECNIC]

Relevance of the project in the strategy of the entity

TECNIC of Rome, Italy, - an SME - is a 45 year old civil engineering firm specialising in the design, rehabilitation and supervision of works, including upgrading and the design of monitoring systems for structures. Outside Italy the company is active in Romania, Albania, Slovakia, South America and the Middle East.

TECNIC has experienced an increasing workload in maintenance and rehabilitation. Included is a recent project (2008-2013) in Romania where TECNIC provided technical assistance for the upgrading of 300 km of railway lines, including several structures. The above led to the conclusion that the structural assessment and upgrading of existing civil infrastructure and innovative inspection techniques is in our opinion a sector of development for the future. In fact the actual high costs of the new constructions of infrastructures and especially of tunnels will led in a big development the activity to maintain in a good efficiency the existing ones. Accordingly, TECNIC has been a partner in twelve EC funded research projects on the inspection/monitoring and assessment of civil structures (bridges, tunnels, pipes, buildings) where it was responsible for the modules on monitoring/inspection based degradation and structural assessment over time. Following below are the most recent 4 such projects:

1. RECONASS (Reconstruction and REcovery Planning: Rapid and Continuously Updated COnstruction Damage and Related Needs ASSessment), SEC-FP7, Grant Agreement no 312718, (2013-2017), where TECNIC is responsible for the monitoring-based damage assessment in non-structural elements.

2. MONICO (Fibre Optics-based Intelligent MONItoring and Assessment System for Proactive Maintenance and Seismic Disaster Prevention in Reinforced COncrete Tunnel Linings), Research for SMEs 2007, FP7, Grant n. 221978, where TECNIC was in charge of the deterministic structural assessment of the monitored tunnels.

3. MEMSCON (‘Radio Frequency Identification Tags Linked to on Board Micro-Electro-Mechanical Systems in a Wireless, Remote and Intelligent Monitoring and Assessment System for the Maintenance of CONstructed Facilities), FP7, NMP-CP-TP212004-2, (2008-2011), where TECNIC was in charge of the Module on structural rehabilitation

4. WATERPIPE (Integrated High Resolution Imaging Ground Penetrating Radar and Decision Support System for WATER PIPEline Rehabilitation), FP6, project no. 036887, (2006-2009) where TECNIC was responsible for the

assessment of the present (at the time of the inspection) and future deterministic structural condition of the inspected water pipes.

Moreover other older projects in which Tecnic was involved in damage assessment of underground utilities are: Utilnets (CTI et al. 1994), Tunneling (Tecnic et al. 1997) and Seislines (Tecnic et al. 1999).

Robo-spect project is not only representing a development of the core business of the Tecnic's activities but also a new strategy to propose at the clients a much more efficient method to analyse the structural performance of the old tunnel structures.

Exploitation strategy

The final exploitation strategy for Tecnic will be structured as follows:

- Business case, first in the domain of Robo-spect and then in adjacent domains; However the main target strategy of Tecnic is to present the developed deterioration models to different Utilities owning Road and Railway tunnels to provide them with information on the evolution and seriousness on the lining materials defects and to guide their rehabilitation planning techniques in a more efficient way.

- Study the business models of the targeted customers to analyse the possible solutions that will be most favorable for Tecnic and the partners. The consortium combines Research Organizations, Academia, SMEs, and large companies. These categories have different Business models and will develop and license different types of components with different licensing policy.

- The targeted market of the integrated System is the domain of tunnel inspection and assessment. However, the targeted market for the sensing and communication system is the civil infrastructure, including bridges, retaining walls, concrete pavements in highways and airfields, quay walls, air-plane hangars and high buildings.

- Tecnic is also ready to license and support commercial organization (including spin-offs) to commercialize the developed Modules as part of the integrated Robo-spect project.

- The organization that will support the marketing of the solution needs also to be defined.

- Finally the degradation module developed by Tecnic is not considered to be confidential.

Background

- Compliance with existing guidelines and standards while standardisation requirements, as identified in this work, will be brought to the attention of relevant European standardisation groups. The outcomes of the Robo-spect project will be presented to the European Tunnelling Societies and Technological Platforms.

- Study the market in tunnel/infrastructure inspection addressing the possible markets (with possible adaptations)

- Study industrialization roadmap(s), as well as, strategies towards the market and procurement schemes

Identification of the foreground

- Identification of the foreground of Tecnic;

- The TRL of the Robo-spect system at the end of the project must be accurately defined by the industrial partners. This means that the industrialisation effort to reach a product should accordingly vary. The exploitation plan will be, therefore, not limited to further research developments, but will also target important aspects towards the commercialisation of the project outputs.

Planned roadmap for exploitation

The Robo-spect industrialisation road map will address both the technical and non technical roadblocks for the integrated package and its components. It will contain road mapping towards obtaining the required standardisations, for providing to the proposed system additional functionalities (e.g., for the inspection and assessment of the functional behaviour of the tunnels) and additional markets (e.g., retaining walls, bridges, tall buildings), development of processes that are more trustworthy in the difficult conditions, better cost/benefit or price/performance ratios and an assessment of the time dependent evolution of the involved technologies while the above are happening. Similar projections and measures in road mapping will be developed for other components of the proposed tunnel system (e.g., lighting, fire equipments, air pollution devices and additionally the sensors with minor modifications to be made appropriate for the inspection of corrosion).

ROBO-SPECT Individual Exploitation Plan [ENPC]

Relevance of the project in the strategy of the entity

ENPC has been at the forefront in solving fundamental research problems in Computer Vision and Machine Learning. Applying this research expertise to solve new challenging real world vision problems is one of the key motivations to participate in the Robospect project. This participation also gives ENPC in particular and the entire Computer Vision community in general, a much more broader perspective on how to build effective intelligent Computer Vision systems, which can cater to / are robust enough to real world conditions such as variations in lighting, surface reflections and capturing technologies. This collaboration also gives an idea of what are the current problems in robotic vision and how the state of art computer vision systems can be better modeled to encompass these challenges.

Exploitation strategy

Being an academic institution, exploitation strategy for ENPC broadly speaking would first and foremost be Intellectual Property Transfer and secondly by pushing forward research for vision applications to robotic systems in the overall computer vision community. Technology transfer can be carried out by reaching out to end-users looking for technique's for defect detection in tunnels / underground rails and licensing them patents owned over the defect detection technology. For the second part, a further improvement in the overall performance of the system is planned before publishing the final results from the algorithm along with the tunnel defects dataset to a vision conference.

Background

ENPC brings with it a whole plethora of domain expertise, having knowledge of recent state of art techniques in computer vision and machine learning which is very much relavant to the task of autonomous defect detection in tunnels for Robospect Project. This comes from continuos participation and active publishing over the years in top computer vision and machine learning conferences like CVPR, ICCV, ECCV, NIPS and ICML. ENPC works on a wide range of vision problems including image classification, object recognition, saliency detection, image segmentation, deep learning and 3D reconstruction. Defect Detection in Robospect is a 2 fold process starting with classification of the type of defect followed by segmenting out the defect pixels in the image. Thus the background of ENPC is inline with the overall goal of Robospect.

Identification of the foreground

ENPC has build and successfully tested an Active Semi-Supervised learning algorithm to automatically classify and segment out defects in an image. A major advantage of using Semi-Supervised approach is that it allows using unlabelled data which is available in abundance as annotation of dataset is time consuming and expensive. Also, since good input features are essential for successful machine learning, ENPC has used some of the state of the art deep learning techniques to compute features for the defected images which are robust enough to translation, rotation and illumination changes and is very much needed in a real tunnel environment. ENPC has also been active enough in building up a real tunnel database with varied kinds of defect images captured from robot mounted camera's. This database has duly been annotated by expert structural engineers from Egnatia and hence can be used by entire computer vision community to build more effective and robust tunnel defect detection models in the future. ENPC has effectively integrated the software inside the Ground Control Station (GCS). The entire system has been successfully tested in real tunnel conditions thus attaining TRL 5.

Planned roadmap for exploitation

ENPC cannot directly participate in the commercial exploitation since it's a government funded academic institution focussed mainly upon academic teaching and research. However the defect detection technology is something which can be patented and the intellectual property can be transferred to interested commercial organizations working in the field of robotic vision for defect detection in tunnels. For example during the end-user workshop held in London, London Rails showed keen interest in the results from the defect detection and could be a potential client. The defect detection algorithm, being fully flexible, can be easily extended to other types of defects depending on the end-user requirement. It can also evolve over time by training with additional dataset from other kinds of tunnels thus making it more robust and generalizable to all sorts of defects that can be found in different kinds of tunnels.

ROBO-SPECT Individual Exploitation Plan [VSH]

Relevance of the project in the strategy of the entity

VSH is a unique test facility active in the entire field of tunneling, safety, testing, training and education. Many aspects of structural assessment and refurbishment are covered in the facility, tests and services provided at present and in the past include automated measurements, material tests, and system tests in order to prove system integration of single components.
The tunnels and caverns of VSH are an ideal testbed for the system integration made in Robo-spect. Relevance for VSH strategy is given by maintaining a holistic understanding of different stakeholder needs in the entire loop of tunnel inspection and maintenance. Further, references of research projects like Robo-spect give VSH a relevant voice in international associations.

Exploitation strategy

Being a test facility for construction things, Robo-spect amongst other research projects gives VSH experience needed for the development of R&D projects for clients. The knowledge gathered during Robo-spect, including the identification of difficulties with collaborating technologies does support the "requirements engineering" for R&D projects, where not necessarily the perfect performance of technologies in development is the first objective, but the identification of potential problems in "real construction life" and how to tackle them.

Background

VSH brought a wide range of expertise in system testing as well as requirements on inspection of underground facilities, tunnels for road and rail, and sewer systems. The international network of experts in relevant associations allowed for dissemination and organization of workshops in international congresses like WTC.

Identification of the foreground

Foreground for VSH is twofold

- The experience in system integration of a robotic inspection systems in relevant environments
- the use and development of latest technologies in structural assessment

Planned roadmap for exploitation

VSH will make use of Robo-spect experiences in future structural assessment work and test concept for the development of and training with new measuring devices.

ROBO-SPECT Individual Exploitation Plan [EOAE]

Relevance of the project in the strategy of the entity

EOAE is the company responsible for the operation of a large motorway tunnel network, 73 tunnels in operation, in the Egnatia Motorway network, with the latter crossing with some 1000km “horizontally” Northern Greece and through its vertical axes is linking neighbour countries and Europe to Asia.

As EOAE prepared and contributed to the carrying out of the successful field testing and benchmarked the ROBOSPECT integrated system, in tunnels of Egnatia Motorway, it knows better than any other the advantages and the drawbacks of the system to meet the operator’s, inspector’s and evaluator’s real needs.

Exploitation strategy

EOAE will be based on its experience gained from this project to provide its valuable and irreplaceable contribution to optimise the functional and basic technical specifications of any future development or upgrading of tunnel robotic systems, in the frame of new research projects or in the frame of new application projects. So the intellectual property of the benchmarking results of the integrated robotic system, developed in this project, can be transferred in the frame of future projects.

EOAE will also exploit the results of this project in upgrading its tunnel inspection methodologies, procedures and techniques by examining the introduction of automated tools in the inspection of its tunnels. One of its priorities will be to examine the possibility to develop a non robotic integrated system (conventional vehicle platform) which will be equipped with one or more of the components developed in this project, in order to carry out fast and accurate tunnel inspection, tunnel condition evaluation and tunnel structural assessment.
Finally EOAE will examine the use of a robotic integrated system in tunnel construction projects, where the needs of systematic monitoring and assessment are time and cost consuming.

5. BUSINESS MODELLING AND SWOT ANALYSES

8.1 Business Model Canvas for the ROBO-SPECT project

ROBO-SPECT, driven by the tunnel inspection industry, 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. Below a Business Model Canvas has been prepared for ROBO-SPECT providing an overview of the business: it's offering, infrastructure, market and finances.

Table 3. ROBO-SPECT Business Model Canvas

<table>
<tr>
<td rowspan="2"><u>Key Partners</u>

ROBO-SPECT consortium partners

Tunnel Operators

Tunnel Maintenance Teams

Consulting companies on tunnel surveillance and maintenance</td>
<td><u>Key Activities</u>

Semi-autonomous, robotic tunnel structural assessment

ICT solutions for tunnel sensing and assessment

Consulting to owners, operators and maintenance teams of tunnels</td>
<td rowspan="2"><u>Value Proposition</u>

Semi-automated tunnel structural assessment of reinforced concrete lining sections of tunnels.</td>
<td><u>Customer Relationships</u>

Cooperation with tunnel maintenance teams

Strong link to tunnel structural assessment personnel</td>
<td rowspan="2"><u>Customer Segments</u>

Owners of tunnel networks, Tunnel operators, Consulting stakeholders</td>
</tr>
<tr>
<td><u>Key Resources</u>

Access to tunnel environment

3D data of tunnel during construction</td>
<td><u>Channels</u>

Concept demonstrations to actual users of the system

System validation and evaluation at actual tunnel environments</td>
</tr>
<tr>
<td colspan="3"><u>Cost Structure</u>

Structural assessment personnel, tunnel inspectors, robotic system transportation costs.</td>
<td colspan="2"><u>Revenue Streams</u>

Manual tunnel assessment costs, whole tunnel shut-down for inspections etc.</td>
</tr>
</table>

8.2 SWOT analysis per component of the ROBO-SPECT solution

What follows is a preliminary SWOT analysis per sub-component of ROBO-SPECT under the framework of individual exploitation of each component.

8.2.1 The robotic platform itself and its navigation system

Robotic platform including navigation system			
Strengths	**Weaknesses**	**Opportunities**	**Threats**
Semi-Autonomous Navigation in tunnel environment	Partial closing of some lanes might be needed	Quick defect scanning of tunnel intrados	Low take-up from tunnelling industry
Customizable mission of inspection	Human operation might be needed during inspection	Overall tunnel structural assessment	No further technological uptake or support by stakeholders
Un-manned tunnel structural inspection			
Reduced down-time operation for tunnel			
Manual system operation			
Deep understanding of end-users needs and required services			
To the best of our knowledge nothing similar exists			
Already evaluated by end-users and optimised based on their feedback			

8.2.2 The articulated arm integrating the sensors (cameras, laser and ultrasound) and its control unit

Articulated arm integrating the sensors			
Strengths	**Weaknesses**	**Opportunities**	**Threats**
Precise movement of robotic arm and tip	Requires high precision calculation of crack coordinates from the computer vision system	Able to reach tunnel cracks at any visible point in tunnel	Might seriously depend on lower accuracy of robotic crane (that will be lower)
Precise positioning of ultra-sonic sensor on cracks	Tip not able to perform behind obstacles/cables or other equipment	Able to reach quite high positions in tunnel	Might lose track of crack due to low accuracy coordinates

	installed on tunnel		
Local 3D creation and trajectory calculations		Perform tunnel crack measurement with high accuracy	Missing position of crack during movement
Automated movement of robotic arm following crack coordinates			
Proper and precise positioning of sensing elements on/around tunnel surface			

8.2.3 The computer vision system

Computer Vision System			
Strengths	**Weaknesses**	**Opportunities**	**Threats**
Autonomous crack detection in real-time	Might be slower in high precision mode	Crack detection on tunnel surface	Might needs pre-training on tunnel surface to increase accuracy
Off-line defects detection and classification	Not sufficient amount of data currently exists	Defect detection on tunnel surface	
Draft measurement of crack during scanning (lower precision)			
3D creation of the defective area			
Not affected by light conditions on tunnel			

8.2.4 The 3D laser system

3D laser scanning system			
Strengths	**Weaknesses**	**Opportunities**	**Threats**
3D creation of tunnel	High capturing time in	3D capturing of tunnel	-

slice	high-accuracy mode	slice	
Configurable angle of scanning		3D capturing of whole tunnel	
Adjustable accuracy level			
Ability to capture whole tunnel in 3D with 2mm precision			

8.2.5 The robot Ground Control Station

Ground Control Station			
Strengths	**Weaknesses**	**Opportunities**	**Threats**
Mission control preparation	Requires full end-to-end communication with the robotic system	Remote robotic system direction	No communication means with robotic system in old tunnels. An ad-hoc solution needs to be provided with the system.
Ability to modify mission before/during inspection		Mission preparation with inspection details	
Full controlling of robotic system			
Remote robot management (co-located application)			

8.2.6 The structural assessment system

Structural Assessment System			
Strengths	**Weaknesses**	**Opportunities**	**Threats**
Structural assessment of whole tunnel	On-line and off-line processing of data captured	Consolidated capturing, displaying and processing/classification of tunnels' defects	Low take-up from tunnelling industry
Consolidation of tunnel	Not sufficient amount	Ability to detect events (cracks or other)	No further technological uptake or

defects	of data currently exists	escalations in future	support by stakeholders
3D representation of tunnel with pins on defects		Organisations that could potentially host the software already identified	Inability of end-users in providing initial cad data (will be of lower accuracy anyway)
User interface for tunnel inspector/operator			
Evaluated system by end-users	Needs numerous end-users feedback to achieve higher impact		

6. CONCLUSIONS

This document provides the exploitation plan for the ROBO-SPECT project. It covers the exploitation strategy, both general (consortium exploitation) and individual.

From a technological point of view, a lot of interesting results have been achieved and are directly usable in the industrialisation processes. The system integration around the GCS has been achieved successfully and meets the requirements and procedures of the end-users.

The domain where the distance between the ROBO-SPECT demonstrator and the product is the greatest is the platform itself. The ROBO-SPECT system should be adaptable to various types of platforms. So an important effort should be done for a better independency from the hardware.

The end-users that would buy this type of system would expect a long lifetime for it (combination between the information system and the inspection tools). An order of magnitude of 20 years is fair. In 20 years, there will be many generations of robots and sensors, so the system needs to integrate these changes without major re-work and/or re-design.

Due to the numerous cycles of inspection/maintenance, the business model of contracting operators for one-shot inspections cannot be envisaged. So the direct procurement is the most adequate solution. In this case however, the system needs to have a sufficient operational tempo (the customer needs to operate it frequently to amortise the procurement costs) and is therefore targeted towards end-users managing an important number of tunnels.

Most of the end-users that manages tunnels are also managing road/railways that go through these tunnels and bridges. So the limitation of the system to tunnels is obviously considered as a drawback by end-users. The extension of the system to the inspection of other structures would be an important plus and would make it more affordable/attractive.