NIC 2018 -RRES Project Progress Report 2

26th December 2018

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ULC Robotics

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Contents

Document Control

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1 Executive Summary

The purpose of this document is to report on the progress the project has made since the last submission on the 5th September 2018. The report contains a summary of the progress made from SGN, with subsequent reports from ULC Robotics as the principle project partner.

RRES is an innovative and advanced robotic system which will be designed to improve existing methods of excavation, repair and maintenance operations performed daily at SGN and the other GDN's. The objective is to reduce the excavation size, costs, labour and equipment while making the work safer.

Since the last PPR, the two key deliverables that have been achieved are the sourcing of the vendor for the robotic arm and the mobile platform. The content of this report and the identified project progress, aligns with the project plan conveyed in the submission.

Notable Achievements to date in the project are:

- Sourced Vendor for Robotic Arm. After a Robotic arm Research and Evaluation exercise the product from the most effective vendor has been procured.
- Delivery of Computer System Specification Document. The document demonstrates the system architecture for managing the flow of data and commands between different components of the system.
- Sourced vendor for Mobile Platform. Development efforts were carried which ensured proper selection of the mobile platform.

This report has been written in accordance with the NIC Guidance Document.

2 Background

The goal of the project is to develop a prototype RRES system that can demonstrate automation of the excavation and reinstatement process and the installation of a Universal Access Fitting (UAF). Two field tests will be executed: one on dead pipe and the following one on a live gas main. Collectively, the two field tests will demonstrate the following:

(a) Transport and setup of the RRES (including a vehicle and a mobile platform with a robotic arm and excavation sensors/tooling)
(b) Removal and reinstatement of asphalt, concrete and soil
(c) Soil vacuum excavation in urban and rural environments
(d) Prevention of damage to buried assets throughout the excavation process
(e) Detection and avoidance of other buried objects
(f) Exposure of the target pipe for operations
(g) Preparation of a low pressure distribution pipe for UAF installation
(h) Installation of the UAF on a low pressure distribution pipe

Element 1 of the project focuses on the selection and development of the robotic arm, mobile platform, a below-ground sensing module, excavation tooling, and the computing platform needed to command and control the RRES.

The subsystems to be developed under Element 1 have been categorized into three main groups: Excavation, Sensing and Deployment System.

1- Excavation

Conventional excavation, when compared with the RRES, requires a much larger excavation to allow direct access for operatives to carry out repairs or install fittings. Due to the larger excavation footprint and the amount of gas and third-party plant exposed within them, the risk of damage is high. If there is too much third-party plant in the excavation, the process must be carried out manually by the operatives using hand tools. This process is time-consuming, physically taxing and carried out in hazardous environments. The RRES core removal technique, 'soft-touch' excavation capabilities and automated above ground tooling will significantly reduce the footprint of the excavation and the risk to third party damage.

2- Sensing

Prior to starting excavation, and during the excavation process, the robot operation will utilize sensors to scan in "layers" to identify buried assets in its excavation path.
To better focus research and development efforts, the sensing operation is broken down into two main categories of sensors. (1) Pre-Excavation Sensing and (2) Post Excavation Sensing

Pre-Excavation Sensors will be used to scan the roadway above the excavation zone prior to cutting the road surface to identify utility lines and other obstructions in the first layer of the work path. Although not a focus, ULC will also review sensors that may be used with the system increase the accuracy of robotic operations in target location.

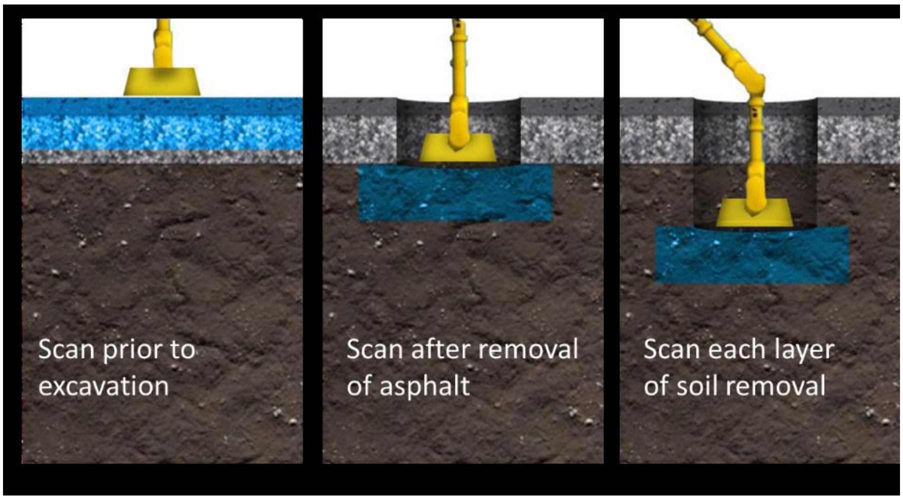

Figure 1 - Below-Ground sensing conducted in layers throughout the excavation process

Post-excavation sensing system can be used after every stage of excavation to create a point cloud and texture model of the bottom of the keyhole. A point cloud is a set of data points which represent points in 3D space and can be used for measurement, navigation and to generate accurate 3D models of environments. Point clouds are generally produced by 3D scanners, which measure a large number of points on the external surfaces of objects around them.

3- Deployment System

The deployment system consists of the robotic arm, the mobile platform and the computing system that carries out all robotic operations. To properly identify, develop and specify different components for the system, and to design the most optimal deployment method, preliminary specifications and capabilities required to perform each of the operations have been defined. These specifications will be adjusted based on the new findings from site visits as well as the feedback from SGN.

3 Project Managers Summary

Since the submission of PPR 1, the project has progressed as planned with substantial development in deployment system. After a technical analysis to determine the specification required for RRES, the vendor of the robotic arm and the mobile platform have been sourced. Furthermore, the computer system specification has been structured which outlines the system architecture for managing the flow of data and commands between different components of the system.

Robotic Arm

After an in depth review of the market leaders of robotic arms, thirteen promising arms from four high ranking manufacturers were considered for potential purchase. According to the latest robotics industry report, these companies have the highest rank among industrial robot arm manufacturers based on the quality and versatility of their products. In order to properly select the most suitable product for the project seven criteria were selected for the evaluation of each robotic arm. The criteria included; payload, mechanical weight, angular speed and working range angle. Each arm was analysed against the different criteria's and ranked accordingly. Based on all the assessments, the product IRB 6650S from the supplier ABB was selected which will cater for all requirements that RRES needs. The arm is capable of full vertical and horizontal stroke motion as well as an increased forward and downward reach. This robot arm is one of the very few robotic arms that are theoretically capable of lifting a 200kg concrete core. [redacted]. These capabilities will enable more control, greater sensitivity during operations and will provide the ideal platform to develop the RRES technology and end efforts.

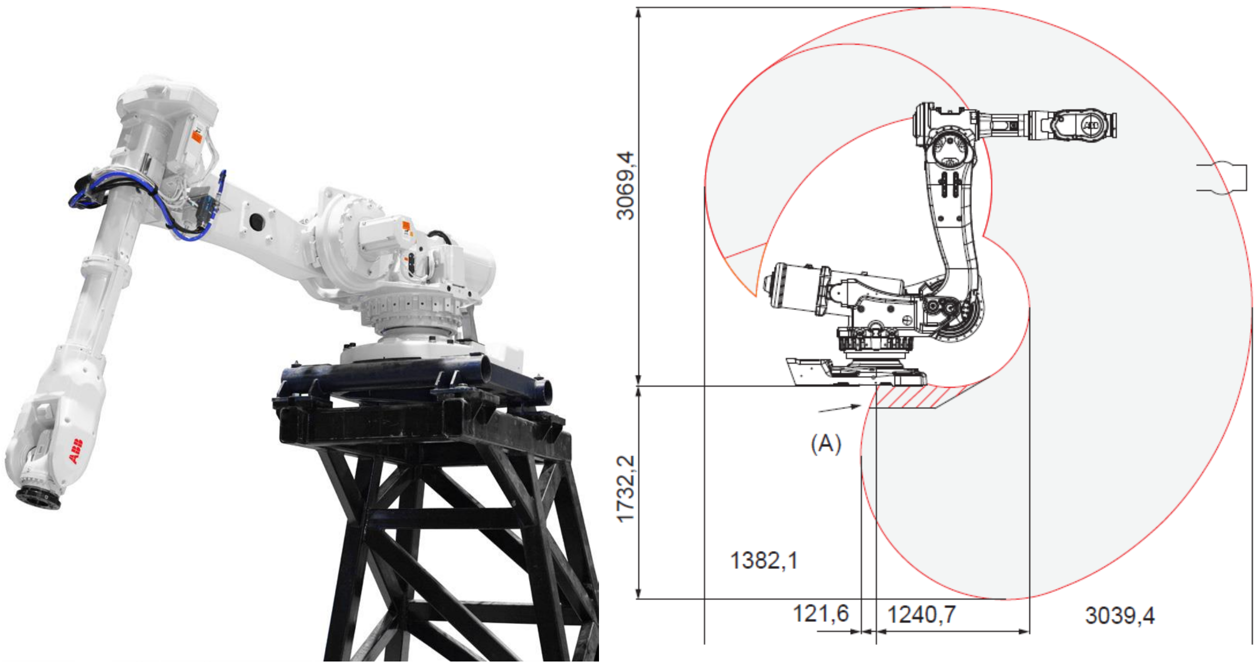

Figure 2 - The ABB 6650s and the arms span can be seen above

Mobile Platform

As the robotic arm, suite of tools and on board computer system will be mounted onto the mobile platform, it was vital that the design of the platform was compact and practical. ULC Robotics conducted a series of mechanical analysis and design tasks to appropriately size the system such that it can accommodate all required system components and operate safely. Different designs were evaluated to ensure the RRES would be compact enough to fit on a trailer bed, whilst able to maintain its design and structural integrity under the systems anticipated payload. [redacted]

Figure 3 - Compact Design of the Mobile Platform – (Top Left) Side View (Top Right) Bottom view of the system, (Bottom Left) Isometric View of the system with a portable tool changing rack at the operation site (Bottom Right) Top view of the system with a portable tool changing rack

During the design process the list of the components on the mobile platform was finalised which can be seen in table 1 with their estimated loads.

[redacted]

By estimating the load the mobile platform would have to transport quickly and effectively, we were able to analyse the stability of the different designs whilst stationery and moving. By performing a static and dynamic load analysis it was determined that the platform does not lose its stability even in the worst case scenario where the arm is outstretched whilst rotating at its max rotational velocity.

In order to properly select the most suitable mobile platform for the project, four criteria were selected for evaluation of different products:

1- Track Length - [redacted]

2- Payload - [redacted] This is far below the typical payload threshold of the track systems available on the market. Driving up an incline also would not be an issue.

3- Drive System - The standard drive system for track undercarriages is hydraulic motors. Advantages of hydraulic motors are mostly confined to performance, where they are capable of providing more power than electric motors. [redacted]

4- Track Material - The options for the materials of the tracks include steel, polyurethane and rubber. Steel is considered the industry standard but may damage conventional road surfaces. Polyurethane is primarily meant for soft surfaces and tends to slip on hard surfaces. Rubber tracks are typically not suitable for smaller applications such as RRES and are usually for heavy-duty jobs and higher payloads.

[redacted]

Based on the requirements of the project, we conducted a global search for mobile platform manufacturers and high potential products that could be used for the RRES project. Promising vendors were contacted to acquire more information about their products. Although all six vendors analysed had products that could be used in this project, only three were willing to provide custom solutions and engage in technical conversation for potential purchase of a single unit.

[redacted]

[redacted]

Control System

A computing system will be developed for the RRES to handle various forms of data input, process information, facilitate communication between subsystems, and orchestrate the different operations performed by the system. Software will be developed and is anticipated to include a graphical user interface, communications modules, a database, and report generation capabilities.

Based on RRES' current anticipated computing needs, we require three main computers:

1. Data Acquisition Computer: Responsible for communication will all the sensors that collect data from the ground or different components of the robot.

2. Data Processing and Visualization: Responsible for filtering and processing all the raw data collected from the sensors and turn them into meaningful visual features for the operator to use and interact with.

3. Navigation, Localization and Control of the Robotic Arm: This computer will be responsible to communicate with different aspects of the robotic operation such as control and navigation of the moving platform or sending commands and receiving feedback from the robot arm for articulation of the end-effector.

4 Future Progress

The table below lists the key stages and deliverables for Element 1 until our next progress report:

Milestone	Description	Due Date
Computing system specification document and documentation of system design.	Order commercially available and custom electronic components for RRES on board computing and communication (PD4)	26/12/2018
Documentation of sensor/camera research	Procure below-ground sensors and cameras for shop testing	08/01/2019
Documentation of excavation tooling mechanical and electrical design	Source and fabricate excavation tooling components	05/03/2019

Table 2 – Summary of Future Progress till next PPR

5 Business Case Update

No developments have been made to the business case as of yet.

6 Progress against Plan

The project has progressed as outlined in the RRES submission. The Gantt chart shown in figure 5 shows the project plan for Element 1.

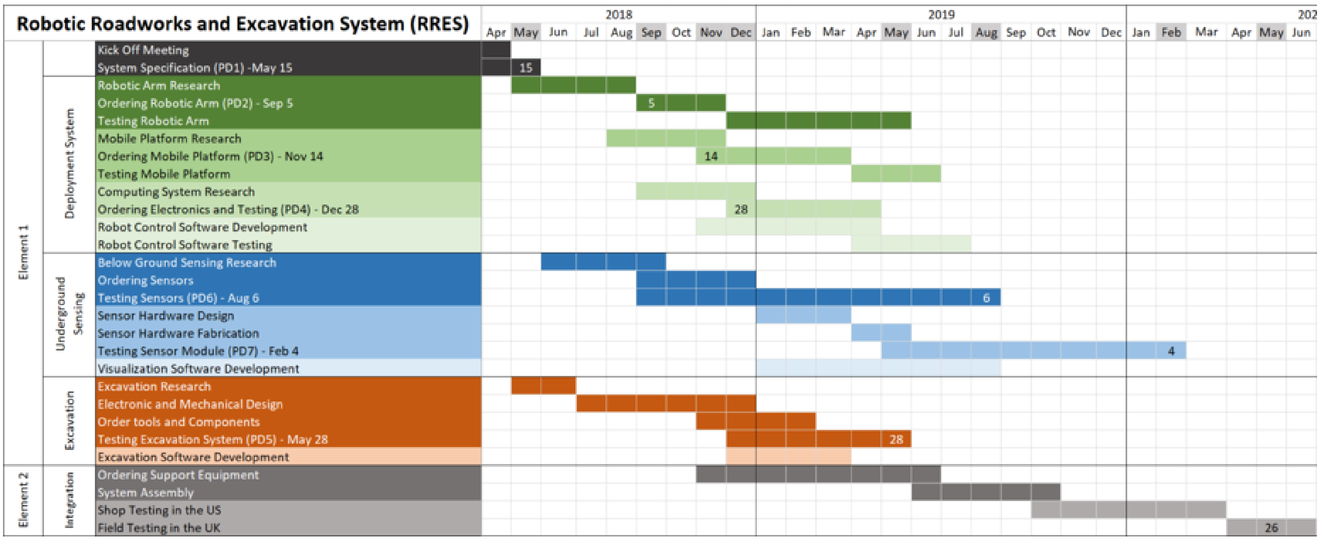

Figure 5 – Element 1 Project Plan

The key deliverables over the period from PPR 2 to our next progress report are highlighted below:

Milestone	Title	Description	Planned Date	Delivered Date
5	Source vendor for robotic arm	**Progress Report 1** robotic arm research and evaluation	09/05/2018	09/05/2018
6	Develop computing system specifications	Computing system specification document	30/10/2018	30/10/2018
7	Source vendor for mobile platform	Summary of mobile platform research and evaluation	14/11/2018	14/11/2018
8	Order commercially available and custom electronic components for RRES onboard computing and communication	**Progress Report 2** Computing system specification document and documentation of system design	26/12/2018	26/12/2018
9	Procure below-ground sensors and cameras for shop testing	Documentation of sensor/camera research	08/01/2019	On Target
10	Source and fabricate excavation tooling components	Documentation of excavation tooling mechanical and electrical design	05/03/2019	On Target
11	Develop software for excavation tooling	Documentation of software development for excavation tooling	25/03/2019	On Target
12	Complete mechanical and electrical design of sensor module	**Progress Report 3** – Sensor module design documentation	02/04/2019	On Target

Table 3 – Summary of key stages and deliverables

7 Progress against Budget

As the project has progressed as planned, the total expenditure to date is £1,999,975 with a further £177,280 set to be released after review of the latest milestone. The Computing system specification document and documentation of system design will be reviewed, and payment will be processed once approved.

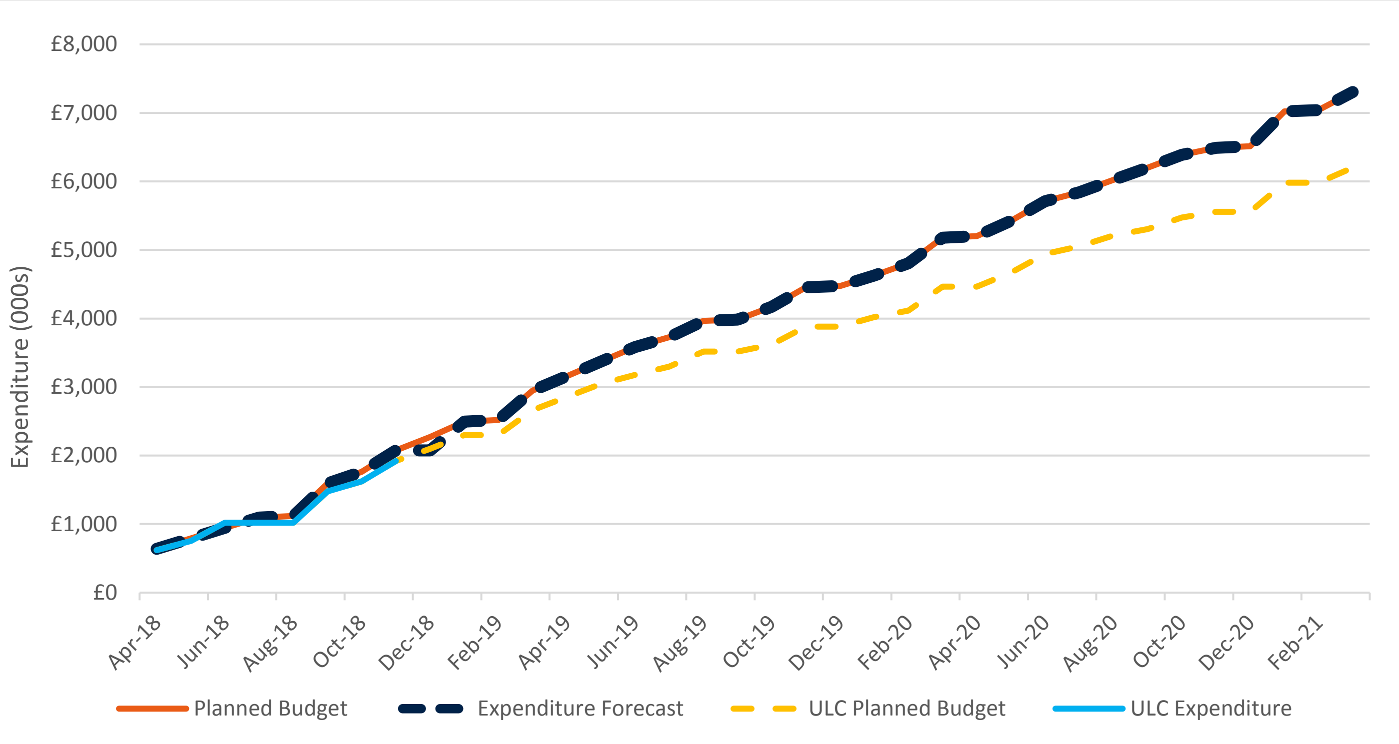

Figure 6 –Summary of financial progress

The key project deliverables are attributed below:

Milestone	Title	Main Project Achievements	Amount	Project Total	Status
5	Source vendor for robotic arm	✓ Design and build of an excavator head with pneumatic rotary motor ✓ Design of a test area with compacted clay for testing the excavator head ✓ Engaging robot arm manufacturers for evaluation of different products ✓ Static and dynamic load analysis for proper selection of robotic arms ✓ Simulation of robotic arm operations ✓ Procurement of a robotic arm from ABB for the project ✓ Design of a CNC machine for testing cutting tools	457,975	£1,476,834	Paid
6	Develop computing system specifications	✓ Air nozzle design, prototyping and testing ✓ Flow calculations on the VacEx unit ✓ Evaluation of alternative techniques for soil removal ✓ Testing EM sensors in the test environment built for below ground sensing ✓ Finalization and procurement of below ground sensors ✓ Procurement of cameras for stereo vision and mapping ✓ Development of an image processing technique for localization and mapping (SLAM)	147,734	1,624,567	Paid

		✓ Development of a specification document for the computing system			
7	Source vendor for mobile platform	✓ Engagement with mobile platform manufacturers ✓ Engagement with MTC on study relative to sensors and robotic arm tool changers ✓ Integration of GPU into stereo vision point cloud generation ✓ Detailed design of the CNC machine and ordering custom designed parts ✓ Design of a chainsaw for cutting the road surface ✓ Static and Dynamic load analysis for proper selection of the mobile platform ✓ Simulation of the robotic arm operation ✓ Conceptual design of the system as a whole with different tools and sensors	295,467	1,920,034	Paid
8	**Progress Report 2** Computing system specification document and documentation of system design	Order commercially available and custom electronic components for RRES onboard computing and communication	177,280	2,097,314	Awaiting Approval
9	Procure below-ground sensors and cameras for shop testing	Documentation of sensor/camera research	£204,349	£2,301,665	On Target
10	Source and fabricate excavation tooling components	Documentation of excavation tooling mechanical and electrical design	£181,289	£2,482,953	On Target
11	Develop software for excavation tooling	Documentation of software development for excavation tooling	£182,610	£2,665,563	On Target
12	**Progress Report 3** Sensor module design documentation	Complete mechanical and electrical design of sensor module	£190,398	£2,855,962	On Target

Table 4 – Summary of delivered and planned milestones

8 Project Bank Account

The statements for the transactions of the bank accounts for the NIC funds over this reporting period are available in appendix B.

9 Project Milestones

In addition to the milestones completed as per PPR 1, there has been a further 3 milestones delivered. The subsequent reports have been submitted to SGN and are available on request.

Source vendor for robotic arm:

The purpose of this report is to demonstrate the development efforts that have been carried out since the beginning of the project for proper selection of the robotic arm as well as criteria that were taken into consideration for selection of the right vendor and product.

Develop computing system specifications:

In this report, we demonstrate the system architecture for managing the flow of data and commands between different components of the system.

Source vendor for mobile platform:

The purpose of this report is to demonstrate the development efforts that have been carried out to ensure proper selection of the mobile platform.

10 Learning Outcomes

The main outputs of this project are the technical and engineering knowledge gained whilst researching new methods to excavate the road surface. Therefore it is essential that learning opportunities generated by this project are successfully disseminated for GB GDN's, the wider gas community, national and international standard bodies, academia, local authorities and other key stakeholders. Learning will be disseminated so that the technology can be incorporated by all GB GDNs upon successful completion of the project.

At present a large proportion of the design work and specification can't be shared with external parties due to the IPR conditions concerning the design. Dissemination of this information prior to patent approval could jeopardise the commercial aspects of the system, and impact on the financial return to the GB gas consumer and SGN. This has been factored in to the Stakeholder engagement plan, with the majority of key events planned after the expected approval date of the patents. An update on the IPR conditions of the project can be found in section 12 of this report.

Key Learning Outcomes
Research into mobile platforms and application of equipment and technology
Research into robotic arm market was evaluated with the requirements of RRES
Development of the Data Acquisition system that will collect data from below ground and navigation sensors to collect, process and interpret data
Development of the control system that will orchestrate the different operations performed by robotic arm
Internal Dissemination
Publication of RRES website and update on company blog– so colleagues can access information
RRES email address – to provide a direct line of communication to the project team
Innovation piece in company team brief to inform the wider business
External Dissemination
LCNI Conference – SGN's Project Manager spoke on the outline and progress of the project. Also, SGN's stand had RRES as part of the backdrop where the project team could talk to interested parties from the Gas and Electric industry.
IGEM Annual Conference - ULC's Vice President of UK operations presented scope of project to the gas industry, under Environment and Low Carbon theme.
RoboBusiness Conference – ULC's Project Manager presented RRES at the Robotics Industry event to share how RRES aims to tackle the conventional dangerous excavation method.

Table 5 –Summary of Key Learning Outcomes and Dissemination

11 Dissemination

Dissemination has progressed in both the US and UK. The project team attended the LCNI conference along with the rest of SGN's Innovation team. The event allowed the RRES team to showcase the project overview and an info-film to reach out to a wide range of stakeholders throughout the energy industry. Oliver Machan was an allocated speaker where he presented the project overview and updated of the current status of the project to the interested parties.

Figure 8 –RRES Engagement at LCNI

12 IPR

In accordance with the Gas Network Innovation Competition Governance Document, ULC Robotics will report on intellectual property rights (IPR) being pursued for the project. In this reporting period, ULC Robotics does not have any IPR to report on. Additional filings are anticipated next year when the final design of several key parts of the system is completed.

13 Risk Management

The live risk register that identifies risks and scores them appropriately is attached in appendix C. Notable updates to risk register are shown below:

Limited Below Ground Detection Capability

The sensor suite is unable to detect all buried objects due to varying object types and sizes, sensor capabilities, and depth of excavation additional process may need to be added to the operation of the RRES which could increase the time and cost of the operation.

In order to maximize below ground visibility prior to excavation a variety of sensors have been identified to be used for below ground sensing. Using a variety of technologies will decrease the dependencies on a single sensor; decreasing the likelihood of the risk.

Truck Size Exceeds Maximum Size Limit

All of the necessary tools, sensors, mobile drive platform with arm, operator control station, support equipment and other accessories need to be transported to site in a vehicle which maintains a minimal site footprint and comply with UK highway vehicle regulations.

During the selection process of the robotic arm and mobile platform, the allowable truck size for deployment of the system to the size was taken into account. However since the entire system has not been designed and built this risk item has not been eliminated yet.

A Commercially available Robotic Arm Cannot Meet project Specification

ULC will identify and purchase a commercially available robotic arm to perform the excavation, pipe preparation, and installation of the UAF. If there isn't an arm that can complete all operations for the budgeted value there is a risk to the project budget and scope.

In order to select the right robot arm for the operation, the most load and torque demanding parts of the operation were identified and the robotic arm was selected to meet the project specifications. 3D simulation of robotic operation has been used to validate the capabilities of the arm for RRES project.

14 Accuracy Assurance Statement

The commercial and technical deliverables associated with this project are progressing on time and within budget. We confirm that we are following relevant SGN process and procedures in order to ensure that the information provided within this report are accurate and complete at the time of writing.

15 Material Change Information

No material change has occurred.

Appendix A - Additional Reports

Below are the milestone reports that are available on request:

- Robotic arm Research and Evaluation Document
- Computer System Specification Document
- Mobile Platform Research and Evaluation Document

Appendix B - Bank Statements

[redacted]

[redacted]

October to December

[redacted]

[redacted]

Appendix C - Risk Register

Ref No	Risk	Business Risk	Inherent Risk			Controls & Mitigation	Owner	Anticipated Date for Retiring Risk (DD/MM/YYYY)	Residual Risk		
			Likelihood	Impact	Score				Likelihood	Impact	Score
1	**Project Team Resource Requirements** There is a risk that ULC Robotics and SGN will not be able to hire personnel in time for the project start date. *SGN have decreased the risk of resources by hiring a designated officer to the project.*	Time / Financial	3	3	**9**	A - Generate requisitions and start hiring as soon as bid is approved. B - A 6-month lag between project award announcement and project start date to allow time for the required resource to be found and appointed before the project starts. C - ULC has an option of moving resource from other projects or utilize additional resource available at the MTC.	ULC, SGN	01/04/2018	1	3	**3**
2	**Challenges with Single Arm-to-Toolhead Interface** IF a single robot arm-to-toolhead interface design cannot accommodate all end effectors due to variations in toolhead size, weight, power, and technical complexity, it may result in increased operational complexity.	Time / Financial / Technical	3	3	**9**	A - Development of the preliminary arm-to-toolhead interface specification has been scheduled to accommodate estimated toolhead specifications. B - Design, development, and testing of tools to be reviewed by robotic arm expert for feedback and modification of the design.	ULC, TSP	28/05/2019	1	3	**3**
3	**Limited Below Ground Detection Capability** The sensor suite is unable to detect all buried objects due to varying object types and sizes, sensor capabilities, and depth of excavation additional process	Technical	3	5	**15**	A - Soft touch excavation tooling will provide additional safety redundancy to support risk mitigation. B -Initial research has been carried out in early concept phases of the project to identify the sensor types available which meet the current	ULC, SGN, TSP	02/02/2021	1	3	**3**

	may need to be added to the operation of the RRES which could increase the time and cost of the operation.					requirements. C - Build a test environment that simulates the variations in the relevant ground conditions and buried infrastructure. D - Consult with sensor vendor and develop additional sensor data processing techniques to improve buried object visualization.					
4	**Truck Size Exceeds Maximum Size Limit** All of the necessary tools, sensors, mobile drive platform with arm, operator control station, support equipment and other accessories need to be transported to site in a vehicle which maintains a minimal site footprint and comply with UK highway vehicle regulations.	Time / Financial / Technical	2	5	**10**	A - Create 3D model of truck with sensors, tools and mobile platform. Develop layout and operator control workstation volume mark out. Determine estimate of size requirements. B - Design modifications to truck to increase storage volume and develop alternate mounting concepts. C - Evaluate low utilization tools, sensors and support equipment and consider transporting them to site only on-demand. D - Review vehicle specification requirements for the target areas of operation and the potential to separate out support equipment into multiple small vehicles instead of one larger one.	ULC, SGN, TSP	16/03/2021	1	4	**4**
5	**Field Trial Location Challenges** Suitable field trial locations for initial controlled testing, urban and rural sites cannot be found.	Time	2	2	**4**	A - SGN to carry out a review of criteria and identify multiple site locations which could be used for the trial. C - SGN and ULC to survey potential sites to determine suitability well in advance of the trials	ULC, SGN,	02/08/2021	1	2	**2**

						B - Engagement sessions with local authorities will be carried out in advance of the trial to ensure relevant stakeholders are supportive of the project and trial requirements.					
6	**A Commercially available Robotic Arm Cannot Meet project Specification** ULC will identify and purchase a commercially available robotic arm to perform the excavation, pipe preparation, and installation of the UAF. If there isn't an arm that can complete all operations for the budgeted value there is a risk to the project budget and scope.	Time / Financial	3	4	**12**	A - Develop the operational strategy, tool specifications and end effector specification early when developing robot arm requirements. B - Consider options for increasing the capabilities by using other strategies such as multiple arms, end-effectors with increased degrees-of-freedom, robot arm support mechanisms to withstand larger loads etc.	ULC	12/05/2020	2	4	**8**
7	**Suitability of UAF for live gas installation** If the UAF design and installation procedure doesn't meet the required industry standards or performance criteria there is a risk its use on live gas infrastructure will not be approved.	Technical	3	4	**12**	A - The relevant design and performance specification and designs will be identified and influence the UAF design. B - A test criteria will be agreed and extensive shop testing will be performed using field pipe of various conditions. C - An independent review of the fitting will be carried out and the process for the application of relevant industry approvals will have begun.	ULC, SGN, TSP	27/10/2020	2	3	**6**

8	**Use of the RRES does not meet SGN's Safety Management Framework Requirements (SMF)** If SGN does not provide approval for the RRES to operate in a field test due to inability to meet SMF requirements, the RRES design or operation may have to be modified, resulting in increased cost and time.	Financial/ Technical	3	3	**9**	A - The SGN Project Steering Group will contain leads from the Engineering Policy, Safety Health & Environment and operations to influence the development process and ensure the design meets all safety requirements. B - Engage with SGN Policy and Safety leads and consult with industry bodies including Ofgem and HSE to ensure all requirements are met. C - SGN will appoint an independent Technical Service Provider with a detailed understanding of industry requirements to review the development process.	ULC, SGN, TSP	27/04/2021	1	3	**3**
9	**RRES Usage is Limited Due to Component Compatibility with Hazard Area Requirements** Once the system has been conceptually designed a review will be carried out to assess its suitability for key components use in all of the target environments. If the specification does not meet the requirements of the review or control measures are required it could cause a delay to the project and additional cost.	Financial/ Technical	3	5	**15**	A - Incorporate a safety review process into the design of each component. Develop a checklist for collaborative design reviews with the project team. B - Incorporate a safety risk management program that identifies, assesses and mitigates safety risks. C - An independent review will be carried out by the technical Service Provider at key stages of the project to identify risk as they become apparent.	ULC, SGN, TSP	11/05/2021	1	5	**5**
10	**Scope Creep** If agreed system requirements or the agreed project scope changes late in the project the cost and time	Financial/ Technical	2	3	**6**	A - ULC and SGN collaborate and finalize the specifications. B - SGN will create a Project Steering Group with leads from key areas of the business.	ULC, SGN, TSP	30/10/2018	1	3	**3**

	needed to complete the project could increase.					The key component specification will be agreed with all members before being finalized to ensure all requirements have been met to mitigate the risk of any changes to the specification being requested later in the development process.					
11	**Communication between Project Team** Communication channels between the project team who are spread across the UK and USA at different time zones cannot be maintained.	Time / Financial	2	4	**8**	A - Face-to-face meetings for key stage gate deliverables B - Use of virtual meeting center and secure file share C - Regular interface meetings with the project team	ULC, SGN, TSP	27/10/2020	1	4	**4**
12	**Vendor Supply** Sub-contractor manufacturers and supplier delays could affect the overall schedule.	Time / Financial	3	4	**12**	A - Review project plan if required for sourcing sub-contracted vendors B - Engage a number of different suppliers to ensure continuity of supply where possible.	ULC	15/04/2021	2	4	**8**
13	**Stakeholder Opposition** A negative customer and wider industries perception of the project could cause issues with obtaining the necessary approvals for access to trial sites and impact wider industry acceptance of the technique.	Reputation	1	4	**4**	A - Implement and maintain a stakeholder management plan. B - Input from the SGN Regulation and Corporate Communications Officer to ensure high level of engagement with customers as early as possible. C - Presentations at industry events	SGN, ULC	02/03/2021	1	4	**4**
14	**Logistical Challenges** There is a risk that customs and shipping difficulties could delay deployment of the system to the UK from the US.	Time / Financial	2	3	**6**	A - Additional shipping time has been including in the project schedule for shipping and customs. B - Controlled testing facilitates will be identified to allow final preparations works to take place in the geographical area of	ULC	15/04/2021	1	3	**3**

						SGN's network, allowing the system to be shipped ahead of the live field trial with limited impact on the test schedule.					
15	**Poor RRES Market Uptake** If the RRES market uptake is poor, the full value of the RRES as described in the cost-benefit analysis may not be realized.	Financial	1	4	**4**	A – Distribute customer and stakeholder questionnaires to ensure that customer needs are being addressed B – Design of soft-touch excavation tooling and below ground sensing systems will be evaluated for use without the use of robotics so as to enable operation and commercialization without the use of a robotic arm C – Disseminate Interface Control Drawing (ICD) for open-source tooling to enable maximum market size potential through alternative application development D – Continue to seek out project partners in the utilities and industrial sectors	SGN, ULC	TBD	1	3	**3**
16	**Low RRES Utilization** If the RRES utilization is low, the cost per excavation will continue to increase and the full value of the RRES outlined in the cost-benefit analysis may not be realized.	Financial	2	4	**8**	A – Design control algorithms for mobile platform and toolpath generation such that the size and shape of excavations that can be performed is maximized B – Disseminate Interface Control Drawing (ICD) for open-source tooling so as to maximize the number repair and inspection operations which can be performed on excavated infrastructure	SGN, ULC	TBD	1	3	**3**

17	**Project Delivery** There is a risk that the project scope cannot be delivered within the allocated budget and schedule.	Time / Financial	2	3	**6**	A – Use a phased approach to project planning with go/no-go milestones such that the project can be revaluated upon completion of key milestones and terminated if needed B – Maintain a prioritized list of potential scope reductions that can be exercised if needed (e.g. elimination of automated tool changing, UAF installation tooling, etc.); C - Pursue funding from alternative sources such as customers in industrial markets or venture capital firms	SGN, ULC	TBD	1	3	**3**