NIC 2018 - RRES

Project Progress Report 6

31st March 2020

Oliver Machan – NIC RRES Project Manager

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Contents

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Version Control

Version	Status	Date	Owner	Action
V0.1	Draft	26/03/20	Gordon McMillan	Initial draft
V0.2	ULC Review	27/03/20	Ali Asmari	Review
V0.3	PM Review	30/03/20	Oliver Machan	Final Draft
V1	Final	31/03/20	Oliver Machan	Published

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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 26th November 2019. The report contains a summary of the progress made from SGN, with subsequent reports from ULC Robotics as the principle project partner. Also, the planned progress and the key milestones to be delivered over the next PPR period is included.

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, we have integrated the subsystems with the robotic arm and testing of RRES' sensing and excavation technology has continued. The learning generated through these tests are being fed back into the design and operation. Furthermore, development of the supporting equipment including the Universal Access Fitting (UAF) and the Automated Tool Changer has commenced. Below is a list of the major achievements by the development team during this period of the project.

- Integration of RRES arm with sensing, excavation and deployment subsystems to assemble the prototype
- Testing of the integrated prototype within medium compacted dense clay
- Design and build of the mock roadway for testing the sensors
- Develop specifications for tool changing method and system
- Develop UAF specification for target pipe material and diameter
- Technical assessment of Element 1 has been validated by our technical service provider

Due to the disruption caused by the COVID-19 virus, we have decided to postpone the shipment of the robotic prototype to the UK for the Interim field testing. To ensure that no time is lost on development, we will bring future milestones forward and delay the interim field trail till 2021. Furthermore, with utility Week Live 2020 being postponed till November, we have updated our engagement plan to ensure that engagement is maintained in this time of uncertainty.

The content of this report and the identified project progress aligns with the project plan conveyed in the submission although some of the above developments will appear in the preceding PPR following engineering document approval.

2 Background

Utility excavations are necessary to inspect and maintain buried infrastructure, but are disruptive, labour-intensive and can lead to unintentional damage to neighbouring plant. Reducing the requirement for extensive safe digging practices could significantly reduce both the social cost of works and associated emissions. By combining cutting edge robotics, advanced custom tooling and artificial intelligence, RRES will improve existing methods of excavation, repair and maintenance operations performed daily within the utility sector.

Figure 1 - Components of RRES

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

The project is arranged around the development of the following elements:

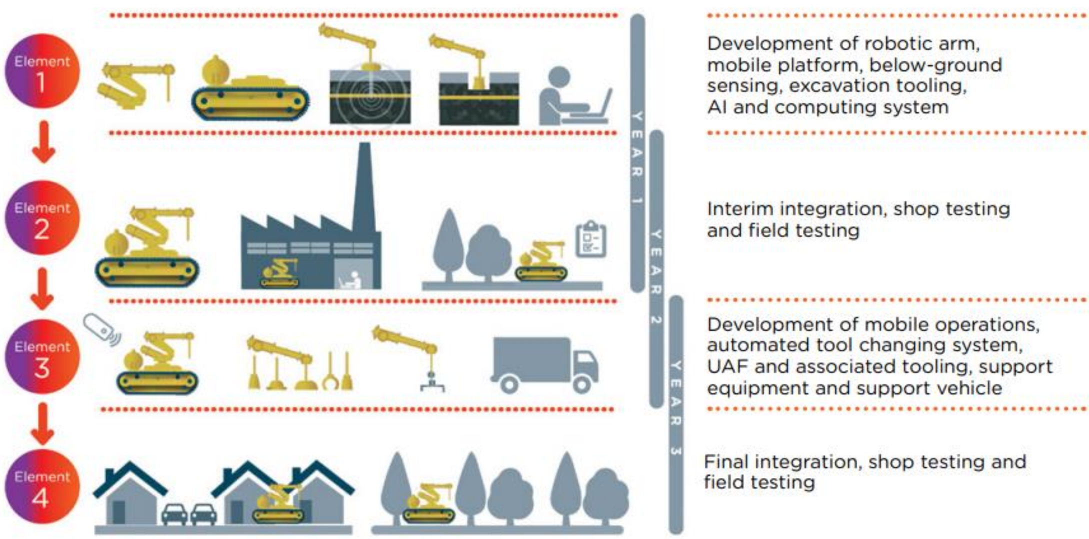

Figure 2 – Project Elements

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.

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.

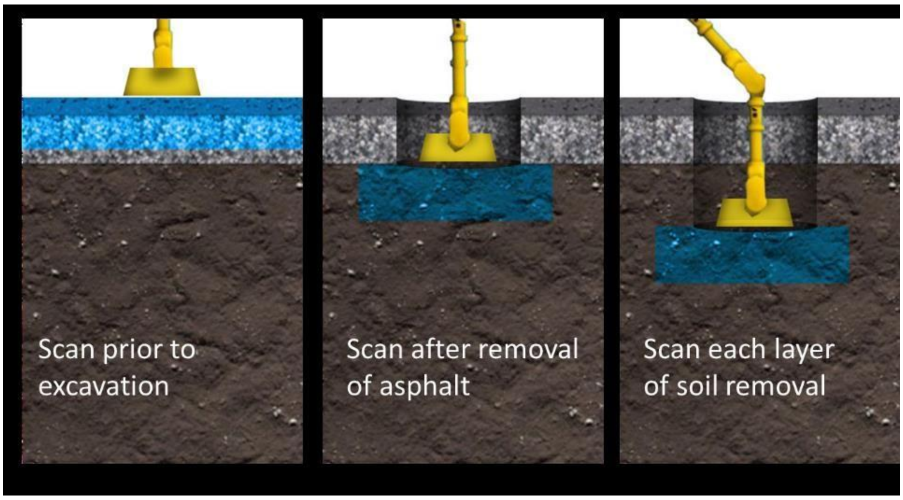

Figure 3 – Below Ground Sensing

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 many points on the external surfaces of objects around them.

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

The project has entered an essential period where each of the subsystems of element 1 have been integrated with the robotic arm and is being put through extensive testing. Also, development of the supporting subsystems critical to the operation of the RRES has commenced. The Universal access fitting and tool changer is at the early stage of development, both of which will enable RRES to perform efficiently and safely.

3.1 Excavation

One of the main benefits of RRES is the ability to excavate the ground without causing any damage to buried utilities. The RRES Excavator head serves to be the main tool to break up and remove the soil under the removed core and uncover the target pipe.

During this PPR period, we tested different versions of the excavator head to assess how the angle of the air nozzles affects performance of the excavation. The testing was performed in compacted medium clay and the starting position was set to 6” above the ground. Hole characteristics were observed, and the following measurements taken:

1. Diameter
2. Total Depth
3. Distance from excavator head to agitated soil
4. Depth of agitated soil

From figure 4, the excavator head has been mounted onto the robotic arm with the various air nozzle arrangements attached.

Figure 4 –Nozzle Angle Test

The soft touch soil-lift excavator, combined with high-efficiency vacuuming, allows the robotic system to excavate rapidly with unprecedented precision and confidence to ensure that buried infrastructure will not be damaged. The results are presented in table 1.

[redacted]

[redacted]

- [redacted]
- [redacted]
- [redacted]
- [redacted]
- [redacted]

More testing will be carried out on different environments including hard compacted clay, to determine the optimum configuration of the excavator head.

3.2 Sensing

Sensors will be used to scan the roadway above the excavation zone before cutting the road surface with the goal to identify utility lines and other obstructions in the first layer of the work path. As proposed in the bid document, the excavation will be carried out in layers. After removing each layer of soil, a combination of one or more sensors will be used to gain more accurate information about the presence of obstacles in the path of excavation.

In 2018 and the majority of 2019, the focus of the development team was to develop the sensor systems and the processing capabilities as an independent subsystem. Toward the end of 2019, as the build and testing of the mobile platform got finalized, we have started the integration of the sensor system into the robotic platform and eventually turning it into a turnkey operation.

The major components of the sensor module include:

Ground penetrating radar (GPR.

- [redacted]

[redacted]

Electromagnetic (EM) sensor

[redacted]

Control PC

- A general PC which communicates with GPR, EM sensor and the robot. It is the interface between the sensor module and the robot, shown in Figure 5.

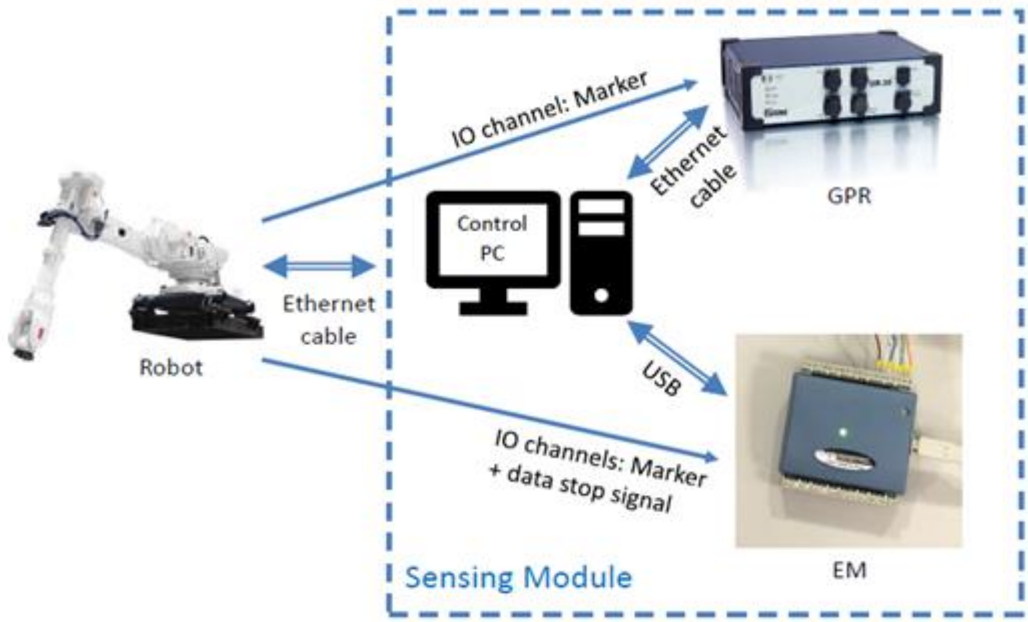

Figure 5 –Sensing Hardware configuration

As shown in Figure, the control PC serves as the interface between the robot and sensor units, i.e. the GPR and the EM sensor. The communication between the control PC and robot is through an ethernet cable. The control PC is connected to the GPR using the ethernet cable and to the EM sensor using the USB cable. In addition, there are one digital I/O channel connecting the robot and GPR directly and two digital I/O channels between the robot and the EM sensor.

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

When we began initial testing, the GPR scan of a straight line of conductive tape came out staggered. We found a mismatch between scans going from right to left and scans going from left to right.

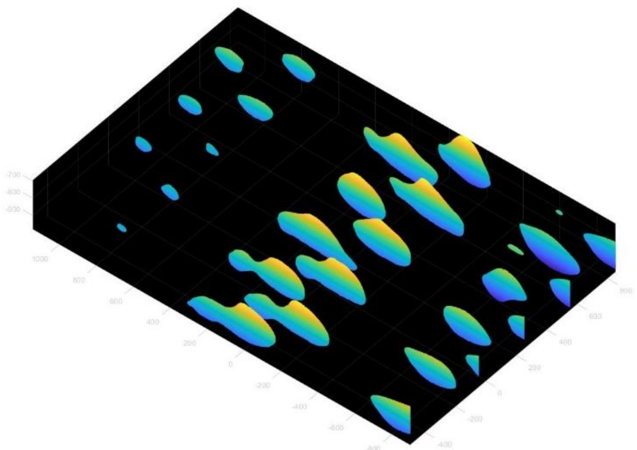

Figure 8 – GPR Mismatch

We conducted further testing to assess the effects of increasing and decreasing velocity, acceleration and GPR marker pulse length. It was determined that the mismatch issue was being caused by the pulse time. After amending the data acquisition process to execute pulses in a parallel system, the robot would not have to wait for the pulse to finish before continuing its motion. This way the robot does not have to wait for the duration of the pulse and the EM system requirements of long pulse length are satisfied.

With this amendment made to the data acquisition process, the mismatch was rectified. Figure 9 shows the results of scanning with the single process system and also with the dual process system.

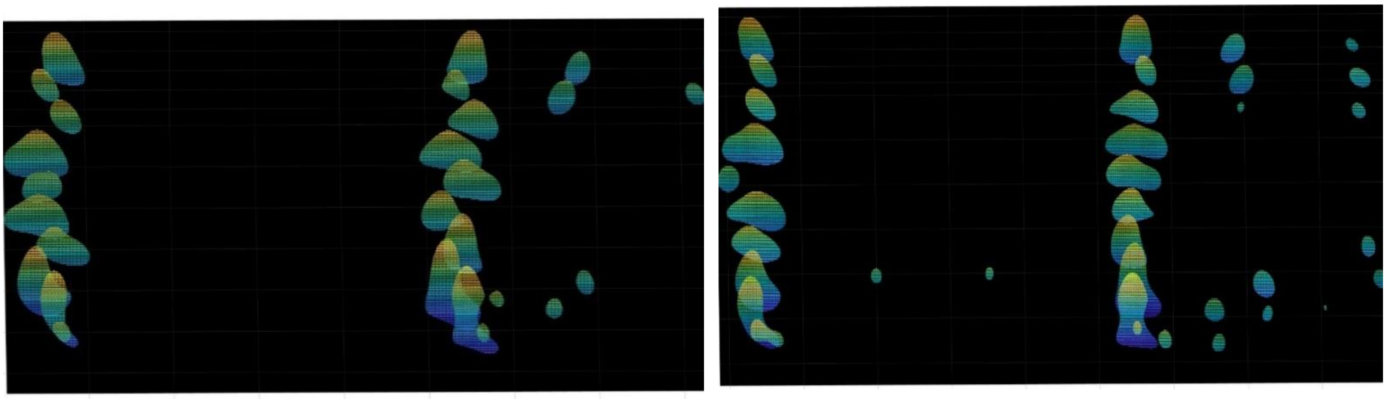

Figure 9 – Old versus New Data Acquisition Process

Data Post Processing

The data collected from the GPR antennas are stored in the form of b-scans that show cross-sectional reflections of the antenna. A sample GPR b-scan is demonstrated in Figure 8. As can be seen in this figure, by just looking at an isolated b-scan, it is not clear as to how the location of the buried assets can be identified. Therefore, further processing is required to turn the collected raw data into meaningful results.

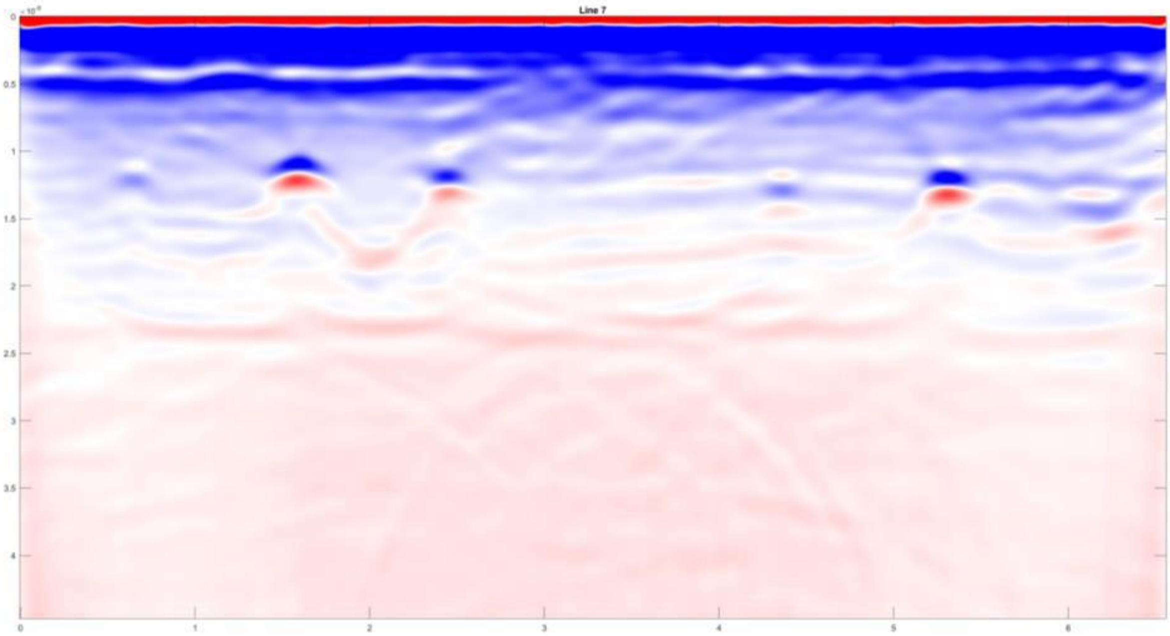

Figure 10 – GPR B-Scan

[redacted]

[redacted]

[redacted]

Testing Procedure

As the robot has been mobilised, the system was ready for field deployment for real-life scenario data collection and processing. The size of the scan area that will be tests is 1350mm x 2300 mm which is determined by the maximum reach of the robot arm.

Testing of the sensor module will be carried out on our mock roadway. Here the performance of the system will be assessed, and amendments needed to improve the accuracy of the results will be made. Sensing will be made over various assets of different sizes and material.

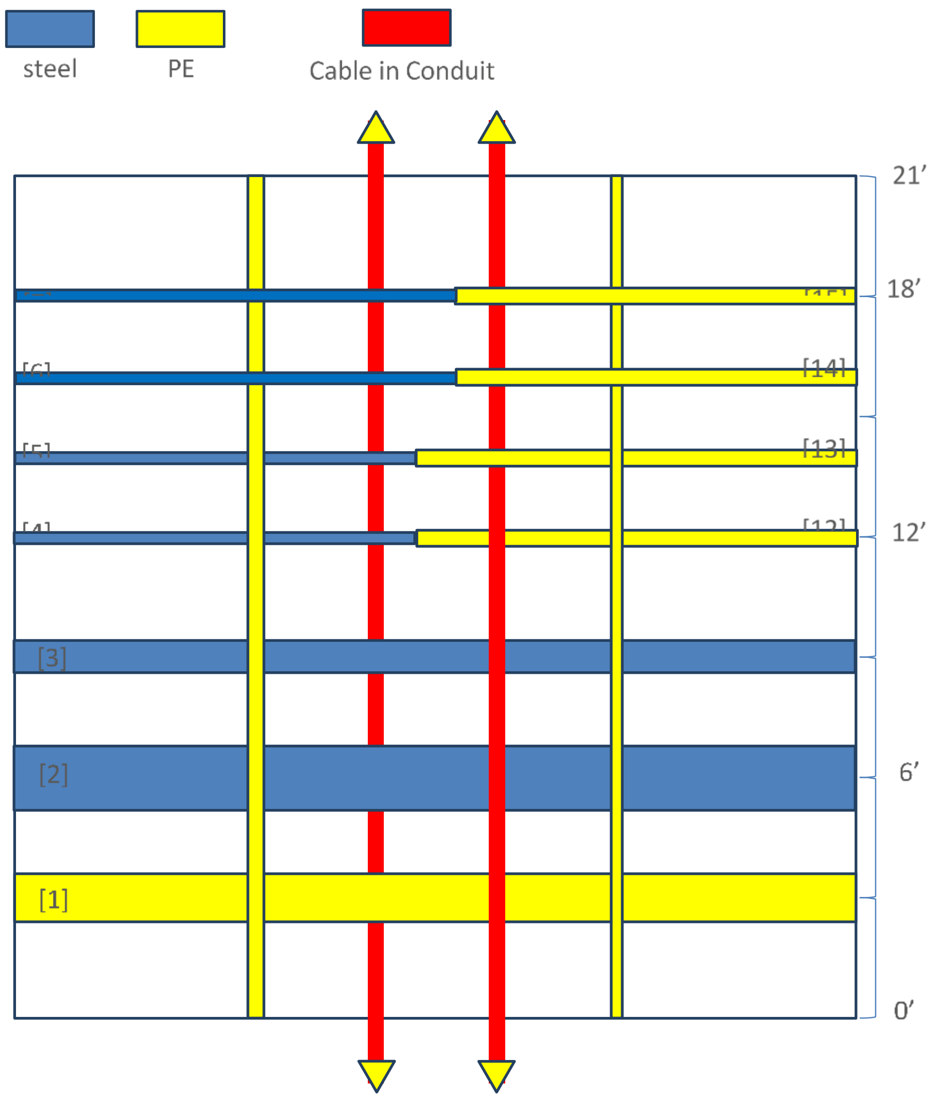

Figure 11 - The layout of the Mock Roadway.

Figure 12 – Mock Roadway

RRES will be tested at pre-selected positions across the whole mock roadway. [redacted]. The robotic arm will then scan 1000mm in the x-axis such that the new scan has an overlapped area with the previous scan. The reason to move the robot in X-axis is that the 1350mm is the shorter dimension and more scans are needed in this direction. Scans will be repeated until the desired area is fully covered.

Figure 13 – Testing of the Sensor Module

Testing has commenced with the findings to be submitted by the 31/03. The results will be documented in PPR7.

3.3 Supporting Equipment

Element 3 of the project focuses on the development of the supporting subsystems that will permit RRES to operate efficiently and safely. Two critical parts of element 3 is the automated tool changer and the universal access fitting.

Automated Tool Changer

For the robotic arm to interface with each tool and operate them properly, the tool changer system will allow for automatic swapping of end effectors on the end of the robot arm. Such end effectors include any tool that the robot may need to perform an operation such as cutting, drilling, lifting, picking, placing, scanning, sensing, imaging, and excavating. This extends the versatility of a robot by allowing a single robot to quickly and automatically set itself up to perform a wide variety of operations that may require a variety of tools. This interface will provide a solid mechanical lock between the robotic arm and end effectors and will provide a reliable connection during operation.

Based on the project’s requirements, extensive research was conducted among the available products in the market and the pros and cons of each product were evaluated. The Manufacturing technology centre was hired to conduct the research and provide their recommendation and assessment of available options. After validation, we have started the procurement and design of the automatic tool changer for the RRES.

The block diagram of the operation of this tool changer is demonstrated in Figure 12.

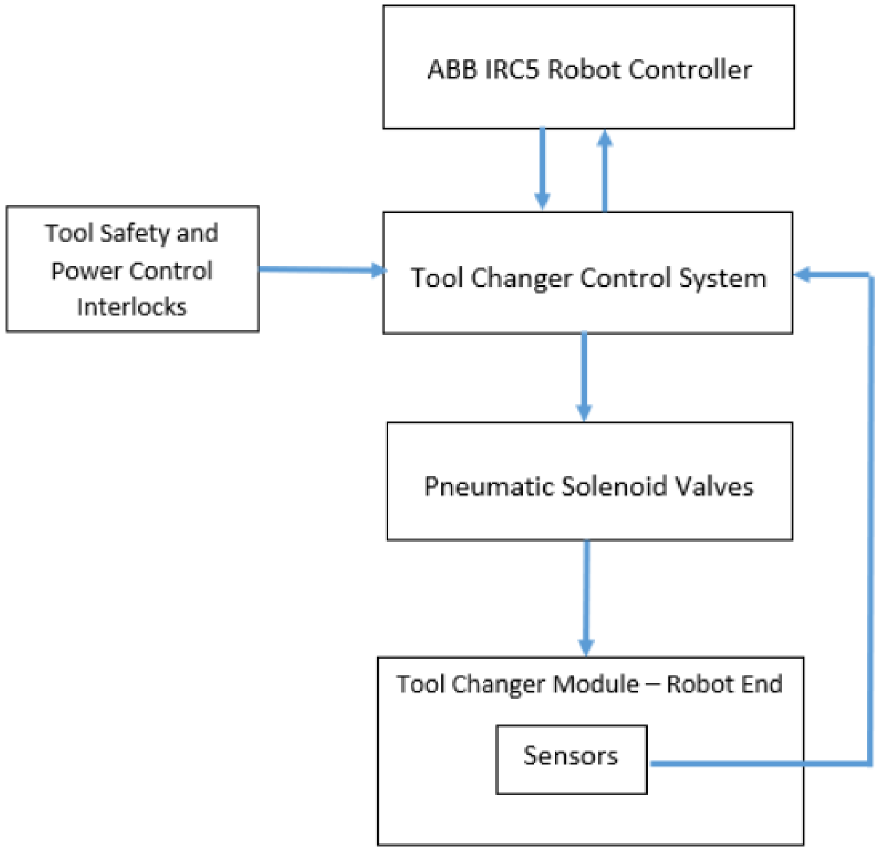

Figure 14 – Automated Tool Changer Schematic

System Components

The tool changer system consists of the following components:

- Tool changer module - Robot End

This is mounted on the end of the robot arm and with the use of a pneumatic clamping mechanism, grips tools and mounts them on the robot. In addition, the modules have provisions for transferring power, electrical signals, gases, and liquids to different tools.

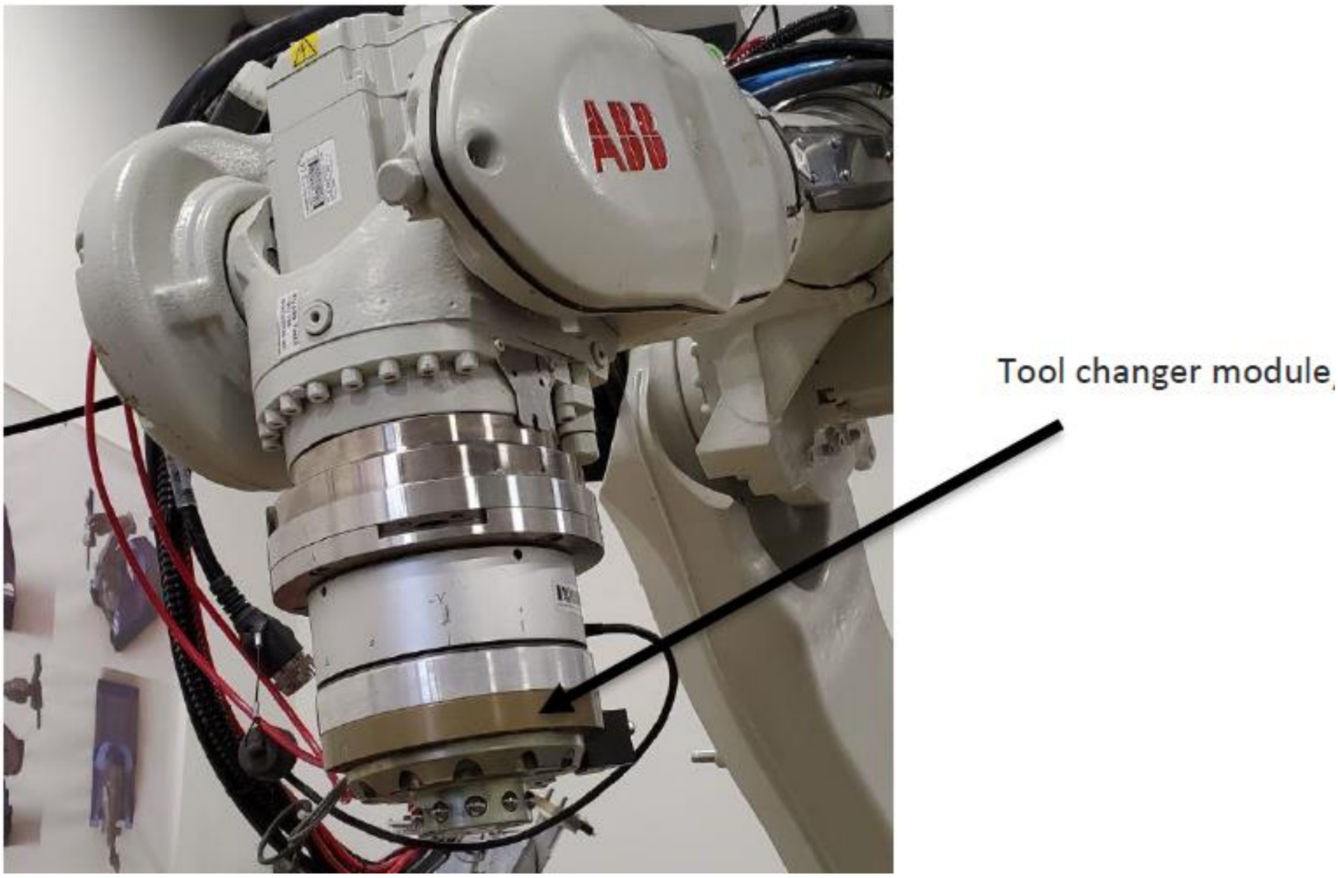

Figure 15 – Automated Tool Changer Schematic

- Tool changer module - Tool End

Each tool to be used with the robot has a tool-end module mounted to it. The tool-end module is gripped by the robot-end module to mount the tool on the robot. The module has the necessary provisions for transferring power, electrical signals, gases, and liquids, as needed by the tool.

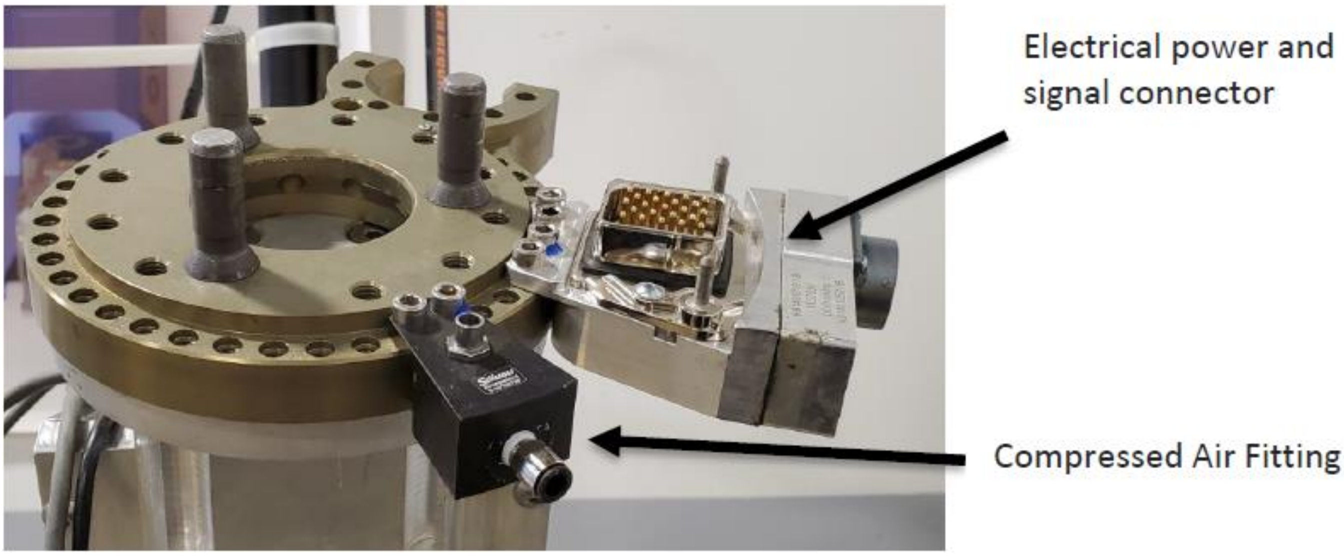

Figure 16 – Automated Tool Changer Schematic

- Pneumatic valves

The tool changer system utilizes pneumatics for gripping and releasing tools. The robot-end tool changer module utilizes a double-acting pneumatic cylinder as part of the locking mechanism. The cylinder is controlled by a 5-port (4 way) 3-position solenoid valve. This valve utilizes two coils to control the direction of air. One coil is used to extend the cylinder, unlock, to allow tools to be installed and the other coil is used to retract, lock, the cylinder to lock tools in place. The tool changer module requires constant pressure to properly lock a tool in place.

Under normal conditions, when a tool is locked, the lock coil should always be powered to securely hold the tool on the robotic arm. As a safety feature, the valve has a third position in which if both coils are either energized or de-energized, the valve seals both the lock and unlock ports preventing the exhausting of air. In the event of control malfunction or power loss, the tool will remain safely locked in place. That would still be considered a fault condition, requiring the system to be shut down, but the system will remain safe and the robot will not drop the tool.

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

Once fabrication and assembly are completed, the system and the process will be tested to ensure the highest level of safety when switching tools, the robot works in tandem with a programmable logic controller to ensure the risk of changing the tools is minimized.

Universal Access Fitting

One of the main use cases of the RRES is to conduct an operation on the exposed assets after the successful excavation of the keyhole. To prove this concept under the scope of this project ULC will develop a custom universal access fitting (UAF) and proper tools to install it on an exposed pipe.

The fitting will be designed to simplify robotic installation and facilitate a wide range of typical inspection and repair activities. Potential operations that would be enabled by the UAF include the insertion of camera equipment, the insertion and deployment of flow stop equipment, water extraction, internal stent pipe repair, and leak detection.

Tooling will be procured or developed to facilitate a robust installation method. It is expected that tooling will include a surface preparation device, a device for handling the fitting and attaching it to the pipe by means such as bonding or fusing, and a pressure test device to verify the integrity of the fitting. Once developed, tooling will be integrated with the robotic arm and programming will be performed to enable the system to perform installation activities.

ULC robotics has started the research process into the fittings and tools that are currently being used in the industry to identify the specifications of the UAF and the proper tooling to be developed for RRES under the scope of this project. The purpose of this report is to demonstrate the results of ULC's findings and the next steps in the design and development process.

The first step in the design and development of the UAF is the identification of the operations that can be conducted on the pipe through the installation of a UAF. Below is a list of these options:

1. Bag off - A bag off is a flow stop device. If flow needs to be stopped to a certain portion of the pipe and a valve is not present an inflatable bag is inserted into the pipe. Once the pipe is inflated it will stop the flow of natural gas.
2. Camera Inspection - A camera attached to a tether can be inserted into the pipe to inspect the interior condition of the pipe. This can be used to look for any damage or debris inside the pipe, as well as mapping the pipe prior to performing any major repairs.
3. Pressure Gauge - The access fitting can be used to test pressure at a specific point in the pipe. A pressure gauge can be installed, and a reading can be taken
4. Robot Insertion - A robot can be launched into the live pipeline to perform inspections or in some cases repairs.
5. Water removal – a device is inserted through the access fitting to remove accumulated water in the pipe.

[redacted]

[redacted]

4 Future Progress

The table below lists the key milestones that are planned to be delivered over the next progress period:

Milestone	Description	Due Date
Test plan/report for shop testing of prototype RRES	Complete shop testing of prototype RRES	31/03/2020
Test plan/report for interim field testing	Perform field testing on prototype RRES	26/05/2020
Design documentation for tether and support vehicle	Source RRES tether and support vehicle	04/06/2020
Design and build documentation for reel cart	Design and fabricate reel cart	21/07/2020
Test plan/report for UAF	Fabricate and test universal access fitting	18/08/2020

Table 3 – Planned Milestones over next PPR period

5 Business Case Update

No modifications have been required to the business case which remains valid in its current form.

6 Progress against Plan

The project has progressed as planned. The Gantt chart shown in figure 16 illustrates the project plan:

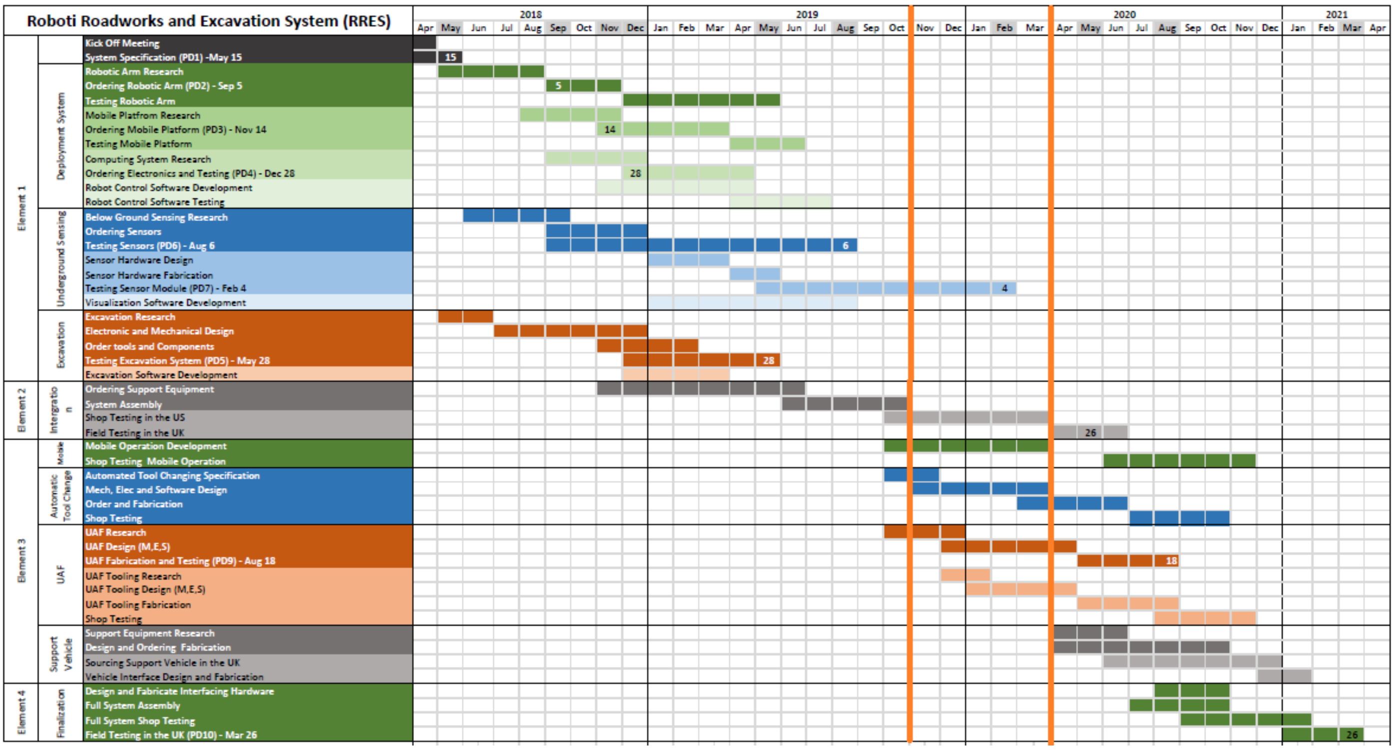

Figure 17 – Project Plan

Below are the milestones that were delivered on time as per this PPR period.

Milestone	Title	Description	Planned Date	Delivered Date
19	**Progress Report 5** Automated tool changing specification document	Documentation of design and build progress	26/11/2019	Approved
20	UAF and UAF tooling specification documents	Develop specifications for UAF tooling	07/01/2020	Approved
21	Test plan/report for below-ground sensor module	Complete shop testing of below-ground sensing capability (PD7)	04/02/2020	Approved
22	Design documentation for automated tool changing system	Source components and raw material for automated tool changing system	18/03/2020	Awaiting Approval
23	**Progress Report 6** – Test plan/report for shop testing of prototype RRES	Complete shop testing of prototype RRES	31/03/2020	Awaiting Approval

Table 4 –Delivered Key Milestones

Due to the disruption caused by the COVID-19 virus, we have decided to postpone the shipment of the robotic prototype to the UK for the Interim field testing. To ensure that no time is lost on development, we will bring future milestones forward and delay the interim field trial until 2021.

Milestone	Title	Description	Planned Date	Delivered Date
23	**Progress Report 6** – Test plan/report for shop testing of prototype RRES	Complete shop testing of prototype RRES	31/03/2020	On time

24	Test plan/report for interim field testing	Perform field testing on prototype RRES (PD8)	26/05/2020	Postponed till 2021
25	Design documentation for tether and support vehicle	Source RRES tether and support vehicle	04/06/2020	On Target
26	Design and build documentation for reel cart	Design and fabricate reel cart	21/07/2020	On Target
27	**Progress Report 7** – Test plan/report for UAF	Fabricate and test universal access fitting (PD9)	18/08/2020	To be brought forward
28	Design and build documentation for operator consoles	Design and fabricate operator consoles	15/09/2020	To be brought forward
29	Documentation of RRES assembly	Assemble full RRES	13/10/2020	To be brought forward

Table 5 –Planned Key Milestones

7 Progress against Budget

As the project has progressed as planned, the total expenditure to date is £4,434,096 with a further £353,838 set to be released by the 31/04. The deliverables for the 22nd and 23rd milestone will be reviewed, and payment will be processed once approved.

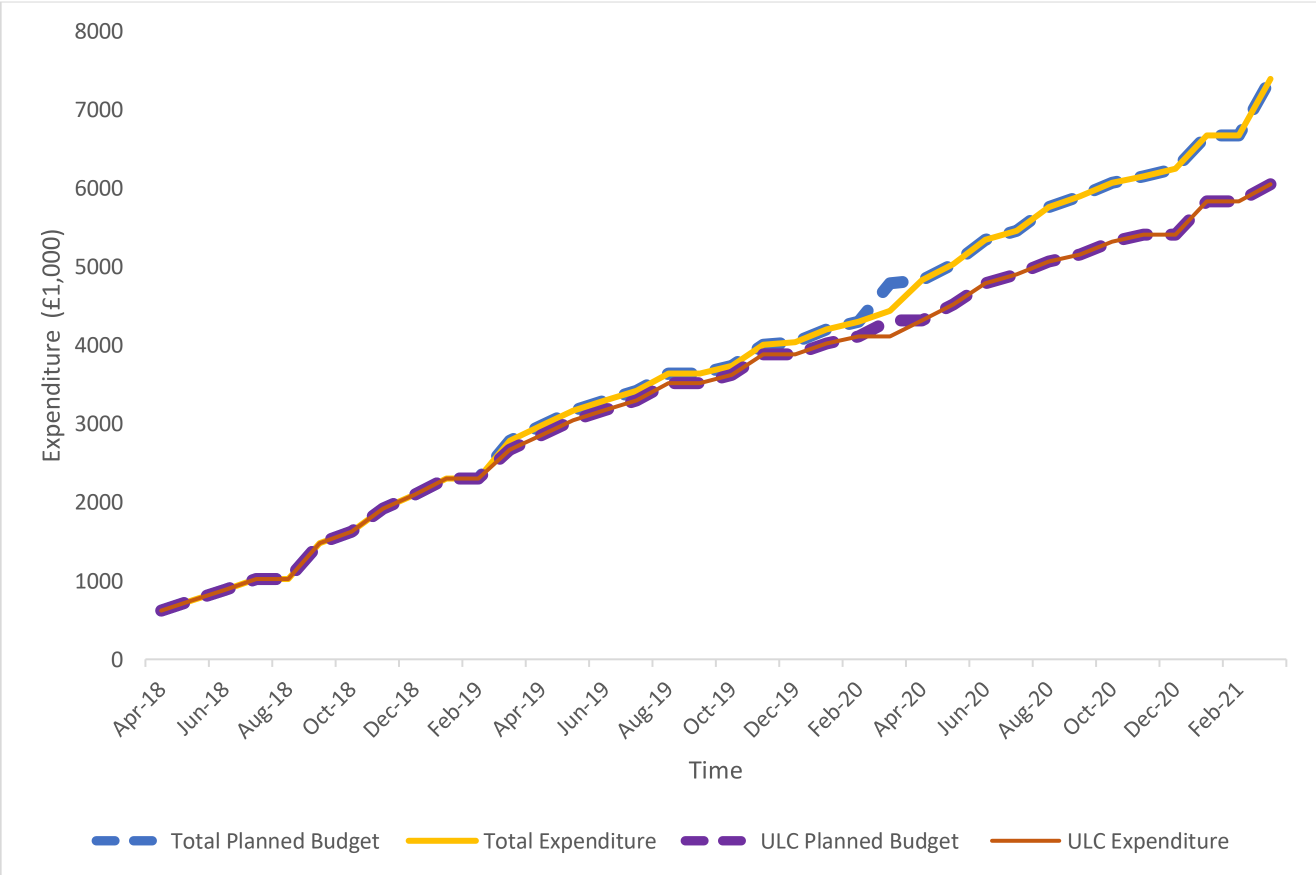

Figure 18 –Financial Overview

The key project deliverables are attributed below:

Milestone	Title	Main Project Achievements	Amount	Project Total	Status
19	Automated tool changing specification document	• Develop specifications for tool changing method and system • Perform detailed mechanical design • Perform detailed electrical design • Develop software for tool acquisition, transportation and removal	£151,110	£4,016,887	Paid
20	UAF and UAF tooling specification documents	• Develop UAF specification and select target pipe material and diameter • Develop UAF specification and select target pipe material and diameter	£137,839	£4,170,195	Paid
21	Test plan/report for below-ground sensor module	• Perform shop testing on sensor module	£92,337	£4,290,946	Paid
	Design documentation for automated tool changing system	• Develop specifications for tool changing method and system • Project progress report 5 – Automated tool changing specification document • Perform detailed mechanical design • Perform detailed electrical design • Develop software for tool acquisition, transportation and removal	£137,839	£4,170,195	Awaiting Approval
PPR6	**Progress Report 6**				
23	Test plan/report for shop testing of prototype RRES	• Update toolpath generation and environment mapping software for use on mobile platform	£201,947	£4,492,893	On Target

Table 6 –Key Project Deliverables

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 Deliverables

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

Automated tool changing specification document:

The purpose of this report is to provide an update on the work that has been undertaken for research and assessment of the end effectors and tool changing equipment for the purchased robot arm.

UAF and UAF tooling specification document:

The research process into the fittings and tools that are currently being used in the industry to identify the specifications of the UAF and the proper tooling to be developed for RRES under the scope of this project. The purpose of this report is to demonstrate the results of ULC's findings and the next steps in the design and development process.

Test plan/report for below-ground sensor module:

The purpose of this report is to provide an update on the development efforts to integrate the sensor system into the robotic platform and the plans for testing the data acquisition and processing software on the robotic platform.

Design documentation for automated tool changing system:

The purpose of this report is to demonstrate the development efforts that have been carried out to properly design all the components, mechanical and electrical, that the mobile platform consists of as well as the latest update on the fabrication and assembly work.

10 Learning Outcomes

The main outputs of this project are the technical and engineering knowledge gained whilst researching new methods to assess and remediate the existing gas distribution network. 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 most 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.

Although Utility Week Live has been postponed from May to November 2020, we intend to continue to disseminate project information via virtual media.

Key Learning Outcomes
Cutting the road surface -Our testing has creating substantial learning in determining the performance criteria that impacts cement road surfaces.
Excavator Head - The most effective approach to agitate and excavate the soil was determined.

[redacted]
Internal Dissemination
RRES update as part of innovation update within our executive monthly report
Steering Group Meeting was held in February with representatives from across the business including; legal, operations, Safety and Policy.
External Dissemination
At Utility Week Live, SGN and ULC had stands where RRES project information was disseminated to the utility industry. Also, RRES was presented as part of the keynote and innovation session.
An update of the progress made by the RRES team was presented at the IGEM AGM for the London Section.
Article in May's Gas International magazine which articulated the collaborative effort behind RRES.
RRES promotional video created by ULC and shared on YouTube

Table 7– Summary of learning outcomes

11 IPR

In accordance with the Gas network Innovation Competition Governance Document, ULC Robotics will report on intellectual property rights (IPR) being pursued on the project. There is one application outstanding, however as the project progresses, additional filings will be pursued as several key parts of the system are finalised.

Application Type	Description	Application No.	Receipt Date.
US Provisional Patent	GROUND PENETRATING RADAR SYSTEM AND METHOD	62821107	20/03/19

Table 8 – Summary of patents

12 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:

Project Delivery

The risk score of delivering the project within the allocated schedule has increased due to the uncertainty around the COVID-19 virus. Within this PPR period, our plan was to transport the RRES prototype to the UK where we would conduct a series of field trails. However due to the travel restrictions, we have taken the decision to delay shipping the system. To mitigate this risk and ensure the project is delivered on time, we have decided to bring milestone 23 -28 forward and will conduct the field trails later. This rescheduling will ensure the requirements of the project plan are fulfilled on time. We will continue to assess how the response plays out and if any additional action is required.

[redacted]

[redacted]

13 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.

14 Material Change Information

No material change has occurred.

Appendix A - Additional Reports

Below are the milestone reports that are available on request:

Report
Automated tool changing specification document
UAF and UAF tooling specification documents
Test plan/report for below-ground sensor module
Design documentation for automated tool changing system

Table 9 –Milestone Reports across PPR6

Appendix B - Bank Statements

[redacted]

December – January Statement

[redacted]

February – March Statement

[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	2	3	3	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 a the option of moving resource from other projects or utilise 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 may need to be added to the operation of the RRES which could increase the time and cost of the operation.	Technical	3	5	10	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 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. E - Use a combination of different sensors to increase the level of confidence in accurately detecting the targets	ULC, SGN, TSP	02/02/2021	1	3	3
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. E - Decrease the overall weight of the system through design and build optimizations	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 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.	ULC, SGN,	02/08/2021	1	2	2
6	**A Commercially available Robotic Arm Cannot Meet project Specification** ULC will identify and purchase an 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 it's 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 needed to complete the project could increase.	Financial/ Technical	2	3	6	A - ULC and SGN collaborate and finalise the specifications. B - SGN will create a Project Steering Group with leads from key areas of the business. The key component specification will be agreed with all members before being finalised to ensure all requirements have been met to mitigate the risk of any changes to the specification being requested later in the development process.	ULC, SGN, TSP	30/10/2018	1	3	3
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	Reputation	2	4	8	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.	SGN, ULC	02/03/2021	1	4	4

	acceptance of the technique.					C - Presentations at industry events					
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	3	3	9	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 preperations works to take place in the geographical area of SGN's network, allowing the system to be shipped ahead of the live field trial with limited impact on the test schedule.	ULC	15/04/2021	1	3	3
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 realised.	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 commercialisation 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 Utilisation** If the RRES utilisation 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 realised.	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 maximised B – Disseminate Interface Control Drawing (ICD) for open-source tooling so as to maximise 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	3	3	9	A – Use a phased approach to project planning with go/no-go milestones such that the project can be reevaluated upon completion of key milestones and terminated if needed B – Maintain a prioritised 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
18	**Challenges with cutting the road surface** There is a risk that the designed chainsaw tool for cutting the road surface cannot cut the core in a timely manner	Time / Financial	2	3	6	A – Design alternative solutions for setting the core such as endmill or a traditional core drill B - Conduct tests in different surface environments with a variety of depths of cut C - Development of different chains and cutting teeth for the chainsaw for operation in different environments D - Engage with tool manufacturers to develop custom made tools for the designed chainsaw	ULC	28/05/2019	1	3	3

Table 10 -Risk Register