DuctRunner Technology
Technical Method Statement

Edition 2017
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Introduction

About Reduct

Reduct is a global market leader in the development of Gyroscopic Pipeline Mapping Systems. Before starting Reduct, the founders were active in the deployment of telecommunication networks in both Europe and the United States. They realized early on that locating existing non-metallic underground pipes and ducts was often an impossible task due to both the small pipe diameter and limited access opportunities. Therefore, in 2001 they started Reduct to develop a technology to solve this locating issue. They key to the solution was a system that would travel autonomously inside an underground pipeline and record the path travelled.

Product Positioning

Location, location, location. That’s the primary concern when it comes to underground infrastructure operations, maintenance and rehabilitation. Many operators and authorities are investing in state of the art Geographic Information Systems (GIS) to store network related data, including XYZ. However, the quality of existing XYZ data is often inaccurate as a result of:

- Ageing or lack of information.
- 2-dimensionality, i.e. depth is often unknown.
- Referencing to no longer existing aboveground landmarks.
- Non-digital format.
- A multitude of scales and coordinate systems used, making exchange of data very inefficient.
- Inability to map infrastructure installed by means of Trenchless Technologies, such as river crossings, underneath buildings, etc.

The risk is therefore high that costly GIS platforms become populated with inaccurate and low value XYZ data, yet the value of a GIS platform is directly related to the quality of the data contained in it.
Survey crews use a number of methods to locate and map the as-built schematics of pipelines.

<table>
<thead>
<tr>
<th>Pipelines</th>
<th>Traditional Surveying</th>
<th>Walkover Beacon Systems</th>
<th>Ground Penetrating Radar</th>
<th>Gyroscopic Systems</th>
</tr>
</thead>
<tbody>
<tr>
<td>Existing</td>
<td></td>
<td>Shallow depth only</td>
<td>Shallow depth only</td>
<td></td>
</tr>
<tr>
<td>Newly Trenched</td>
<td>✓</td>
<td>Not economically viable</td>
<td>Not economically viable</td>
<td></td>
</tr>
<tr>
<td>Trenchless</td>
<td>✓</td>
<td>Shallow depth only</td>
<td>Shallow depth only</td>
<td></td>
</tr>
</tbody>
</table>

Most non-gyroscopic mapping systems require personnel to trace the path of a pipeline, using either a beacon system or ground-penetrating radar to map the utilities. However, none of these systems get the exact measurement of the pipe’s centreline. Moreover, beacon-based systems can measure to a limited depth and are highly susceptible to electromagnetic interference, rendering them virtually useless in densely piped areas or near railways and power lines.

**Brief introduction to Inertial Measurement Systems**

The DuctRunner Technology is the world’s first small diameter pipeline mapping technology based on inertial sensor technology. Inertial sensors include gyroscopes, accelerometers, magnetometers, thermometers, etc. and are typically found in the airline and defence industry as well as GPS systems. However, in these applications, the systems are used as on-line systems.
Particularly gyroscopes have a natural tendency to drift over time. In **on-line systems**, this drift does not get a chance to be of significant influence on the object (plane, car, ship, etc.) because the object can re-assess its actual position via satellite regularly and take corrective action. The impact of the drift (resulting in deviations) is therefore minimized.

In **off-line systems** (or free run systems), this frequent repositioning is not possible. For example, because the object is underground it can not make contact with satellites, and as a result the full impact of the drift needs to be considered. In essence, the standard free run accuracy is affected negatively as the time (distance) required to travel between known points increases.

The fundamental change in approach to overcome this shortcoming in inertial measurement systems and to make them applicable for accurate off-line measurements is the basis of the DuctRunner technology and subject of the patent applications US/10/536,006, PCT/BE03/00203, JPN/2004-554084, EUR/03811699.2. and HKG/06102043.7.

**The DuctRunner Technology**

In its current form, the DuctRunner technology consists of 3 major components:

1) The **Orientation Measurement Unit (OMU)** containing all sensors except for the odometers, which are typically placed outside the OMU.
The OMU is carefully calibrated to determine the alignment of each mechanically assembled sensor to within 0.01 degree.

The OMU is fully autonomous, i.e. it is battery powered and the data logged is stored internally during a measurement run. This eliminates the need to drag a data and/or power cable behind the system. Also, autonomy means that it does not need to be traced above ground as it moves from a pipe’s entry to exit point. It can thus travel to any depth and underneath any obstacle (such as rivers, railways, highways, buildings etc.).

2) An application specific housing and centralizing system, such as the D2 for internal diameters 40 to 75mm or the DR-4 for internal diameters from 90mm to 1500mm+.

3) Proprietary X-Change® data transfer software and X-Traction® data processing software.

These software programs transfer the autonomously logged data from the OMU to a PC and then relate the path travelled by the OMU to known coordinates at the entry and exit points, hence creating an accurate 3-dimensional line in the coordinate system chosen.

The unique approach taken by Reduct means that it is not necessary to know the exact position of the OMU as it travels from entry (A) to exit point (B). Rather, the software establishes where it has been after it is retrieved from the pipe. This means that the system can travel autonomously during the logging of data.
As it travels from A to B, each of the 20+ sensors of the OMU log passively, i.e. there is no intelligent software inside the OMU to compensate for change in forces on the OMU. Logging occurs at 100Hz, or 100 samples per second.

Essentially, for each sample, the X-Traction® software calculates change in the X-direction (distance), Y-direction (heading), Z-direction (pitch) and Roll position.

From the multiple odometers on the tool the travelled distance per sample is derived and the resulting length profile is integrated with vector results, thus giving each vector (sample) a length. When samples are placed in sequence, the path travelled is reconstructed. Then the reconstructed trajectory is linked to the known coordinates of A and B to obtain the final result in the chosen coordinate system.

The standard X-Traction® software generates three open platform output file formats; 1] comma separated values (.csv), 2] Excel table (.xls), and 2] AutoCad script (.scr). This enables minimum conversion time when loading results into GIS or other platforms.

In summary, the key unique features of the DuctRunner Technology are:

- It operates autonomously (no tethering of data cable) and as a result can map to any depth.
- Due to its high logging rate, the OMU can travel up to 2m per second.
- The sensors are insensitive to electromagnetic interference and can therefore be used near power cables, train tracks, etc.
- The systems can be used in any type of pipe material, including steel, PVC, HDPE and concrete.
- The technology is modular to fit in single or compartmentalized casings.
- Open platform output files for seamless integration of data in most commonly used GIS platforms.
Calibration Procedure

Objective

Reduct pipeline mapping probes are manufactured and assembled using state of the art machinery and the best materials and components. The primary nine inertial measurement sensors are assembled such that they are placed as accurately as possible on the X, Y or Z axis of the probe. However, all mechanical assembly is invariably imperfect, i.e. the angles between the nine key inertial sensors are not exactly 90 degrees. The objective, therefore, of the Reduct calibration procedure is to measure the angular errors and compensate them mathematically.

Method

Reduct has developed the DR-CR-002, a proprietary calibration robot. Over a period of about two hours, the robot moves a probe through over 440 static positions and dynamic moves in an inclination range between -600 to +600 (red arrows) while rotating the unit 3600 around its X-Axis (yellow arrow) and 3600 around it Y-Axis (blue arrows).

Upon completion of the calibration procedure the data gathered by the probe during the calibration procedure is uploaded to the calibration software for further analysis.

Mathematical adjustment

A perfectly assembled system calibration data yields perfect sine curves. The data gathered from a probe is processed and an initial match to the perfect sine curve is made in the form of a scaling to the curve (BLUE columns in the table on the reverse side). Then, a series of proprietary algorithms will mathematically adjust the assembly angle of each primary sensor until it finds the best fit to the perfect sine curve. The remaining scaling values for the primary inertial sensors must be below 0.4% for the probe to pass the SCT test. The resulting calibrated settings are then uploaded into the X-Traction software that matches the probe’s serial number.
**Track validation**

As a final check, the probe’s performance is tested on a fixed track. The probe is passed through the track in both directions and moving forward as well as backward. The repeatability of these measurements must be high: the spread (as a percentage of pipe length) on the XY-plane may not exceed 0.25% and in the Z-plane may not exceed 0.10%.

Once a probe meets Reduct’s stringent post-calibration specifications, an *OMU Calibration Certificate* is issued for a period of one year.

**System Accuracy**

The Calibrated Accuracy of an OMU is 15cm in XYZ over a 500m distance between waypoints assuming the following mapping conditions:

- HDD shaped track
- Temperature change < 5°C
- Pulling speed of 1.25m/s
- Flush pipe interior
- Perfect OMU alignment
- Acceleration/shocks < 2G
- Average of 4 valid runs (2 in each direction).

The above accuracy is equivalent to 0.03% or 1/3333.
### System Output

<table>
<thead>
<tr>
<th>Pipe length</th>
<th>Coordinates</th>
<th>Orientation</th>
<th>3D and 2D Bend radii</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Easting (X)</td>
<td>Northing (Y)</td>
<td>Depth (Z)</td>
</tr>
<tr>
<td>0</td>
<td>35678.838</td>
<td>31845.640</td>
<td>101.274</td>
</tr>
<tr>
<td>1</td>
<td>35677.985</td>
<td>31845.163</td>
<td>101.031</td>
</tr>
<tr>
<td>2</td>
<td>35677.161</td>
<td>31844.669</td>
<td>100.775</td>
</tr>
<tr>
<td>3</td>
<td>35676.337</td>
<td>31844.163</td>
<td>100.506</td>
</tr>
<tr>
<td>4</td>
<td>35675.522</td>
<td>31843.660</td>
<td>100.231</td>
</tr>
<tr>
<td>5</td>
<td>35674.704</td>
<td>31833.750</td>
<td>99.947</td>
</tr>
<tr>
<td>6</td>
<td>35673.881</td>
<td>31823.851</td>
<td>99.671</td>
</tr>
</tbody>
</table>

- User defined sampling interval
- Supports both metric and imperial systems
- Inclination in degrees and percentage
- 3D and 2D bend radius analysis
Pipeline Mapping System Description: DR-4

The DR-4 Pipeline Mapping System is the most versatile standard system on offer and will therefore be used as an example for the system description.

The system comprises of a measurement probe 1 and one or more centralizing wheel sets 2.

**OMU System Components and Specifications**

<table>
<thead>
<tr>
<th>Code</th>
<th>Component</th>
</tr>
</thead>
<tbody>
<tr>
<td>OMU-84442</td>
<td>Orientation Measurement Unit (stand alone)</td>
</tr>
<tr>
<td>BP-4</td>
<td>3 Batteries + 2 Chargers</td>
</tr>
<tr>
<td>CU8444X-R</td>
<td>2 Control Units</td>
</tr>
<tr>
<td>LPC8444X-R</td>
<td>Semi-Ruggedized Laptop PC</td>
</tr>
<tr>
<td>FC84441</td>
<td>Custom Flight Case</td>
</tr>
</tbody>
</table>

**Technical Specifications**

<p>| | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Length OMU</td>
<td>642 mm</td>
<td>Water resistance</td>
<td>IP67</td>
</tr>
<tr>
<td>Diameter in middle</td>
<td>42 mm</td>
<td>Power supply</td>
<td>5V</td>
</tr>
<tr>
<td>Weight</td>
<td>1.6 kg</td>
<td>Operating temp</td>
<td>-10 to 60 °C</td>
</tr>
</tbody>
</table>
**Centralizing Wheel Sets**

Measurement accuracy is directly related to the degree that the OMU is aligned with the direction of the pipe it is measuring. The standard centralising wheel sets are specially designed to ensure an optimal alignment in the pipe. The standard sets cover a pipe ID range from 90mm up to 1000mm.

<table>
<thead>
<tr>
<th>Code</th>
<th>Component</th>
</tr>
</thead>
<tbody>
<tr>
<td>WUS-0320</td>
<td>DR4 Centraliser Sets for Pipe ID 90-500mm</td>
</tr>
<tr>
<td>WUS-2040</td>
<td>DR4 Centraliser Sets for Pipe ID 500-1000mm</td>
</tr>
</tbody>
</table>

If larger diameters are required, bespoke frames can be supplied.

**Invert wheel sets**

In addition to the centralizing wheel sets Reduct offers a Standard Invert Wheel Set for pipes with internal diameters starting from 150mm. Invert wheel sets run along the bottom of the pipe and can bypass more irregularities than the standard centralized wheel sets.
<table>
<thead>
<tr>
<th>Product Code</th>
<th>Component</th>
</tr>
</thead>
<tbody>
<tr>
<td>IWS-0612</td>
<td>Pipe ID range: 6-12&quot; DR4.2 Invert Wheel set + Ø73mm/3&quot; Wheels + Ø125mm/5&quot; Wheels</td>
</tr>
<tr>
<td>IWS-1440</td>
<td>Pipe ID range: 14-40&quot; DR4.2 Invert Wheel set + Ø125mm/5&quot; Wheels Ø150mm/6&quot; Wheels Ø200mm/8&quot; Wheels</td>
</tr>
<tr>
<td>IWS-Set</td>
<td>IWS-0612 + IWS-1440 + Case</td>
</tr>
</tbody>
</table>

**Laptop and Software**

The standard OMU system laptop is a Semi-Ruggedized Panasonic Toughbook (or equivalent). The following pre-installed software is part of the OMU:

- **X-Change®** - Communication software, creates the interface between the OMU and the computer.
- **X-Traction®** - Post processing software, is used to process the collected data and provides XY, XZ and 3d graphic information. The software creates output files as Comma Separated Value or Script files.

In addition to the standard software, Reduct recommends the following optional software programs to further enable data assessment:

- **X-View®** - Multi measurement averaging, provides interactive 3D imaging similar to AutoCad and it provides the average from a multitude of the runs done on the same stretch of pipeline again in one graphic 3D image.
• X-Bend® - Bending radius analysis, has the ability to determine the bending radius in pipelines. This is especially important when determining potential stress points in pressurized pipelines (Gas, Water, Crude, Chemicals).

High Speed Electrical Winches

The performance of the DuctRunner Pipeline Mapping Systems is best if pulled at a relatively constant speed of about 1 to 2 meters per second. Therefore, Reduct has developed a custom rapid electrical winch system, the DRW 560S.

A survey team requires two winches, one on at each man hole. This significantly improves efficiency and allows for multiple runs to be executed in a very short time frame.

<table>
<thead>
<tr>
<th>Technical Specifications</th>
<th>Winch 560S</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>110V</td>
</tr>
<tr>
<td>Frame Size [lxwxh]</td>
<td>70x55x40mm</td>
</tr>
<tr>
<td></td>
<td>28x22x16&quot;</td>
</tr>
<tr>
<td>Drum external diameter</td>
<td>56cm / 22&quot;</td>
</tr>
<tr>
<td>Drum internal width</td>
<td>37cm / 15&quot;</td>
</tr>
<tr>
<td>Drum capacity [6mm polypropylene wire]</td>
<td>1,500m / 5,000ft</td>
</tr>
<tr>
<td>Drum capacity [Muletape® WP1250]</td>
<td>2,500m / 8,300ft</td>
</tr>
<tr>
<td>Power supply</td>
<td>110V</td>
</tr>
<tr>
<td>Nominal Mains Power [W]</td>
<td>800</td>
</tr>
<tr>
<td>Maximum Mains Power [W]</td>
<td>1800</td>
</tr>
<tr>
<td>Pulling speed per second [Empty-Full drum]</td>
<td>1-2m / 3-6ft</td>
</tr>
<tr>
<td>Nominal Pulling Force [Empty-Full drum]</td>
<td>80-40 kg</td>
</tr>
<tr>
<td>Maximum Pulling Force [Empty-Full drum]</td>
<td>170-85kg</td>
</tr>
<tr>
<td>Manual cable winding mechanism</td>
<td>Yes</td>
</tr>
<tr>
<td>Total weight [fully assembled without wire]</td>
<td>55kg</td>
</tr>
</tbody>
</table>

Per winch Reduct recommends a EuroPower EP3300 generator (see Annex 1 for technical details).
General Method Statement

This General Method Statement outlines the operational procedures of Reduct’s Pipeline Mapping Systems when the system is propelled by means of a pulling wire only. Should propulsion by means of pulling not be an option, please contact Reduct so that a suitable alternative propulsion method can be agreed.

Despite the fact that certain safety recommendations are made, local Health and Safety regulations (i.e. at the location of the job site) prevail over the recommendations in this document.

Scope of the Works
The objective is to map an underground pipeline segment from a known entry point to a known exit point and obtain accurate three-dimensional coordinates at regular intervals. The standard propulsion method described herein is by means of pulling the DR-4 probe through the pipe segment.

General Site Preparations
To ensure optimal productivity, certain site preparations are assumed to be carried out in advance. Amongst these are:

- Arranging all necessary permits from the municipality.
- Ensuring site safety measures are in accordance with local Health and Safety regulations.
- The pipeline entry and exit points are freely accessible by foot and that there is sufficient hard soil to place the winch on.
- The pipeline is empty and clean. Ideally its integrity (roundness) is tested in advance using a standard calliper pig.
- A pulling cord is installed (6-8mm Polypropylene preferred) prior to arrival.
- The contractor have available the XYZ coordinates of the TOPSIDE of the pipe that will be mapped at entry and exit point (See picture).

Access Point Safety Arrangements
<table>
<thead>
<tr>
<th>Type of access</th>
<th>Safety requirements</th>
</tr>
</thead>
<tbody>
<tr>
<td>Street manhole</td>
<td>▪ General safety requirements.</td>
</tr>
<tr>
<td>Open dug pit</td>
<td>▪ General safety requirements.</td>
</tr>
<tr>
<td></td>
<td>▪ Groundwater drainage pump.</td>
</tr>
<tr>
<td></td>
<td>▪ Ladder.</td>
</tr>
<tr>
<td></td>
<td>▪ Shoring up of pit walls.</td>
</tr>
<tr>
<td>Shaft access</td>
<td>▪ General safety requirements.</td>
</tr>
<tr>
<td></td>
<td>▪ Ladder.</td>
</tr>
<tr>
<td></td>
<td>▪ Toxic gas metering.</td>
</tr>
<tr>
<td></td>
<td>▪ Operator must have successfully completed a locally approved Confined Space Training course.</td>
</tr>
<tr>
<td>Underground chamber</td>
<td>▪ General safety requirements.</td>
</tr>
<tr>
<td></td>
<td>▪ Ladder.</td>
</tr>
<tr>
<td></td>
<td>▪ Toxic gas metering.</td>
</tr>
<tr>
<td></td>
<td>▪ Operator must have successfully completed a locally approved Confined Space Training course.</td>
</tr>
</tbody>
</table>
## Plant

<table>
<thead>
<tr>
<th>Equipment</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pipeline Mapping Tool</td>
<td>Example: DR-4</td>
</tr>
<tr>
<td>2 x Electrical Winches</td>
<td>(one with sufficient rope for the segment length)</td>
</tr>
<tr>
<td></td>
<td>For lengths shorter than 150m manual handling is recommended.</td>
</tr>
<tr>
<td>2 x Petrol Powered Generators</td>
<td></td>
</tr>
<tr>
<td>Semi-Ruggedized Laptop PC</td>
<td></td>
</tr>
</tbody>
</table>
**Space requirements**

Typically, about 3-4m of firm underground directly behind the entry and exit points is required to set up the pulling winches (and generator if applicable). The Reduct van can be parked off-site if space is limited.

The winches are operated by an electrical motor and emit no harmful fumes. They are designed to dissemble easily so that they can easily be lowered into an underground chamber by hand.

The winches can be placed on an HDD rig in case of mapping pilot bore strings.
Description of the operational procedures

A standard measurement broadly contains three steps:

Step 1: Raw data collection

1. At entry and end points a winch and generator are prepared.
2. The (pre-installed) pulling cord is connected to the DuctRunner probe. Another cord is attached to the back of the probe.
3. The probe is switched into logging mode.
4. The probe is manually inserted into the entry point of the pipe in the FORWARD direction.
5. Underneath the entry point coordinate a 30-60 second period of calibration is observed.
6. The probe is pulled through the pipeline (+/- 1m/sec) until the nose of the probe arrives underneath the end-point coordinate.
7. A 30-60 second period of calibration is observed.
8. The probe is pulled back to the entry point of the pipe (+/- 1m/sec).
9. Back at the entry point a 30-60 second period of calibration is observed.
10. The probe is pulled out of the pipe turned around and reinserted into the pipe in the BACKWARD direction.
11. Steps 5 to 9 are repeated.
12. The probe is retrieved from the pipe and logging is stopped. The recorded data is uploaded to a PC and checked for validity.
Step 2: Data Processing
Raw data logged by the DR-4 probe is combined with known entry and exit point coordinates to produce the following output:

- Coordinate table at a customer defined frequency (e.g. 1 sample per meter)
- 3D pipeline profile
- 2D depth profile
- Inclination analysis
- Bend radius chart (optional)
- The DRC-1 and DRC-2 Pipeline Inspection Systems will also provide an XYZ synchronized in-pipe video image.

Results from multiple measurements in opposite directions can be compared and averaged in X-View®.

Step 3: Upload into GIS platform
Resulting pipeline data is saved in open platform formats (.csv and .scr) for seamless integration in common GIS platforms such as:

- AutoCad
- MicroStation
- Excel

Seamless integration into other GIS platforms can be programmed upon demand.

The entire process typically takes about 1 hour per pipe segment of 500m.
Skill Requirements and Documentation

A survey team consists of a minimum of two persons (Operators 1 and 2), one at each side of the pipeline segment.

At the entry point (usually also the location where the laptop resides) Operator 1 should have sufficient knowledge and experience to safely perform the system preparation and handling, data downloading and processing procedures of the Pipeline Mapping System used. At the exit point Operator 2 should have sufficient skills to operate the electric winch and power generator.

Operators are trained by Reduct during a two-day training session. This training includes all operational features of the system and detailed data assessment. Most of the second day will be focused on troubleshooting and recognising operational errors and unsuccessful measurements. Successful trainees will obtain the title Certified DR-XXXX Operator.

The basic two-day course only familiarizes the Operators with the system and operational tools. However, extensive field trials are required to become experienced Operators. Reduct will include in its offer a fee for two weeks of field supervision by an experienced Reduct engineer.

Required knowledge of the following manuals and instructions:
- DR-XXXX User Manual
- Wheel Unit User Manual
- Winch Manual
- Power generator Manual
- Health and Safety Instruction card

In case of Shaft Access or underground Chamber access, Reduct recommends a certified first-aid worker is present at each access point.

Personal Protective Equipment (PPE)

Reduct recommends that all operational personnel wear safety clothing with a minimum of:
- An approved helmet
- A reflective vest/coat
- Steel tipped safety shoes
- Gloves
- Safety glasses
## Annex 1: Europower Generator – technical specifications

Type quoted: EP3300

![Europower Generator](image)

### Table of Specifications

<table>
<thead>
<tr>
<th>Type</th>
<th>KVA</th>
<th>KwA</th>
<th>Amp</th>
<th>Motor</th>
<th>Engine</th>
<th>Tank</th>
<th>Reserve</th>
<th>Deposito</th>
<th>Autonomy</th>
<th>Autonomia</th>
<th>Uitvoering</th>
<th>Version</th>
<th>Ausführung</th>
<th>Maße</th>
<th>cm</th>
<th>kg</th>
<th>dF(A) @ 7m</th>
<th>L</th>
<th>mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>EP3300</td>
<td>3</td>
<td>2,7</td>
<td>12</td>
<td>1500</td>
<td>Honda</td>
<td>50</td>
<td>198</td>
<td>3.6</td>
<td>2.8</td>
<td>4.5</td>
<td>58x29x44</td>
<td>42</td>
<td>10</td>
<td>95</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- **A** = 2 Sockets 230V - 16A
- **F** = Frame
- **O** = Oil guard
- **R** = Recoil Starter
- **Th** = Circuit breaker