UNEXMIN DELIVERABLE D7.4

Pilot Report from Idrija Mercury Mine, Slovenia

Summary:

This deliverable describes mission objectives, detailed description of the second UNEXMIN pilot tests in the mercury mine in Idrija in Slovenia, technical details of the tested equipment, and the results and recommendations for the next steps.

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Reviewer 1	Jussi Aaltonen	17.12.2018	
Reviewer 2	Luís Lopes	17.12.2018	
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List of Abbreviations

Abbreviation	Description
ASL	Above Sea Level
CUDHg Idrija	Idrija Mercury Heritage Management Centre
DVL	Doppler Velocity Log
EC	Electric Conductivity
EMET	Ecton Mine Educational Trust
ESC	Electronic Speed Controller
GeoZS	Geological Survey of Slovenia
Hg	Mercury
INESCTEC	Institute for Systems Engineering and Computers, Porto
INS	Inertial Navigation System
LED	Light Emitting Diode
MSU	Multi Spectral Unit
N/A	Non Applicable
pH	Negative logarithm of the hydrogen ion concentration
RPM	Rounds Per Minute
RCI	Resources Computing International Ltd
SBP	Sub Bottom Profiler
SLS	Structured Light System
TUT	Tampere University of Technology
UNIM	University of Miskolc
UPM	University of Madrid
USB	Universal Serial Bus
UX-1	Autonomous Explorer for Flooded Mines
VESC	Vedder Electronic Speed Controller

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1 Introduction to the UNEXMIN project

UNEXMIN is an EU-funded project that develops a novel robotic system, primarily for the autonomous exploration and mapping of Europe's flooded mines. The Robotic Explorer platform, made by three robots – UX-1a, UX-1b and UX-1c, will use non-invasive methods for autonomous 3D mine mapping for gathering valuable geological, mineralogical and spatial information. This can possibly open new exploration scenarios so that strategic decisions on the re-opening of Europe's abandoned mines could be supported by data that cannot be obtained by any other ways, without major costs. The Multi-robot Platform will represent a new technology line that is only made possible by recent developments in autonomy research which allows the development of a completely new class of mine explorer service robots, capable of operating without remote control. Such robots do not exist nowadays and UX-1 will be the first of its kind. Major research challenges are related to miniaturisation and adaptation of deep-sea robotics technology to this new application environment and to the interpretation of geoscientific data.

In Europe, it is estimated that there are 30,000 closed mine sites and many of these may have considerable amounts of essential raw materials. Many of these closed mines are now flooded and the most recent information on their status and layout can be decades or more than a hundred years old. The complex underground layout, topology and geometry of most underground mines, make it impossible to do any surveying by conventional or remotely controlled equipment. One of these examples is the usage of human divers, which can prove dangerous and even lethal in harsh deep mine conditions: many underground mines are deeper than maximum safe diving depths.

The **main objective** in the UNEXMIN project is to develop a fully autonomous multi-platform Robotic Explorer, made by three robots which will share the workload, that will use non-invasive methods for 3D mine mapping of flooded and deep mines, otherwise inaccessible, in Europe. UNEXMIN's pioneer developing technique could open new exploration scenarios for European abandoned mines, with the help from data that cannot be acquired in any other way, without major costs.

Specific goals of the UNEXMIN project are as follows:

- Design and build a multi-platform Robotic Explorer for autonomous 3D mapping of flooded deep mines
- Demonstrate the operation of the prototype at a set of representative pilot sites
- Develop an open access platform for technology transfer and further development between stakeholders
- Develop a research roadmap in support of further technology development
- Develop commercial services for exploiting the technology

These major objectives are being supported by a science and technology merger of deep-sea robotics solutions with user requirements from the mining industry. They will lead to a fine-tuning of UX-1 and its equipment so that the novel developed technology could best serve end-users.

The objective of this deliverable is to present a report of the second testing of UX-1a that was held in the Idrija mercury mine in Slovenia from the 10.9.2018 until 21.9.2018. The Idrija pilot was the second test mission out of four planned. The first pilot was in the Kaatiala mine, Finland, conducted in June 2018. The results from Kaatiala mine are presented in the deliverable D7.2. After Idrija, the next tests in real conditions are planned to be conducted in the Urgeiriça uranium mine, Portugal during spring 2019.

All project partners, which participated at this pilot, contributed to the preparation of this deliverable. Local pilot organisers were experts from Mercury Heritage Management Centre (CUDHg Idrija) and Geological Survey of Slovenia (GeoZS).

2 The Idrija Mission Objectives

The objectives of UNEXMIN's pilots, as part of work package 7, is to test the UX robot prototypes in real environment, to obtain data and experiences of how the robot's sensor systems, manoeuvring and navigation is behaving in real environments. These data and experiences are later used to adjust the robot's software and hardware, before tests are conducted in the next mine. The whole cycle is repeated four times in order to get the fully operational underwater explorer of flooded mines, fully capable of autonomous navigation and mapping. Four UNEXMIN test sites have been selected in order to obtain consequentially more and more challenging test environments. These tests sites are 1) the Kaatiala pegmatite mine (Finland), 2) the Idrija mercury mine (Slovenia), 3) the Urgeiriça uranium mine (Portugal) and 4) the Ecton lead and zinc mine (UK). The Idrija tests are the second in a row.

Idrija's mission objectives were to test the Prototype operation in much more challenging real-life environment as in the first test site in the Kaatiala mine, Finland. The Idrija mine is an underground mine with limited visibility, narrow passages, limited air flow and no electricity. As the visibility in the water was very low due to the mines' murky water and the amount of debris floating in it, the operators had to rely solely on the robots' navigational systems while navigating the robot. The team planned to operate UX-1a at the start of the test using an umbilical connection and as the tests progressed, to disconnect the robot and trial the first fully autonomous dive.

Idrija's pilot key success factors:

- UX-1a to reach the deepest part of the mine's flooded part of the shaft and return to the surface.

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- Testing of UX-1a in harsh mining conditions.
- Navigation and movement of UX-1a in confined spaces and murky waters.
- Emergency protocols successfully tested.
- Testing of Multi Spectral Unit (MSU) in low visibility conditions.
- UX-1a to achieve the first fully autonomous dive.

The following tests were planned to be conducted during the pilot mission:

- Communication
- Testing systems for lowering/lifting the robot and equipment into the shaft
- Testing different workplace setups due to harsh conditions
- Multiple pitch testing
- Multibeam tests
- Tritech tests
- Mapping of structures in the shaft
- Navigation in the shaft (poor visibility)
- Pendulum control tests
- Image (photo) logs in the shaft
- Multispectral camera logs and tests
- SLS and sonar tests in the shaft
- SLS synchronization test
- Verification of all systems (power on, working condition)
- Mapping and navigation tests
- MSU global synchronization tests
- Camera functionality validation
- Scanning sonar preliminary tests

3 The second test site – The Idrija mine

3.1 The Idrija mine

The second test of the UX-1a robot was carried out at an underground Idrija mercury mine in Slovenia.

The mercury deposit in Idrija, Slovenia, was discovered in 1490. Shortly after the discovery, the first mining operations began, and after that the mine was under continuous development for the next 500 years. The mine produced approximately 12.7 Mt of cinnabar ore and 145 000 t of Hg in its 500-year mine life. 13% of total historic world Hg production comes from Idrija. During its production phase, approximately 700km of tunnels were excavated and the total depth of the mine reached 420 metres. Historically, the Idrija Mercury mine was always the leading centre of the technological development of mining technology in the world thanks to its long-term massive production. The production ceased in 1995 and has since 2017 been placed under the supervision of a new public institute "The Idrija Mercury Heritage Management Centre" (partner CUDHg Idrija) that was founded in 2011. Today, the Idrija Mercury mine is listed as part of the UNESCO World Heritage site.

3.2 Location

The Idrija mercury mine is situated in the town of Idrija app. 60 km west of the capital city of Ljubljana (Figure 1). Idrija is the oldest mining town in Slovenia and is today a well-known touristic destination; interested public can visit the Mercury mine museum and the old Hg smelting plant. Idrija is apart from mining also well known for the making of lance and a local dish 'Idrijski žlikrofi'. Idrija is geographically located in a steep valley with the Idrija Hills surrounding it and the river Idrijca running through the town centre.

LONGITUDE: 14.0025° E
LATITUDE: 46.0250° N

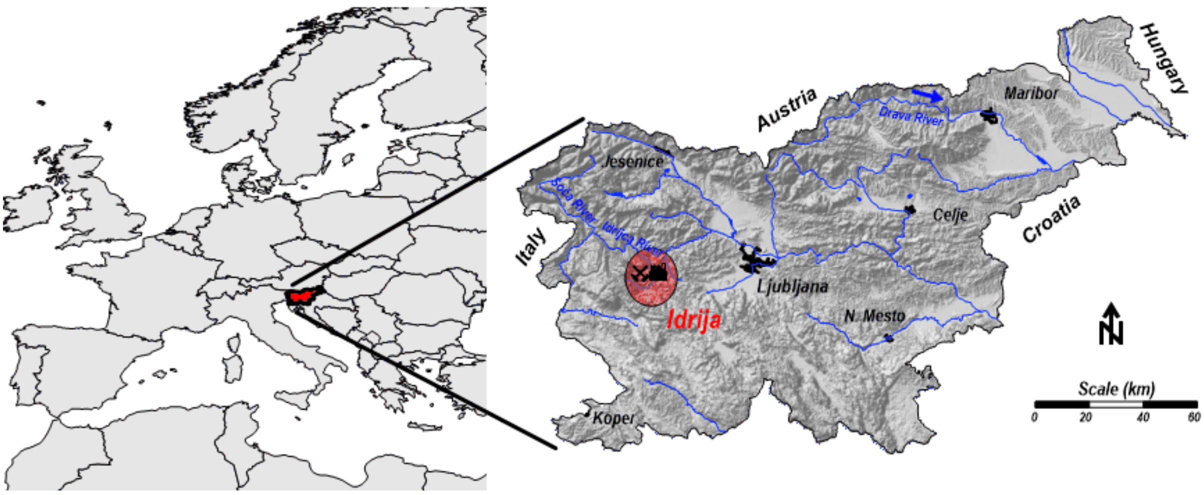

Figure 1. Location of Idrija mine.

3.3 Geology and mineralogy

Due to the vast and rich history of the Idrija Mercury mine lots of geological and mineralogical studies have been done throughout history. The Idrija mine and the production of Hg in Idrija was extensively described in the important historic book *De Re Metallica* from Georgius Agricola, published in 1556, and remained as an authoritative text of mining for the next 200 years. Among the first scientists to study the ore body was Balthasar Hacquet (1739-1825). In his monography *Oryctographia Carniolica* he dedicated approximately 100 pages to geology, mineralogy and mining of the Idrija deposit (Rečnik, 2012). Throughout the years several other Austro-Hungarian, Yugoslavian and later, Slovenian geologists studied the origin, sedimentology and minerology of the deposit.

The Idrija deposit is by its origin and local tectonics an extremely complex ore body (Figure 2). It hosts numerous different syngenetic and epigenetic types of mineralisation. The deposit formed 230 million years ago during massive tectonic events. Hot solutions rich in Mercury that originated in the Earth's mantle, rose through the fault. During the lift, part of the solution cooled and mineral cinnabar crystallised, replaced host rocks and formed epigenetic ore types. Part of the solution reached the surface before cooling and formed syngenetic ore types. The richest and most important types of mineralisation were mined from 'Skonca' ore-bearing horizon, which included epigenetic and syngenetic ore. Some sedimentary ores contained on average between 6 and 50% Hg with the highest values of Hg at 78%. Due to their colour and composition the miners named them Steel ore, Brick ore, Liver ore, Coral ore, and other (Čar, 2013). Mercury can be found in two forms, as native Mercury (Hg) and in the mineral cinnabar – mercury (II) sulphide (HgS).

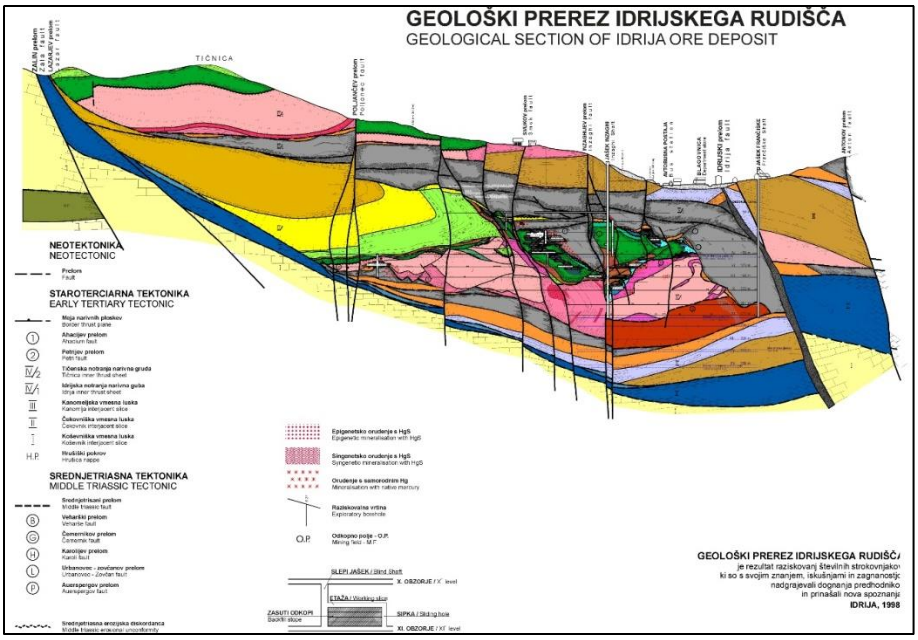

Figure 2. Geological cross section across the Idrija deposit (latest), source: CUDHg Idrija.

3.4 The test site

Idrija was selected as a trial site to test the prototype due to its more challenging environment when compared to the first test site in Kaatiala. The Idrija test site with its' murky water, confined spaces and limited ventilation and electricity provided the team a perfect place to test the robot's functionality in very realistic and harsh mine conditions. The part of the flooded shaft where the robot was tested also contained lots of debris and old structural beams and cables which had to be avoided by the robot during the dives not to damage the equipment. The test dives were carried out in the main Borba shaft (Figure 3), which is currently used by the mine for pumping and regulating the mine's water table and for the transportation of miners and maintenance materials to underground level III. Due to limited space, ventilation and electricity the team had to work on different levels of the mine. Part of the mine, which was not used for testing, is open for visitors (Figure 4).

Figure 3. Test site - Borba shaft at Idrija Mercury mine, source: CUDHg Idrija web page.

Figure 4. Touristic attraction, a 500-year-old Anthony's drive in the Idrija Mercury mine, source: CUDHg Idrija web page.

Before the testing started the staff from CUDHg Idrija had to prepare working spaces on the below listed levels, to ensure a safety working environment for the UNEXMIN team. Data, audio and visual communication between working stations have also been set-up by the UNEXMIN team. Four stations were used for UNEXMIN tests (Figures 5 and 6):

SITE 1 - The main control room (Figure 5a and site 1 on Figure 6): The main control room on the surface has been set up on the first floor of the mine building with 5 workstations with two 24'' screens for monitoring robots' functions and sensors. Adjacent to the control room, all other necessary amenities were available, including workshop, a room for eating and coffee, toilets, dressing room, etc.

Infrastructure:

- GigaBit communication with the launch site (site 4) and field control room (site 2)
- Lights
- Electricity
- 4G internet connection
- 2 24'' screens

SITE 2 - Field control room (Figure 5b and site 2 on Figure 6): A field control room in the mine has been set up on Level III which the personal were able to access from the surface via an elevator. The robot has been lowered into the shaft to the launch site (site 4) via a set of winches from this level.

Infrastructure:

- GigaBit communication
- Lights
- Electricity
- Winch for lowering/lifting the robot
- Place for 5 workers

SITE 3 - The repairs platform (Figure 5c and site 3 on Figure 6): On level IV, which is app. 44m above the launch site a wooden platform for quick UX-1 repairs or batteries replacement has been set up.

Infrastructure:

- Can be fitted for 4 or 5 people
- No lights
- Electricity provided

SITE 4 - The launch platform (Figure 5d and site 4 on Figure 6): A platform has been set up on 143,2 m ASL (above sea level) which was approx. 20cm above the water level in the pumping station where the robot was launched into the water. Due to the restricted air flow only three people (2 UNEXMIN people + CUDHg Idrija Underground Safety manager or his assistant) were allowed to work on this platform at the same time.

Infrastructure:

- GigaBit communication
- TV camera connected to the surface
- No lights
- No electricity
- Limited air supply

Figure 5. (a) Site 1 - Main control room, (b) Site 2 - Field control room, (c) Site 3 - The repairs platform, (d) Site 4 - The launch platform.

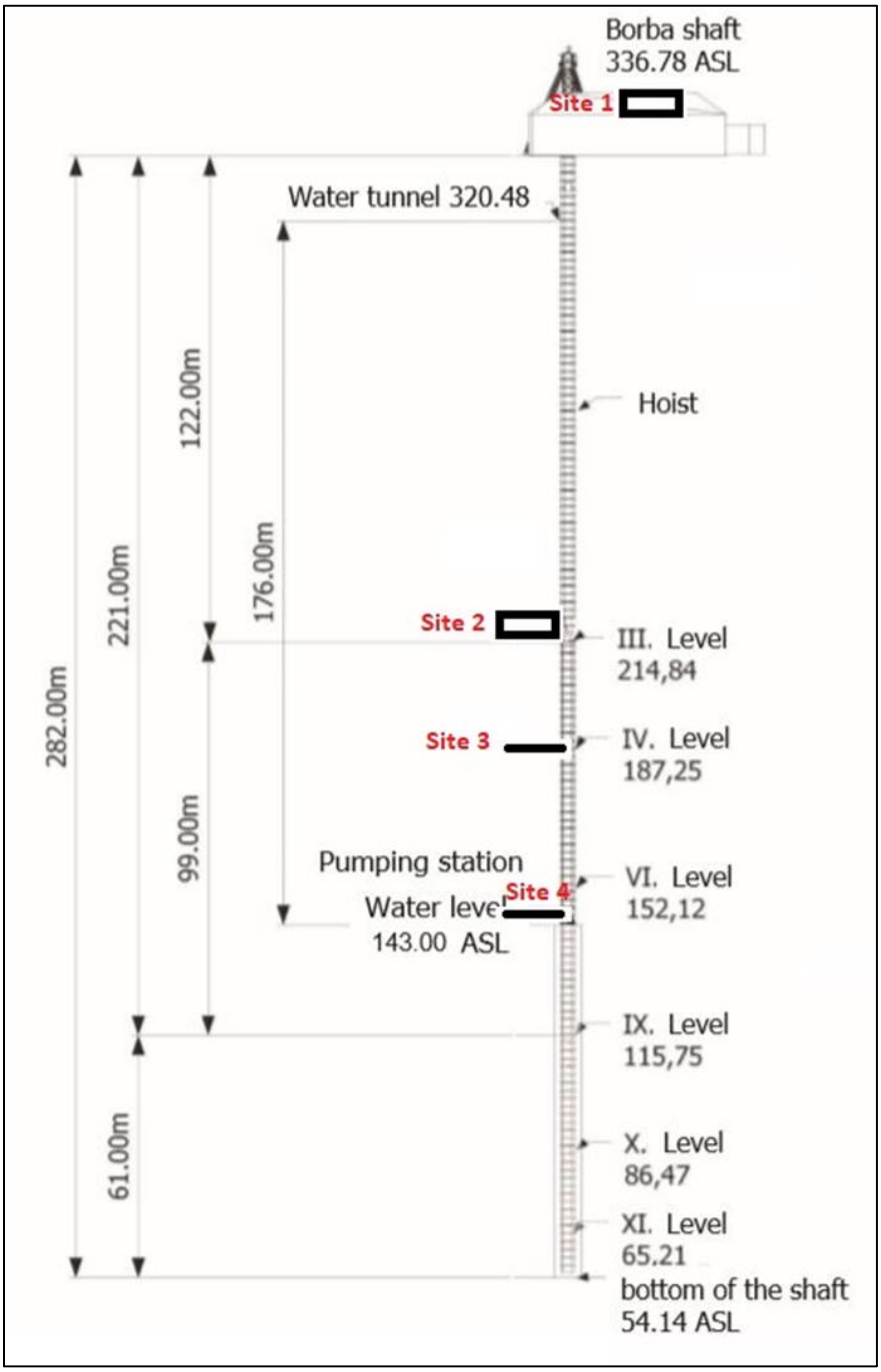

Figure 6. Cross section of the shaft 'Borba' with the indicated four sites, needed for the UX-1 testing.

4 Participants and the schedule

Tables 1 and 2 list the core of experts who participated at the Idrija UNEXMIN pilot and Figure 7 represents almost the majority of the team. During the trials a few other members of the UNEXMIN project inspected the test site during their short visits. Decisions during the Idrija pilot were made collectively, in a similar way as during the Kaatiala pilot. However, for safety reasons, three managers with their distinctive responsibilities were appointed by CUDHg Idrija:

- General manager – Tatjana Dizdarevič (CUDHg Idrija)
- Underground Safety manager – Robert Majnik (CUDHg Idrija)
- Chief UX-1 Technical Supervisor – Norbert Zajzon (UNIM)

Table 3 shows the mission agenda, and table 4 the anticipated daily schedules. Each morning the team meet at the morning briefing and discussed the progress of the tests and any modifications to the planned work.

During the Idrija trials the team of CUDHg Idrija miners worked in 2 shifts: Safety manager and 4 miners from 6 AM to 2 PM and 4 miners from 2 PM to 10 PM. General manager was present in both shifts from 6 AM to 10 PM.

Table 1. The Idrija pilot participants, UNEXMIN team.

	Name and surname	Institution	Role
1	Emil Pučko	GeoZS	Logistics, local organiser, pilot report preparation
2	Gorazd Žibret	GeoZS	Local organiser, pilot report preparation, communication with media
3	Tatjana Dizdarevič	CUDHg Idrija	General manager, communication with media
4	Robert Majnik	CUDHg Idrija	Underground Safety manager
5	Norbert Zajzon	UNIM	Chief Technical Supervisor
6	Richárd Papp	UNIM	Scientific instrumentation unit.
7	Márton L. Kiss	UNIM	Scientific instrumentation unit.
8	Máté Koba	UNIM	Scientific instrumentation unit.
9	James Tweedie	RCI / 4DCoders	Observation & Data.
10	Jussi Aaltonen	TUT	Mechanics and mechatronics
11	Jouko Laitinen	TUT	Mechanics and mechatronics
12	Zorana Milošević	UPM	Navigation software.
13	Ramon Suarez	UPM	Robot control software.
14	Ricardo Pereira	INESCTEC	Localization, perception and mapping software.
15	Eduardo Soares	INESCTEC	Localization, perception and mapping software.
16	José Almeida	INESCTEC	Localization, perception and mapping software.
17	Alfredo Martins	INESCTEC	Localization, perception and mapping software.
18	Carlos Almeida	INESCTEC	Localization, perception and mapping software.
19	Richard Shaw	EMET	Geological and logistics observer.

Table 2. List of miners from CUDHg Idrija who assisted UNEXMIN team during the Idrija pilot.

	Name and surname	Role
1	Aleš Svetik	Supervisor and mine rescuer
2	Gregor Klemenčič	Supervisor and mine rescuer
3	Aleksander Rupnik	Miner
4	Gordan Stepančič	Miner
5	Peter Vončina	Miner and mine rescuer
6	Matej Homec	Miner and mine rescuer
7	Branko Demšar	Electrician and mine rescuer
8	Andrej Mrak	Electrician

Figure 7. Team photo

Table 3. Mission Agenda.

Date	Activity
10th September 2018	- Meet at CUDHg Idrija - Safety Induction - Site set-up (offices, UX-1 working place). - Start pilot
10th – 15th 17th – 21th September 2018	Pilot tests daily 8:00 – 20:00
14th September 2018	Public presentation workshop with test site visit for public (for key UNEXMIN partners only), press conference
16th September 2018	Rest Due Overtime (RDO) Sunday, CUDHg Idrija closed, expert excursion
19th September 2018	Open ceremony of Exhibition of Minerals in Idrija (optional, not part of the UNEXMIN project)
20th September 2018	- Last tests: Autonomous waypoint navigation. - Site decommissioning. - Evaluation workshop for UNEXMIN partners.
21st September 2018	Check-out

Table 4. Daily schedule.

Time	Activity
– 8:00	Breakfast
8:00 – 8:15	Morning briefing
8:15 – 10:00	Tests
10:00 – 10:30	Coffee break
10:30 – 12:30	Tests
12:30 – 13:30	Lunch break
13:30 – 16:00	tests
16:00 – 16:15	Coffee break
16:15 – 20:00	Tests
20:00 –	Dinner

5 Preparation of the test site, documentation and dry tests

5.1 Preparation of the test site before the trial

Before the testing started CUDHg Idrija prepared all the necessary documentation according to the national mining legislation. This documentation included technical plans, rescue plan, safety instructions and others.

CUDHg Idrija prepared working and protective platforms on stations 2, 3 and 4 (shown on Figure 6) in the shaft for quick repairs and as a launching pad for the robot as well as ladders which were fixed prior to the beginning of the trials. Also, two winches were provided which were used during the test for lifting and lowering of the robot from III. level to the launching site.

A team of mine rescuers from CUDHg Idrija was always present at the site to provide safety for the project participants going into the mine and out of it as well as for managing the transportation of the UX-1a.

Saturday, 8/9/18

As part of the safety plan a scuba dive team exercise (Figure 8) in the shaft was organised two days before the testing took place. This was necessary because a national scuba dive team was on a standby during the Idrija trial in case UX-1a would have to be recovered from the water in the shaft Borba.

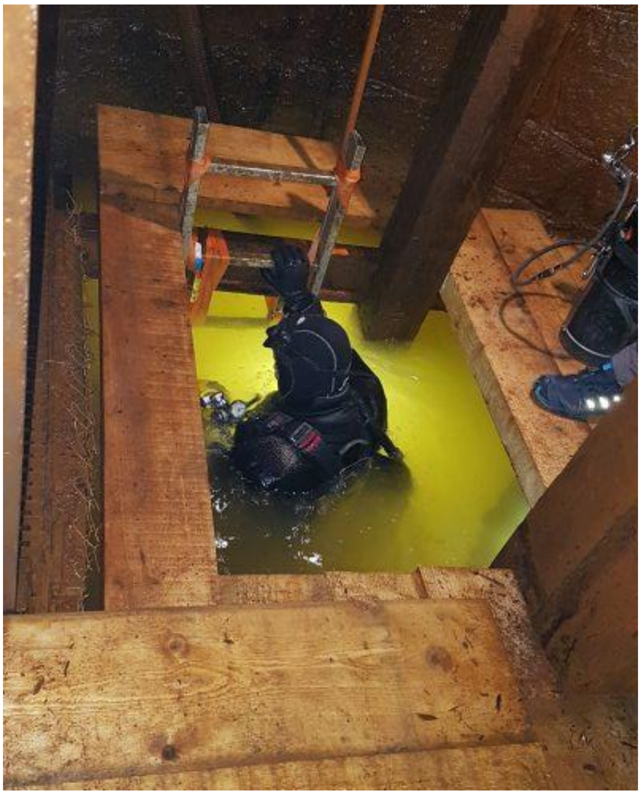

Figure 8. Exercise of scuba divers at the launch site.

5.2 Safety induction, testing equipment and dry tests

Monday, 10/9/18

Obligatory mine safety induction and familiarisation with mine site regulations has been conducted. Below are the highlights of safety instructions, and Figure 9 presents the detailed health and safety plan:

- As the testing is going to be carried out at a mine site, Slovenian mining legislation applies (beside others) regarding safety, health and other issues within the mine site.
- All participants working on the mine site must complete safety induction which will be provided by CUDHg Idrija before the start of the testing.
- All participants shall attend daily morning briefings.
- All participants must be aware of all safety rules and comply with them at all times.
- All participants will need to confirm with their signatures that they are aware of all safety rules and that they will comply with them at all times.
- Non-compliance with these regulations will result in banning that person from the mine site.
- Underground Safety manager is Robert Majnik, his assistant is Emil Pučko.
- Only participants who are on the List of Authorised Persons to test the UX-1 robot between 10. and 21. September 2018 in the Borba Shaft (hereinafter: List), are allowed to enter the underground part of the mine (underground mine).
- All participants from the List will be entering and working in the mine at their own risk
- To enter underground mine, everyone on the List must wear appropriate personal protective equipment (PPE): protective overalls, helmet, mining light which must be attached to the helmet, safety Gloves, all terrain shoes.
- Before each entry and exit of the underground mine, everyone on the List must fill out the Register book with the following details (name, surname, number of the mining light, time of entry and time of exit from the mine).
- UNEMXIN relevant risks mitigation measures still apply during IDRIJA tests.

Tuesday, 11/9/18

Due to limited communication at the bottom of the shaft a WI-FI connection had to be set up between the underground workstations and the surface with a GigaBit wireless internet connection. The optical cable had to be connected from the surface to the site 4. The overall distance between the bottom of the shaft and the surface is 193 metres. Communication tests and verification of ethernet link on Station 4 had been performed.

Testing and troubleshooting of Veeder Electronic Speed Controller (VESC) has been conducted (Figure 10). This system controls the thrusters and can be communicated via PPM signal (RC servo type), analogue, UART, I2C, USB or CAN-bus interfaces and provides rotational speed feedback from the thrusters.

Based on Article 33 of the Rules on Health and Safety Regulations and Technical Regulations for the Exploration and Extraction of Mineral Resources in Underground Mining (Official Gazette of the RS, No. 68/2003), I am issuing the following instructions:

INSTRUCTIONS
for safe walking and safe execution of works during the test of the UX-1 robot in the Borba Shaft part of the UNEXMIN project

1. *Only personal who are on the List of Authorised Persons to test the UX-1 robot between 10 and 21 September 2018 in the Borba Shaft (hereinafter: List), are allowed to enter the underground part of the mine (underground mine).*
2. *Underground safety manager and the person responsible for health and safety at work will instruct everyone on the List on safe walking and safe execution of works during the test of the UX-1 robot in the Borba shaft before the work begins.*
3. *By signing the instructions everyone on the List confirm that they understand and agree with all the safety rules specified in the instructions.*
4. *For the period between 10 and 21 September 2018, CUDHg Idrija has taken out an accident insurance policy in case of an accident during the test of the UX-1 robot in the Borba Shaft.*
5. *Everyone on the List shall enter the mine at their own risk.*
6. *To enter underground mine, everyone on the List must wear appropriate personal protective equipment (PPE)*
    - *Protective overalls,*
    - *Helmet,*
    - *Mining light which must be attached to the helmet,*
    - *Safety Gloves,*
    - *All terrain shoes.*
7. *Before each entry and exit of the underground mine, everyone on the List must fill out the Register book with the following details (name, surname, number of the mining light, time of entry and time of exit from caves).*
8. *Everyone on the List will travel between surface and Level III via transport elevator. During the transport, a miner of CUDHg Idrija must always accompany them. Transport without an accompanying miner of CUDHg Idrija is prohibited.*
9. *Members of the working group, that will be situated at station on Level 3 in the Borba Shaft will need to have one accompanying miner of CUDHg Idrija present with them at all times.*
10. *The work team, consisting of three members, uses the walking section to go up and down the Borba Shaft from level III to the working scaffold at the water level in the pumping station of the Borba Shaft, i.e. approx. 80m. There are four-metre-long aluminium ladders in the shaft, however, only one person is allowed to use a ladder at a time. A person climbing the ladder must always maintain 3 points of contact with the ladder. When climbing one must move hands alternately, holding the ladder rungs.*
11. *The team working at the water level at the pumping station in the Borba Shaft will consist of the following three members:*
    - *Underground safety manager or the CUDHg Idrija mining supervisor, authorized by the Underground safety manager, who ensures safety during the test of the UX-1 robot at the pumping station and constantly monitors air quality at the site, and is also a mine rescuer,*
    - *Two persons from the List.*
12. *Lowering and lifting of the shock absorbent cage with the robot between Level III and the work platform at the water level will be supervised by a CUD Idrija miner who will be positioned on the ladders in the walking sections.*
13. *Communication with the operator of the winch will be via radio communication system.*
14. *Communication between the working group at the water level at the pumping station in the Borba Shaft (working scaffold), the miner, located at the winch for the transportation of the UX-1 robot, and the accompanying team at level III will be via radio communication system.*
15. *A safety scaffold (roof) will be installed in the shaft above the working scaffold across the entire surface of the shaft to ensure safe work of the three person working group, positioned at the water level at the pumping station in the Borba Shaft during the test of the UX-1 robot, and to prevent possible damage due to the fall of material from a height into the shaft.*
16. *To secure the team, the safety scaffold (roof) must be covered.*
17. *In case of intervention to rescue the UX-1 robot from the pumping station of the Borba Shaft Report and Plan for Submersion into the pumping station of the Borba Shaft has been made. Potential rescue mission will be carried out by a technical rescue unit for diving of the Administration of the Republic of Slovenia for Civil Protection and Disaster Relief, the Ministry of Defence, Report and Plan for Submersion into the pumping station of the Borba Shaft have been made.*

19\. *In case of an accident in the Borba Shaft, emergency number 112 must be called to inform the regional notification centre (ReCO). Rescue from the bottom of the shaft will then be performed with the rope technique.*

Good luck!

Technical Manager:
Robert Majnik, mining technologist

Approved by authorized person for safety and health at work: Tatjana Dizdarevič, BSc in Mining

Figure 9. Safety rules and regulations at CUDHg Idrija mine site.

Figure 10. Troubleshooting of Vender Electronic Speed Controller (VESC).

Wednesday, 12/9/2018

Testing equipment for lifting/lowering of the robot from site 2 to site 4 (Figure 11). Operation of the winch was tested using a 100kg dummy weight with a lifting/lowering speed of 0,5 m/s. To lower the risk of damaging the robot during its lift between site 2 and site 4 a wooden frame has been created and tested by CUDHg staff.

Figure 11. Testing of the winch.

Thursday, 13/9/2018

Due to the problems with supplying the original umbilical cable necessary for the execution of dives a new umbilical cable had to be made (Figure 12). After that phase, the UX-1a can be lowered from the surface to the launch site (site 4) and dives can begin. In the meantime, film crew was filming a documentary about UNEXMIN project for a Slovenian national TV (Figure 13), science documentary series 'Ugriznimo znanost', which was broadcasted on national TV on the 18.10.2018 and viewed by app. 400.000 viewers. This show can be seen (after logging-in) using the following link: https://4d.rtvslo.si/arhiv/ugriznimo-znanost/174569559

Figure 12. Preparing umbilical cable.

Figure 13. Filming for the documentary 'Ugriznimo znanost'.

6 Dives performed and the results

Table 5 presents the basic information about dives performed in the Idrija mine. More detailed description of each dive, with characteristic results, is presented in the following pages.

Table 5. Information about dives performed in Idrija mine.

Dive #	Date	Time	Duration	Details	Responsible
1	14/9/18	10:27	app. 1,5h	Testing of the pendulum and ballast system.	Ramon A. Suarez Fernandez
2	15/9/18	10:40	app. 1h	Multibeam tests at various pitch angles and rotations.	Alfredo Martins (multibeam sonar) Ramon A. Suarez Fernandez (pitch control)
3	15/9/18	16:40	app. 2h	Test of mapping sensors and depth tests	Carlos Almeida
4	17/9/18	12:30	app. 0,5h	Testing of multispectral unit.	Richard Papp
5	17/9/18	14:25	2h	Dive to the full depth: Mapping and Auto-Heading Test.	Carlos Almeida (Mapping) Ramon A. Suarez Fernandez (Auto-heading)
6	18/9/18	16:45	app. 0,5h	Verifying the pendulum.	Ramon A. Suarez Fernandez
7	19/9/18	8:23	app. 1h	Balancing UX-1a for 90° pitch down dive.	Ramon A. Suarez Fernandez
8	19/9/18	10:45	app. 1,5h	Recording IMU and DVL sensor data for localization software troubleshooting.	José Miguel Almeida
9	19/9/18	13:50	2,5h	Nose down manoeuvring tests.	Ramon A. Suarez Fernandez
10	20/9/18	10:01	2h	Full Depth Mapping Dive.	Alfredo Martins
11	20/9/18	16:30	app. 1h	Autonomous waypoint navigation.	Zorana Milošević

Dive #1

Date: 14/9/2018

Test: Testing of the pendulum and ballast system

Description: During the first dive (Figure 14) in Idrija, the pendulum system and the ballast system, assuring negative buoyance were tested. In vertical shafts the ballast system can provide long distance vertical motion which saves on electric energy. The ballast system consists of a ballast tank, reservoir and pump. The pump is driven by a small brushless electric motor controlled by a VESC (that was tested during the dry tests) and a reduction gear to match the rotational speed of the motor and pump. The volume of UX-1 is controlled by using the transformer fluid and a bladder (Zavari et al., 2017).

- **Time:** 10:27

Log of inertial data for estimation of local gravity value and IMU bias on site 4. This is used in the localization software.

- **Time:** 11:18

Dive to test the negative buoyancy. During the dive, the team on the surface on Site 1 closely observed robot's surroundings from the data obtained from UX-1a instrumentation, to avoid collision between UX-1a and submerged objects. Figure 15 presents the information, obtained from the scanning sonar.

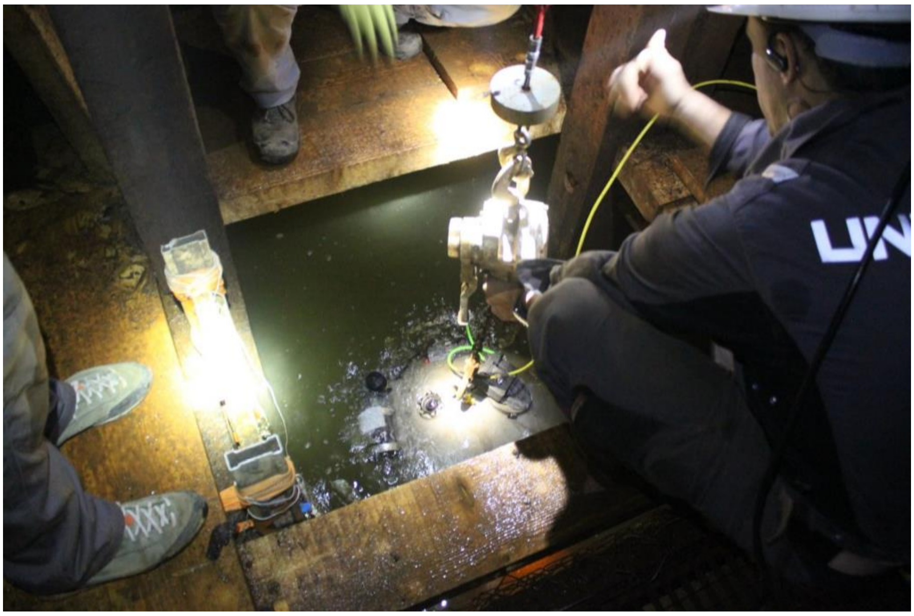

Figure 14. Launch of the UX-1a into Borba shaft.

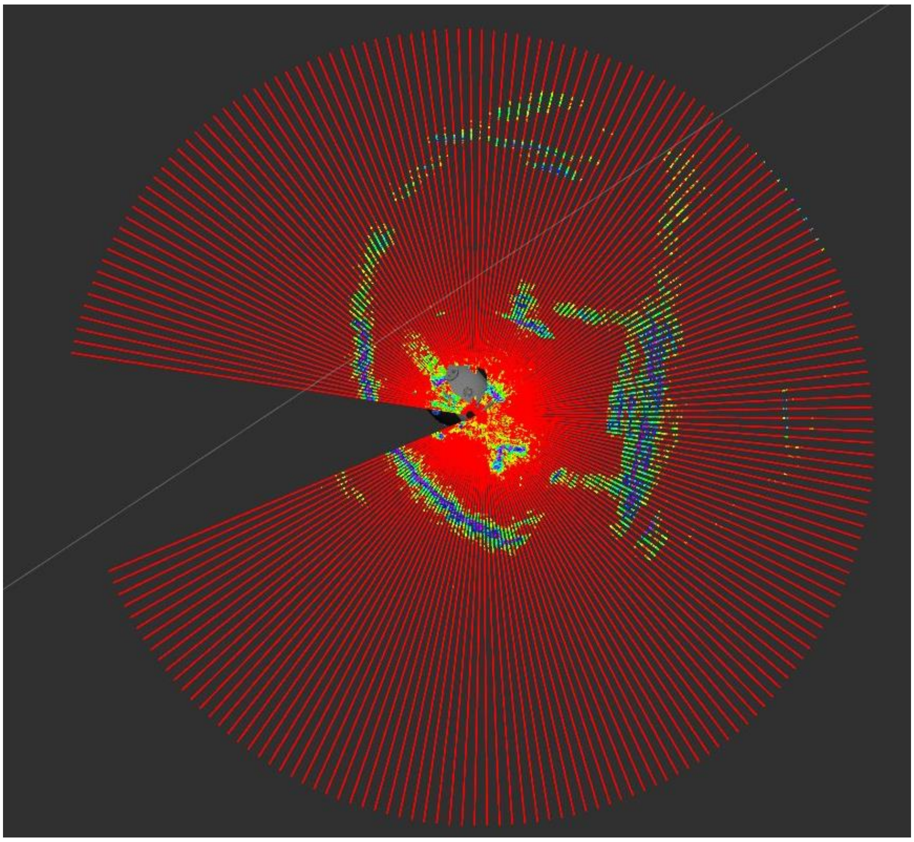

Figure 15. Screenshot of the scanning sonar test.

- **Time:** 16:00

Correcting the pendulum and trimming the vehicle in a 2m^3 water tank on the surface (Figure 16).

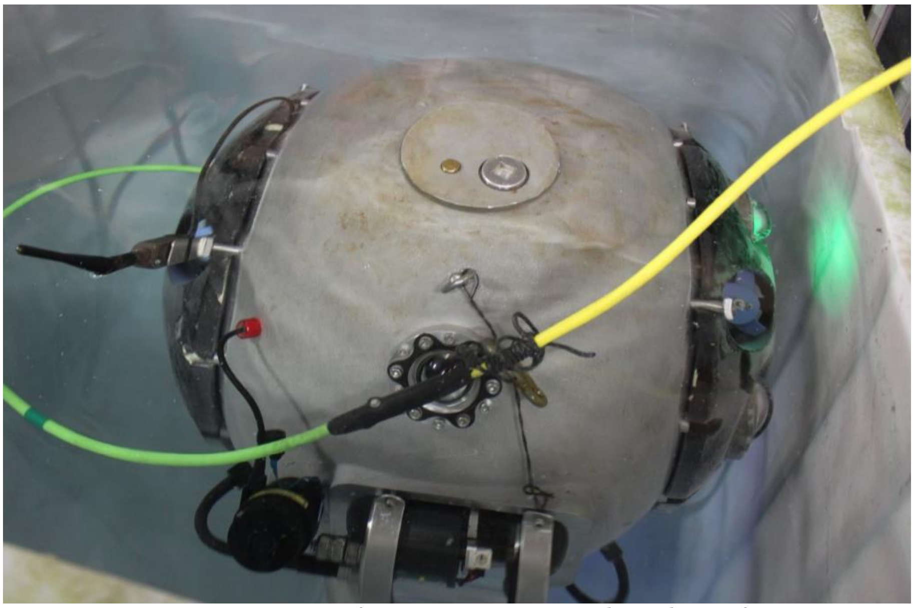

Figure 16. Testing of UX-1a in a water tank on the surface.

Results: Pendulum had passed the designated limits and operated as anticipated. Robot successfully returned to the surface and was taken out of the water.

Responsible: Ramon A. Suarez Fernandez

Dive #2

Date: 15/9/2018

Test: Multibeam tests at various pitch angles and rotations

Description: The second dive was made to test the multi beam sonar of the robot while diving at different pitches (0 degrees and 90 degrees; Figure 17). The robot's pitch (around the vertical (y) axis) is adjusted with the pendulum system. Planetary gear and stepper motor are used to rotate the pendulum which then creates a torque that changes the robots' pitch angle.

The purpose of these tests was to obtain initial characterization of the data provided by the multibeam sonar in tight spaces and shaft conditions (depending on the relative configuration of the sonar beam swath and different environment).

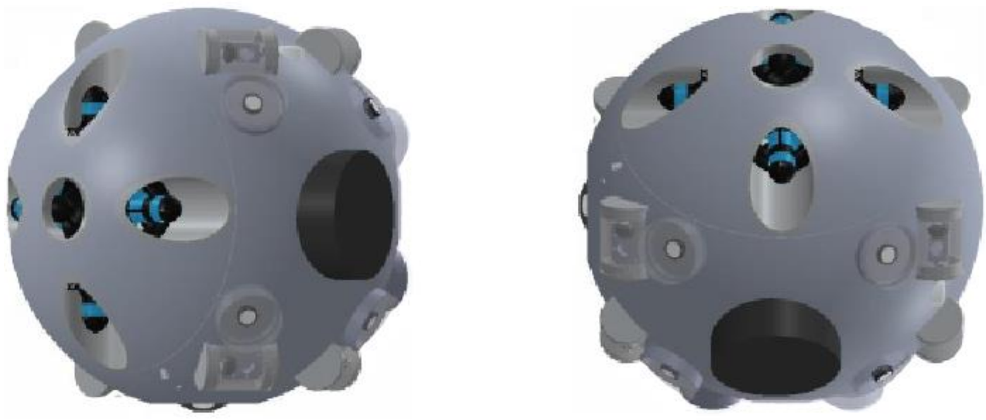

Figure 17. Robot diving at different pitches (left: 0 degrees, right: 90 degrees).

- **Time:** 11:35

Pitch down 90° test, multiple pitch and rotations at shallow depths (app. 2 metres) to test multibeam sonar and pendulum.

- **Time:** 13:04

New calibration of the pressure sensor and multi beam tests on the surface.

Results: Successfully tested manoeuvrability of the robot at different pitches (0 degrees and 90 degrees) at shallow depths. Due to the tests being performed very close to the surface the quality of multibeam sonar data was very low with a large number of reflections and dropouts.

Responsible: Alfredo Martins (multibeam sonar), Ramon A. Suarez Fernandez (pitch control)

Dive #3

Date: 15/9/2018

Test: Testing of mapping sensors

Description: Dive up to approximately 7.5m depth. This dive was performed in order to test the basic functions of the UX-1a robot, previously validated in Kaatiala, at a reasonable depth. During the test dive several visual cameras (Figure 18) and sonar were tested:

- Camera validation.
- SLS lighting sequence validation.
- Scanning sonar validation.

- **Time:** 16:40

Diving to the depth of 7.5 metres in the shaft.

Results: During mapping of the shaft (Figure 19) a horizontal beam has been detected. Tritech tests were also carried out.

Responsible: Carlos Almeida

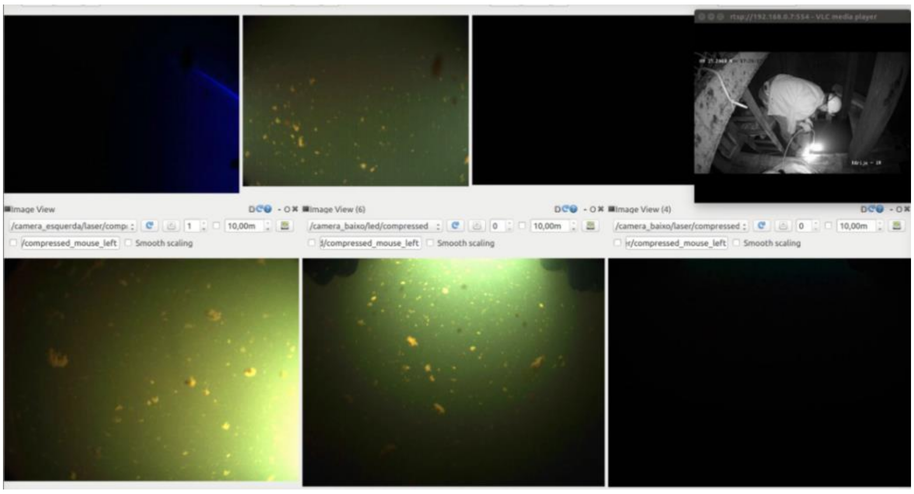

Figure 18. Testing of cameras.

Figure 19. Mapping of structures in the shaft.

Dive #4

Date: 17/9/2018

Test: Testing of multispectral unit

Description: For the purpose of testing UX-1a's multispectral unit (MSU) the robot had to be manually positioned (Figure 20) in front of three different mineral sample boards which were previously submerged into the shaft water. The sample board (Figure 21) contained most common ore and waste rock minerals and different mineral samples from Ecton mine, glued on the black board. Because the effect of the robot's movement on the MSU data acquisition were tested and evaluated, the robot was manually assisted during the procedure. For the MSU measurements a new sample holder was made and has been fixed to a long ladder and placed in the shaft. The test was conducted on various depths.

Reference minerals were imaged using a sequence of 14 different light wavelengths (405, 420, 450, 490, 525, 590, 630, 670, 700, 720, 750, 780, 810, 850 nm) using a monochrome camera. The measurements were repeated several times to ensure all of the images were available for post-processing. During the MSU tests the reflections from the water surface could generate false data during measurement, so the exact position of the board needed to be precisely adjusted. The time sequence of the different light sources from UX-1a was also successfully tested.

Results: The signals for each light source (multispectral unit, SLS system, UV light, other light sources) need to be triggered correctly to avoid interference with each other. The time sequences were developed for different exposition times (5ms, 10ms, 15ms, 20ms) of the multispectral unit. We had to test the correct timing of the MSU so it could work in collaboration with the SLS units. MSU trigger times were selected and the controller board timing was verified so it did not interfere with other light sources. An example of obtained images using MSU is shown on Figure 22.

Responsible: Richard Papp

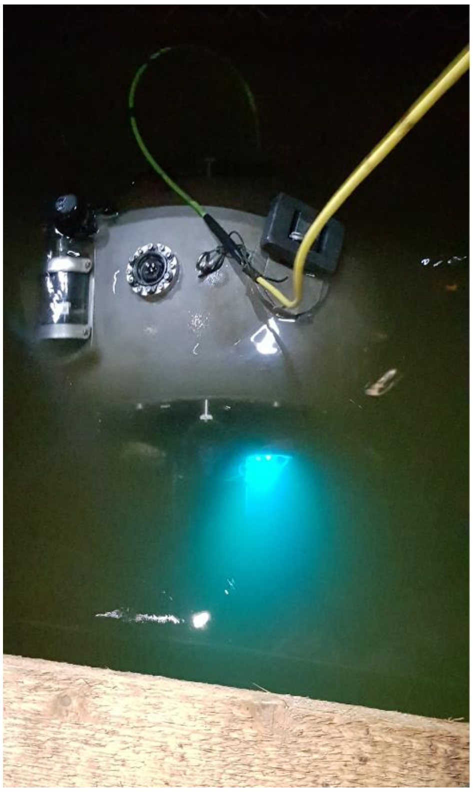

Figure 20. Real life testing of multispectral unit.

Figure 21. Reference sets of minerals prepared by the University of Miskolc, which were placed under water in the Idrija shaft in order to obtain reference spectra in real mine conditions.

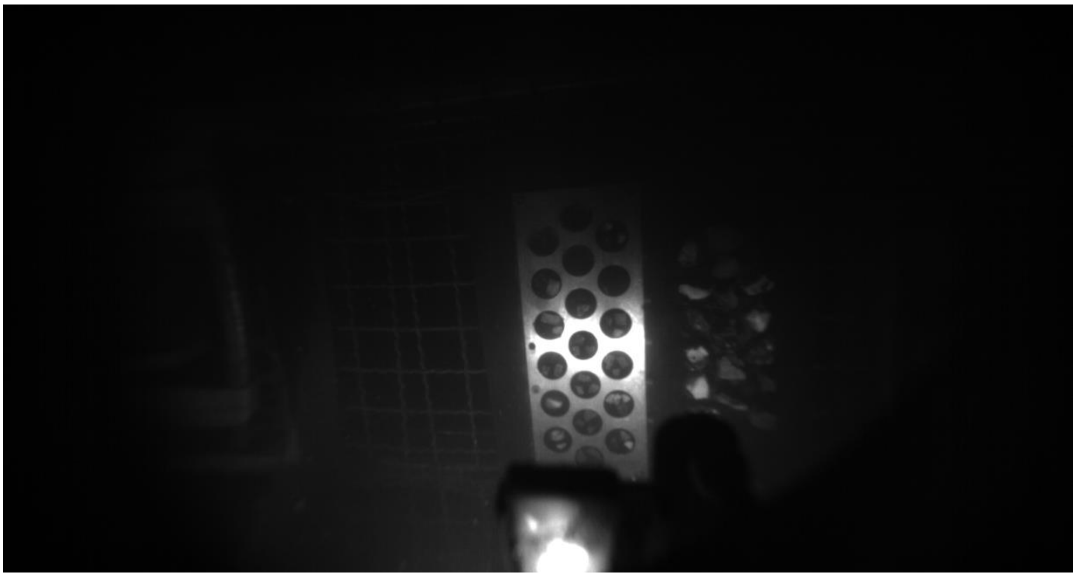

Figure 22. Multi-spectral imaging of the reference mineral set at 700nm wavelength, showing the polished reference mineral set in the middle, and the Ecton samples to the right.

Dive #5

Date: 17/9/2018

Test: Dive to the full depth: Mapping and Auto-Heading Test

Description: The auto-heading function was tested in order to maintain a constant heading during the controlled descent to the deepest part of the Idrija mine shaft. During the dive the heading and surge motions were tele operated.

- **Time:** 14:25

Dive to the bottom of the shaft. Log of multi beam and tritech data. Dive with pitch 0°.

- **Time:** 16:07

UX-1a reached the bottom of the mine.

- **Time:** 16:34

UX-1a returned to the surface.

Results: The Auto-Heading manoeuvre (Figure 23) was successful in maintaining reference heading set points even under external disturbances. During the dive, the depth controller operated normally (Figure 24). The information provided by the Tritech sonar was used for obstacle detection and avoidance during the dive. Multibeam sonar data was obtained during the entire dive and provided a map of the whole shaft (Figure 25).

Responsible: Carlos Almeida (Mapping), Ramon A. Suarez Fernandez (Auto-heading)

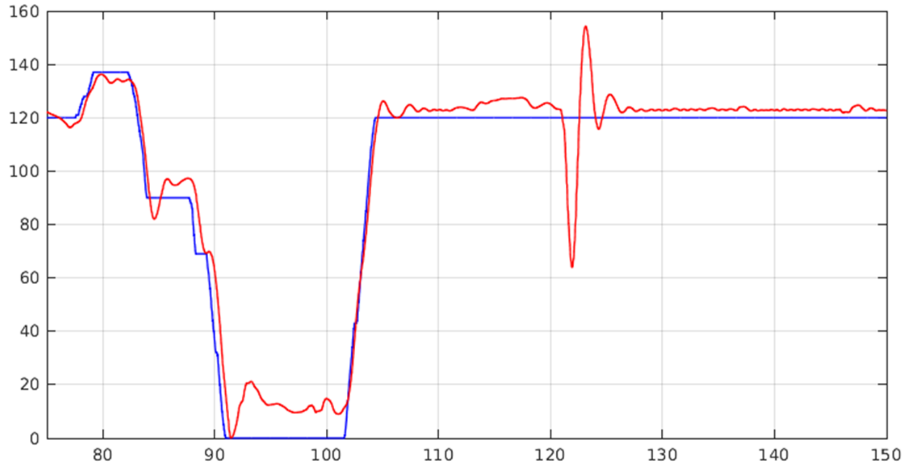

Figure 23. Yaw vs. time graph of auto-heading control tests. Blue line represents modelled (anticipated) yaw, while the red line the actual one.

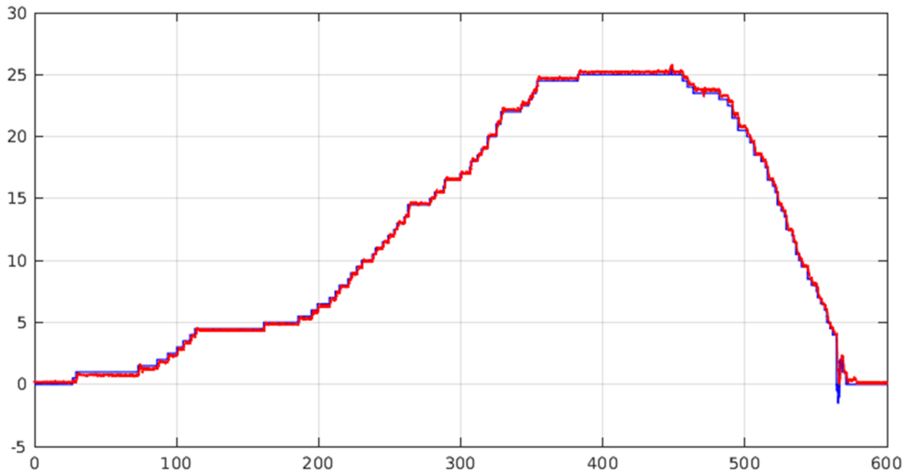

Figure 24. Depth (m) vs. time graph of full depth dive. Blue line represents modelled (anticipated) depth, while the red line the actual one.

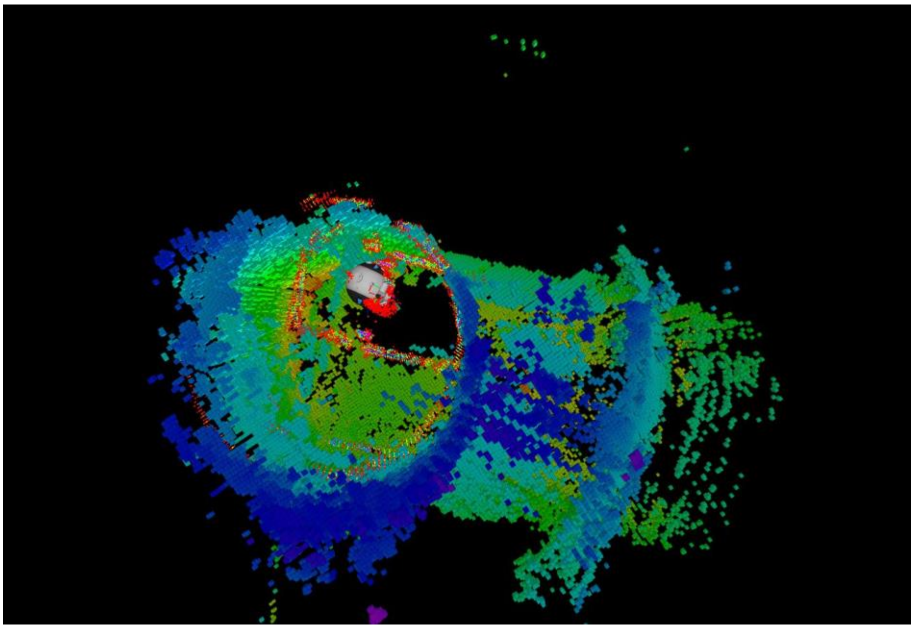

Figure 25. Mapping of the shaft.

Dive #6

Date: 18/9/2018

Test: Verifying the pendulum

Description: A short dive was performed to verify the pendulum after troubleshooting the pendulum by TUT.

- **Time:** 16:45

Dive to verify the pendulum.

Results: UX-1a pendulum was found to be working well after the repairs.

Responsible: Ramon A. Suarez Fernandez

Dive #7

Date: 19/9/2018

Test: Balancing UX-1a for 90º pitch down dive.

- **Time:** 8:23

Description: Testing of new weights for trimming.

Results: During the dive at 90º pitch some issues with navigation parameters have been detected. Further dives to resolve these issues have been planned.

Dive #8

Date: 19/9/2018

Test: Recording IMU and DVL sensor data for localization software troubleshooting.

- **Time:** 9:30

Dive to record navigation data for troubleshooting.

- **Time:** 10:22

MSU tests and logs.

- **Time:** 10:46

Controlled dive at 90º pitch to 2m.

Results: Navigation issues were resolved.

Responsible: José Miguel Almeida

Dive #9

Date: 19/9/2018

Test: Nose down manoeuvring tests

- **Time:** 13:50

Description: Since the pendulum system issues were corrected, the robot was tested for rotation in pitch to stabilize in a nose down configuration. (-90 deg. pitch) or a nose up configuration (90 deg. pitch).

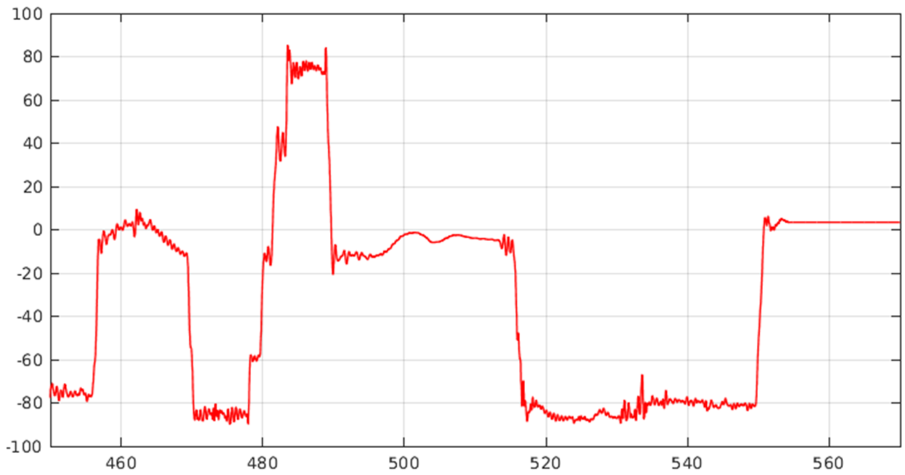

Figure 26. Pitch (deg) vs. time graph of nose down manoeuvre tests.

Results: The pendulum mechanism is able to perform the pitching manoeuvre to the necessary accuracy and precision to navigate nose down inside mine shafts (Figure 26).

Responsible: Ramon A. Suarez Fernandez

Dive #10

Date: 20/9/2018

Test: Full Depth Mapping Dive

Description: A second controlled descent dive was performed to reach the deepest part of the mine shaft and map the tunnel section located at 27m depth. During the dive the heading and surge motions were tele operated.

- **Time:** 10:01

Dive with pitch 0 deg., camera and SLS tests.

- **Time:** 11:32

UX-1a dived to the bottom of the shaft. Logging of multi beam data.

- **Time:** 12:00

UX1-a returned to the surface.

Results: The UX1 robot was able to reach the deepest part of the mine shaft with exceptional accuracy (Figure 27) and data gathering for 3D mapping was acquired for offline post processing (Figures 28 and 29). Using robot's data from the dive it was discovered that a drainage gallery connected to the shaft that was assumed to be blocked was accessible. The robot advanced 7 metres into the gallery and successfully mapped it.

Responsible: Alfredo Martins

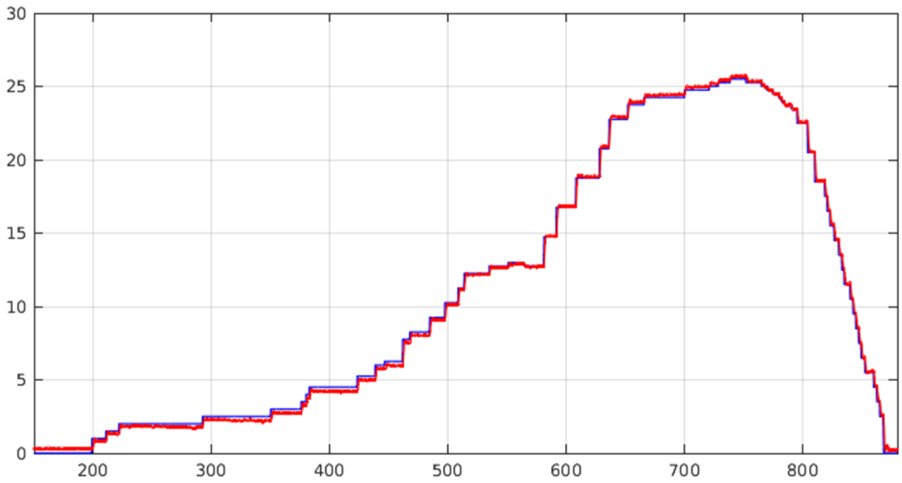

Figure 27. Depth (m) vs. time graph (full depth dive).

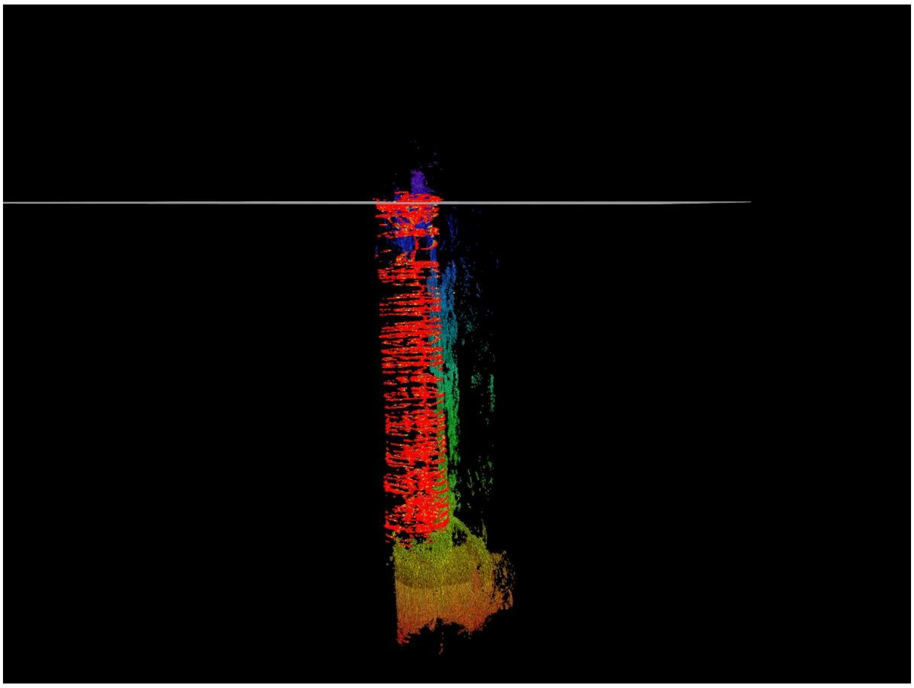

Figure 28. Mapping of the shaft.

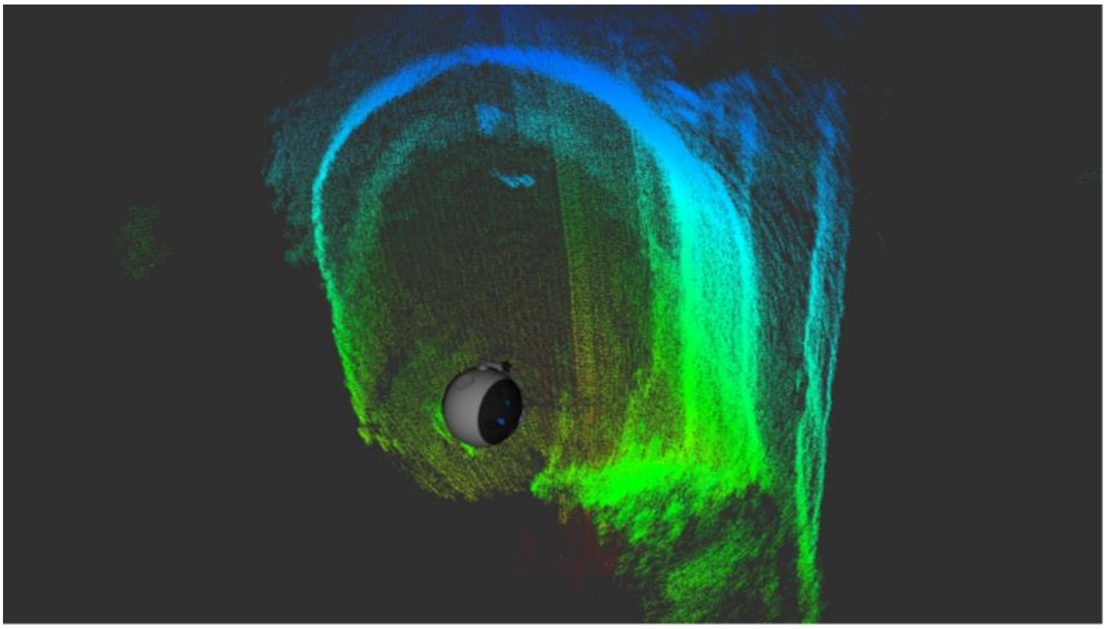

Figure 29. Mapping of the bottom of the shaft.

Dive #11

Date: 20/9/2018

Test: Autonomous waypoint navigation

Description: During the last dive, a simple autonomous waypoint navigation was tested. The waypoints were predefined in a .xml file shown in Figure 30. Since testing took place in a shaft the robot was able to move only vertically, thus the sent waypoints were keeping the x and y constant (heading and surge), i.e. to keep the distance from the walls, and to change position in z direction (depth). The mission consisted of the robot diving to 1 meter, waiting for a few seconds, then going down to 1.5 meters, waiting, then going down to 2 meters and finally returning to the surface.

Result: All waypoints were reached autonomously and the UX_1 returned safely to the surface. The position in z axis is shown in Figure 31.

Responsible: Zorana Milošević

```xml
<mission description="Waypoint navigation">

	<task description="Go to point A">
		<point>
			<x>0.0</x>
			<y>0.0</y>
			<z>1.0</z>
		</point>
	</task>

	<task description="Go to point B">
		<point>
			<x>0.0</x>
			<y>0.0</y>
			<z>1.5</z>
		</point>
	</task>

	<task description="Go to point C">
		<point>
			<x>0.0</x>
			<y>0.0</y>
			<z>2.0</z>
		</point>
	</task>

	<task description="Go to starting point">
		<point>
			<x>0.0</x>
			<y>0.0</y>
			<z>0.0</z>
		</point>
	</task>

	<event_handling>
		<event name="Low battery">
			<task description="ABORT_MISSION"/>
		</event>

		<event name="Emergency">
			<task description="ABORT_MISSION"/>
		</event>
	</event_handling>

</mission>
```

Figure 30. Predefined waypoint navigation.

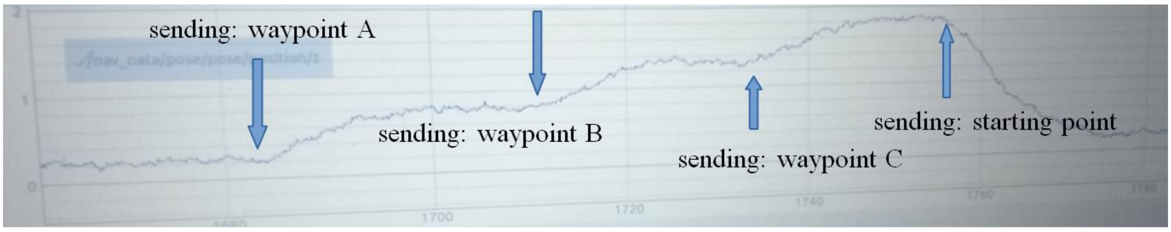

Figure 31. Position in z direction (depth).

7 Data post-processing

7.1 Data post-processing

The raw data, obtained by UX-1a instrumentation units during the Idrija pilot dives, needed to be transformed to more common data formats, timestamped, attributed, placed in the reference coordinate system and synchronised before it is inserted into database for further data processing and visualisation. The ROS bag files from the Idrija pilot (navigation and M3 multi beam sonar) were unpacked into CSV format files and imported into the VMINE software system. The sequence of processing was as follows:

(1) import of M3 data. Each sequential data set contained 256 beams held in one record. These were separated into 256 independent records each holding one set of {x,y,z} coordinates in the sensor reference frame.

(2) join of M3 data with navigation data {navx, navy, navz} coordinates in the world reference frame, together with quaternion data defining the orientation of the UX-1a submersible. Because the timestamps of the M3 data did not precisely match the timestamps of the navigation data, it was necessary to do a linear interpolation of navigation coordinates and quaternion values.

(3) rotation of M3 data from the sensor frame into the UX-1a reference frame, and the resultant coordinates into the 'world' reference frame.

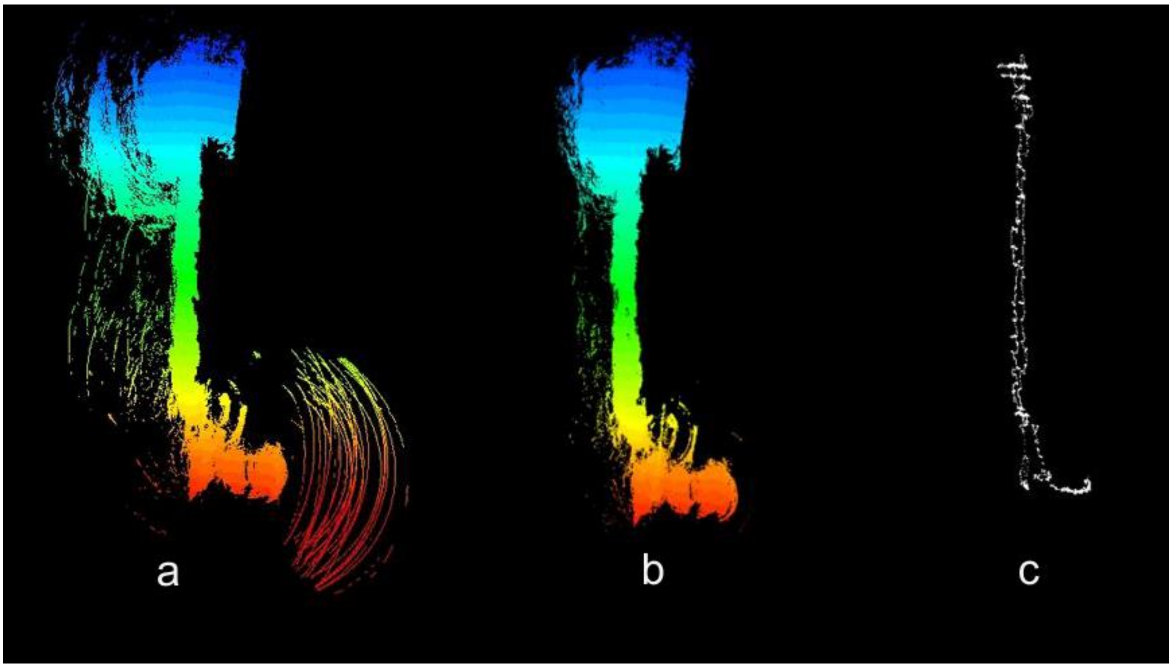

Figure 32. Idrija M3 data from 17 Sept.2018, (a) as received, (b) after cleaning, (c) navigation track.

The data were exported into VRML-2 format files (*.wrl) which could be examined interactively. Figure 32a, shows the result of this operation. It was clear that there were a large number of false echoes, generally at a large distance from the M3 instrument. Statistical summaries indicated that most, and perhaps all echoes recorded from distances greater than 5 metres were artefacts. Filtering out these longer echoes from the data, a cleaned 3D model was obtained as shown in Figure 32b. At the bottom of the explored part of the shaft there is known to be a horizontal side passage, and this is clearly seen in the models. However, at the top, the model appears to show the shaft to be much wider. This is not the case. The navigation track (Figure 32c) indicates that there were multiple passes at these shallow depths. The apparent greater width of the shaft here is probably a result of imprecision in the survey control, as the position and orientation of the submersible are reset between dives.

A mid-section of the shaft (data between depths of -14m and -16m, Figure 33) shows that there are further questions over the M3 data. There appear to be multiple internal reflections within the shaft. It is not altogether clear what is causing this effect, but the effective minimum range of M3 is 1 metre, and it is probable that there are strong internal reflections from the flat surfaces of the shaft when UX-1a approaches this minimum distance from one wall.

RCI also imported data from photographic images obtained by multispectral unit, pixel-by-pixel, and selected points within each mineral sample, for each wavelength, to record the reflected light intensity. A square block of 9 pixels was used for each mineral, and the reflection intensities averaged to obtain reference spectra. These spectra will be used in subsequent pilots (Urgeirica and Ecton) for characterisation of the geology.

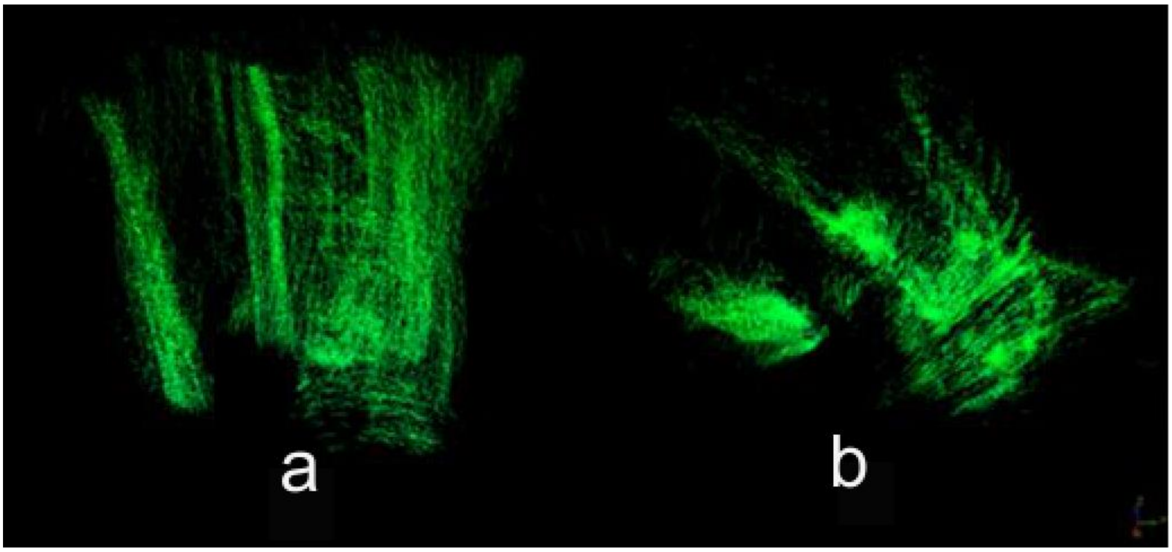

Figure 33. M3 reflections from -14m to -16m in the Idrija shaft. (a) side view, (b) plan view.

7.2 UNEXMIN data inventory

Table 6 presents the data inventory from the two finished test campaings, the Kaatiala and the Idrija pilots. This data will be used for the geoscientific evaluation of the pilots and the technology as a whole before the end of the project, as well as to prepare the most relevant showcases for the stakeholders, showing the UX-1 platform capabilities.

Table 6. UNEXMIN data inventory from 2 pilot missions.

PILOT	DATE	FILE NAME OR DESCRIPTION	FILE TYPE	SIZE (Kb)
KAATIALA	18/06/2018	2018-06-18-14-50-02.bag	ROS BAG	3.693.125
KAATIALA	18/06/2018	KAA_UX1A_20180618_01DVL0001.csv	DVL	46.072
KAATIALA	18/06/2018	KAA_UX1A_20180618_01IMU0001.csv	IMU	355.673
KAATIALA	18/06/2018	KAA_UX1A_20180618_01NAV0001.csv	NAV	12.454
KAATIALA	18/06/2018	KAA_UX1A_20180618_01M30001.txt	M3	13.374
KAATIALA	19/06/2018	2018-06-19-19-06-22.bag	ROS BAG	6.073.760
KAATIALA	19/06/2018	KAA_UX1A_20180619_01DVL0001.csv	DVL	54.925
KAATIALA	19/06/2018	KAA_UX1A_20180619_01IMU0001.csv	IMU	442.517
KAATIALA	19/06/2018	KAA_UX1A_20180619_01M30001.txt	NAV	12.979
KAATIALA	19/06/2018	KAA_UX1A_20180619_01M30001.txt	M3	14.685
KAATIALA	19/06/2018	SLS IMAGE FILES (down,front,left,top)		
KAATIALA	19/06/2018	sbp_2018-06-19-19-06-22.txt	SBS	4.011
KAATIALA	20/06/2018	2018-06-20-13-00-45.bag	ROS BAG	5.109.322
KAATIALA	20/06/2018	KAA_UX1A_20180620_01DVL0001.csv	DVL	46.951
KAATIALA	20/06/2018	KAA_UX1A_20180620_01IMU0001.csv	IMU	376.608
KAATIALA	20/06/2018	KAA_UX1A_20180620_01NAV0001.csv	NAV	11.175
KAATIALA	20/06/2018	KAA_UX1A_20180620_01M30001.txt	M3	13.245
KAATIALA	20/06/2018	SLS IMAGE FILES (down, front, left)		
KAATIALA	20/06/2018	sls_20062018_meio_2018-06-20-14-30-51.bag	ROS BAG	1.709.729
KAATIALA	20/06/2018	sls_20062018_meio_2018-06-20-14-49-46.bag	ROS BAG	200.182
KAATIALA	20/06/2018	sbp_2018-06-20-13-00-45.txt	SBS	1.123
KAATIALA	20/06/2018	kaa20.db	SQLITE	285.480
IDRIJA	15/09/2018	IDR_UX1A_20180915_01DVL0001.csv	DVL	40.583
IDRIJA	15/09/2018	IDR_UX1A_20180915_01DVL0002.csv	DVL	45.697
IDRIJA	15/09/2018	IDR_UX1A_20180915_01IMU0001.csv	IMU	348.476
IDRIJA	15/09/2018	IDR_UX1A_20180915_01IMU0002.csv	IMU	389.067
IDRIJA	15/09/2018	IDR_UX1A_20180915_01NAV0001.csv	NAV	368.273
IDRIJA	15/09/2018	IDR_UX1A_20180915_01NAV0002.csv	NAV	420.861
IDRIJA	15/09/2018	IDR_UX1A_20180915_01M30001.txt	M3	14.031
IDRIJA	15/09/2018	IDR_UX1A_20180915_01M30002.txt	M3	25.057
IDRIJA	15/09/2018	SLS IMAGE FILES (bottom, front)		
IDRIJA	15/09/2018	15-09-2018.db	SQLITE	3.470.652

Table 6, continue.

PILOT	DATE	FILE NAME OR DESCRIPTION	FILE TYPE	SIZE (Kb)
IDRIJA	17/09/2018	2018-09-17-14-26-23.bag	ROS BAG	8.412.312
IDRIJA	17/09/2018	IDR_UX1A_20180917_01DVL0001.csv	DVL	53.278
IDRIJA	17/09/2018	IDR_UX1A_20180917_01IMU0001.csv	IMU	431.221
IDRIJA	17/09/2018	IDR_UX1A_20180917_01NAV0001.csv	NAV	471.997
IDRIJA	17/09/2018	IDR_UX1A_20180917_01M30001.txt	M3	34.408
IDRIJA	17/09/2018	SLS IMAGE FILES (bottom, front,left,right)		
IDRIJA	17/09/2018	17-09-2018.db	SQLITE	2.017.212
IDRIJA	19/09/2018	IDR_UX1A_20180919_01DVL0001.csv	DVL	19.486
IDRIJA	19/09/2018	IDR_UX1A_20180919_01DVL0002.csv	DVL	0
IDRIJA	19/09/2018	IDR_UX1A_20180919_01DVL0003.csv	DVL	7.375
IDRIJA	19/09/2018	IDR_UX1A_20180919_01DVL0004.csv	DVL	19.151
IDRIJA	19/09/2018	IDR_UX1A_20180919_01DVL0005.csv	DVL	32.726
IDRIJA	19/09/2018	IDR_UX1A_20180919_01IMU0001.csv	IMU	173.471
IDRIJA	19/09/2018	IDR_UX1A_20180919_01IMU0002.csv	IMU	37.006
IDRIJA	19/09/2018	IDR_UX1A_20180919_01IMU0003.csv	IMU	75.459
IDRIJA	19/09/2018	IDR_UX1A_20180919_01IMU0004.csv	IMU	170.322
IDRIJA	19/09/2018	IDR_UX1A_20180919_01IMU0005.csv	IMU	278.401
IDRIJA	19/09/2018	IDR_UX1A_20180919_01M30001.txt	M3	12.847
IDRIJA	19/09/2018	IDR_UX1A_20180919_01NAV0001.csv	NAV	184.855
IDRIJA	19/09/2018	IDR_UX1A_20180919_01NAV0002.csv	NAV	31.794
IDRIJA	19/09/2018	IDR_UX1A_20180919_01NAV0003.csv	NAV	74.202
IDRIJA	19/09/2018	IDR_UX1A_20180919_01NAV0004.csv	NAV	186.453
IDRIJA	19/09/2018	IDR_UX1A_20180919_01NAV0005.csv	NAV	985.129
IDRIJA	19/09/2018	SLS IMAGE FILES (bottom, left)		
IDRIJA	19/09/2018	19/09/2018.db	SQLITE	2.178.944
IDRIJA	20/09/2018	2018-09-20-09-28-23.bag	ROS BAG	8.985.465
IDRIJA	20/09/2018	IDR_UX1A_20180920_01DVL0001.csv	DVL	63.913
IDRIJA	20/09/2018	IDR_UX1A_20180920_01IMU0001.csv	IMU	538.986
IDRIJA	20/09/2018	IDR_UX1A_20180920_01M30001.txt	M3	5.597
IDRIJA	20/09/2018	IDR_UX1A_20180920_01NAV0001.csv	NAV	591.478
IDRIJA	20/09/2018	20-09-2018.db	SQLITE	1.896.348

8 Recommendations and steps forward

Idrija was selected as a pilot site to test the functionality of the robot in a real-life underground mine. Navigational systems have been tested in confined space and at almost zero visibility and have proven to be working well. The multispectral camera unit was tested and is functional. The robot also completed its first autonomous dive to the depth of two metres. A lot of new data has been obtained, which will be used to improve autonomous navigation systems, and to further calibrate UX-1 instrumentation before the next real-environment tests, scheduled for spring 2019.

After the Idrija pilot the robot was sent to INESC TEC in Porto, Portugal for further lab testing. It has been proven, that more work needs to be done especially on navigational systems and the autonomy of the robot. Although the first autonomous dive was achieved in Idrija, due to the confined space and very harsh conditions in the shaft, the autonomous dive was only planned to be to the depth of two metres. The team needs to test the full autonomy of the robot in a water tank before testing it in the next real life mine site. It is also important to focus on testing a selection of scientific instrumentation, such as the gamma ray counter unit, magnetic field measurement unit, water sampler etc. as these haven't been extensively tested in real life conditions yet.

Currently the UNEXMIN team is in the process of developing the second robot UX-1b. The Urgeirica mine was selected as a first test site for the trial of the second robot. The most challenging part of the Urgeirica pilot will be to conduct simultaneous test dives with two robots, UX-1a and UX-1b.

9 Media coverage

During the Idrija pilot, a press conference was organised (Figure 34) and a press release published. The project got a surprisingly high media attention from local and national sources. More than 30 media appearances occurred mostly in Slovenian media, two in prime-time news on television. We were also invited to two approx. 30' talk shows, one on national television, and the second one on national radio. Media coverage during the trials of the UX-1 robot held in the Idrija mine is summarised in Table 7. GeoZS also hired a professional filming crew, which recorded 1 day of Idrija trials, and this material will be used to prepare promotional videos.

Table 7. Media coverage during Idrija trials.

Media	Type	Date	Visitors /listeners	link
times.si	Web article	29.1.2018	61010	N/A
Finance newspaper	Newspaper article	29.1.2018	147682	https://oe.finance.si/8864017?cctest&&cookietime=1517922360
Radio Slovenia	radio	31.1.2018	125000	N/A
Radio Odmev	radio	5.2.2018	9000	N/A
STAznanost	Newspaper article	30.1.2018	unknown	http://znanost.sta.si/2477138/na-bledu-o-razvoju-robotov-za-pridobivanje-surovin-iz-tezko-dostopnih-nahajalisc
Dnevnik (newspaper)	Newspaper article	31.1.2018	98000	https://www.dnevnik.si/1042799865/lokalno/gorenjska/robot-bo-raziskal-tudi-idrijski-rudnik-zivega-srebra
Primorski val	News on radio	29.1.2018	91108	http://www.primorskival.si/novica.php?oid=9328
Delo (newspaper)	Newspaper article	6.9.2018	141000	N/A
Radio Slovenija 1, Danes do 13-ih	News on radio	11.9.2018	125000	https://4d.rtvslo.si/arhiv/danes-do-13-00/174561539
Sta.si (Slovene press agency)	Newspaper article	14.9.2018	520.000	N/A
RTVSLO.SI	Web article	14.9.2018	509494	N/A
TV Slovenija 1, Odmevi - 22:27	News on TV	14.9.2018	418920	https://4d.rtvslo.si/arhiv/odmevi/174562353
Times.si	Web article	14.9.2018	61010	N/A
TV Koper, Primorska kronika	News on TV	14.9.2018	45588	N/A
STA.SI (Slovene press agency)	Web article	14.9.2018	Unknown	https://www.sta.si/2553145/robot-v-potopljenem-delu-idrijskega-rudnika
Primorskival.si	Web article	14.9.2018	Unknown	N/A
Primorske novice	Newspaper article	15.9.2018	53000	N/A
Primorske novice	Newspaper article	15.9.2018	21000	N/A
Primorski val, Novice – 7:00	News on radio	15.9.2018	7000	N/A
Primorski val, Regijske novice - 11:00	News on radio	15.9.2018	7000	N/A
Delo	Newspaper article	20.9.2018	141000	N/A
Radio Slovenija 1, Danes do 13-ih	News on radio	22.9.2018	125000	https://4d.rtvslo.si/arhiv/danes-do-13-00/174563898
Radio Koper, Jutranjik	News on radio	24.9.2018	30000	https://4d.rtvslo.si/arhiv/jutranjik/174564147
Nedeljski dnevnik	Newspaper article	26.9.2018	212000	N/A
TV Slovenija 1, Odmevi	News on TV	1.10.2018	418920	https://4d.rtvslo.si/arhiv/odmevi/174565811

TV Koper, Primorska kronika	News on TV	2.10.2018	45588	https://4d.rtvslo.si/arhiv/primorska-kronika/174565994
Radio Odmev	News on radio	8.10.2018	9000	N/A
TV Slovenija 1	Talk show on TV	18.10.2018	418920	https://4d.rtvslo.si/arhiv/ugriznimo-znanost/174569559
Radio ARS	Talk show on radio	26.10.2018	9000	https://ars.rtvslo.si/2018/10/podobe-znanja-118/
www.rtvslo.si	Web article	26.10.2018	530251	N/A

Figure 34. Press conference at CUDHg Idrija.

10 Conclusions

Despite the challenging environment seen in the Idrija underground Mercury mine, the UNEXMIN team successfully finished the second set of tests of its UX-1a robot prototype in a realistic underground environment. During the trials a total of 11 dives were made within the span of two weeks. The most successful test in Idrija was the fully autonomous dive of the robot to the depth of app. two metres. Due to murky waters and numerous objects and debris in the water, the team had to fully rely on the robot's navigational systems in order to conduct the tests safely. The robot reached the bottom of the shaft at 26,2m and mapped the entire area. The total time of the aforementioned dive was approximately two hours, 1.5h for the descent to the bottom of the mine and app. 0.5h for the return to the surface. During the dive to the bottom of the mine UX-1a collected valuable information about the shape of the shaft that will be available to the public after processing of the data finishes. By using robot’s mapping data from the deep dive No. 10, CUDHg Idrija obtained new information regarding access to a drainage gallery connected to the shaft that was presumed to be blocked, but UX-1a data showed that this was not the case, and the side tunnel is open. UX-1a then mapped the area 7 metres into the side gallery. The pendulum system was thoroughly tested with dives performed at different pitches (0 degree and 90-degree angles).

During the Idrija trials real-environment measurements were made with the multispectral unit using three mineral sample boards with different minerals from Ecton mine, which will be used to prepare mineral identification model for the Ecton trial. The multispectral camera unit has been proven to be working well. Although a team of professional scuba divers were on standby during the entire trial the robot always returned to the surface without their intervention. What is even more important, due to careful planning for health and safety, no injuries or any other damage was recorded, despite the harsh working environment of the dark, humid, deep and narrow underground shaft.

During the Idrija mission the media coverage was very good with over 30 media reporting about the UNEXMIN project and the tests that were carried out in Idrija. A hired filming crew also filmed the event and recorded a few hours of material to be used for future documentaries.

Overall the test of the fully autonomous robot for exploring flooded mines UX-1 in Idrija was successful. The robot has proven to be working well in very challenging environments, due to the murky waters and the fact that navigation of the robot is fully dependent on its navigation systems. The test also proved that the team managed to work in real life underground mine environment in narrow spaces without electricity.

11 References

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