This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No 690008.
UNEXMIN: Underwater Explorer for Flooded Mines

To boldly go …

…where no robot has gone before
REASONS FOR THIS PROJECT

- There are about 30,000 closed mine sites in Europe - many of them potentially contain considerable amounts of valuable raw materials.
- Many of these mines are now flooded and information on their status and layout is decades old, sometimes over 100 years.
- The closure of a mine was usually more related to economics and technological challenges than to the actual depletion of mineral resources.
- Often minerals were disregarded during the operational life of the mine (such as fluorite in lead/zinc mines).
- Either very dangerous or impossible for exploration by divers.
- Difficult/impossible to use “tethered” robot systems for exploration.
KEY FACTS ABOUT THE PROJECT

EU funded H2020 research project (RIA: Research and Innovation Action)

Grant Agreement number: 690008 (H2020-SC5-2015)

13 partners (7 countries)

45 month duration (1st Feb 2016 – 31st Oct 2019)

Funding: ca. 4.87 million Euro

Deliverables:

Three working prototype robots (UX1-UX3)

Spin-off company offering the technology
PARTICIPATING ORGANISATIONS

- University of Miskolc, Hungary (coordinator)
- Geological Survey of Slovenia
- Tampere University of technology, Finland
- Universidad Politecnica de Madrid, Spain
- LaPalma Research S.L., Spain
- INESC TEC, Portugal
- Resources Computing International / 4DCoders, United Kingdom
- Geoplano, Portugal
- Ecton Mine Educational Trust, United Kingdom
- European Federation of Geologists, France
- Geo-Montan, Hungary
- Empresa de Desenvolvimento Mineiro, Portugal
- Idrija Mercury Heritage Management Centre, Slovenia
UNEXMIN PROJECT GOALS

“… to develop a fully autonomous robotic surveying solution for mapping abandoned and flooded deep mines.”

Specific goals

- Design and build a multi-platform robotic Explorer for autonomous 3D mapping of flooded deep mines
- Demonstrate the operation of the prototype at representative pilot sites (flooded mines)
- Develop an open-source platform for technology transfer and further development
- Develop a research roadmap in support of further technology development
- Develop commercial services for exploiting the technology
ROBOT DESIGN CONSIDERATIONS

- Autonomous: No communications with surface – neither cable nor wireless
- Must be small enough for mine shafts/adits but large enough to carry required instrumentation
- Must be capable of safe navigation through a maze of changing tunnels and shafts. Must recognize obstacles and dangers.
- Must create a 3D map of it’s route and, simultaneously, gather geological data
- Must be capable of withstanding water pressure to depths of 500m

“\textit{It would be easier to perform the same task on the surface of the Moon.}”
ENVIRONMENT: HAZARDS & OBSTACLES
SUMMARY OF DESIRED END RESULTS

Autonomous exploration and 3D mapping of flooded mines using non-invasive methods and not risking human lives

Valuable geoscientific data that cannot be obtained by other means without having significant costs

New and improved geological models and new exploration scenarios

OUTPUT
ROBOT (UX1): INITIAL CONCEPT

Physical Parameters
• Max operational depth: ~500m
• Shape: Spherical
• Size: ~ 0.6 m diameter
• Expected weight: 112 Kg
• Neutral Buoyancy
• Power consumption: 150–300 W
• Max speed: 1–2 Km/h
• Autonomy: up to 5 hours
• Thrusters power: 2–5 Kgf

Propulsion:
• one tail thruster (2), plus two thrusters for longitudinal (sway) motion (8) Vertical
• movement (heave): based on buoyancy control (3) and vertical thrusters (4)
• Attitude control (pitch and yaw): pendulum-based (displacement of the centre of mass)
ROBOTIC FUNCTIONS VALIDATION
“FINAL” LAYOUT AND BLUEPRINTS

Technical specifications

- Maximum operational depth: 500m
- Shape: Spherical with diameter 0.6m
- Material: Aluminium Alloy

Subsystem modules

- Propulsion
- Ballast
- Pendulum

Structure

Middle Pressure hull
Two Lateral pressure hulls
FINAL APPEARANCE & CONTROL FEATURES

- 60 cm diameter sphere
- Neutral buoyancy
- 3-part cast aluminium pressure hull
- Thruster manifold either side, total of 8 screw propellers
- Ballast system for vertical movement
- Pendulum system for pitch and yaw
- Laser-stripe (structured light) for SLAM navigation (simultaneous localization and mapping)
SMALL SCALE TEST UNITS

Quarter and half size test units.

Half size has thrusters as they will be implemented on the final system.
STABILITY TESTS IN POOL

https://youtu.be/P9OaiHRc-Fg

Acceleration [m/s²] vs Horizontal Thrusters [ERPM]

Angle [degrees] vs Horizontal Thrusters [ERPM]
Two sets of instrumentation needed on board:

1) Navigation
2) Geo-Scientific

Some instruments are common to both areas.
BASIC / NAVIGATION INSTRUMENTATION

- Acoustic cameras
- Thrusters
- DVL (Doppler Velocity Log)
- Inertial navigation system
- Laser scanner
- Computer
- Batteries
- Integrated pressure hull

Components for functionality: navigation, control, autonomy, mapping, interpretation, evaluation
Selection of possible (feasible) methods:

Limitation: physics (environment), prices, time

Other limitations: size (weight, energy), attitude (continuous mov)

Selected devices:

pH and electrical conductivity measuring units
Magnetic field measuring unit (3 axes flux-gate sensors)
Natural (integral) gamma ray activity measuring unit
Water sampler unit
Multi-spectral unit
UV fluorescence imaging unit
Sub-bottom sonar
INSTRUMENT CONSIDERATIONS

- Size and weight – both are constrained by size / shape of robot
- Operating range – pressure and temperature
- Location in Robot – dictated by data gathering requirements and other instruments
- External interface – e.g. glass “lens” for camera/light devices
- Type and amount of data produced – storage
- Internal connections, data storage, synchronization
- Power requirements for 5 hour mission
- Accessible storage – download Terabytes of data
- CPUs to control all aspects of robot: navigation; mapping; data gathering; data storage
Test measurements were performed up to mid 2017.

- Water sampler unit tests in Rudabánya open pit and in a pressure chamber at 15.06.2017.
- Multispectral camera unit tests in Rudabánya open pit and in a pool at 12.06.2017.
- Magnetic field sensors test under open air on field at 09.06.2017.
- Sub-bottom sonar tests in Rudabánya open pit and in a pressure chamber at 06.06.2017.
- Gamma-ray counter test in a pool at 12.06.2017 and in Rudabánya open-pit on 07.06.2017
SCIENTIFIC METHODS TESTING
2016-2017, Rudabánya, Hungary
WATER SAMPLER AND STORAGE UNIT

Number of collected samples: 16
Volume of samples: 5 ccm

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FLUORESCENT IMAGING
Long UV (and short UV?)

<table>
<thead>
<tr>
<th>Part number</th>
<th>Voltage Vf(v)</th>
<th>Current (mA)</th>
<th>Wave Length(nm)</th>
<th>Output power (mW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TY-365nm 10W</td>
<td>12-13V</td>
<td>900-1200</td>
<td>365-370</td>
<td>320-360</td>
</tr>
</tbody>
</table>
The multispectral system has two units:
- lightning module (LED light and control)
- camera module
- (distance and colour correction is essential)
MULTISPECTRAL CAMERA
LIGHTNING – IMAGING – POST-PROCESSING

- Post processing:
  - Building xyz-point database
  - Multiple corrections to create spectra of the points
  - Search, evaluation, identification → visualization

Front - White
Sideway - Multispectral 400 nm
Sideway - Multispectral 450 nm
Sideway - Multispectral 470 nm
Sideway - Multispectral 500 nm
Sideway - Multispectral 530 nm
Sideway - Multispectral 568 nm
Sideway - Multispectral 590 nm
Sideway - Multispectral 615 nm
Sideway - Multispectral 630 nm
Sideway - Multispectral 660 nm
Sideway - Multispectral 690 nm
Sideway - Multispectral 730 nm
Sideway - Multispectral 780 nm
Sideway - Multispectral 850 nm
Front – UV (365nm)
Front – UV (250–280nm??)

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MULTI-SPECTRAL CAMERA LED PROTOTYPE
DATA PRODUCED DURING UX ROBOT MISSION

Navigation / mapping data produced (Terabytes for reasonable length of mission)

- Robot orientation, location, velocity, angular velocities/accelerations
- Mapping – wall / floor / ceiling.
- Simplified 3D navigation mapping / “points of interest” for navigation
- Detailed mapping -> point cloud – for mission planning, analysis, final 3D imaging and displays

Geo-Scientific data (Gigabytes)

- Multi variable sensor data for all sensors
- Photographs / video

All data linked by nano-second time stamp
POST-PROCESSING AND DATA ANALYSIS

- Data standards defined
- Data conversion requirements agreed
- Database structure defined
- Database management system and import data file formats and content defined for navigation and sensor subsystems
- Core point-cloud modelling and visualisation coding completed and demonstrated

SQLite
DATA USAGE

Navigation / Mission planning
- “Rapid” analysis and processing used to provide “control” of next mission.
- Uses minimum data possible to characterize 3D mine environment

Storage, Detailed Analysis and Visualisation
- Permanent storage of all mission data on large drives
- Analysis of data: Water chemistry; Mineral identification; Structural analysis; Object / hazard identification; Identification of changes in mine (e.g. rock fall)
- Visualisation and 3 D displays / Virtual Reality (VR)
- Publication
PILOT SITE TESTS

1. Kaatiala, pegmatite (feldspar-quartz mine), Finland
2. Idrija (mercury mine), Slovenia
3. Urgueirica (uranium mine), Portugal
4. Ecton (copper mine), UK

In order of increasing complexity!
IDRIJA MERCURY MINE, SLOVENIA
Now flooded below this level
UNEXMIN AT ECTON MINE

- Ecton to be fourth and most challenging pilot site: summer 2019
- Preliminary visit by consortium, May 2016
- EMET has purchased the land around Deep Ecton adit, preparatory to major repairs of unstable stone arching
- Submerged part of mine 300 metres below river level. Not seen since 1850s. No reliable mine surveys
- Two main launch locations. (a) pumping shaft, (b) pipe workings
Ecton mine - two main launch sites for UNEXMIN

Main pumping shaft

Pipe workings
Ecton Mine Educational Trust’s aim for UNEXMIN – a full 3D model including accessible parts of the mine ABOVE water level.

1. Salts Level - Faro laser scan survey in 2011 (Joe Allott)
2. Deep Ecton, ladderway, and Salts Level laser survey in 2017 by Geoterra and GeoSLAM (Mark Hudson and Stuart Cadge)
3. Ground-Penetrating Radar (GPR) survey in 2017 by TerraVision (Natalie Staffurth and Dan Sherwin)
Point cloud:
- 500 million points
- Processed/displayed in GeoReka

Faro scans
Salts Level

(Click to play)

See slide 45 for links to website with videos
Geoterra / GeoSLAM laser survey
July-August 2017
Deep Ecton and Salts Level
“To boldly go.”
Getting lost in a virtual Ecton Mine!

Play video

(spot the Pipe Workings)

See slide 45 for links to website with videos
An on-line, public access inventory of potential target mines in Europe is being created:

- Focus will be on mines that cannot be surveyed by any other means due to complex topology or depths that are below the range of scuba divers (max 50 m)
- Metallic minerals will be of primary importance, but others also
- Existing databases reviewed (PROMINE & Minerals4EU)
- Missing data will be collected from mine authorities covering at least 24 countries (EFG Linked Third Parties (LTPs) involvement)
Objectives:

✓ Identification of Stakeholders and the further extension of the Advisory Group
✓ To gather, understand and process Stakeholder views and requirements
✓ Collection and analysis of Stakeholder requirements for creating initial specifications of UX-1
✓ Creation of detailed stakeholder database as well as the database of flooded mines that will serve as a starting point for the commercial exploitation of the technology
✓ Adaptation of the robot design to Stakeholder needs and to develop working contacts with future customers.
UNEXMIN DISSEMINATION CHANNELS AND MATERIAL

- Website continuously updated
- Blog (News in the website – 2 per month)
- Brochures (First in 7 languages; Second in development)
- Press releases (three issued)
- Documents (images, deliverables, presentations) available for download
- Social Media: Twitter, Facebook, LinkedIn, YouTube
- Wikipedia: UNEXMIN, Mine dewatering, Flooded mines

Can be accessed through website
http://www.unexmin.eu/
Thank you

Further information:
UNEXMIN project: http://www.unexmin.eu/
Ecton Mine Educational Trust (EMET):
http://www.ectonmine.org/