Introducing ICEMS – the Integrated Caves Environmental Monitoring System

Jana Marikovičová, **Jozef Omelka** and **Adam Krovina** of MicroStep-MIS outline their data-logging system for monitoring a cave's microclimatic and environmental conditions for scientific research. These integrated systems build on the use of individual sensors as reported previously in *CREGJ*.

History of Cave Monitoring System Development

The first specialized cave microclimate and hydrological monitoring systems developed by MicroStep-MIS were installed in 2007 in five show caves, managed by the Slovak Caves Administration. The basic goal was to set up a system which would be able to continuously monitor selected parameters in caves with automatic data transfer to a central database, remote access to data loggers in caves, and with the possibility to use the system in caves without electric power supply.

ICEMS is a result of a joint research and development project involving two partners: the Slovak Caves Administration and MicroStep-MIS. ICEMS employs key products from MicroStep-MIS.

Cave monitoring systems are uniquely integrated systems consisting of permanent and mobile data loggers, a communication network, data collection, and a central database and management system. Such systems employ sensors for measuring a range of different environmental parameters. In addition, the climatic conditions outside the caves are measured at the same time using meteorological stations on the surface near the cave entrances, which are interfaces to the monitoring system.

Since then, cave monitoring systems have been installed in Postojna Cave, Slovenia, and Katerinska Cave in the Czech Republic. The network in Slovak caves was extended in 2013 and there are now further monitoring sites in two additional show caves and in several non-show caves. There are mobile systems in various caves too. Three new monitoring stations were produced for the EMIL RACOVITA Institute of Speleology of the Romanian Academy, in January 2015 and this latest installation is currently in progress.

Monitoring Objectives

Caves have specific microclimates and for scientific research, it is very important to monitor their behaviour to better understand the caves' geosystems, in order to determine the anthropogenic influence on climatic changes in caves, the cave's climatic stability and its ability for quick regeneration, mainly in show caves.

MicroStep-MIS systems are installed in several of Eastern Europe's leading show caves including Demänová Cave of Liberty in Slovakia. Photo: Juloml

Monitoring a cave's microclimate involves detailed measurement and recording, plus storing the data relating to selected natural parameters of the cave environment.

The main requirements for the functionality of the system were: (1) sufficient capacity of the internal batteries for at least two or three months of independent operation (this was later extended to one year for operation in caves with difficult access where mobile systems were installed), (2) protection against overvoltage in the case of those units powered from the mains, due to lightning in this case, (3) reliable functionality of probes in the cave environment (high relative air humidity and low temperature in ice-filled caves), and (4) a ranges of measurement options.

To achieve this, a specific microclimate and hydrological monitoring system was developed and is now installed in seven show caves in Slovakia, was developed. This required selected parameters relating to the cave environment to be monitored continuously and the measured data to be transmitted automatically to a central database.

System Technical Description

A cave monitoring system is a unique integrated system consisting of sensors, permanent and mobile data loggers, a communication network, plus a data collection and central database and management system.

Sensors are connected to the data loggers, specially designed for the cave environment (high humidity, small size, water-tight, etc.). Measured values are stored locally on each logger's SD card.

The software and hardware equipment and the advanced monitoring system were developed by MicroStep-MIS who also carried out the integration of the environmental system to provide a unified network.

The system has two modes of measurement: Standard mode and Micro mode. Standard mode allows measurements to be made every 10 or 60 minutes. Micro mode allows measurement to be made every minute or every 10 seconds. The system further consists of sophisticated data collection, database, data processing and data presentation software. The data collection application is designed for collecting data from the data logging network.

The cave monitoring system is an open design that can be extended or modified according to the customer's requirements. The number of connected sensors can also be varied. One of the main system advantages is the possibility to perform remote control and maintenance.

Sensors

Different types of sensors, according to the customer's requirement, can be connected to the system. The following are available:

- Air temperature
- Relative humidity – specially designed for high humidity in caves
- Rock mantle temperature
- Wind speed and direction
- Air flow speed and direction (2D, 3D)
- CO2
- Radon (^{222}Rn)
- Water temperature
- Water quality – conductivity, pH, NOx, Cl^-
- Water level
- Air pressure
- Precipitation
- Drip inlet
- Evaporation
- Global solar radiation

Data Logger

All the sensors are connected to a data logger. The monitoring system is scalable from one mobile station powered by a battery to a national monitoring network for all the caves in the country with a powerful central system.

The logger is easy to maintain and has a very low power consumption. It is flexible and can easily be configured to any combination of sensors. Measured values are stored locally on an internal SD card. Storage is not limited by the card capacity due to the availability of high capacity cards. Online data transmission is via RS485, wi-Fi, GSM / GPRS, etc., and is managed by the central system.

The effective overvoltage (lightning) protection was designed and developed during the initial period of operation by taking account of experience in the field.

The data logger makes use of standard equipment including the touch screen, battery, external / internal memory, and its communication interface. It has a DC input, a main battery, and a backup battery for the memory. The data logger contains an integrated RS485 data communication port and an RS232 service port. It can be equipped with an optional GSM modem. Tablets or PDAs can be connected to the data logger via Bluetooth for file browsing. Using a tablet or PDA allows the current data to be checked, the logger parameters to be configured, and configuration files or data files to be downloaded or uploaded.

A touch screen display is an optional user interface which can be used to preview measured values, to adjust the system time, to set system variables, etc.

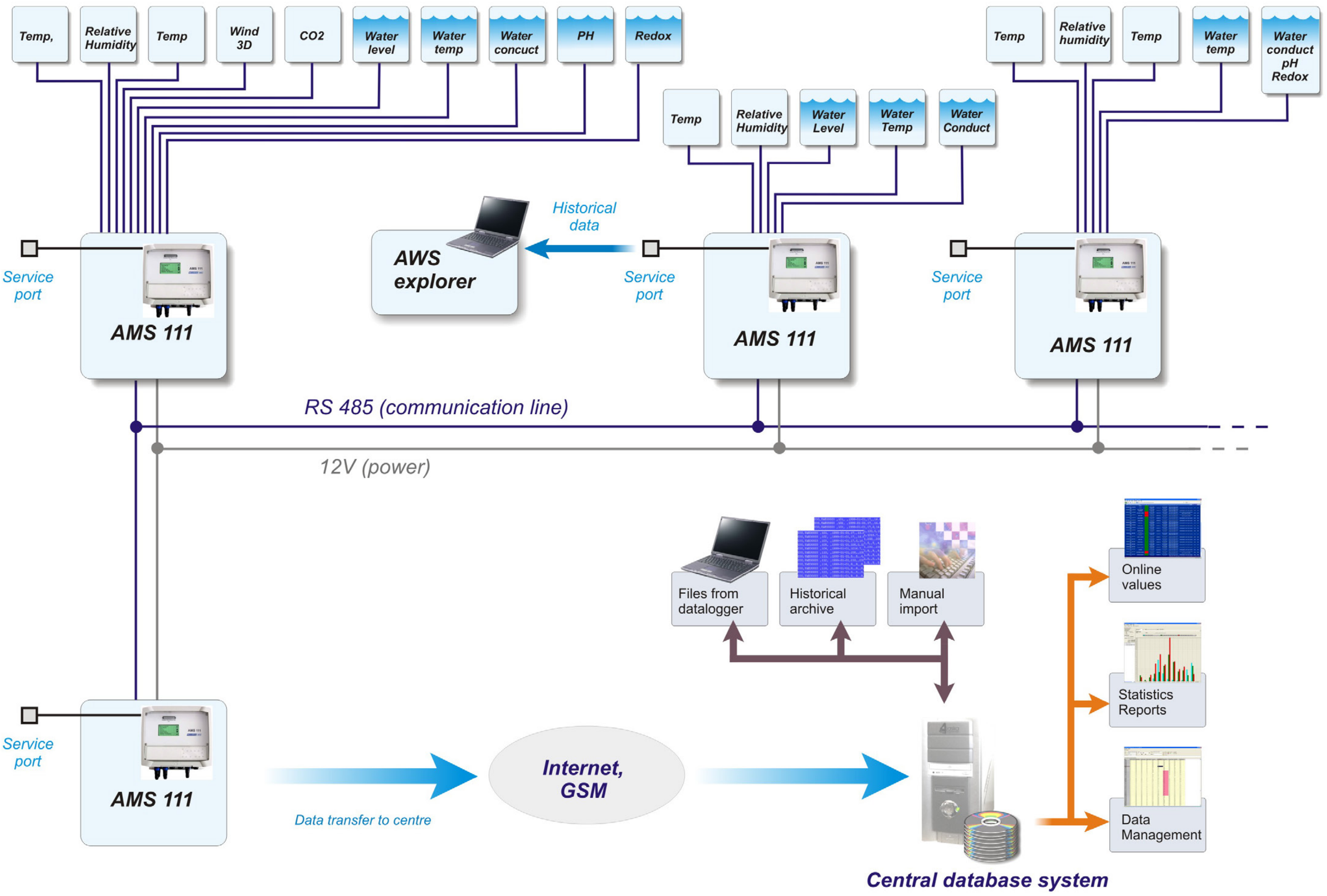
Data loggers are usually powered by a 230V supply. In case of mains power supply loss, the data-logger is powered by a main battery that provides backup power. When the logger is operating on the backup battery, sensors with a high power consumption are switched off automatically.

The data logger has built-in compact flash memory with a capacity of several GB. The measured data can be stored in this memory for several months.

The data-logger's RS232 service port allows users to download data and change settings on site, using a tablet, PDA or portable computer.

Communication Network

Several data loggers can be installed in a single cave. They are usually connected via two-wire RS485 communication ports. Also connected to the system is an external data logger with a GSM modem module installed outside the cave. This data logger is connected to GPRS network and establishes a VPN connection with the data centre. The external data logger routes communication between in-cave data loggers the cave and the data centre. The VPN connection is secured by the telecommunication operator.



Structure of a Typical Cave Monitoring System

Fixed Monitoring Station with Sensors and Data Logger

Mobile Monitoring Station with Temperature and Humidity Probes

Data Collection and Management System

This part of the complete monitoring system is designed for sophisticated data collection from the monitoring sites, data processing and data presentation.

The data collection application collects data from the monitoring network. It sends requests to data loggers and downloads all data and any other necessary information from the monitoring sites. Data is sent to a central database (EnviDB). Further operations include automatic procedures for data management and processing, data integration, storage of environmental data and metadata, data quality control, data provision and distribution to end users, and other services.

The system is open for historical data import and importing data from other different measurement systems. Measured data collection is an automatic operation via a GPRS VPN network. The data collection interval can be set according to the customer's requirement. Data collection software allows the user to view all data loggers installed within a monitoring network, the communication status, browse messages, or view decoded values. The software also allows the regime mode type and schedule operations to be defined.

Central Database

Downloaded data is stored in the central database.

Before data storage, various pre-processes are carried out. These include decoding the original messages sent by the data loggers, converting to a unified database structure, quality check, etc.

Mobile Monitoring Station with Air Temperature and Humidity Probes, Water Temperature, Water Level and Conductivity Proves and Data Logger

Data quality control is performed to ensure that only unique and high quality measurements are submitted for further database processing. These checks include duplicate elimination, internal consistency checking, global range comparisons, and time-stamp comparisons. Other available functions include manual monitoring and correction.

Research and Development

During the years of operation, and as a result of our experiences, MicroStep-MIS has developed and is continuing to develop various sensors and techniques.

For example, the special cave conditions are forcing us to use "moving average" filters for data processing by the micro-controller.

Cave environments exhibit very high relative humidity. This causes problems to the operation of relative humidity sensors, and our developments in this area are discussed in some detail in the box on the next page.

A new type of water-level sensor, TSP, is now used in the latest installations. The probe – the digitally-compensated pressure transmitter – combines an advanced piezo-resistive metal sensor and transmitter design. The probe has integrated overvoltage protection with an RS485 or SDI-12 interface.

Data logger improvements – for mobile monitoring stations used for measurements in caves with difficult access that need to be in operation for long period without any control or maintenance – are aimed at providing a more robust logger but with smaller dimensions.

A new generation of data logger features a more powerful processor, additional communication interfaces (USB, Ethernet), and changes in logger's firmware. It also has two memory card slots so it is not necessary to carry a tablet, PDA or laptop into the cave to download the data. It is easy just to insert an SD card to an external slot and download the data. Higher logger accuracy is used to support higher accuracy of measured values of parameters such as temperature or humidity.

The development of a more sophisticated overvoltage protection and grounding system in caves offers additional protection for the monitoring stations against damage due to overvoltage or lightning.

Batteries, which are the main power supply for mobile stations or monitoring stations in non-show caves or in show caves with difficult access, have to last for a long period of time. According to our experience we can't completely trust the manufacturer's specification information in this respect. We have experienced some loss of data because the batteries used in some installations have discharged much more

The Challenge of Relative Humidity Measurement

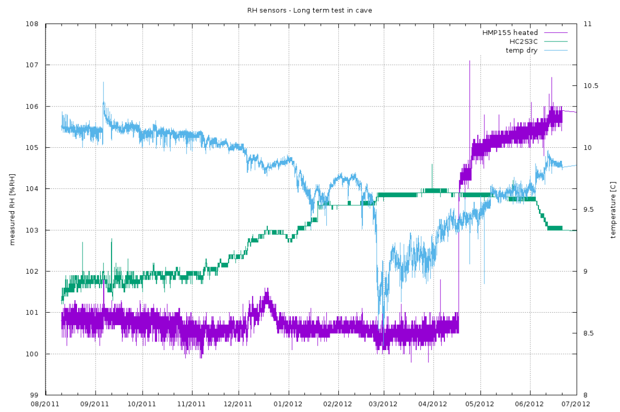
This box provides some insight into the difficulty of measuring relative humidity in a cave, and illustrates progress by describing a long term in-cave evaluation. The cave environment is known for high relative humidity (RH), very close to saturation. This causes difficulties for humidity measurement. RH Probes have a significantly higher measurement error in the upper part of measuring range and commonly drift out of their measurement range (above 100 % RH). We have evaluated the following two capacitive RH probes from different producers which have been installed in Domica Cave since August 2011 with data collection being managed by a MicroStep-MIS AMS 111 II data logger.

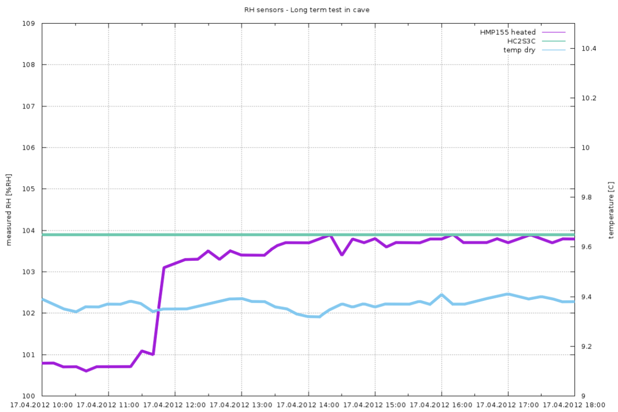
The HC2-S3 relative humidity probe, from Campbell Scientific, is a commonly used in meteorology. It does not feature a heating function.

The Vaisala HMP155 heated probe is designed especially for the sites where the probe is exposed to prolonged periods of high relative humidity conditions. Probe heating is intended to protect the humidity sensor from condensation. The probe uses an external temperature sensor to measure ambient temperature so that relative humidity can be calculated using this additional parameter.

Initially, the probes showed a value of 100% RH for most of the time, this being the default upper limit for many humidity probes. Therefore, the two probes were reconfigured to have an output range of 40-140% RH. This enabled us to monitor performance above 100% RH. As can be seen in the graphs (HMP155 – purple, HC2S3C – green, temperature – cyan), both probes almost always show the value greater than 100% RH.

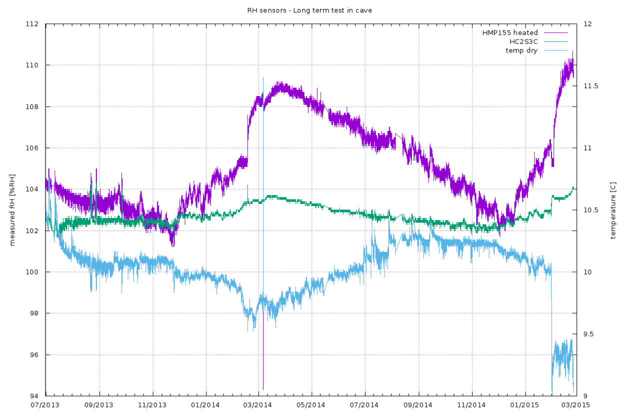
The left-hand graph below shows data from August 2011 to June 2012. Initially, the HMP155 heated probe performed better than the HC2S3C, not drifting too far from 100 % RH although there is a sudden step of +3% RH on 17th April 2012 which does not correspond to measurements from other sensors, as shown in the detailed graph below right. We do not know the source of this event – perhaps water dropping on the sensor.

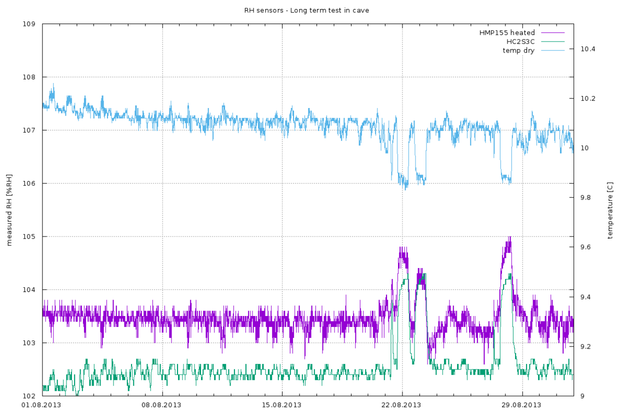




Data for a further recording period from July 2013 to March 2015, following an interruption of measurement during which time sensors were still in place, is shown below left. The HMP155 probe has drifted up to 110% RH which suggests that he heating is not helping enough. The measured RH data is above 100% RH all the time which means that it is out of range. It is unclear whether the sensor's output has any correlation with RH or is meaningless. Since we do not have any reliable reference instruments, we cannot make any direct comparison.

The graph below right for August 22nd 2013 shows the temperature and RH changing significantly. Furthermore, the curves of RH are similar in shape but inverted compared to the temperature curve. This resembles the relation of RH and temperature in an enclosed volume of air. If we have a saturated volume of air (dew point equals to the temperature of air and we're assuming 10°C) and we increase the temperature by 0.2°C, the RH drops by approximately 1.3% according to psychometric calculations. This roughly corresponds to the data below right.





We have been collecting data for more than three years now and from the data obtained we can say that the probes behave as expected. They have drifted out of range – above 100% RH, however. Furthermore, the HMP155 introduces unexplained inconsistencies in measured values. Laboratory calibration is planned to investigate like how the long-term exposure to moisture affects the probes' performance.

quickly than calculated and we are currently running some tests to identify the cause of this problem.

Measurement of some parameters such as water conductivity and water level, and the difficulties associated with choosing the right sensor for these measurements, and monitoring the behaviour of these sensors in the cave environment, is still under development as a part of our research – see, for example, the box above.

Radon monitoring and measurement tests are running in cooperation with the Geophysical Institute of Slovak Academy of Sciences and the Department of Nuclear Physics and Biophysics, Faculty of Mathematics, Physics and the Informatics of Comenius University, Bratislava. The sensor (radon mobile head) measures the alpha decay of ^{222}Rn (the most stable isotope of radon, having an atomic weight of 222) in a measurement chamber. This measurement is a part of research into cave microclimate regime and of the impact of ^{222}Rn on employees' health, as well as the relationship between radon activity concentration changes and meteorological and cave microclimatic conditions.

Further development and improvement of the ICEMS is ongoing at MicroStep-MIS as a part of the research and development of our different products and systems.

Jana Marikovičová

Jana gained a Master of Science in Transportation and Traffic Engineering from the Faculty of Civil Engineering of the Slovak University of Technology in Bratislava, Slovak Republic. She has previously worked as an analyst and GIS (Geographic Information System) specialist at the Slovak Hydro Meteorological Institute.

Joining MicroStep-MIS in 2008, Jana works as a project manager for several programmes, including all the cave systems. In this capacity her responsibilities include customer liaison, interfacing with the hardware and software departments to ensure correct system operation, dealing with suppliers of the components used in the cave systems, cave system promotion and publicity, and system documentation.

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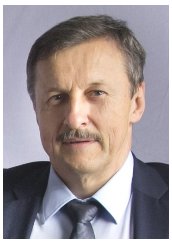
Jozef Omelka



Jozef Omelka is a majority shareholder and Managing Director of MicroStep-MIS. He holds the degree of Master of Science in Technical Cybernetics and Robotics from the Faculty of Electrical Engineering of the Slovak University of Technology in Bratislava, Slovak Republic.

Mr Omelka's university specialisation in cybernetics and robotics has become his main hobby. He is a founder and co-sponsor of robotics-oriented civic association, Robotika.sk (**www.robotika.sk**), which supports education and training of young highly talented pupils and students interested in robotics. MicroStep-MIS co-sponsors the Virtual Robotics Laboratory which is one of the basic projects run by robotika.sk.

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Adam Krovina

Adam holds a Master of Science in Measurement and Information Technology from the Faculty of Electrical Engineering and Information Technology at the Slovak University of Technology in Bratislava, Slovakia.

Since 2012 he has worked for MicroStep-MIS where he is responsible for the hardware and firmware design of electronic sensors and calibration systems, sensor adjustment and calibration, and environmental testing of electronic devices. He works on the development of meteorological sensors, mainly relative humidity probes and barometers, and has experience with design, implementation, commissioning and maintenance of monitoring and information systems in the field of meteorology.

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Cave Monitoring System Installations

So far we have used 12 mobile systems in Slovakia plus permanent installations in several show caves in the Slovak Republic.

In 2007, permanent systems were installed in Demanovska Ice Cave, Demanovska Cave of Liberty, Dobsinska Ice Cave, Gombasecka Cave, and Domica Cave. More recently, in 2013 a further two systems were installed in Jasovska Cave and Ochtinska Aragonite Cave.

There is also a mobile system in the Czech Republic plus a permanent system at Katerinska Caves. In addition, a permanent system was installed in 2010 at Postojna Cave in Slovenia.

Three monitoring stations were produced and delivered in January 2015 for the EMIL RACOVITA Institute of Speleology of the Romanian Academy. These will monitor relative humidity, air temperature, air movement, CO_2, and atmospheric pressure.

Company Details

MicroStep-MIS, based in Bratislava, Slovak Republic, is a company specializing in complete process development and manufacturing of monitoring and information systems, processing of acquired data, research and numerical modeling.

MicroStep-MIS can be found at Čavojského 1, 841 04 Bratislava, Slovakia, or **www.microstep-mis.com**.

CREG

Admittedly he couldn't actually think of any, but Greg was sure there were plenty of uses for a laptop underground. But with prices three or four times as much as ordinary models, surely only those with more money than sense would waste their cash on those fancy tough models. How hard could it be to find a DIY solution to ruggedisation and waterproofing?

For the cost of a roll of Cling Film, Greg figured his quad-core pride and joy would be every bit as cave-proof as costlier models. To avoid embarrassment to Greg, let's just make passing reference to sharp rock flakes and move hurriedly along. Laptop number two was considerably more waterproof but encasing it in a solid block of epoxy resin had a decidedly detrimental effect on the responsiveness of the keyboard. To cut a long story short, Greg's face became a very familiar one in his local PC World store over the next few months.

In an uncharacteristic moment of self-doubt, Greg wondered if spurning rugged laptops was such a smart move after all. However, thoughts of another new laptop with a self-bailing mechanism soon put paid to any such silly notions.