Emerging Technologies of Field Instrumentation, Data Collection and Reporting

Amod Gujral and Deb Biswas

Encardio-rite Electronics Private Limited, Lucknow, India

Introduction

Field instrumentation used for safety monitoring during construction of dams, tunnels, bridges and other civil engineering structures or for monitoring geological hazards like landslides has become highly sophisticated and advanced over time. As adoption of safety monitoring is getting more comprehensive and widespread there is a need to design the safety monitoring network system to be cost effective to either reduce the cost of instrumentation or to allow monitoring of more parameters within the same budgeted cost.

Another essential feature of safety monitoring network is to make the collected data readily available in real or near real time to the different stake holders where ever they may be sitting around the globe. The collected data needs to be presented in an easy to understand format like suitable charts or graphs including historical data of the parameters at that location. Stake holders today also expect the safety monitoring network to identify potential hazardous conditions or developments well before a catastrophic failure takes place and alert personnel with authority to take remedial measures as early as possible. This is very important as affected communities, governments, project owners and stake holders are increasingly adopting a zero tolerance towards loss of human life even for projects undertaken under the most trying conditions.

In this paper the authors discuss some of the recent trends noticed in safety monitoring instrumentation networks used for monitoring civil engineering projects and zones subject to geological hazards.

Advances in sensor technologies

One of the most used sensors for monitoring both horizontal and vertical ground surface or subsoil movement is the tilt sensor in many different forms. Although, strictly, a tilt sensor measures the tilt at the point where it is mounted, when mounted on a horizontal or a vertical beam of specified gauge length and installed as a linear array of sensors, it can be used for recording and plotting of vertical or horizontal movement profile over time.

The prime requirement for the tilt sensors for such measurement is high resolution, high accuracy and ruggedness for withstanding unavoidable field abuse like those from jerks, vibration, impact and other environmental factors. As any single type of tilt sensor is not able to provide all the desirable features required by different applications, different types of tilt sensors have to be used for different applications. Knowledge of different sensor types and their advantages and limitations will help in choosing a suitable tilt sensor for each particular application.

One of the most commonest use of tilt sensors is to measure ground settlement or tilt in buildings and structures like railway lines over time due to ground settlement. A typical example is monitoring tilting of buildings in urban areas on account of ground settlement due to tunnelling activities for metro rails or sewage systems. The allowed tilt limits are very small and a tilt sensor with a very high sensitivity is required to detect the possibility of alarming tilt levels as early as possible.

The electrolytic tilt (EL tilt) sensors with a range of +/- 0.5 degrees are able to monitor change in tilt with a typical resolution of around 1 arc second. Due to the inherent averaging action of the sensor the output is relatively noise free. However, due to its high sensitivity to temperature change the sensor needs to be mounted at a location that experiences least change in temperature over time. Electrolytic tilt sensors provide the highest resolution at a very economical cost.

Earlier the EL tilt sensors were difficult to integrate with off the shelf data acquisition systems as they required dataloggers with ac bridge inputs and were sensitive to cable capacitance that increases with cable length. Manufacturers are currently offering electrolytic tilt sensors with integral signal conditioners that provide a voltage output signal so that the output of these EL tilt sensors can be measured by a wide variety of standard data acquisition systems.

For measuring sub soil horizontal ground movements, such as in In-Place Inclinometers, tilt sensors with a measuring range of +/- 30 degrees are preferred. The prime requirement is for a tilt sensor that provides the highest possible resolution. Earlier this could be achieved with tilt sensors based on servo accelerometer technology. However, servo accelerometer type tilt sensors are quite expensive, very susceptible to damage from even low level of shock or impact, and experience zero drift over time.

As a replacement for servo accelerometer based tilt sensors manufacturers are now offering tilt sensors based on MEMS (Micro Electro Mechanical System) technology. These tilt sensors have performance that nearly meets that obtained with servo accelerometer type tilt sensors but in addition are extremely rugged and provide a stable output over their life. Typical resolution is around +/- 10 arc seconds near zero degrees. MEMS tilt sensor are also much less expensive than servo type tilt sensors for the same performance level.

Another significant trend in sensor technology is replacement of sensors with analogue output like voltage, current, resistance with digital output sensors. The analogue output sensors experience loss of accuracy when the output signal needs to be transmitted over long cable lengths.

Output from digital sensors can be read by a variety of hand held or fixed location computing devices like palm top computers, mobile phones, notebooks, laptops and PC networks. As the digital sensors provide a numeric output to the data collecting device, the accuracy of the output signal never gets degraded irrespective of the distance between the sensor and the data collection device.

Most digital sensors store the calibration parameters inside the sensors and output the value of the measured parameters directly in terms of suitable engineering units which was not possible with analogue output sensors. Digital sensors equipped with certain type of electrical outputs can be connected over a single signal cable reducing cabling requirement.

An advantage with many digital sensors is that they can be connected to a remote DAS or a computer using standard wireless modems. Analogue sensors require a sensor specific interface for connecting them to a wireless modem. Wireless links are discussed in more detail later on in this paper.

Use of Mobile Phones as a means of data collection

Different types of analogue sensors require different types of hand held readout units for monitoring their output at site. Even when using central DAS for collecting and recording data it is essential that the data acquisition system has the necessary signal conditioners matching with the output of the sensors deployed in a project. As an example most general purpose dataloggers do not have a suitable interface for accepting input from vibrating wire sensors. Only dataloggers specifically designed for use in geotechnical instrumentation are provided with suitable interface for use with vibrating wire sensors.

The use of digital sensors allowed the use of standard palm top computers to be used to collect data from any digital sensor provided it met certain communication standards. With the development of Bluetooth technology it is no longer necessary for the hand held computer to be connected to the sensor using a copper wire cable and the data from the sensor can be fetched wirelessly over the Bluetooth interface.

Because of the low production volumes and proprietary nature of the operating system palm top computers are quite expensive and the availability of software is severely limited. The palm top computer required the operator to go to a designated central location at the end of the day and transfer data to a host computer. It generally did not allow the operator to go through the earlier historical data for any sensor if the requirement arose.

The mobile phone is changing all that and promises much more. Today's mobile phones have evolved to become a very powerful computational platform. Most of the higher end mobile phones have a high resolution large colour graphics display, internal memory capacity that is specified in Gigabytes, Bluetooth wireless serial data link, cellular phone coverage nearly throughout the inhabitated areas of the world, cameras with pretty high resolution and image quality, connectivity to internet, and in built GPS receivers that can tell the user his position anywhere in the world.

A few geotechnical instrument manufacturers have realized the potential of this new multifunctional device and are exploiting its features for field data collection in geotechnical or civil engineering safety instrumentation networks. To highlight the advantages of using the mobile phone as a data collection device a typical application is described below

The most common method of monitoring sub-surface horizontal ground movement is with a traversing type inclinometer system. A borehole is drilled in the area where sub-surface ground movement is required to be monitored. A special plastic tubing with four orthogonally arranged grooves is grouted in the borehole. The operator then lowers a bi-axial inclinometer probe fixed to the end of a cable marked in increments of 0.5 m or 2' intervals down to the bottom of the borehole. The operator then lifts the probe up by one mark interval and records the inclinometer reading on the portable readout. The probe is then rotated by 180 degrees and the process repeated.

At the end of the day the operator would go to a central location and download the data to a host computer (PC). There the reading would be added to a database and the readings processed to yield a vertical bore hole profile. Finally the PC software would compute the difference of the current profile from a reference profile logged at an earlier date and present the result to the user.

This approach prevented the logged data to be monitored in near real time as the operator had to physically go to the central location and download the data. Also in most cases the operator did not have access to the earlier plots to detect if any unintentional error has crept in the logging process. Once the error was discovered at the end of the day the operator had to go back to the same borehole the next day and repeat the logging process.

The conventional inclinometer dataloggers used till now were custom built instruments and required a physical cable to be connected from the indicator to the cable reel connected to the inclinometer probe for data transfer. As the reel rotated with the length of cable being wound or unwound on the reel, the data transfer cable would also get twisted. A slip ring connection was provided on the cable reel for connecting the datalogger so that the connecting cable would not rotate.

The mobile phone has changed all that. One of the newer inclinometer offerings from a manufacturer can work with Android operating system based mobile phones from different phone manufacturers. The data transfer between the inclinometer system and the mobile phone is through a blue tooth connection. As the inclinometer probe is a digital sensor, the output is a numeric value directly in terms of sine of angle of tilt.

The mobile phone runs an application software that collects data from the digital inclinometer and appends it to a database. With an 8 GB memory the mobile phone is virtually capable of storing historical data for a large number of boreholes in the phone itself. The operator can see different types of plots for the logged data and compare the data with all earlier logged data in both tabular and graphical form. He can also zoom in to minutely inspect areas of interest. Once the operator is satisfied that the borehole has been correctly logged he can transfer the data over the GSM/GPRS network to the central server immediately. At the server end another application software plots the logged data and publishes it over the internet within a few minutes of receiving the data file. The latest bore hole log is thus immediately available to all authorized personnel of that project.

Figure 1: Mobile phones as readout unit (left) and on site analysis of movement profile (right).

If the project is employing a web data service the operator can check out the historical data of any sensor that is part of the project instrumentation network from the location of the sensor itself using the standard web browser built in the mobile phone.

The phone camera allows the operator to photograph any significant development or accidents that can affect or cause an unexpected change in the sensor reading and send it in real time to the central monitoring station. It will help in understanding the reason for the sudden change in readings or serve as evidence in case the instrument readings are subject to doubt.

While installing sensors for the first time, especially in the open, it is required that the sensor location be determined using surveying techniques. Traditionally a qualified surveyor with optical surveying instruments was required to determine the geographical coordinates of the sensor location. This process took some time and required additional surveying resources. With the in-built GPS receiver of a higher end mobile phone the operator can determine the sensor location without requiring help of a surveyor.

The video clip recording facility of the mobile phone allows the operator to record the installation of sensors if desired. The video clip can serve as a record of the actual method followed to install the sensor, or can serve as a training video for other installation personnel.

For installation of very sophisticated sensors or sensors requiring strict adherence to laid down procedures, the operator can use the video clip playback facility of the mobile phone to see an instructional video for installing that sensor at the site itself. Similarly, the internet browsers of the mobile phone allows the operator to access such training videos uploaded to video sharing portals like YouTube at the sensor installation site itself.

If a project uses many different types of digital sensors or distributed DAS with Bluetooth interface a mobile phone loaded with different application software would be able to down load and visualize data from all such devices. Thus the mobile phone can save the cost of many different readouts/dataloggers required to read the different types of sensors in a conventional instrumentation network.

As mobile phones are mass produced devices they have much more features and cost much less than proprietary portable readouts and dataloggers used earlier. Use of mobile phones with standard operating system like Android allows the users to choose from a wide variety of phones from many different manufacturers around the world. Earlier if a proprietary readout unit developed a fault the unit had to be returned to the manufacturer for repairs that took a lot of time. With mobile phones the user only needs to get another mobile phone and load the application software supplied by the sensor manufacturer. The memory card from the old phone can simply be transferred to the new phone and all the earlier data would be available to the user again.

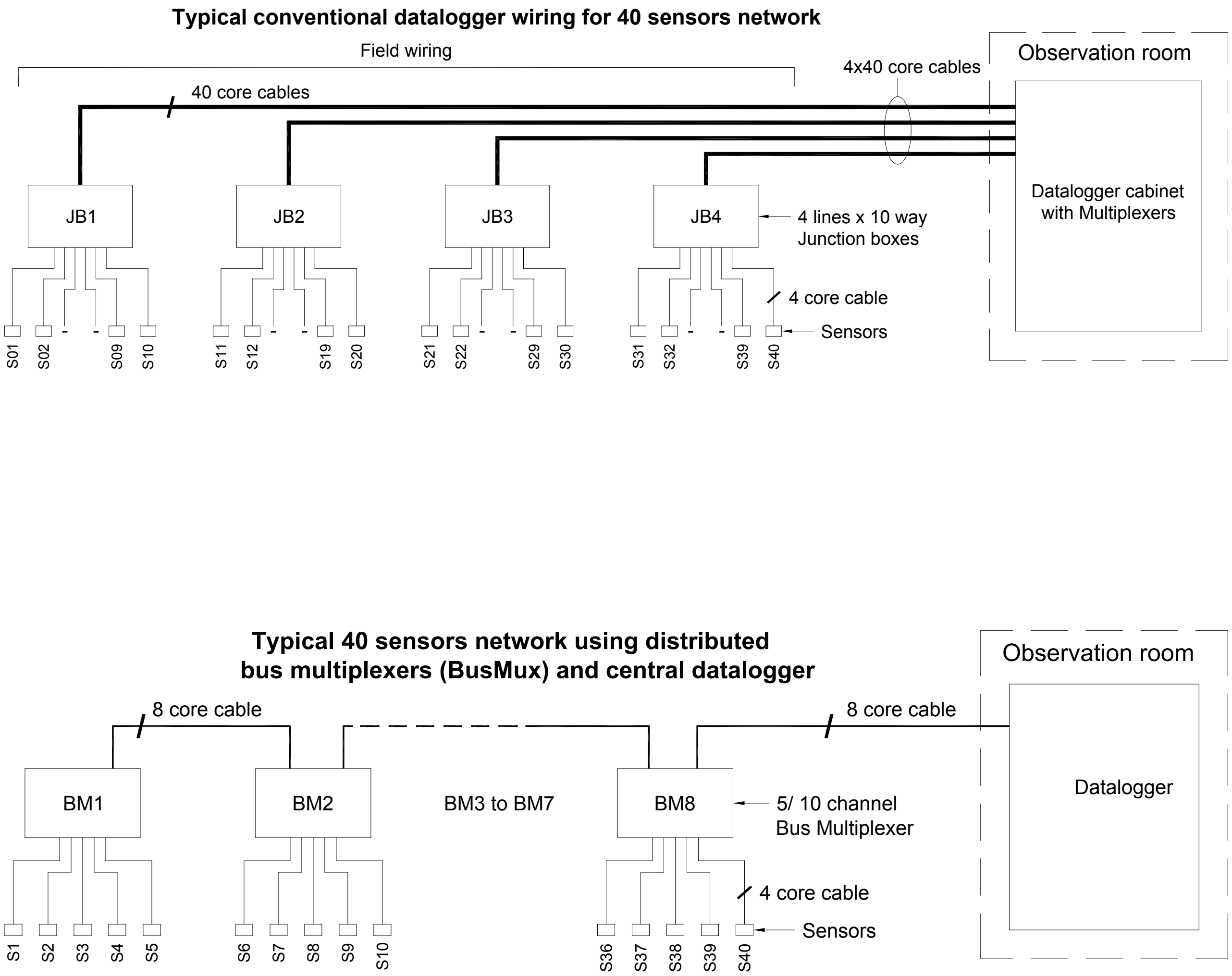
The ubiquitous mobile phone of today will fast become the Swiss Army knife of geotechnical instrumentation. It equips the field engineer simultaneously with a phone, camera, location fixing, personal computer, web browser, video recorder and player, training manuals on demand and a host of sensor readouts and dataloggers in a small compact and economical palm top unit.

Reduction in cabling using Bus technologies

Traditionally all sensors in a typical instrumentation network are connected to a central data acquisition system (DAS) through copper cables. The output of the sensors are measured by the DAS using multiplexers which connect the output from the individual sensors one by one to the DAS input. Most current generation DAS after measuring the sensor output would mathematically compute the output in terms of suitable engineering units and store the result in its internal memory. The contents of the DAS internal memory is then retrieved by a PC which displays the measured values as a set of tables or graphs in a suitable format.

The traditional method requires that each and every sensor be connected to the central DAS using individual copper cable with at least two conductors at the minimum. A large number of sensors may require even more number of conductors between the sensor and the DAS.

To reduce the cost of cabling it is a common practice to combine the individual sensor cables, where ever possible, in a multi conductor cable using suitable junction boxes. A same length of 40 core cable is much cheaper than 20 individual 2 core cables. However even with this approach the cost of cabling required in an instrumentation network is a very significant fraction of the total instrumentation cost if the sensors are spread over a very large area.


Typical conventional datalogger wiring for 40 sensors network

Typical 40 sensors network using distributed bus multiplexers (BusMux) and central datalogger

Figure 2: Schematic diagram showing savings in cabling by adopting distributed Bus Multiplexers.

To address this issue a few manufacturers are now offering distributed or bus multiplexers. Instead of providing all the multiplexers required by the DAS at a central location, the use of bus multiplexer allows the multiplexers to be placed nearer to each cluster of sensors. The output of the bus multiplexers can then be connected to a single multicore cable that is finally connected to the central DAS. As a typical example the Encardio-rite EAM-405B Bus Multiplexer requires a single 8 core cable for connecting all the distributed Bus Multiplexers and the central DAS in an instrumentation network. Depending on the area covered by the instrumentation network the savings in cable costs can be substantial even though the bus multiplexers themselves cost much higher than the conventional multiplexers provided inside the central DAS cabinet.

On the flip side all the bus multiplexers connected to a single bus can generally cater to a single type of sensor only. For example voltage output and resistance bridge output sensors cannot be connected to bus multiplexers that are connected to the same bus cable. They will need bus multiplexers that are connected to two different buses dedicated to each sensor type. Despite this limitation it is seen that in most of the large civil engineering projects only a few distinct types of sensors are used in significant quantities and the use of Bus Multiplexers allow the cabling costs to be reduced substantially.

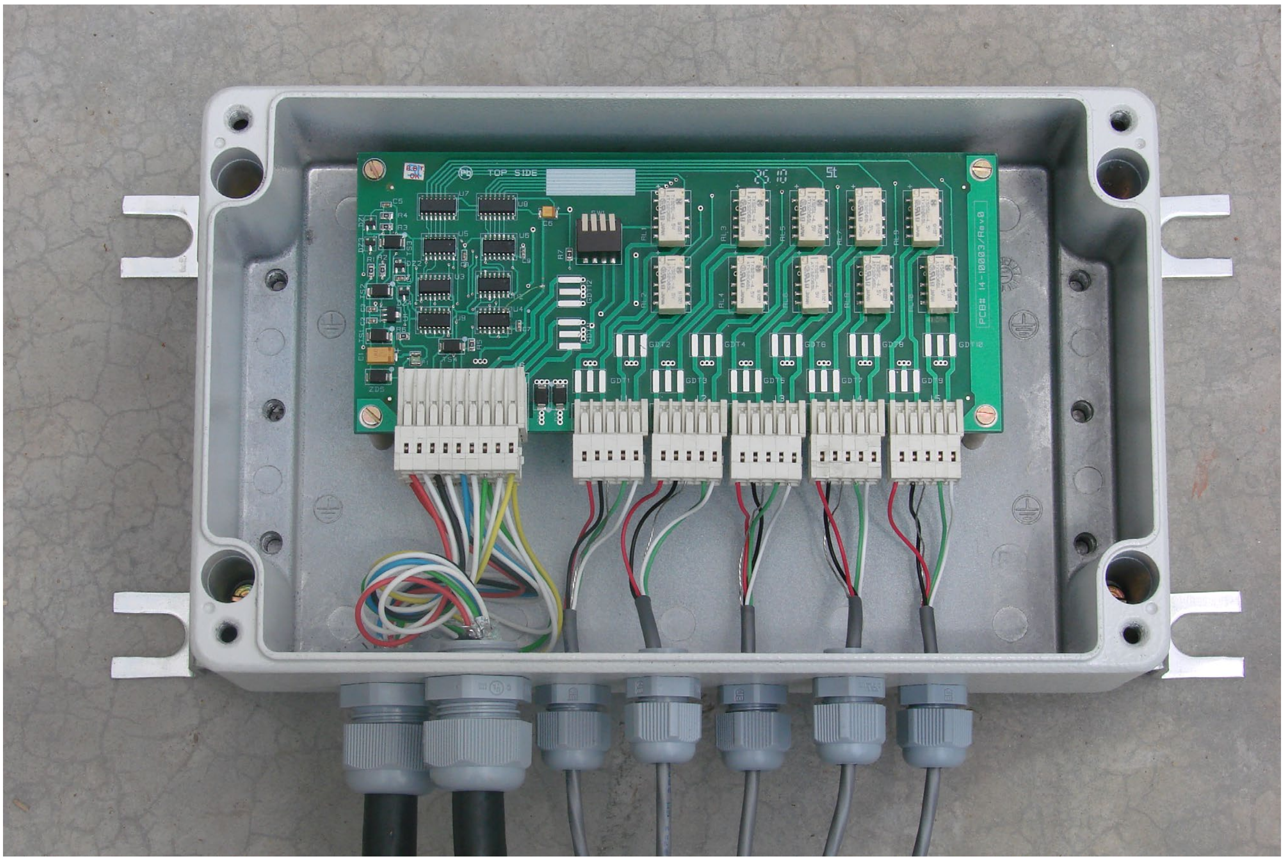


Figure 3: A field mountable Bus Multiplexer in weather proof IP-67 housing shown with its cover removed.

Another means of reducing cabling costs is to use digital sensors with SDI-12 interface. Sensors equipped with SDI-12 interface require a single 3 conductor cable for connecting all the sensors to the central DAS. A single cable can be used to connect from 10 to 25 sensors depending on the type of sensors. An additional advantage is that different types of sensors can be mixed on the same SDI-12 bus which is not possible with analogue output sensors. As the SDI-12 sensors are digital sensors the accuracy of the output (measured) value is not affected by the length of cable between the sensor and the DAS.

Adding a SDI-12 interface to an individual sensor adds to the cost of the sensor. Simply adopting the SDI-12 bus for an instrumentation network may not reduce the cost of instrumentation as the added sensor cost may offset the cost savings due savings in cost of cabling. To address this issue some manufacturers supply interfaces that can accept input from a number of sensors with similar analogue output, convert their output values to a digital value (numeric value) and then transmit it over a standard SDI-12 bus. This approach allows conventional sensors to be connected to a SDI-12 bus network. A typical example is the Model EVM-108 from Encardio-rite Electronics that can connect eight conventional vibrating wire sensors to a SDI-12 bus. The eight vibrating wire sensors can be of eight different types for monitoring different parameters if required.

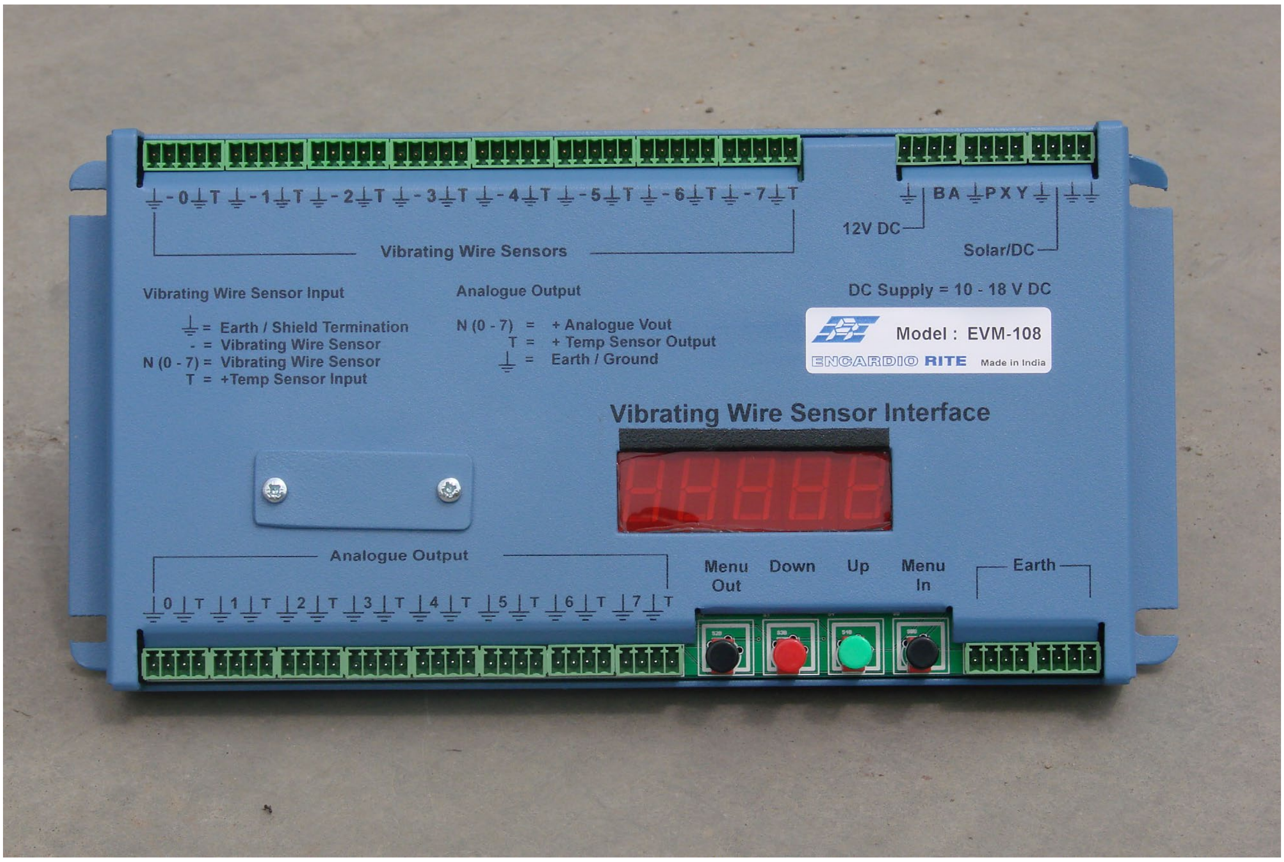


Figure 4: A SDI-12 Interface for connecting 8 vibrating wire sensors to a SDI-12 bus cable.

Wireless links

Wireless links are becoming very popular for connecting sensors to the central DAS or host computer. Wireless links as the name implies eliminates all cabling between the individual sensors and the central DAS. There are many different types of wireless links but no one type of link is suitable for all situations found in the field. A knowledge of the advantages, disadvantages and limitations of each type of wireless link is essential for designing an economical and reliable wireless sensor instrumentation network.

The theory and practice of wireless links is a vast subject and research is currently on for development and standardization of very sophisticated wireless sensor networks. Here we will only discuss the most common solutions currently being adopted in safety instrumentation networks.

The use of radio frequency spectrum for establishing a wireless link is tightly controlled by respective national governments and generally requires a license from the national radio frequency regulatory body. Only a very small fraction of the total available spectrum is earmarked as free for unlicensed use. Even these frequencies vary from country to country; so a knowledge of local regulation regarding use of radio frequencies is a must before choosing a particular type of wireless link. However, in general the 2.4 GHz and 5 GHz bands are free for unlicensed use in most countries. In some countries the use of certain frequencies in the 800 to 900 MHz range is also allowed without requiring a license.

Sensors and Data collection units that operate at 2.4 or 5 GHz require a near line of sight access between the two communicating devices. Except for small obstructions any significant obstruction that comes between the two communicating devices can render the wireless link unusable.

Wireless links operating at 800 to 900 MHz band are more tolerant towards in line obstructions and the radio signals between the two communicating devices can to some extent travel around the obstruction provided it is not very large.

A bluetooth standard wireless link operates at 2.4 GHz and is generally used for very short distance communication of up to 10 metres but the link can be used for distances up to 100 metres using higher power. This low power link is generally used for communication between a digital sensor or datalogger and a hand held or a portable data collection unit. For example connection between the cable reel of a digital traversing type inclinometer to the hand held readout unit is nowadays done through a wireless link avoiding the use of cables and problematic slip rings to make the connection to the rotating reel.

The higher power Bluetooth link is used for link distance above 10 metres. For example the data from a difficult to reach borehole extensometer / anchor bolt load cell combination installed at the crown of a large tunnel or underground chamber can be accessed from the base or floor wirelessly using Bluetooth wireless link.

Large instrumentation project sites generally have a large number of sensors spread over a wide area that need to be connected to a central DAS. Connecting all the sensors to the central DAS using copper cables may not be a viable solution due to many factors. However, the distance between most of sensors and the DAS may often be beyond the range of low power wireless links or near line of sight location may not be possible for all sensor locations. A similar situation is also found in tunnel instrumentation as the sensors are spread out over a large linear distance from the face of the tunnel. A curved tunnel section introduces more problems in using low power point to point wireless links.

Digital sensors equipped with ZigBee RF modems allow what is known as mesh networking. The ZigBee modems allow each sensor to get data from its neighbour farther away from the DAS and relay them to another neighbour that is more nearer to the central DAS. The communication links established between the sensors themselves make up what is commonly known as a mesh network. Mesh networks are only suitable for low data transfer rates and the ZigBee modems are increasingly being designed for lower power consumption. This makes the ZigBee mesh networking a good candidate for use in civil engineering instrumentation projects.

In some projects the sensors may be spread out over many square kilometers area. Typical examples are ground water monitoring, surface settlement and building monitoring over metro or sewage tunneling activity in urban areas, rainfall monitoring around dam catchment areas etc. The above wireless technologies are not suitable for such applications due to the very long distances between the sensors and the central DAS.

For covering very long distances or wide areas, GSM/GPRS modems are used either with individual digital sensors or more commonly with a small DAS that caters to a cluster of sensors deployed at the same location. GSM/GPRS modems leverage commercial cellular phone service provider's network and the internet to relay sensor data to a central DAS or host computer connected to the internet. For using the GSM/GPRS modems it is essential that the sensor location is covered by a cellular service network provider. Using GSM/GPRS modems sensor data can be transmitted to a DAS or host computer even at the other end of the world.

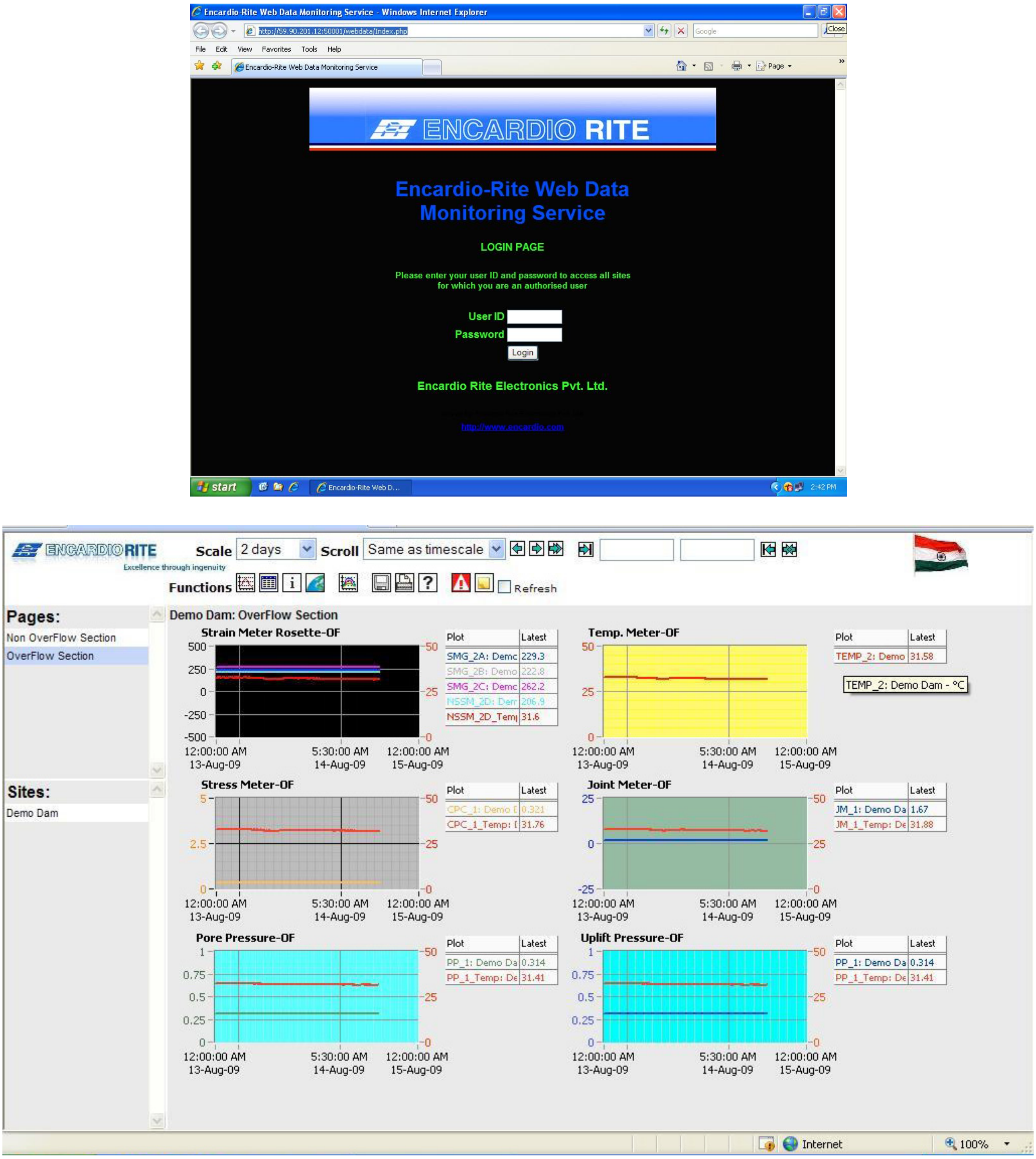
Caution should be exercised when using GSM/GPRS data links for relaying time critical or hazard warning data. Often during an emergency like a natural or a manmade disaster the cellular phone system gets overloaded with massive volume of calls which renders the phone network temporary non-functional. Such a situation will not allow critical data to be passed on to the recipient in time to prevent either immense damage or even loss of life.

Distribution of processed data over internet

A civil engineering project during the construction phase will have many stake holders who would be interested in the safety status of the project. Typical stake holders would be the project owners, designers or consultants, contractors and site engineering and safety monitoring personnel. For large projects the stake holder's empowered personnel may have offices located hundreds of kilometers away from the actual project site. Consequently there is a need to provide all the stake holders with near real time access to data from safety monitoring instrumentation network irrespective of their actual location.

Another important function of safety instrumentation network that is becoming an essential part of project contracts is providing means for alerting authorized personnel about development of potential hazardous development in near real time so that remedial actions can be started without delay.

A few geotechnical instrument manufacturers and geotechnical instrumentation service providers are now providing proprietary software that can be hosted on servers connected to the internet. The software is capable of collecting data from the various sensors and dataloggers deployed in a project over conventional copper cables, optical fibre cables, or various types of RF links according to a preset schedule. The collected data is added to a database. The software can present the collected data as a set of meaningful graphs or tables in a format appropriate to the parameter or parameters being monitored on demand by the various users from different locations around the world over the internet.



Encardio-Rite Web Data Monitoring Service

LOGIN PAGE

Please enter your user ID and password to access all sites for which you are an authorised user

User ID

Password

Login

Encardio Rite Electronics Pvt. Ltd.

http://www.encardio.com

Scale 2 days Scroll Same as timescale

Pages:
Non OverFlow Section
OverFlow Section

Sites:
Demo Dam

Demo Dam: OverFlow Section

Strain Meter Rosette-OF

Plot	Latest
SMG_2A: Demc	229.3
SMG_2B: Demo	222.8
SMG_2C: Demc	262.2
NSSM_2D: Dem	206.9
NSSM_2D_Tem	31.6

Temp. Meter-OF

Plot	Latest
TEMP_2: Demo	31.58

TEMP_2: Demo Dam - °C

Stress Meter-OF

Plot	Latest
CPC_1: Demo [	0.321
CPC_1_Temp: [	31.76

Joint Meter-OF

Plot	Latest
JM_1: Demo Da	1.67
JM_1_Temp: De	31.88

Pore Pressure-OF

Plot	Latest
PP_1: Demo Da	0.314
PP_1_Temp: De	31.41

Uplift Pressure-OF

Plot	Latest
PP_1: Demo Da	0.314
PP_1_Temp: De	31.41

Figure 5: Screen shots from a web based data monitoring service showing login screen (top) and a graph page (bottom).

If different alarm thresholds are defined for the logged parameters, the software can also issue an alert to authorized personnel through e-mail or SMS (Short Messaging Service) about any parameter or a set of parameters exceeding the preset alarm thresholds. Most software will allow setting up of up to 2 alarm levels corresponding to a general alert that the parameter has exceeded a preset alert level that demands immediate remedial action or the parameter has exceed the safe limits specified by the designer and further work should be stopped.

For those users who are unable to setup and maintain their own data servers some instrumentation service providers also provide hosting services where the monitoring and reporting software is hosted on the service providers servers. These servers are high reliability servers, with redundant power supplies for high availability and have sufficient internet bandwidth for meeting the project requirement. Leasing of hosting services for the monitoring and reporting software is an advantage for smaller project owners or contractors who need not dedicate personnel and resources for maintaining the high availability severs which in itself requires a degree of sophistication best left to experts.

Conclusion

This paper highlights some of the advancement and recent trends taking place in the areas of sensor technology, data transmission, data recording and presentation in field instrumentation employed for safety monitoring of geotechnical and structural engineering projects.

Keeping a watch and adopting new sensor technologies can increase accuracy of measurements with reduced costs. Using digital sensors allows many benefits like calibrated outputs, non degrading accuracy and easy transmission of data over long distances to a remote host computer.

The use of mobile phone as a data collection device, if provided by the instrumentation manufacturer, can like the Swiss Army knife allow the field engineer to carry the equivalent of a phone, camera, location tracking, web browser, training and user manuals, video recorder and playback, and a host of readout units in a single compact palm held device.

The use of an appropriate bus technology for transmission of sensor data over copper cables to the central DAS will result in substantial reduction in cabling as well as total project cost. For this an understanding of the advantages and limitations of the different available bus technologies is a must.

Wireless links eliminate the need to connect the installed sensors and the central host computer with cables. In some situations wireless links would be the only solution as laying of cables may not be feasible. An understanding of advantages and limitations of different wireless links will help in choosing the most optimum solution for a particular project.

Adopting a web based data access service will allow all stake holders to have access to safety instrumentation network data and analysis in near real time from anywhere in the world. The system will also allow authorized personnel with authority to initiate suitable remedial action to be alerted to potentially hazardous developments that can give rise to a catastrophe over time. Timely alerts can prevent loss of human life, time and money due to catastrophic failures.

Authors

Amod Gujral agujral@encardio.com
Deb Biswas dbiswas@encardio.com

Encardio-rite Electronics Pvt. Ltd.
A-7, Industrial Estate,
Talkatora Road, Lucknow, India 226011 www.encardio.com