A Monitoring System for Landslides and Geotechnical Works Using Statistical and Artificial Intelligence Models

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SUMMARY: Many accidents in geotechnical works and landslides have occurred in locations where there was instrumentation. Most of these failures have been attributed to communication failures, errors on data interpretation, data presentation or others non-technical factors; that is, failures of the monitoring system. This paper reviews concepts on planning and importance of instrumentation and monitoring systems in slopes and geotechnical works, introducing new concepts. In structures with large life cycles the monitoring over time is fundamental for correct prediction of their behavior. However, changes in technology can generate information losses and interruption of the monitoring data which, together with the mismanagement of the information, decreases the overall reliability. Solutions for these problems involves the concept of interoperability, systems that work with different technologies, aiming at coexistence, autonomy and low levels of interdependence. The Active Monitoring System (SAM - Sistema Ativo de Monitoramento) was designed to support low-cost electronic devices using the latest IoT (Internet of Things) concepts, providing compatibility for new and old instruments and providing interoperability among them. The communications network can be done point-to-point or through gateways. The data is then sent to the cloud, where data validation is done and stored in relational database. The results are made available to be plotted, visualized or printed in many platforms. Data analysis can be of historical series with neural networks, machine learning or applying analytical/empirical equations to the data. SAM is more a concept and system rather than a standalone product and it can be made to work with a variety of hardware architectures and configurations. One application has been made for urban landslides forecast in Salvador (BA), integrating battery-powered network of sensors, through a low-power protocol or directly to the cloud. These sensors can be part of an array of several instruments such as piezometers and inclinometers or any other instrument. As IPT had established a relationship between the amount of rainfall and the occurrence of landslides. SAM was used to create a data mining system, cloud computing and online viewing plots of the real-time rainfall curves based on information obtained

through the public data of CEMADEN (National Center for Monitoring Natural Disasters). The system aims to provide alternatives of low-cost implementation and high-power of analysis, in almost instantaneous timing, providing to the stakeholders an effective predictive maintenance tool, a better support in decision-making for mitigation of accidents and application of emergency resources.

KEYWORDS: monitoring system; geotechnical work; slopes, artificial intelligence; interoperability; landslides.

1 INTRODUCTION

Many natural disasters are related to landslides. These events can be generated by a variety of external conditions such as high volume of precipitation, change in pore pressure, erosion and seismic movements and their consequences are aggravated by population growth and unplanned urbanization (DAI et al., 2002). Climate change and the potential for more extreme weather conditions may also be a new contributing factor (NADIM et al., 2006). One of the ways to mitigate these types of events is a continuous real-time monitoring of these processes, as well as their modelling, which serves as a basis for system and alarm operation (KOBIYAMA et al., 2006).

However, these accidents are not restricted only to natural disasters but are also present in large geotechnical works. Instrumentation and monitoring systems should be integral parts of the construction project of many geotechnical works allowing the prediction of possible design flaws due to undetected features or inefficiency of investigations (NEGRO JR. et al, 2009). But there are many reports of accidents and failures in earthworks which had monitoring systems. For example, Skempton (1985) reports the Carsington Dam failure in 1984. Vail et Beattie (1985) reviewed the history of ruptures and accidents over the last 100 years in Asia and many of these have caused loss of life and extensive economic loss. Other historical case described in the literature is the tunnel accident under the central terminal area of Heathrow airport in the United Kingdom in 1994. The Brazilian scenario there is also some major accidents. In January 2007 there was a rupture in the excavation of the Yellow line of São Paulo subway resulting in a crater with approximately 80 meters in diameter and with 7 fatalities. Recently (2016) the rupture of the Fundão Dam in Mariana, Minas Gerais, was responsible for what is considered the largest environmental accident in Brazil generating very large social and environmental damages.

These facts leads to some questions. Why monitored earthworks fail? What are the vulnerabilities of instrumentation? How to make systems more reliable? The errors are mostly related to instruments or interpretation and data analysis or even other causes?

Previous studies indicated that failures can be credited to technical problems, such as measurement errors (instrumentation failure) and errors in data interpretation or to non-technical factors, such as communication errors, negligence or poor information management. It does seem that problems occur at all levels of the system and many are related to human error.

This paper presents many concepts about instrumentation and monitoring systems but also brings a vision of new technologies in data processing and analysis and new precepts related to instrumentation such as system interoperability. The system presented is called SAM (Active Monitoring System in Portuguese) and is being developed to be applied to earthworks and potential landslides. The system uses artificial intelligence as a means of data processing to enable early warnings generation so giving conditions for faster decision making to the stakeholders involved.

2 GEOTECHNICAL MONITORING SYSTEM

Geotechnical Engineering is not an exact science and the limits of confidence are much narrower when compared to other areas of Engineering due to the variability of natural materials, subsoil stratigraphy and other conditioning factors of difficult determination or control. For such reasons monitoring is important to verify the design hypothesis, validating them fully, partially or not, with its majority derived from information of geotechnical investigations (NEGRO JR. et al, 2009).

Dunnicliff (1988) quotes the benefits of monitoring during three phases:

- During design the instrumentation can be used to provide input to the initial design of a facility or for the design of remedial treatment.
- During construction the instrumentation is used to ensure safety, minimizing costs, improving control procedures or schedules, provide legal protection, provide data for measurement of quantities, enhance public relations and advance our knowledge (state of the art).
- After the end of construction the instrumentation is important to ensure long term safety by measuring and identifying possible changes in the environment, both natural and built.

Bressani (2009) also emphasizes that the instrumentation may be use as an investigation tool, that is, a way to obtain additional information which may, or may not, be conflicting with the previous investigation campaigns.

For the monitoring system achieve the objectives and deliver a correct control of behavior prediction and their respective levels of hazard it is important to remember some principles. According to Dunnicliff (1988) "*the engineering practice of geotechnical instrumentation involves a marriage between the capabilities of measuring instruments and the capabilities of people*" and his general recommendations are concentrated in these two aspects. Regarding the instruments and data the author emphasizes that the instrumentation does not guarantee a good project or a construction without problems. It must be implemented considering the specific problems to be monitored. Sensitivity and reliability must be more important than amount of data and the records have a fundamental importance for long-term analysis. More sophisticated instruments are not necessarily the most appropriate choice. Bressani (2009) also agrees with the previous indications recommending the installation of a larger number of simpler and lower cost sensors along with a few more sensitive and accurate sensors thus ensuring consistency, reliability and quantity of data. In addition simple sensors can be deployed in a wider area allowing greater comprehensiveness within the cost limits imposed by the work. In the past, that usually had a drawback of generating too much data for processing and larger costs of monitoring, but this is now changing.

Dunnicliff (1988) also emphasizes the importance of qualification of technicians involved and the interaction between personnel-instrument. The installer and the engineer responsible for the interpretation must have extensive knowledge about the geotechnics fundamentals and the details of the instrumentation to be used. Particularly, the engineer who will interpret the data needs to know deeply the instrument in order to guarantee a better data understanding. Hopefully this will allow him to distinguish a geotechnical problem from a bad instrument response or calibration. Hanna (1985) also mentions that the field engineering staff must cooperate fully with the designer in the interpretation of field data and when a critical decision have to be taken it may be necessary to draw on the expertise of independent consultants.

2.1 Planning a Monitoring System

A monitoring system is also a geotechnical project as the design process is closely connected to knowledge of topographic data, geology, pore pressure (actual and future) and behaviour of the monitored works. At this stage is imperative to cover a wide range of aspects of instrumentation which might include a) objectives of the instrumentation work, b) overall organization of site hierarchy, staff training, data processing and reporting, c) levels of alert of measured parameters, and d) contingency plans if the alert is set. Only after considering these points it is possible to assess costs, define problem areas and ensure that the instrumentation objectives can be achieved (HANNA, 1985). Dunnicliff (1988) proposes a series of 20 steps to systematize an approach to creating a monitoring system, all listed on Table 1, and some are discussed below in more detail.

Table 1 – Systematic planning of monitoring

Step 1	Define the project conditions
Step 2	Predict mechanisms that control behavior
Step 3	Define the geotechnical questions that need to be answered
Step 4	Define the purpose of the instrumentation
Step 5	Select the parameters to be monitored
Step 6	**Predict magnitudes of change**
Step 7	Devise remedial action
Step 8	Assign tasks for design, construction, and operation phases
Step 9	**Select instruments**
Step 10	Select instrument locations
Step 11	Plan recording of factors that may influence measured data
Step 12	Establish procedures for ensuring reading correctness
Step 13	List the specific purpose of each instrument
Step 14	Prepare budget
Step 15	Write instrument procurement specifications
Step 16	Plan installation
Step 17	Plan regular calibration and maintenance
Step 18	**Plan data collection, processing, presentation, interpretation, reporting, and implementation**
Step 19	Write contractual arrangements for field instrumentation services
Step 20	Update budget

2.2 The importance of variables predictions

A requirement for the correct choice of instruments (step 9) and action plans (step 7) is the prediction of behavior changes in variables to be measured. Franklin (1977) states that always there must be a predetermined measurement value that can be accepted as normal. With this value it is possible to recognize any abnormalities at the beginning of the monitoring work and to assign the hazard warning levels and their associated plans of actions.

This defined value is extremely important in the final instrument choice as the industry offers a series of instruments with different sensitivity ranges and accuracy which can be applied to a large spectrum of geotechnical works. For example, cut slopes in colluvial soils have a different expected behavior than a cut slope in residual (saprolitic) soil due to differences in permeability, observed displacements and failure modes which requires a different set of instruments and monitoring strategy (Bressani, 2009). In addition, these definitions also serve to establish the most appropriate scales for quick results interpretation (cm/hour; mm/day).

2.3 Select instruments and systems based on longevity and interoperability

The choice of instruments passes through a series of factors and analyzes that can be specified by description or by performance: a) range, accuracy, resolution, precision or repeatability, b) geometry e weight, c) price, d) robustness and quality, maintenance, e) installation characteristics and operation, and finally, f) longevity.

Many of these topics have been discussed extensively in the literature and we will be concentrate on the last item, longevity, and the concept of interoperability which is been addressed in various engineering disciplines, such as project management and information management.

The number of instrument types and operating modes present in the market is very large. They are based on mechanical, hydraulic, pneumatic or electrical transducers. The older instruments and systems had very rudimentar data acquisition techniques many being manual and depending on the personnel being at the site for recording or, when they had automatic processing, the capacity was low and limited to a few instruments. In addition, the technology advances has been taken in a gradual and adaptive way, that is, the process of acquisition, transmission and processing was in the operator hands then dependent of some external resource. Nowadays the rapid advance of technology, sensors, instruments and data boards generates compatibility with previous generations.

But the evolution of technology has brought a paradox. It is easier and cheaper to get a lot of reliable data with new sensors than to build communication and compatibility between systems and previous models. That is a big problem because the systemic exchange of instrumentation can generate data loss and/or interruption of fundamental data for analysis of long term behavior of earthworks.

Specifically in infrastructure works, such as large dams, the life cycle can be decades or more and the correct monitoring is fundamental to guarantee the good performance throughout the structure lifespan. According to Gallaher et al. (2004) infrastructure systems have a life expectancy of 75 to 100 years and many resources (monetary and time) are spent due to information problems. According to the same author after construction completion about 10 billion dollars are lost annually in the US due to management problems and access to information.

Therefore, instrument obsolescence is a major problem in the longevity of monitoring systems, generating interruption, data losses and difficulty in data management which impairs the structures behaviour evaluation or prediction throughout theirs life cycle. It is important to emphasize that these can be responsible for major damages or even failures of geotechnical structures in the long term. Christoulou (2000) reaffirms that proper monitoring, data collection, analysis and system maintenance are vital components for a successful operation of any infrastructure.

The key to improvements is related to the concept of interoperability through the creation of flexible systems capable of communicating different languages and technologies. This concept is defined as the ability to use resources from diverse origins as if they had been designed as part of one system (BOLLINGER, 2000). Amaral and Soares (2014) in a deep analysis of the concept cite three characteristics: coexistence, autonomy and loosely coupled.

Therefore, the choice of individual instruments or whole monitoring systems need to be based on a coexistence structure of technologies, autonomy and independence between measures where a failure of a particular instrument should not influence the capacity and reliability of the system and should be easily replaced or adapted without any data quality loss.

2.4 Data collection, processing and interpretation.

Hanna (1985) says that the reading frequency of a particular instrument is a function of the rate at which the quantity being measured is expected to change. Dunnicliff (1988) warns that too many readings overload processing and interpretation capacity and may cause the waste of relevant information to judge the structure behavior. Although these concepts are still correct they are fundamentally related to the manual process of data recovery, processing and interpretation, a reality far away from current technological capacity. For example, in the early 90's, Teal et al. (1990) shows a cordless digital data transmission technique as an interesting alternative to traditional "umbilical" data links between buried instruments and surface monitoring stations. Now, we have the capacity of data transfer much faster to a server located in the "cloud" and this completely changes the size of safe data storage.

New technologies on data processing, data storage and presentation have also emerged. DiBiagio (1979, apud DUNNICLIF, 1985, p.374) almost 40 years ago already listed the advantages of automatic data processing via computers. Today we are able to process and storage billions of bytes quickly.

The problem of all this technological power is that the amount of data can become so large that the engineer no longer has the ability to manage and interpret the fundamental data. Dunnicliff (1988) already predicted this as a disadvantage of automatic data processing. According to the author: "*Replacement of a knowledgeable engineer by an item of hardware [or software]. There is a real possibility that engineering judgment will be given second place, that correlations will not be made with visual observations and with factors that influence measured data*." This problem will be discussed bellow.

The correct presentation of the results is also an important point in monitoring system. Bressani (2009) emphasizes the importance of some aspects related to technical reporting and its consequences: a) represent key parameters, b) maintain the original spreadsheets or files for reference, c) deliver synthetic and sequential reports, d) establish adequate and standardized scales, e) plot cumulative graphs (over time), f) report equipment adjustments and possible measurement errors and g) establish clear personnel hierarchy and responsibilities in the report's elaboration facilitating future enquiries. It is emphasized that most of the issues dealt with are related to clarity and transparency of the information management and most are related to avoiding non-technical problems.

2.5 Monitoring system failures

When a failure in earthworks occurs usually many factors can be appointed as concurrent causes. Using the well studied accidents in aviation as comparison failures seem to be a sequence of technical and human errors.

Regarding the human aspect Peck (1981) pointed that 90% of dam ruptures did not occur due to a lack of technical knowledge in design or execution but because of negligence that could have been avoided. Quoting the same author "*A failure of a dam is indeed a failure, whether caused by a slipshod inspector, an unclear contract document, or an erroneous stability analysis. Our concentration on investigating the properties of the materials of which dams are made, and on the technical analyses of the anticipated behavior, should be matched by attention to the nontechnical and human factors that are no less a part of this branch of engineering*" (PECK, 2000).

From the technical point of view, we can also mention: misunderstanding of the problem, failure to understand some geotechnical mechanisms, failure to predict behavior changes in time, error in the choice and location of instruments, inadequate contingency plans (too late responses, for example) and instrumentation malfunctioning. Specifically on the monitoring system, inefficiency in data acquisition and interpretation may lead to delays in the implementation of a corrective measure, which may become little effective or even useless.

Osterberg (1979) cites errors in the geotechnical investigation, which may be analogous to the monitoring process discussed here. According to the author, adopting misconceived ideas about geological processes can lead to errors in the earliest stages of design. In addition, not use all the tools, techniques and instruments available, or communication problems between the stakeholders (owner, project manager, contractor) and the instrumentation team decrease the reliability of the system.

The economic pressure is also other important cause, especially when this over pressurizes the time schedules for proper investigation or installation. The urgency in the execution of the earthworks can be easily superimposed on the (hidden) safety and so less priority is given to the team responsible for monitoring (BRESSANI, 2009).

Leung et Tan (2007) exemplify well these conditions. The rupture in the Nicoll Higway tunnel in Singapore, 2004, did not happen by chance but it was caused by a series of technical and administrative errors from the early stages of the design up to execution. Among the most important factors were the lack of risk sensitivity, design problems, misinterpretation of geotechnical conditions, inadequate contingency plans and incorrect data treatment and instrumentation failures.

3 THE CHALLENGE OF BIG DATA

Big data is a term for massive data sets having large varied and complex structure with the associated difficulties of storing, analyzing and visualizing it for further processes or resulting presentations (SAGIROGLU e SINANC, 2013).

In large earthworks such as tunneling, embankment dams or large excavations, monitoring systems with a large number of instruments and high readings frequency generates an enormous amount of data. In addition, technological evolution has reduced the cost of using large number of sensors and has improved the quality of data acquisition and transmission which naturally implies a greater source and generation of information.

The increase in data collection capacity is appealling, however, large-scale interpretation may be impractical without adequate computational resources. This is the challenge of big data.

According Fan et al. (2014) Big Data are characterized by high dimensionality and large sample size and this cause some problems in the analysis field. First, high dimensionality brings noise accumulation, spurious correlations and incidental homogeneity. Second, the massive samples in Big Data are typically aggregated from multiple sources at different time points using different technologies. This creates issues of heterogeneity, experimental variations and statistical biases.

As a solution to all these challenges imposed by the amount of data, the use of statistics and artificial intelligence (AI) models may be of great help to data processing. AI is the process of learning and cognition via algorithm that a computer applies when analyzing a certain process. Under situations of large volumes of data, artificial intelligence allows detection of difficult pattern recognition, learning and other tasks to computer-based approaches (O'LEARY, 2013).

It is important to remember, the machine can be trained to recognize patterns, eliminating non-conforming data or generating alerts for behavior changes. However, the engineer's view will always be necessary at first to "teach" the machine and secondly to validate the results because the decision-making is not only based on data, but on experience, intuition and understanding of the problem. "*Big data's power does not erase the need for vision or human insight.*" (McAFEE e BRYNJOLFSSON, 2012).

Another important point to be addressed is the storage capacity and ease of printing the results. Cloud storage and processing technology makes it easy to operate Big Data in virtually any situation. The most striking feature of cloud computing is its elasticity and ability to scale up and down which makes it suitable for storing and processing Big Data (FAN et al. 2014). Finally, it is notable the evolution in the capacity to acquire, process and interpret data which will reach the limits of human cognitive ability and more and more it will be increasingly necessary to understand subjects related to Big Data, AI and machine learning. Although the themes appear so far from the geotechnical reality, the increasing needs for interdisciplinary teams in the elaboration of large on-time monitoring systems is becoming irrefutable.

4 ACTIVE MONITORING SYSTEM - (called as SAM in Brazil)

The Active Monitoring System (SAM - Sistema Ativo de Monitoramento) is designed to support low-cost electronic devices using the latest IoT (Internet of Things) concepts, using the architecture illustrated in Figure 1. The premise is to reduce costs through the use of low-cost sensors, providing compatibility for new sensors and instruments with the ones already installed in the field, thus providing interoperability among equipments.

The communications network can be done point-to-point or through gateways, depending on the each particular demand. The data is then sent to the cloud, where data validation is done and stored in a relational database. The data is transmitted via GPRS (General Packet Radio Service), 3G / 4G, WiFi or other available technologies. After the data is processed, the results are stored and are made available to be plotted, visualized or printed in many platforms, such as smartphones, tablets or desktop computers.

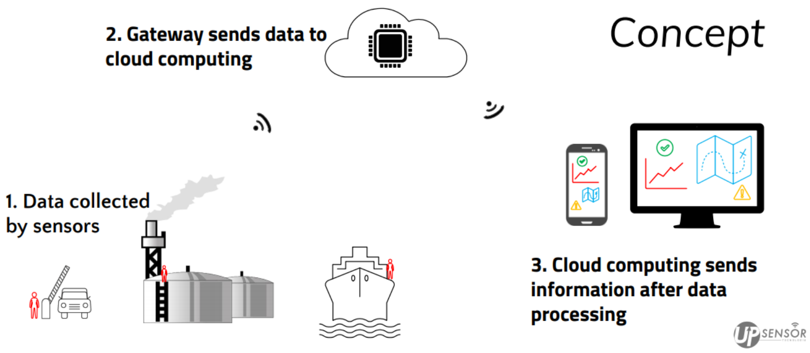

Figure 1. SAM architecture.

Data analysis varies with the type of problem scenario. It can be an analysis of historical series with neural networks, machine learning or applying analytical/empirical equations to the data to forecast the possibility of landslides, for example. In the process of data analysis translating to the machine the relationship between the geotechnical engineer, who knows the expected behavior, and the system programming team, that trains the machine to recognize patterns and deviations, is the key of success. It's important to emphasize that the system is not able to understand the problem, but it is capable of analyzing and processing data much quicker by using an infinite combination of variables that can lead to a combination of potential risks.

4.1 Application architecture - description

The application was developed in the cloud. The operational system chosen was Linux. The programming language used was PHP, together with NGINX webserver and TimescaleDB database, an open-source time-series database. The data format coming from the devices are essentially time oriented, that is, the sensor reading and the timestamp are stored in each reading, therefore forming a time-series sequence. The database should support for a high number of inserts due to the fact that many devices will report at the same time. Data analysis and graphic plotting are activities that are resource consuming, not only of CPU time but also memory. In most databases, selecting data from a certain time period requires loading the entire table into memory. If this table is not segmented properly, that is, split into many time-oriented segments, it will overload the system and downgrade the performance. After testing other databases, Time scaleDB has shown to be effective to store high volumes of data and to support the insert load, due to its internal engine that automatically segments data and handles multiple insert operations effectively. Many modules were developed to perform separated tasks and offer optimal communication with the users and devices. The gateway module, which is responsible for receiving and decoding the data coming from the devices, supports three adapters: HTTP, HTTPS and MQTT. The message management module handles all incoming and outcoming data streams from the gateway. It also performs data evaluation, eliminating spurious sensor readings and reducing excessive data insertion attempts. The message management module is also responsible for sending messages to the gateway module, which will be consumed by the devices. The consumed messages are used by the device to perform certain actions, such as sensor calibration or device reset. The database layer is responsible for data persistance in the database and, finally, the presentation layer is responsible for displaying the persisted information to the application user in any platform, desktop or mobile. The infrastructure is shown in figure 2.

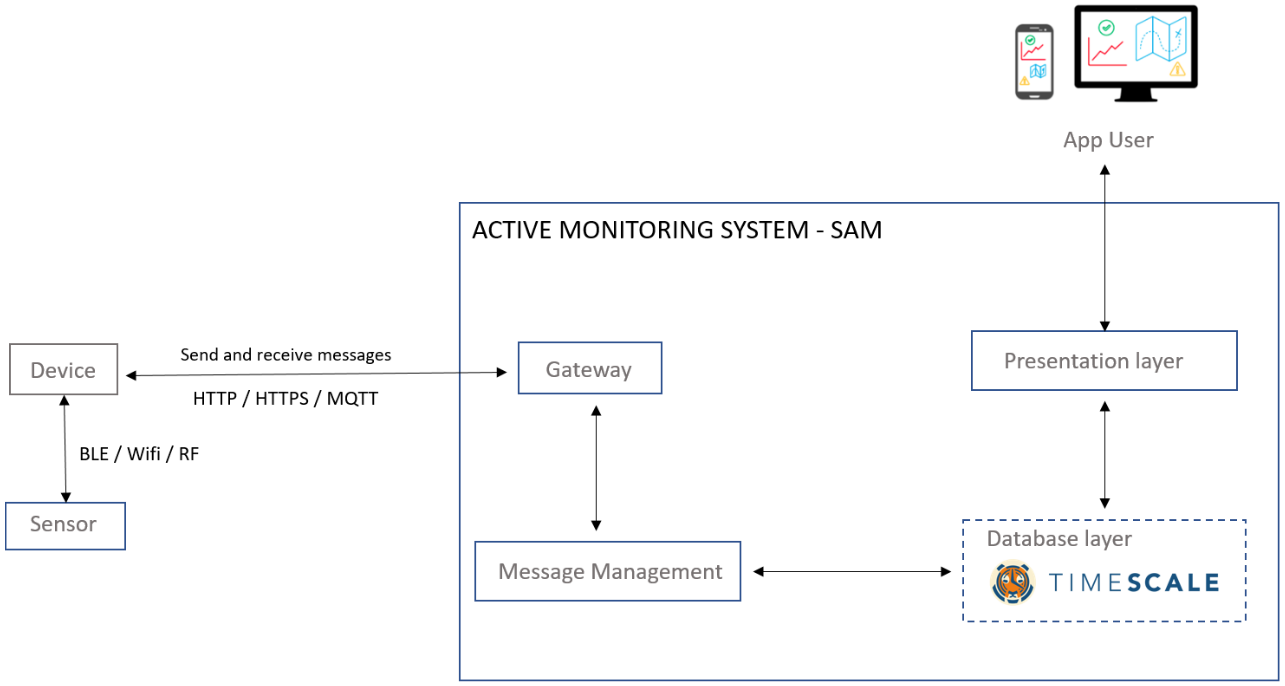

Figure 2. Cloud architecture

4.2 Hardware proposal description and alert system

SAM is more a concept and system rather than a standalone product and it can be made to work with a variety of hardware architectures and configurations. That being said, in one application for landslides monitoring, it was proposed a battery-powered distributed network of sensors, either communicating with each other and a gateway, through a low-power protocol (such as Bluetooth Low Energy) or directly to the cloud through GPRS or WiFi, that is, on those rare occasions where they are brought back from hibernation to report a landslide event. These sensors can be part of an array of several instruments such as piezometers, inclinometers, extensometers or any other instruments capable of generating data on slope behavior.

Another key part of the system is the ability to send alert messages in the CAP format which facilitates the communication between the governing bodies in different spheres. The CAP - Common Alerting Protocol has a simplified format for exchanging emergency alerts and public notices using all types of networks. The CAP protocol allows a warning message to be disseminated simultaneously on many different alert systems, thereby increasing the effectiveness of the warning while simplifying the alert task. The CAP is being developed under the auspices of the OASIS - Organization for the Advancement of Structured Information Standards and fosters the adoption of open standards for the global information society. The CAP protocol was also standardized by ITU-T (TAROUCO et al., 2017).

Standard programming languages are another important aspect related to system interoperability. The use of one same language breaks communication barriers and guarantee the duration of communication and increases the interaction and reliability of information provided to stakeholders.

4.2 Case study – Salvador landslides

The city of Salvador, Bahia, deals with landslides ever since it was founded. The first records of such events are from the 16th century and go on throughout time accumulating dozens of lives lost and much property damages (SEMIN, 2002). Mattos et al. (2005) suggested the monitoring of 433 areas of the municipality that were diagnosed as susceptible to landslides.

Recently the work of Instituto de Pesquisas Tecnológicas de São Paulo (IPT) on demand of CODESAL (Civil Defense of Salvador) established that it was possible to use a relationship between the amount of rainfall and the occurrence of landslides. The methodology proposed por Tatizana et al. (1987) was used. Using local data, envelope curves of rainfall-landslides (of the types induced, sparse, generalized and mud flow) were adapted from a historical series of accumulated 4 days of rainfall against hourly rainfall (Equation 1) where: I=intensity for landslide triggering, K=dependent parameter of geotechnical slope conditions and intensity of landslides, Ac=accumulated rainfall in the 4 previous days e b=geometrical relation constant.

$$I(Ac)=k*Ac^{b} \qquad (1)$$

For the validation of this model the observed failures of Salvador' 2015 landslides events in which slides in the localities of San Martin and Bom Juá victimized 15 people were used. Using rainfall data collected by CEMADEN at the Alto do Peru station an off-line SAM simulation was performed using this methodology in conjunction with the hour-by-hour collected rainfall of the event. Thus it was possible to establish risk curves versus hourly precipitation. The parameters adopted were: b = -0.933 for all curves and K = [2603, 3579, 5466, 10646] for each of the plotted curves. In Figure 2 the exponential blue curves represent very low risk levels and the orange curves very high risk and the filled figures are the observed (2015) accumulated rainfall.

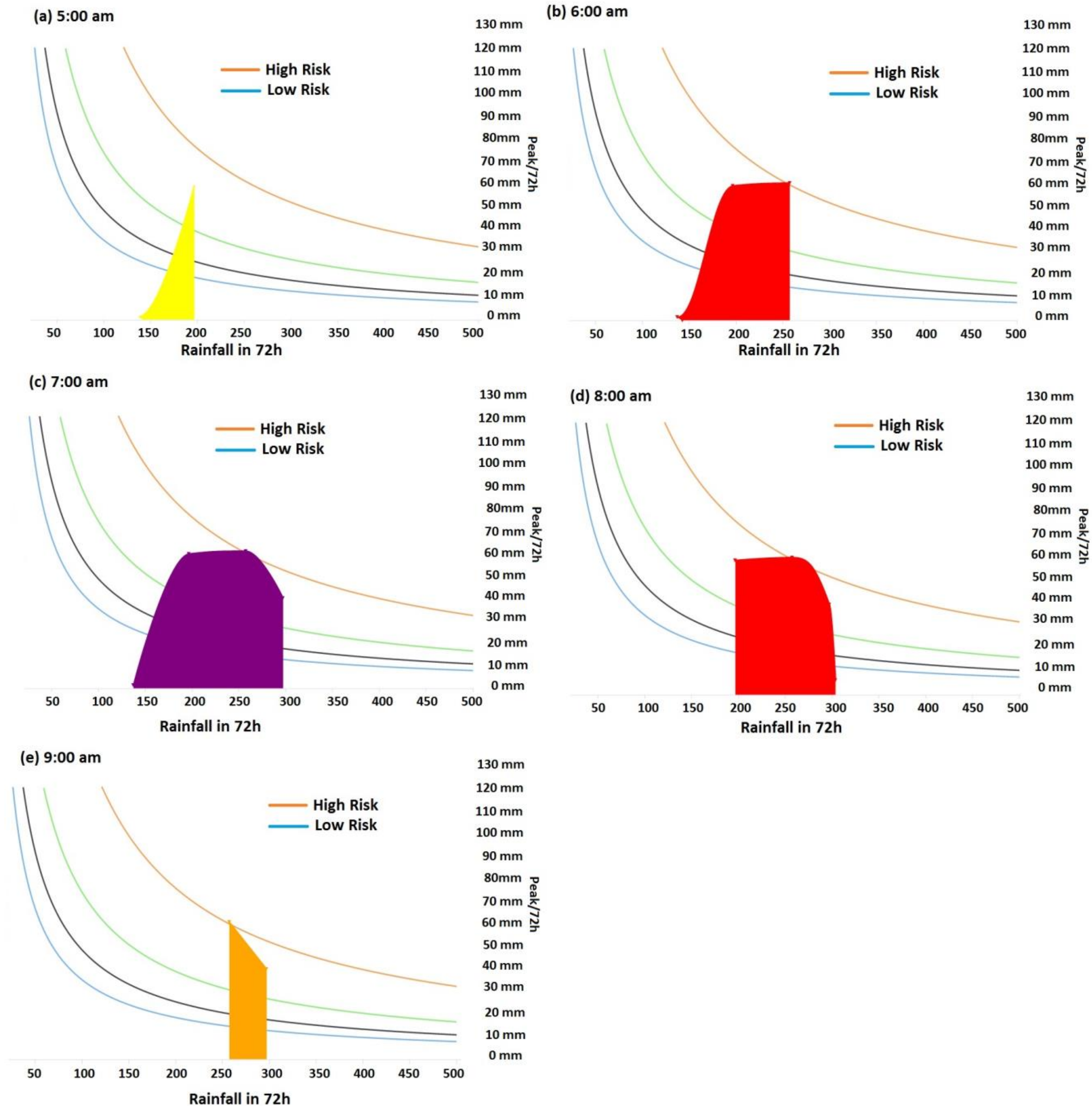

Figure 3. Plots of accumulated rainfall used for alarms.

The observed hourly rainfall sequence started at 04:00 in the morning when the precipitation accumulated in the last 72h show a value close to 140mm. Figure 3 (a) from 05:00 has an accumulated in 72h near 200mm rain and with a hourly accumulated close to 60mm (yellow area). In Figure 3 (b) of 06:00 shows that the rainfall remained constant and intense, the accumulated of 72h reaches near 250mm (red area). At this time the slides started. In Figure 3 (c) at 7:00 am the rainfall starts to reduce the intensity to less than 40mm/h but comes close to the maximum accumulated in 72h (purple area). From this time the rescue teams began the rescue work of the victims. The Figure 3 (d) from 08:00 shows the accumulated in 72h peak a little higher than 300mm and accumulated/hourly already under 10mm (red area). Figure 3 (e) from 09:00 there was no rain anymore.

Therefore using the adjusted prediction equations SAM was used to create a data mining system, cloud computing and construction of online viewing windows of the limit curves with rainfall information obtained through the public data of CEMADEN (National Center for Monitoring Natural Disasters). Or it could be using data of a specially assembled arrangement of rainmeters. Figure 4 shows a bar graph of the cumulative precipitation of 72h from the various observed stations in Salvador and the real-time alert levels in a normal day.

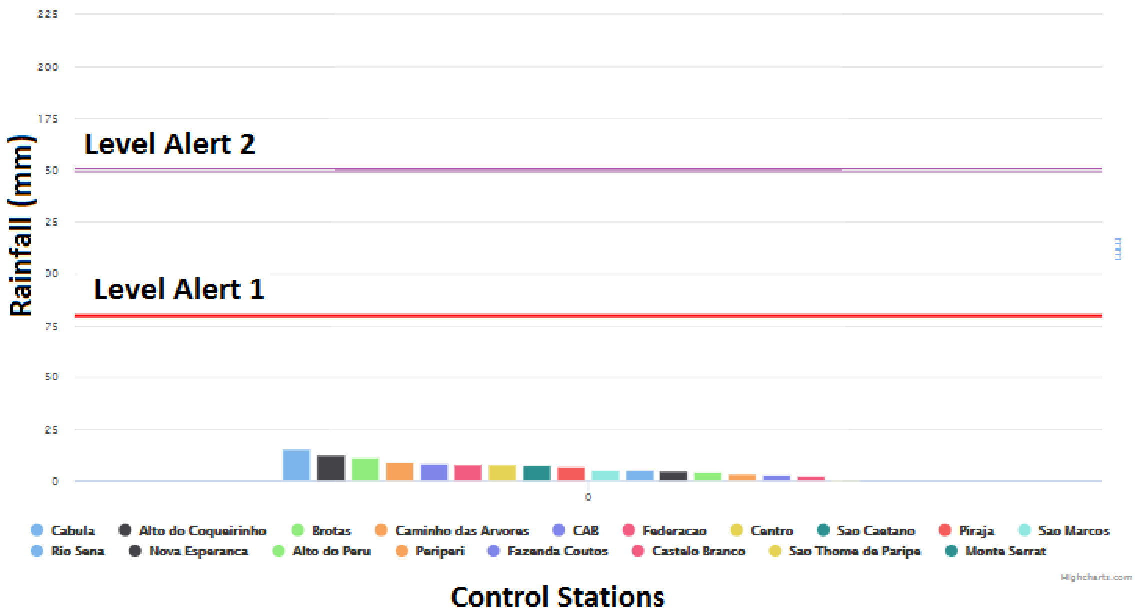

Figure 4. On-line updated graph with rainfall accumulated in the last 72h and alert levels (control sites of Salvador).

In addition to using data from existing rainfall stations it has been proposed to use low-cost inertial sensors in one of the risk areas. Initially the Bom Juá location was chosen with the distribution of 50 inertial sensors between 1m and 2m deep with up to 3 gateways for the communication of the sensors and the cloud computing. In this particular instance of the system the sensors chosen were manufactured by Signal Quest, specifically the tilt and vibration sensor SQ-SEN-200, which is very sensitive and omnidirectional, fit for the kind of interactions required to be monitored. The sensor is monitored by a NodeMCU microcontroller whose features include a WiFi module - once awake, it connects to a local WiFi network and is able to send the event information - the sensor itself can be used to trigger the waking up routine. Figure 4 shows the system to be implanted.

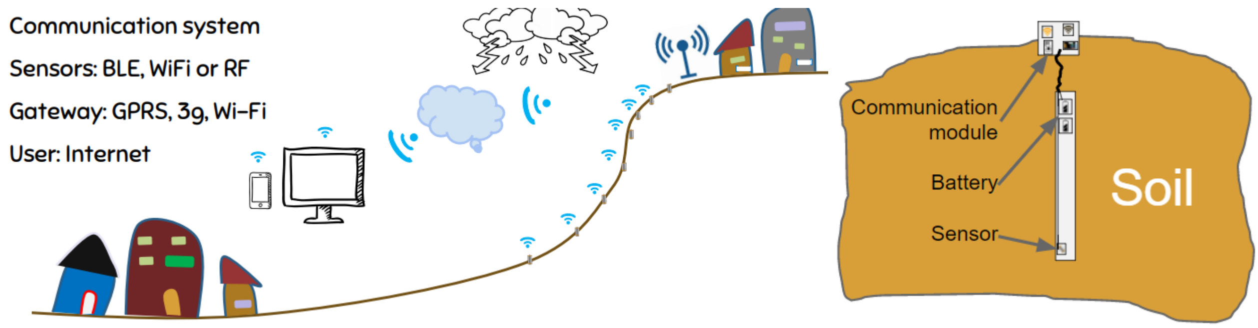

Figure 4. Monitoring system with vibration sensor.

The project was presented by IPT to CODESAL (local government) which opened a public bid for such projects. The Upsensor was the only company that showed interest and until the moment of writing is waiting ratification of the process to begin the deployment of the sensors. The data of the rainfall threshold curves are already a great contribution to the alert system and the expectation is that with inertial mass movement sensors there may be greater security in issuing warnings and alarms to the population.

5 CONCLUSION

Monitoring systems are fundamental in the process of control and safety of geotechnical works and also as an important tool in the prevention and mitigation of accidents related to landslides. Currently, the combination of low-cost sensors and high data-processing capacity opens new horizons but also new challenges for geotechnical engineers.

Reconcile the generation of large data bases (Big Data) with efficiency in interpretation is a challenge to be considered. Although large quantity of data is not synonimous with a more efficient system, its potential quality cannot be overlooked. Therefore, new techniques must be developed to maximize the quality of information extracted from large data systems. Artificial intelligence is one of these techniques that when correctly developed and applied are able to synthesize a large amount of data into vital information for correct decision making.

But the creation of functional systems should be also based on longevity and interoperability. In practice, different technologies should talk to each other over time. The obsolescence of previous systems may cause loss of fundamental data in assessing the structure behavior throughout its life cycle. For that reason, systems must be constructed in an open way allowing associations and adaptations with other technologies and architectures.

With these concepts in mind, the Active Monitoring System (SAM in Brazil) was designed to support low-cost electronic devices using the latest IoT (Internet of Things) concepts. An application of this system has been made at Salvador city, BA, Brazil following the work by Instituto de Pesquisas Tecnológicas de São Paulo (IPT). There, it was established that a relationship between the amount of rainfall and the occurrence of landslides could be used for prevention. Using the adjusted predictive equations described above, data mining and cloud computing, SAM was used to create on line plots of the curves with rainfall comparing with the threshold curves. The rainfall information was obtained from public data (CEMADEN - National Center for Monitoring Natural Disasters). The operational system aims to provide alternatives of low-cost implementation and high-power of analysis, in almost instantaneous timing, providing to the stakeholders an effective predictive tool, a better support in decision-making for mitigation of accidents and application of emergency resources.

ACKNOWLEDGEMENTS

The authors want to thank Conselho Nacional de Ciência e Tecnologia (CNPq) for continuing support to the first author, Instituto Senai Sistemas Embarcados (SENAI-SC) for various tasks in the project, colleagues from UFRGS for their general help and CODESAL for his support at Salvador works.

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