**CHAPTER 1**

**INTRODUCTION**

**1.1 Background**

IoT has become so vital in our daily life and it is going to create a big impact in the near future. For example, solutions can be provided instantly for the traffic flows, reminding about the vehicle maintenance, reduce energy consumption. Monitoring sensors will diagnose pending maintenance issues, and even prioritize maintenance crew schedules for repair equipment. Data analysis systems will help metropolitan and cosmopolitan cities to function easily in terms of traffic management, waste management, pollution control, law enforcement and other major functions efficiently.

Monitoring, forecasting and warning of landslide are the essential features for saving the lives and assets from devastation. There are three fundamental ways for monitoring the landslide viz, visual, surveying and instrumentation.

Each monitoring technique has its own advantages, Disadvantages and application range. Surveying equipment such as levels, theodolites, electronics distance measurement (EDM), and total station provide some of the prominent landslide features however, aerial or terrestrial photogrammetric provides contour maps and cross section of landslides. The compilation of photogrammetric data enables a quantitative analysis of change in slope morphology and determination of the movement vectors. Instrumentations may include installing equipment for periodic reading of the different monitoring sensors such as inclinometer, strain gauge, rain gauge, clinometers, extensometer, pore pressure sensor etc. The monitoring techniques also can be divided into two groups:

i) Geodetic technique

ii) Non-geodetic technique.

It focuses on instrumentation monitoring and non-geodetic techniques for detecting the landslide. WSN has the capability of large scale deployment, low maintenance, scalability, adaptability for different scenarios and low maintenance requirement which made it one of the best suited technologies for real time monitoring. A landslide detection system with use of wireless sensor network can detect the slides moments of soil or slope instability due to the several reasons such as dielectric moisture, pore pressure etc. that may occur during a landslide. All this data will be sending and stored in cloud for further analysis for researchers.

Considering it to the next level, linked devices can help the people personally like you get an alert from the refrigerator reminding you to shop some vegetables when the vegetable tray is empty, your home security systems enables you to open the door for some guest with help of connected devices(IoT). Since there is a massive growth in number of devices day by day, the amount of data generated would also be enormous. Here is where Big Data and IoT go hand in hand.

**1.2 Motivation**

It was not too long ago that we visualized houses of the future where things would be done on their own- lights coming on by themselves, coffee being brewed just the way you like as you are about to wake up and your shower knowing the weather outside and adjusting the water temperature accordingly. And now we are at a point where technology to achieve all that has been around for a while and has now become affordable. Hence, it is not a particularly big surprise that we are witnessing some amazing things happening in the world of automation.

Although, the primary driving force of a landslide is gravity, there are other contributing factors as well, such as soil composition, precipitation, variations of soil and air temperature and human activity. Landslides may have great adverse effects severely affecting human activity and lives, sometimes to the degree of natural disasters. Indicative examples are the 2010 Uganda landslide that caused 100 deaths and the 2011 Rio de Janeiro landslide that caused 610 deaths. In this context, landslide monitoring and prediction has been a hot research topic.

**1.3 Objective**

In this work we present an innovative landslide monitoring system that leverages state-of-the-art IoT technologies. The system consists of a set of autonomous sensing devices equipped with a sensor suit specifically tailored for monitoring landslides.

**1.4 Report organization**

The seminar report is organized in such a way that, first part includes the introduction section which explains the background, motivation and the objective in detail. In the second section literature survey is included. Third section is proposed system, fourth section future scope, fifth section conclusion and then sixth section is reference.

**CHAPTER 2**

**LITERATURE SURVEY**

Landslides are a geographical disaster occurs in a short period due to the variations in environmental actions and causes damages in human lives, properties of agriculture. During the rainy season, unlike divisions of India are affected by the landslide natural hazard every year. IOT based technology has the capacity of large scale deployment and real time detecting of landslide losses. IOT based network detect the slightest movements of ground or slope instability due to the several reasons such as dielectric moisture, pore pressure and so on that may occurs during a landslide.

In this work we present an innovative landslide monitoring system that leverages state-of-the-art IoT technologies. The system consists of a set of autonomous sensing devices equipped with a sensor suit specifically tailored for monitoring landslides. The devices take sensory measurements at frequent intervals - while operating at a very low duty cycle - and transmit them over the SigFox network to a data server powered by ELK stack for curation and visualization. The system has been successfully deployed in a landslide site at Bournemouth, UK providing the local authorities with a new means of efficient and remote monitoring.

**2.1 IOT based rainfall monitoring system using WSN enabled architecture [1]**

The effect of climate change and human activities ends in a chain of risky phenomena, inclusive of landslides and flood. The environmental problems are also a captious part of human’s quality of life and the advancement of civilization. Old methods of monitoring the environmental parameters which as physically receiving information rainfall data from stations can be brutal and inhibiting monitoring required for careful imposition. This paper makes specialty of a flexible and efficient WSN for detecting rainfall-induced landslides. WSN which offer the high quality rainfall monitoring at very cheap rate in terms of labor invested and capital. This paper includes the WSN-enabled architecture for rainfall monitoring system to transmit and collect real time data using GPRS (General Pocket Radio Service) via a cellular network. The data is sent from remote stations to the web server known as Weather Underground. Contribution work is an approach is bandwidth compressed waveform signal for increasing the number of connected devices Performance analysis using SVM machine learning classifier for prediction of rainfall.

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**FIG 2.1** Architecture of rainfall prediction using SVM

Water management from rainfall helps to reduce risk of peoples and economic impact. There are many countries whose water needs depends on rainfall. But if we don’t have water management system then it will be very difficult to determine the water level or ground water level. Hence rainfall management and monitoring is an important for water management. Sometimes rainfall percentage will be very good but after that period or after that year who kows rainfall percentage will be good. That’s why we also need the rainfall prediction System. Due to rainfall prediction we also can save the peoples life who will be affected by flood. Rain gauge is a very effective tool or sensor for the rainfall measurement. Rain gauge is a very advanced and improved tool which also best for agriculture. There are so many sensors which can be used for obtaining the information like soil moisture, rainfall, temperature, humidity soil temperature. By processing this data we will get a good result for water management. The system uses a tipping bucket RG sensor, micro-controller, heat sensor, GPRS module, air-water sensors, and rainfall information to a web module, also a energy panels are provided for power backup in critical area for WSN.

**2.2 Landslide monitoring system implementing IOT using video camera [2]**

Landslide is a natural calamity which has devastating effects that can lead to multiple deaths and loss of property. Thus, landslide monitoring is of substantial importance in reducing the catastrophic effects of landslides. In this paper, we propose a landslide monitoring system based on Raspberry Pi implementing IOT using a video camera. It performs real-time analysis of the region, based on the video stream acquired by the camera and applies computer vision algorithms to detect landslide and notify stakeholders via Android app. Raspberry Pi being a low-cost device with low power demands can be installed in any region.

The principal requirement for designing any system is the availability of sufficient test cases. Landslides being a natural phenomenon that generally occurs in remote regions, thus the videos of landslides are not available with us for research purposes. So to develop the above said system we have modeled our landslide test case against a waterfall due to opening of gates in a dam. The waterfall can be approximated to a layered landslide and thus, a landslide detection mechanism based on it has been developed. The flow of the paper is as follows: Section 2 gives a brief of the proposed system. Finally Section 3 and Section 4 provides the results and conclusions respectively.

Similar to other IOT based systems, the system proposed in this research uses a camera to sense the surroundings to update relevant information to the server. The camera captures frames and based on the previous data, moving objects are detected. Analogous to the theory of center of mass in Newtonian mechanics our system considers the center of mass of moving "pixels" to detect and estimate the direction of motion. Although this is a primitive method for motion detection and estimation, it proves to be a faster methodology to implement on a low cost computer like raspberry pi for real time notification.

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**FIG 2.2** Architecture of landslide monitoring system implementing IOT using video camera

**2.3 Image-based landslide monitoring system [3]**

A novel image-based landslide monitoring system proposed in this paper, which is using digital image processes methods to detect landslide occurred in any landslide occurred situation to achieve a non-contact landslide monitoring system by one image. The theory of this system is based on using a laser projector to project a laser beam to measurement box, which have two acrylic boards in the measurement box. When landslide occurred, the laser beam will generate two laser spots in image. To identify the coordinate of laser spots through an easy calculation, the system could get the landslide displacement and offset angle. According the measurement result, it could announce the warning and prevent the damage.

There are many mountains and hills in Taiwan, because rapid increase in population and rapid economic development, the hillside been developed, however it has a serious soil and water conservation problem. When the typhoon season comes, heavy rain, earthquake, steep terrain, fragile geology and many nature factors will make the landslide occur. In this paper, it focuses on a “long-term” landslide monitoring system, which can achieve measure landslide displacement, angle and predicts the landslide area; the measurement result send by wireless network, the power solution is use solar-cell. According the monitoring result, it could be announce the warning; to earn more time to evacuation and control, reduce the disaster form landslide occurred. The traditional landslide monitoring system is contact monitoring system, the equipment shall installation in observation area, but the repetition rate is not high. When the landslide occurred, the monitoring equipment will be destroyed

This system could be achieve a non-contact landslide monitoring system and accomplish combine “before-and after” landslide monitoring system. The second section will introduce the theory of image based landslide monitoring system. It will elaborate the machine vision based landslide monitoring system process methods in the third section then the experimental results in the section four before landslide monitoring detects; the system needs to identify two laser spots in image, one is on the acrylic 1, another on the acrylic 2. The coordinate in image substituting formula to calculate the landslide displacement, landslide offset angle and landslide direction. There is an image-based landslide monitoring system propose in this paper, which use a laser projector to project for long distance to accomplish a noncontact monitoring system. The CCD camera is measurement equipment in this system, not only for monitoring. The acrylic board 1, acrylic board 2 and CCD camera setup in measurement box; the angle and distance between acrylic board 1, acrylic board 2 and are fixed, the camera will have same range of image. When landslide occurred, the coordinate of laser spot will change. In the nighttime, the system could not monitoring environment, the dark environment is easier to do digital image processes, it still could identify the coordinate of laser spot, and calculate the landslide displacement and landslide offset angle.

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| **CCD Camera**  **image source**  **Capture**  **Smoothing**  **Gray Process**  **Binary**  **Dilation**  **Erosion**  **Hole filling**  **Edge Detection**  **Calculate laser coordinate**  **and pixel numbers**  **Compare with Central Point in**  **image. Calculate landslide**  **displacement and offset angle**  **Save Measurement Result** |

**FIG 2.3** Image processes flowchart

**2.4 Using motion sensor for landslide monitoring [4]**

The monitoring of landslide usually adopted visual inspection or manual monitoring per month. Real time landslide displacement monitoring system is including in-hole extensometer, ground extensometer, building crack meter. However, in-hole extensometer requires boring hole and costs a lot of funding. Ground extensometer has to be cross landslide crack on the surface, where is not easy to define before slip happens. Building crack meter has to be set up on the position where crack happens. Thus a landslide displacement tracking sensor with high efficient and economically is required, The location of research area and the buildings are located in the community.

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The 3D building was acquired from Google Earth 3D database. The sliding direction is from the community to down slope. The dip angle of the rock formation underneath the community is about N80°~90°E/30°~40°S. Cracks of brick wall at station was observed and the tilt direction is consistent with the direction of dip slope.

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**FIG 2.4** System architecture

**2.5 Comprehensive application of slope monitoring and early-warning techniques in landslide monitoring [5]**

With the development of new technology, more and more deformation monitoring techniques are applied in landslide monitoring. This paper, first of all, took one landslide for example and introduced the application of early-warning monitoring techniques in landslide deep and surficial monitoring. according to monitoring data, landslide stability is analyzed then. Finally, merits and drawbacks of various monitoring techniques are categorized.

Firstly, the system can measure each monitoring points inside the slope accurately when the slope deep presents larger displacement or inclinometer tube is broken. Secondly, according to monitoring precision, it can flexibly adjust the number of sensors and monitoring frequency, and receive remote monitoring data by wireless transmission device. Thirdly, according to the system displacement and rate of early-warning value send alarm messages automatically, it can achieve real-time warning. Compared with traditional manual monitoring inclinometer, this system has the advantages like low labor intensity, monitoring frequency, timeliness, flexibility, small error and higher automation. So, after large deformation appearing, BK1-2 monitoring hole was switched to DTS monitoring sensor

Landslide of Zhangyong express way is located in middle Luoxi mountian, Huaan county, Fujian Province, where Yingxia railway passes through from the foot of the mountain, and the distance between the expressway and the railway is around 55m. Due to continual strong rainfall and adverse geological conditions, K40 landslide formed and developed to be a large landslide from June to August, 2013. Because of the weak supporting and retaining reinforcement the landslide revived in June 2014, which posed great threats to expressway construction and railway operations. Therefore, application of various monitoring techniques is needed to understand the sliding direction, speed, and development rule of the landslide.

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**FIG 2.5** DTS displacement sensor and its installation diagram

**2.6 Security considerations for a real time landslide monitoring system [6]**

The development of Wireless Sensor Network (WSN) used in various industrial applications and remote monitoring has been motivated from the military applications such as battlefield surveillance. The wireless sensor networks contains a group of sensors which monitor or sense several physical parameters like temperature, pressure, moisture content, etc., and pass the data through the network wirelessly to other sensors or to a remote location without being lost or being eavesdropped. WSNs for landslide monitoring are deployed by our research center in some areas of the Western Ghats and another location in the north eastern India which are prone to landslide due to heavy rainfall. The landslide research work includes various sensors for sensing and monitoring the parameters which may lead to landslide, which is one of the natural calamities that can cause several life losses. The sensor values at the landslide prone area are monitored in the data management center, which is situated several kilometers away from the sensors. The paper focus on the architecture of the landslide project, the security threats faced in real world applications.

Wireless sensors technologies is an fast emerging technology that can have applications like remote environment monitoring, tracking, etc., where we need sensors to sense rapid changes of data and send the sensed data to a remotely located data centre wirelessly. Sensors which are equipped with wireless interface, so that they can communicate with other sensors within the range forms a sensor network. A sensor network is independent on the type of sensor, but it depends on the type of wireless technology used to connect between sensors. So a sensor network can have some sensors which senses the temperature, another set of sensors to measure moisture content, another set of sensors which senses the pressure, all connected together by using a common wireless interface, say Zigbee. As the sensor network becomes large, the sensed data which are dependent from each other also increases.

Security is widely used term comprising of privacy, authenticity, integrity, anti-playback. The need for the security increases when information dependency for transmission in a network has increased. Security threats can be seen in each part of the wireless sensor networks like raw sensor data, routing mechanism through which the data are forwarded, etc., where it affects the entire system performance. This paper focuses on the possible security issues faced at different stages of the real time monitoring of the landslide and its detection, the cause for the threat and the prevention techniques needed for the security threats at each stage of the landslide detection system. The architecture of the real time landslide monitoring system is described in the next session, followed by the security issues faced and their prevention.

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**FIG 2.6** System for Real Time Monitoring and Detection of Landslide

**2.7 Landslide monitoring based on high-resolution distributed fiber optic stress sensor [7]**

A landslide monitoring application using a high-resolution distributed fiber optic stress sensor. The sensor is used to monitor the intra-stress distribution and variations in landslide bodies, and can be used for the early warning of the occurrence of the landslides. The principle of distributed fiber optic stress sensing and the intra-stress monitoring method for landslides were described in detail in this paper. By measuring the distributed polarization mode coupling in the polarization-maintaining fiber, the distributed fiber stress sensor with stress measuring range O-15Mpa, spatial resolution 10cm and measuring range O.5km, was designed. The warning system was also investigated experimentally in the field trial.

Landslide is one of the most costly catastrophic events in terms of human lives and infrastructure damage, early warning monitoring for landslides becomes more and more important. Especially, the monitoring for landslides in man-made structures, such as bridges, dams and hydraulic engineering, plays a key role in the prevention and mitigation of risks related to natural and technological hazards. In most cases the occurrence of landslides is originated by the loss in equilibrium of the soil mass due to changes in one or more parameters, such as seismic noise, ground displacements, piezo metric level and rainfall, which contribute to leaving the mass itself stable. Through continuous monitoring the correlative parameters.

The dynamics activity of the landslide can be observed. In the past twenty years, many monitoring methods were proposed, but the dominant method is displacement amount testing, such as mechanics-electronics displacement measuring, topographic surveys and GPS surveys. These traditional monitoring techniques give information about displacements only in a few numbers of points. In addition, it takes much time and money for a large number of points to measure on a continuous basis. In fact, the landslide will occur when the balance between the hill's weight and the countering resistance forces is tipped in favor of gravity. So, if the intra-stress distribution and changes of the landslide bodies can be monitored, the occurrence of landslides will be predicted accurately. With particular advantage, a distributed fiber optic stress sensor can be used to monitor the intra-stress distribution and changes in landslide bodies. According to the characteristics of the intra-stress distribution and changes detected by the distributed fiber optic stress sensor, combining with some applications of specific mathematical models, the movement the landslides can be predicted, thus the disaster can be avoided. Early warning monitoring method to predict the occurrence of landslides, using a distributed fiber stress sensor based on polarization coupling coherence to monitor the intra-stress distribution and changes. According to the requirements for the application in landslides monitoring, a distributed fiber stress sensor with stress measuring range 0-15Mpa, spatial resolution 10cm and measuring range O.5km, was designed.

**2.8 Landslide disaster monitoring by distribution sensing nodes [8]**

The construction of sensing node network is for monitoring natural landslide disaster. The sensing node consists of sensors, data processing unit and wireless communication unit. The main aims of the sensing node are to sense landslide beforehand and transmit the information to a host system. In natural field, it is obviously very difficult to distinguish landslide. This paper will propose a method which distinguishes landslide by analyzing the sensor and the use of GPS data in the system.

Network structure consists of host system, relay nodes consist of top node, and two or more local nodes. Host system is for monitoring the data collected by sensing nodes, monitoring area condition by nodes and network topology. Top node is the only node that communicates directly to the host system, transmitting data from local nodes to the host system. Hence, top node is installed at a position with the lowest possibility of slop failure and has stable communication with the host system. The prototype of sensing nodes and block diagram, respectively. It shows the installation of nodes at the monitoring area and communication route between nodes.

Recently, wireless sensor networks (WSN) become one of the emerging areas which have equipped scientists with the capability of developing real-time monitoring systems. This paper will discuss the development of sensing node network system (SNNS) in detecting landslide by implementing WSN. In this application, miniaturized sensor nodes deployed to operate autonomously in unattended environments. In addition to the ability to probe with its surrounding, each sensor installed with embedded radio modem for communication within relay nodes to host monitor either directly or over multi-hop path. In the development of SNNS, the idea of measuring mass movement is being use. Rapid and gradual inclinations of mass movement are measure using accelerated sensor and GPS installed in the nodes respectively. For optimum performance, the ease of nodes installation, using small energy consumption, capability to re-construct the system autonomously and flexibility had been consider during the development.

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| Prototype of sensing node  Sensor Unit  bit A/D &  10  8  bit D/A  Converter  CPU  Serial Port Interface  Interruput  Controller  Mbyte  4  Flash ROM  1  Mbyte  EPROM  Mbyte  32  SDRAM  128  Kbyte  SRAM  TMU  Digital I/O  Analog I/O  Node Control Board   |  | | --- | | Wireless Communication Unit |   GPS Unit |

**FIG 2.8** Block diagram of sensing node

**2.9 Monitoring system for landslide disaster by wireless sensing node network [9]**

Sensing system to monitor natural disasters faces much hard conditions. Natural disaster occurs suddenly, and damages sensor system. Then, the sensor system should be designed as distributed node network. In addition to that, the network should have some characteristic functions like self-recovery, autonomous operation and effective data transmission in urgent. This paper describes the construction of autonomous sensing node network to recover the damage by landslide disaster and to transmit urgent data effectively. The sensing node network is operated by three mode (initializing mode, measuring mode and urgent mode). By switching these operation modes autonomously, the sensing node network becomes robust system to the loss/insert of sensing node and the dynamic control of data transmission. Finally by some experiments, the effectiveness of operation is shown.

It is so difficult to predict exact the time, date and place of occurrence of natural disasters like landslide. Then, diary monitoring around the dangerous area is important. If we can get indications before the occurrence, the information is very helpful to report to inhabitants and to operate the monitoring system. To monitoring the landslide disaster, the monitoring system should have some characteristic functions. The monitoring system should transmit precision measuring data urgently to host system corresponding to the disaster occurrence. And as the occurrence place of disaster is not known exactly, it is necessary to monitor an area by using distributed sensing nodes. And the monitoring system should prevent the loss of measuring data as possible by redundant data storage with cooperation among the sensing nodes. And also, as the sensing node is easy damaged and stops the functions, the sensing node network should have self-recovery function. This paper describes the construction of sensing node network system which operate flexibly toward disappear/insert of sensing nodes and urgent data transmission. And the operation is shown by monitoring of landslide disaster.

The local network is connected to host system by long distance communication function. The sensing node has measuring function, data processing function, temporary memory function and communication function. To monitoring landslide, plural sensing nodes are distributed on a closed area. These sensing nodes are constructed tree type local network autonomously.

Node0 is a special node to communicate message (commands and measuring data) to the host system. Then the Node0 has wireless communication unit to out of network with normal wireless communication function among sensing nodes. Each sensing node measures land movement, acceleration of landslide and temperature regularly. Usually, stationary measuring data is stored temporally. And simultaneously, they are also stored by surrounding sensing nodes redundantly. The local sensing node network has three characteristic operation modes (initializing mode, measuring mode, urgent mode).

**2.10 Wireless sensor network system for landslide monitoring and warning [10]**

This paper presents a wireless sensor network system (WSNS) for effective, reliable, and efﬁcient monitoring of landslides. The system incorporates a network of wireless inertial measurement unit (IMU) sensor devices for collecting movement data, a local base station for data gathering, a capture server for data processing and storage, and a warning system. The major contributions of this paper are: 1) two approaches for deﬁning movement thresholds; 2) landslide classiﬁcation concept based on IMU sensor data patterns and magnitudes; and 3) a conceptual framework for building an intelligent and reliable wireless monitoring and warning system. The IMU sensor data collected by three-axis accelerometer and three-axis gyroscope were utilized to deﬁne the movement thresholds and classify landslides based on specially designed laboratory experiments. The performances of the IMU sensors and the base station for data collection and communication were tested through a rock-fall experiment conducted in the ﬁeld conditions. The WSN-IMU system is capable of monitoring all types of slope movements independent of the triggering factors. The unique ability of the WSN-IMU system to determine landslide types allows designers and authorized personnel to predict subsequent movement pattern and duration so as to implement appropriate risk management and control measures to alleviate the socioeconomic losses. This paper outcome serves as the foundation for future studies and technological advancements that will facilitate landslide stabilization or mitigation actions as well as to predict the intensity of damages associated with those landslides.

**CHAPTER 3**

**FIELD SURVEY MONITORING**

There are several common tools and practices to record surface displacement, monitor and characterize landslide development. However, is it possible to use only total station monitoring network to gain useful information for mass movement detection characterization? In our study, we focus on the field monitoring of the Castle Hill area (south-eastern Transdanubia, Hungary) and provide a methodology to monitor and characterize displacement processes. A 5 × 5 m resolution grid network was set up to cover active and stable parts of the hill and was surveyed 27 times between 2011 and 2016 using a total station device. The total station–based monitoring network was found suitable for the detailed monitoring of the study area at a low cost, with low maintenance, quick data processing capabilities and moderate but manageable precision. Using 3D coordinates, we differentiated the individual parts of the moving block (MB), knowing that the displacements of the MB were several orders of magnitude greater than the precision of the actual surveillance method. The main displacement component (direction) was the vertical subsidence here, which was less than 4 m on the northern MB and exceeded 4 m on the southern MB. The whole MB moved to the east; however, the southern MB moved to the east 1 m shorter distance than the northern MB. y component movements ranged between 125 and − 271 mm over the entire MB. Small-scale displacements have been detected on the stable background (BA) using normality testing of data, and displacements were identified on the field as shallow hollows (growth cracks).

Considering the measured displacements of the research area, different data processing methods were applied on the BA and on the moving block (MB). Firstly, x, y and z displacement components were calculated for each point on the MB for each campaign data using the first campaign as a zero measurement. Cumulative displacements were mapped until the end of measurement campaigns 1 and 2 according to displacement components. Secondly, empirical probability density functions (histograms) were built for relative y, x and z displacement values of each survey point separately. Interval (class) widths on histograms were also determined in respect of the precision of the survey method. The precision of the total station ranged between ± 5 mm therefore, a class width (10 cm) of an order of magnitude higher was applied to account for device imprecision. Histogram bins represent the observation number of displacements at a certain displacement range. However, the number of classes also describes the temporal pattern of movements. Survey points were cauterized based on their patterns of the histograms of their displacement components using visual interpretation to spatially and temporally separate a uniform part from the MB. Low numbers of histogram classes close to the zero value of the histogram suggest low magnitude of displacements, while the appearance of individual classes describes further movement phases. Clusters were mapped applying gradual colour tables, where light yellow colour indicates clusters with a single movement type and red colour highlight cluster was used where the numbers of displacement phases were the highest.

Well-timed warning of the population about possible landslide threat is one of the main positions in order to provide safe and stable country development. The system of monitoring over dangerous geological processes includes such components, as observation, forecast, control and management. Aspects of forecasting take special place. Having wide row of observations there can be possible to reveal some regularity of the phenomena, basing on which, it is possible to proceed forecasting. We looked through many approaches of forecasting that are used in different countries. The analysis of the available work has allowed to draw up a conclusion that while referring to the question of landslide forecasting, it is necessary to approach in system form, taking into account interacting components of the nature. The study of landslide processes has shown that these processes lies within the framework of engineering-geological directions of the science and also interacts with tectonics, geomorphology, hydrogeology, hydrology, climate change, techno genesis and etc. Thereby, the necessity of system approach, achievements of modern science and technology the most expedient approach to make a decision at landslide forecasting is probabilistic-statistical method with complex use of geological and satellite data, specific images processed through geo information systems. In this connection, probabilistic-statistical approach, reflecting natural characteristics of interacting natural system, allows to take into account multi-factored processes of landslide activations. Among the many factors, influencing on landslide activation, there exist ones that are not amenable to numerical feature. The parameters of these factors have descriptive, qualitative, rather than quantitative nature. Leaving these factors with lack of attention is absolutely not reasonable. Proposed approach has one more advantage, which allows taking into account not only numerical, but also non-numeric parameters.

**CHAPTER 4**

**EFFICIENT IOT-ENABLED LANDSLIDE MONITORING**

**4.****1 Methods using wireless sensor networks**

Wireless Sensor Networks (WSNs) are peer-to-peer adhoc networks consisting of small autonomous sensing devices (a.k.a. sensor motes) that are able to collaboratively carry out complex tasks. WSNs are a key enabling technology of IoT and their paradigm has contributed a lot in developing core IoT technologies such as IEEE802.15.4. There is rich literature on WSNs being employed in several applications such as smart buildings, forest fire detection and smart grid.

Regarding landslide monitoring with WSNs, the line of research presented in, is probably the most notable one. The authors design a column that houses several sensors for detecting landslides. In particular, the sensor suite consists of:

* Dielectric Moisture Sensors: Measuring water content of the soil.
* Pore Pressure Piezometers: Measures groundwater pore pressure.
* Strain gauges: Measures movement of soil layers attached to the
* Deep Earth Probe (DEP).
* Tilt-meter: Measuring movement of soil layers in regards to creep,
* Slow or sudden movements.
* Geophones: Measures vibrations caused during a landslide.
* Rain Gauges: Measures the effect of rainfall on a slope and therefore the ancillary effects such as pore pressure.
* Temperature Sensors: Physical properties of soil and water change with temperature, recorded every fifteen minutes.

The success of these devices was demonstrated by the early detection of a landslide in July 2009, providing validation for the authors’ design during a heavy rainfall period in India’s monsoon season. Criticisms of this system rely on the large physical form factor of the sensor columns (20 meters in length), their high energy.

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**FIG 4.1** High level architecture of the deployed IoT system for landslide monitoring

Consumption (the column relies upon a constant, wired power source which is backed by a power bank and a solar panel) and their high cost. The motes communicate via Bluetooth to a transceiver where the accelerometer sensor data can be analysed. The system is evaluated using a small scale artificial slope fitted with sensor motes. Although this presents a cost-effective means to monitor landmass, the system presented features the use of Bluetooth - which has an effective range of 30 meters in line of sight - and high battery consumption that makes the system unsuitable for real-life deployment. Most importantly, the system needs to be calibrated for each individual site by pre-defining slope condition thresholds in order to reduce false-positive and false-negative detections.

**4.2** **The landslide monitoring IOT network**

The proposal was preferred over the rest due to the reduced inferred costs, ease of use and fidelity of data it could deliver. In the following, we provide a detailed presentation of the developed system which is currently (late 2018) deployed and operating.

**4.2.1 Architecture and instrumentation**

The sensor motes developed for the needs of the system are based on the BlueFox v2.7 platform, provided by Net Sensors Ltd. The boards feature two low-power microprocessors, a SigFox modem, a 3-axis digital output accelerometer, humidity and temperature sensors. The sensing capabilities of the board were extended by means of a DS18B20 Waterproof Digital Thermometer and the Analog Capacitive Soil Moisture Sensor V1.2 by DFRobot. Finally, the motes were powered by two IFR32650H 4200mah batteries each. Since the motes were to be deployed in an outdoor environment exposed to weather conditions and other hazards (seagulls and rodents have been proven to pose great threats for any type of equipment), particular care was taken to protect the motes. They were waterproofed by the application of an acrylic conformal coating and an epoxy resin to protect the circuit boards of the capacitive sensor and they were encased in industrial graded enclosure casings. The boards needed to be firmly attached to the casings so us not to affect the accuracy of the accelerometer readings; at the same time the attachment should not be permanent for development purposes. For this purpose a customized base was 3D printed. It depicts one of the boards in its casing while depicts the device in its final form.

The devices are organized in a one-hop star topology, each one connecting individually to a SigFox antennae located within proximity. The devices are partially buried at the landslide site, with the external soil sensors buried completely underground. The devices operate on a low duty cycle, waking every 10 minutes to take and transmit sensory readings, then returning back to the deep sleep mode. With this scheme and the two 4200mAh batteries that each device is equipped with, the expectant longevity of the system is estimated at circa two years of continuous operation.

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**Fig. 4.2.1.** Various functional components and their inter-connectivity.

**4.2.2 SIGFOX packet structure**

The SigFox packet structure allows for a maximum of 12 bytes, containing the data required to perform the analysis. The majority of the payload is allocated to the built-in accelerometer alongside the external temperature and soil moisture probes. Two bytes are reserved for the battery level and software version. The network allows for 140 messages per day to be delivered, although this is subject to the subscription model - alongside payload size - available to the users.

**4.2.3** **Node-RED**

Node-RED is a flow based development tool developed by IBM for connecting hardware devices and APIs towards the IoT paradigm [28]. It is implemented in JavaScript utilizing the Node.js framework, establishing a data-flow driven design tool that consists of JSON (Javascript Object Notation) data generated internally and externally from the application. NodeRED was employed to provide a means of establishing a modular framework for future extensions, and providing the means to export the data with ease towards the Elastic Stack.

**4.2.4** **MQTT server and client**

Message Queuing Telemetry Transport (MQTT) is a lightweight publish and subscribe protocol for IoT and resource-constrained devices. MQTT was chosen in similar regards to providing a modular system design, by publishing topics, such as landslide data, and subscribing to these so that they may be logged and sorted within the Elastic Stack. The MQTT client is featured as part of a Python script, which specifies which topics to subscribe to, and converts the timestamp and JSON packet into a searchable variable within Kibana.

**4.2.5** **Elastic stack**

The Elastic Stack or ELK stack is the terminology to define three open source projects, namely ElasticSearch, Logstash and Kibana. ElasticSearch - which is based off of Apache’s Lucene Project - is a distributed, RESTFUL search and analytical engine as JSON over HTTP, and excels at indexing large amounts of text. Logstash manages events and logs, collecting them and parsing them for storage and later usage with the two complimentary technologies. Kibana is data visualization and exploration tool that acts as a dashboard for the stack. ELK has a low requirement for usability, making log analysis an almost trivial process evidenced by installing their own data-sets.

The open source, distributed, RESTful, JSON-based search engine. Easy to use, scalable and flexible, it earned hyper-popularity among users and a company formed around it, you know, for search. A search engine at heart, users started using Elasticsearch for logs and wanted to easily ingest and visualize them. Enter Logstash, the powerful ingest pipeline, and Kibana, the flexible visualization tool. Whether it was to find the top N results in a jungle of text-based documents, analyze security events, or freely slice and dice metrics, the worldwide community kept pushing boundaries with ELK.

**CHAPTER 5**

**CONCLUSION AND FUTURE SCOPE**

In this work we presented an innovative landslide monitoring system that leverages state-of-the-art IoT technologies. The system is highly reliable and scalable while its deployment and operation introduces significantly reduced costs when compared to existing alternatives.

Field observations of groundwater which may induce slope failures and landslides were conducted at mountain slopes from the1960s, and various physical models were developed at around the same time. After the 1980s, measurement techniques were developed that can acquire the data of pore water pressure fluctuations during not a snow cover period but an earthquake. With the evolution of investigation technologies, the flow processes of groundwater in slopes can now be visualized. In addition, large-scale analyses using a distributed model are possible to simulate the change in spatial distribution and flow of groundwater before and after the construction of landslide control works like drainage boring, well and tunnel.

In future, observed data should be classified into types and made available as open data sets. It is necessary to improve investigation technologies to clarify the hydro-geological structure and three-dimensional groundwater flow analysis in fissured and weathered slopes. A fluidized moving body, whether generated by a slope failure, deep-seated landslide or reactivated landslide, flows down over long distances and spreads widely, causing severe damage in the lower catchment. Therefore, studies on the interaction between displacement and deformation of landslides and pore-water pressure should be conducted by indoor or outdoor experiments and numerical simulations. In addition, groundwater hydrology and hydraulics in landslide areas should be established as a new research field based on the knowledge gained from previous studies. This work nicely demonstrates the profound impact of IoT not only in terms of reducing the costs of existing services but also in terms of enabling new innovative ones.

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