Landslide Monitoring System Using an IoT Wireless Sensor Network

Gian Quoc Anh, Tran Binh Duong, Vijender Kumar Solanki, and Duc-Tan Tran

1 Introduction

Landslides are a slow or fast motion of a large landmass and rocks down a hill or ridge. Little or no flow occurs over a particular slope until heavy rain, resulting in rainwater facilitating the movement causing landslides. Landslides are significant threats to people, seriously affecting infrastructure, property, and people's lives. According to a summary of the SafeLand (http://www.safeland-fp7.eu), Europe is the region with the second-highest number of deaths and the highest economic loss from landslides compared to other continents in the twentieth century with a statistic of 16,000 people, deaths from landslides and physical damage amounted to more than $1.7 billion. The findings were made using factors related to landslides, estimating a landslide's likelihood, thereby establishing a relationship between the factors involved, and the landslide can predict future landslide risk and give the most sensible warning.

Some constructive solutions warn systems such as landslide warning information based on rainfall, based on slope displacement monitoring, and analysis model permeability. However, based on observation and statistics, the warning threshold

G. Q. Anh
Nam Dinh University of Technology Education, Nam Dinh, Vietnam

VNU – University of Engineering and Technology, Hanoi, Vietnam

T. B. Duong
Vietnam Paper Corporation, Hoan Kiem, Hanoi, Vietnam

V. K. Solanki
Department of Computer Science & Engineering, CMR Institute of Technology, Hyderabad, TS, India

D.-T. Tran (✉)
Faculty of Electrical and Electronic Engineering, Phenikaa University, Hanoi, Vietnam
e-mail: tan.tranduc@phenikaa-uni.edu.vn

V. K. Gunjan et al. (eds.), *Modern Approaches in IoT and Machine Learning for Cyber Security*, Internet of Things, https://doi.org/10.1007/978-3-031-09955-7_13

shows the limits of the influencing factors that are likely to occur landslides [51]. Therefore, the method is based on rain information using real-time data monitoring at rain gauging stations [9, 34, 38, 40, 41, 46, 48]. This system's advantage is simple, but elements of topography, geology, cover, drainage that reflect pore-water pressures of specificity are ignored, leading to low accurate warnings.

Many devices and techniques have been applied to monitor slope displacement, including geotechnical sensors and remote sensing technology [13]. The method of monitoring the slope's displacement is limited; the tension sensor cannot track the displacement inside the ground at different depths. Inclinometers are often used to overcome this obstacle. The inclinometer is usually connected in series and placed in boreholes at different depths. Tilt measurement data are converted to displacement distance.

GPS and radar technologies are also applied to monitor shifts over large areas [4, 23]. Ground radars are installed in a safe location to track and digitally map the slope. This method can calculate the actual surface displacement with an accuracy of millimeters. However, this technology does not allow monitoring of underground displacement under the slope surface.

Studies have shown displacement and acceleration; at the same time, the slope's foot shows an 80–90% water saturation ratio before a landslide occurs. Integrated systems of monitoring data and physical or numerical modeling are evaluated as effective systems for the early prediction of landslides. In this case, the sensor network monitors the factors causing the slide built. Several successful integrated models have been published, such as the seepage model [12, 15, 26], the slope equilibrium model [54], and the slip transmission model [39, 60].

In 2005, Towhata's team proposed a soil slip warning system based on soil slip identification, including a moisture meter [56]. Data from the measuring equipment are sent to the central station for processing and alarming if necessary. However, the use of an inclinometer is energy inefficient. To overcome this obstacle, it is possible to use a three-dimensional accelerometer module based on micro electro-mechanical system (MEMS) technology to measure the accurate angle of inclination while a compact, more efficient configuration. In addition, in this system, the processing of alarm information is not automated yet.

In 2006, Terzis et al. announced to build a warning using wireless sensor networks [53]. In this system, sophisticated sensor boxes can detect small soil deformation, and sensor position information is fed into the finite element model. The system cost is too high to be implemented in practice.

In 2010, Huggel Christian's team initially integrated the finite element method into the warning model and conducted experiments in Colombia [30]. However, the finite element method's disadvantage is that the volume of computation is huge; it is challenging to implement in practice on a large scale. The article goes into depth analysis of landslide monitoring system using a wireless sensor network from the above research.

In this chapter, Sect. 2 discusses landslide events and Sect. 3 presents Wireless sensor network (WSN) Technologies. Section 4 introduces the landslide mapped to sensors. Section 5 reviews related work and shows the research issues and challenges, whereas Sect. 6 concludes the conclusion.

2 Landslide Events

Landslide refers to the geological phenomenon in which the rock and soil on the slope slide down the slope in a whole or scattered manner along a specific weak surface or weak zone under the action of gravity. Landslides mostly occur on slopes with a slope of less than 50. According to the composition, landslides' stratum lithology characteristics are divided into soil landslides and rock landslides. According to the landslides' structural features and the sliding surface's relative positions, and the rock (soil) layer, soil landslides can be divided into homogeneous landslides and bedding landslides. According to the landslide's structural characteristics and the sliding surface's exposed position, rock landslides can be divided into landslides on the slope, landslides at the foot of the slope, and landslides at the bottom of the slope. Landslide formation conditions and predisposing factors are divided into the following.

2.1 Landslide Formation Conditions

1. Topography. The formation conditions of landslides can only occur on slopes with a particular slope in a specific landform. The terrain and landforms prone to landslides can be summarized into three categories: rivers, lakes (reservoirs), and seas, which are eroded by flowing water. Bank slope; artificial side slope for railway, highway, and engineering buildings; the upper and lower slopes are steep, and the middle part is gentle, and the upper part is a belt-shaped slope.
2. Formation lithology conditions. Rock and soil are the material basis for landslides. Generally, all kinds of rocks and soils may constitute landslides, in which the structure is soft, the shear strength and weathering resistance are low, and they are affected by water. Rocks and soils prone to change in nature, such as loose overburden, shale, mudstone, coal-measure strata, schist, slate, phyllite, tuff, and other soft and hard rock layers, are prone to landslides.
3. Geological structural conditions. The slope rock and soil can only slide down when they are cut and separated into discontinuous states by various structural surfaces. At the same time, the structural surfaces provide channels for rainfall to enter the slope. Therefore, multiple joints, fractures, bedding planes, lithological interfaces, and slopes with developed faults, especially when the steeply inclined structural surfaces of parallel and vertical slopes and the gently inclined structural surfaces develop, are most prone to landslides.
4. Hydrogeological conditions. Groundwater activities play an essential role in the formation of landslides, which are mainly manifested in softening of rock and soil, reducing the shear strength of rock and soil, especially the softening effect and reducing the strength of the sliding (belt) protruding; generating or increasing hydrodynamic pressure and pore water pressure, eroding rock and soil, increasing rock and soil bulk density, causing floating force on permeable rocks, etc. Below is a brief description of some of the more common types of landslides.

2.2 Swivel Slides

Swivel slides are the most common type of skidding, occurring mostly along pavement walls with a gradient of over 60 degrees, a few milled on steep slopes above 35 degrees, and occurring in the weathered rock portion of all walls create geology. Slides have a rather diverse morphology, but the most common is the arc shape, the inverted funnel shape, and the trapezoidal shape. The slip surface is mainly a convex surface developed according to the weathering layers.

Rotation sliding mainly occurs according to the sliding-slip mechanism, sliding from outside to inside to decrease the slope's slope angle or sidewall. Slip material in the form of soil, clay powder, weathered rock chips. Swivel mainly occurs during or immediately after heavy rains.

2.3 Translational Slide

A translational slide occurs along the road's slope, where the rock is intensely layered and in the same direction as the terrain slope. Simultaneously, the fracture systems are perpendicular to or near perpendicular to each other, resulting in almost separated rock blocks.

2.4 Streamflow or Slip Flow

Streamflow or slip flow occurs in areas where tectonic destruction exists—characterized by discrete, weakly bonded materials that only maintain equilibrium on the slopes. On the slopes with high slopes or slippage, landslides can happen at any time under the impact of factors such as rain and vibration. The material mass moves very quickly and has great destructive power.

2.5 Mixed Slip

In some areas with relatively thick weathered crust covered on the rock with the cracked structure under the developed ground, it will form an intermediate slide between translational and rotating shear. The sliding wall has a high slope; when moving downward, the sliding block controlled by the intermediate sliding surfaces suddenly changes the slope angle. Then, the sliding body will move almost flat to the bottom.

3 WSN Technologies

WSN is a network of devices called sensor nodes distributed in space and collaborating to exchange the information obtained from the surveillance environment over a wireless connection. Data obtained from the sensor networks are sent wirelessly to a central station (also called a sink node) in accordance with a predetermined protocol over a single-hop or multi-hop link for internal use or to connect to other networks for remote access through the gateway [50]. Sensor network (SN) and the central station's connection is bidirectional for data exchange, and SN operation can be reestablished. WSN combines devices to collect (monitor), exchange, and process information, thereby making results and meaningful decisions corresponding to the monitoring environment's phenomena and events. WSN is designed to be application-oriented, with solutions tailored to a specific application. WSN includes three main types: event detection, query-based monitoring, and continuous monitoring and tracking [17]. WSN is often connected to other networks such as the Internet and telephones to expand operational capabilities and exchange information.

WSN is widely used in industry, agriculture, smart home, mining, medical, military, etc. due to remote monitoring's advantages, a large number of sensor nodes, low cost, and easy deployment. Specifically, WSN has been successfully applied in food and agriculture monitoring [61], flash flood warning [14], soil moisture monitoring [32], civil structure monitoring [16], underground monitoring structure [36], and underground coal mine monitoring [37].

WSN has desirable features such as small SN size, low energy consumption, flexible large-scale deployment, and scalability. In addition, WSN is limited by low bandwidth, short transmission distance (for PAN technology), and low ability to process data and store information at nodes. Another critical issue is that SNs are often deployed in hazardous, inaccessible environments, while battery power is used to power all SN operations.

Some WSN applications in landslide studies have been made, specifically detect landslides [49], predicting landslides [52], early warning systems landslide [5, 31]. The SN is designed to operate continuously for months or even years without replacing the battery in the ground slip warning system. Due to technological advances, research and application of WSNs for ground slip early warning systems are still ongoing. WSN is recommended for precipitation landslide warning and monitoring systems. With the advantage of its collection flexibility, its real-time data transmission has been proven in environmental monitoring applications [8, 19, 50].

The monitoring and warning system of landslides caused by rain enables the sensors in the sensor nodes to measure ground slip parameters (such as pore water pressure, inclination, and vibration) and transmit data received and get to the central station via wireless links. The environmental parameters are measured at the sensor nodes and then sent to the central station via the wireless link. The central station provides data to users connecting to the Internet through a gateway. The data are then passed to a data server connected to the Internet or other networks through a gateway [1, 11, 20, 21, 25, 33, 43, 45, 57, 59].

4 Landslide Mapped to Sensors

The early warning system's design and successful implementation for landslides caused by rain are highly dependent on the sensors and networks used. A large amount of monitoring data is collected, processed, and transmitted by sensors and networks [40]. Therefore, it is necessary to determine the correct type of sensor, the number and position of the monitoring point, and the monitored parameter sampling rate [10].

For the landslide warning system, the sensor selection depends on the slide trigger parameter. One type of sensor cannot provide enough information to predict a slide, so it is necessary to combine different sensors to collect information. Observed information includes environmental/weather conditions affecting slides and displacement to varying positions on the slope and slope parameters. The parameter is monitored according to (i) rainfall, groundwater level, humidity, and pore-water pressure in sliding mass at different depths are indirect parameters; (ii) the amplitude, speed, and direction of landslide displacement of the slope are direct parameters. For landslides due to rain, catastrophes are mainly influenced by groundwater conditions, rainfall intensity, and soil properties of the slope [47]. Water seeps into the slope during rain, increases pore water pressure, and reduces shear resistance, reducing Factor of Safety (FoS) [7]. Therefore, pore water pressure sensors and soil moisture sensors are used to collect and monitor the slope's soil properties, determining the unstable state. The acceleration sensor monitors slope surface motion.

Sensors placed close to the surface and buried under a slope are selected based on accuracy, response time, energy consumption, and long-term use. A wireless data transmission protocol connects sensor nodes.

The wireless sensor network uses sensors that have direct contact to collect information. Figure 1 illustrates the diagram of a WSN assembled at a field site, and Fig. 2 presents a photo of a sensor node.

Deformation Measurement

There are many ways to track deformation and measure deformation in geotechnical applications, vibratory wire gage, resistance type measuring device, and fiber optic sensors. A robust, durable technology commonly used for geotechnical applications is vibrating wire strain gauges.

The vibrating wire strain gage works on the following principle: a tension wire, when pulled, vibrates at a frequency proportional to the wire's strain. The resonant frequency of the wire is the basis for determining the strain frequency. The resonance frequency (f) and tension force (T) depend on length (L), cross-sectional area

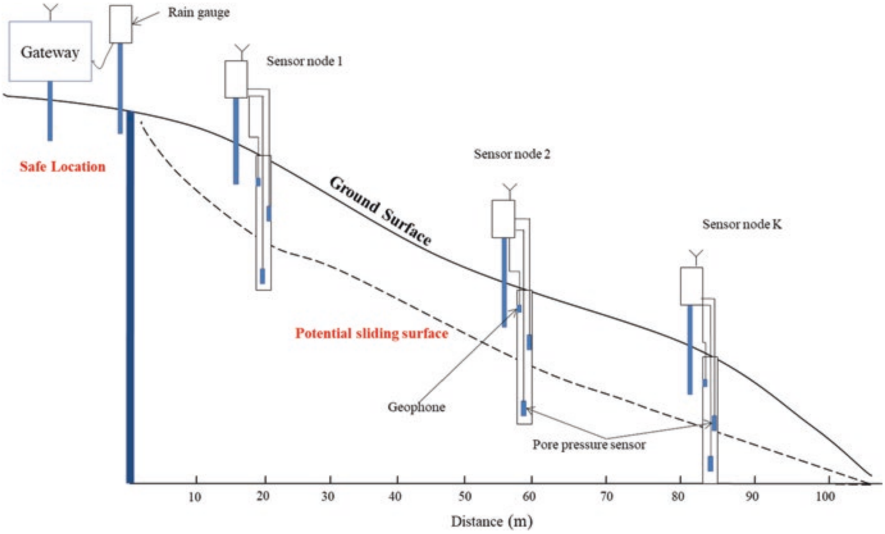
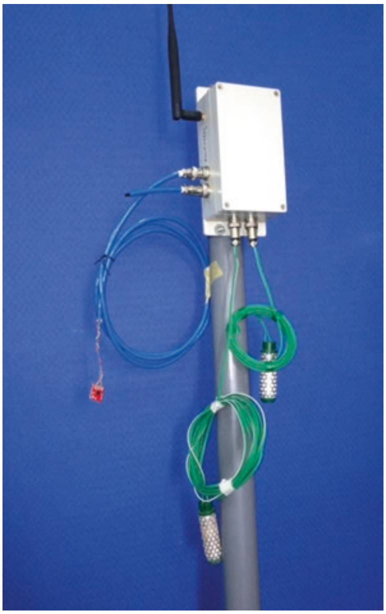


Fig. 1 WSN is deployed in the field site

Fig. 2 A photo of a sensor node



(A), and wire material density (ρ), which are related and expressed by the following formula:

$$f = \frac{1}{2L}\sqrt{\frac{T}{\rho A}} \tag{1}$$

The strain can be calculated using the following formula:

$$\varepsilon = GF\left(f^2 - f_0^2\right) \tag{2}$$

where ε is the strain, G and F are the coefficients depending on the material properties, length, and tension.

Resistance strain gage works on the dependence of conductivity on the shape of conductors under strain.

Inclination Measurement

Tilt measurement is the measure of the angle deviation from the vertical gravity vector. In geotechnics, tilt is one of the versatile measurements due to calculating deviation or displacement. In fact, there are many types of inclinometers that are classified based on the measuring mechanism, such as electrolytic inclinometer, accelerometer, and vibrating wire.

Electrolytic tilt sensors include a conductive liquid glass vial, and a wheatstone circuit type is applied to connect three electrodes. As the device tilts, bubbles in the vial move, increasing the resistance between the two electrode pairs and decreasing the opposite electrode pair's resistance. A constant voltage is supplied to the sensor, and tilt is correlative to the voltage change.

Tilt is measured by accelerometer type inclinometer using a force-balance servo. Anatomy of the device includes a block of steel pendulum hanging on a hollow precisely detector, while pairs of moment coils surround the pendulum. As the device tilts, the pendulum moves and the hollow detector activates the feedback control circuit to excite the torque coils to push the mass back to zero. The current flowing through the coil, which exerts the magnetic field to push the pendulum back to zero, is adjusted by the servo amplifier. The power required to push the pendulum to a hollow position is adjusted for inclination.

Vibrating wire inclinometer includes a mass of pendulum that moves under the effect of gravity. Attached to the pendulum is a vibrating wire strain gage. Mass fluctuations can alter the tension in the strain gage.

Tilt sensors are based on MEMS technology in which the sensor is packaged in a semiconductor base together with a signal-processing circuit. MEMS-based sensor size components are approximately 1–100 microns, with sensors typically less than a millimeter in size. Tilt is usually measured based on gravity's effect on a small mass suspended in an elastic support structure. As the device tilting, mass moves, causing the capacitance changes between it and the supporting structure. The angle of inclination is calculated from the measured capacitance. MEMS is low cost and impact resistant and has good frequency response and low power requirement, so it is becoming more and more popular in many applications related to inclination and acceleration monitoring. The need for constant monitoring of strain events leads to the need for high-performance and low-cost measurement systems for on-site installation. The use of MEMS technology is a viable solution.

Vibration Measurement
Stress reduction is effectively partly due to vibration that increases the pore water pressure in the ground. Granular soils lose stiffness when the effective stress is close to zero (total stress deduct pore water pressure). The hardness of granular soils is directly related to the effective stress of the surrounding environment.

The geophones and accelerometers are often used to monitor vibrations. Typically, the geophones, the device that converts ground-to-voltage displacement speed, are used to analyze the displacement speed of landslides, as in Ramesh's study, Maneesha Vinodini [40]. A geophone is the motion sensor of choice because it does not need a power source to operate and detect extremely small ground displacements. Vibrate wire strain gages are also commonly used for measuring strain. The vibrating wire device's principle is based on the relationship between the vibration frequency and the string tension. The two ends of the wire are attached to the structure under supervision. When there is a change, displacing the distance between these two points will result in a change in the string tension, resulting in a change in the vibration frequency. A magnetic core, surrounded by an electrical coil, is placed in the device. The casing and magnetic core are tied together and move together, while springs are used to attach the coil. When the ground shakes, the cabinet moves but the coil tends to stand still. Movement of the magnet in the coil creates an electric current that corrected follow speed of oscillation.

To measure and record, the accelerometer was used. The most popular application in geotechnical is an accelerometer of piezoelectric type. The instantaneous charge is generated by piezoelectric quartz when under load or pressure. Signals dissipate rapidly over time, even when load or pressure is maintained. An accelerometer comprises a piezoelectric crystal that supports a vibrating mass. A spring and a damping device are used to adjust the properties of the accelerometer. The accelerometer can only monitor accelerations at lower frequencies than its natural frequency; this is an important characteristic. The natural frequency is common in the 5000–20,000 Hz range. Hence, the accelerometer is more flexible than the geophone and is often used to measure velocity by integrating acceleration time records. In recent years, accelerometers based on MEMS technology have been developed and applied.

5 Research Issues and Challenges

In recent years, many authors have applied WSN in the monitoring and early warning system of landslides because of its outstanding advantages [24].

System Constraints Need Design Continuous operation time should last at least one rainy season. The sensor button is deployed at a fixed position on the track slope and is not continuously accessible. The communication range is around several hundred meters. The system is designed on the assumption that the sensor button is provided by limited battery power, which must be active for a long time. Calculation speed and memory capacity at the sensor node are limited. Therefore, the algorithm deployed at the sensor node must have low computational volume. Sensors are pre-grouped according to geospatial, and the center cluster is pre-selected based on position and distance to the central station. The center cluster is supplemented with energy from the solar energy source.

Installation and commissioning are factors to consider when designing a monitoring system. If the system is complex, requiring technicians to have high installation and operation techniques will increase the system's investment and operating costs. The system works in a harsh, risky environment, so the network's lifetime must be large enough to reduce human intervention. Many solutions have been implemented to optimize the sensor node's energy, such as optimizing the hardware design and choosing to use MEMS sensors. Adopting an adaptive network configuration ensures system reliability even when some sensor nodes are not working correctly. Remote, automatic algorithm updates are also one of the requirements for WSN.

Typically, WSN is deployed in harsh environments in energy constraints, computational capabilities, sensor node storage, communication range, and bandwidth. On the other hand, many influencing factors in the analysis and prediction of landslides are nonlinear, with changes over time. There is no clear boundary on the threshold, so deciding based on the hard threshold can lead to inappropriate warnings. Furthermore, the quality of information obtained from the sensor is usually not high due to sensor limitations and operating conditions. Therefore, it requires algorithms to adapt to each factor. The adaptive algorithm is applied to optimize the system's resource and energy efficiency while enhancing system flexibility.

One of the Bottlenecks of WSN Application Is the Energy Limitation It affects system design decisions such as sampling frequency and type of sensor to be used. Battery power, with limited energy, is often used to power all SN operations. Depending on the deployment environment, the battery supplied to the SN can be replaced or recharged. When deployed in harsh or dangerous environments, battery power replacement is not always possible.

Many solutions have been proposed, such as harnessing energy from the surrounding environment (solar energy, wind, oscillation, sound, heat, etc., converted into electrical energy for direct use or storage) [2]. However, the solution in a specific project is not always feasible. For example, they are harnessing solar energy during the rainy season or where the mountainous terrain, the slope direction is not suitable, while this time SN uses the most energy. In addition, this energy source is not stable depending on the time of day and the season.

Recently, wireless charging technology has also been studied to apply to WSN [3, 18, 42, 47, 58]. It is a potential technology because the energy is transmitted without contact between the transmitting and receiving equipment with many advantages of water resistance and the device's dust resistance due to no direct connection [18]. However, there are still many obstacles to implementing this technology due to technical factors such as topographical conditions, distance, and transmission efficiency [3].

Many scientists use the research direction to optimize SN's energy consumption to prolong the operating time of SN [62]. Energy consumed at the sensor node is due to three parts: sensor, processing, and communication. The energy-saving solution at SN can focus on three parts: (i) data collection (adaptive sampling, reduced data collection, sensor hierarchy in which the sensor has high energy consumption. Works only under defined conditions); (ii) data processing (compressing data by encoding data at SN and decoding at the central station, predicting data based on time and space correlation, the central station only sends data if any differences between obtained data and predicted data, group data processing); and (iii) data transmission over the network (grouping, network protocol, network coding, etc.) [6, 28]. In particular, communication is generally assumed to have much greater energy consumption than processing energy. The wireless transmission takes a large amount of power; the transmission energy is proportional to the transmission distance's square. The power to transmit one bit is equivalent to the energy to execute several thousand instructions [48]. Communication operation mode consists of receiving data, transmitting data, and idle state with the same power consumption.

Meanwhile, in sleep mode, energy consumption is reduced. Therefore, the transmitter should be turned off when possible [6]. The SN returns to operating mode only when there is a request to transmit information from another SN or is scheduled to work (the SN is programmed to return to the operating mode at the same time). One solution is used to let the sleeping SN know when another SN is required to use different communication frequencies for data (high speed, energy-consuming) and signal (low speed, less energy saving) [6]. Solutions are given at SN to solve energy problems such as design optimization and adaptive sampling in Nguyen et al. [44]; compressing and arranging data based on the time and spatial correlation of the data obtained at SN in Liao et al. [38]; using low-power communication standard, optimizing network configuration, and dividing the operation process of SN into states in Nguyen et al. [44]. There are many solutions to reduce energy consumption and extend the lifetime of WSN, including data compression [35]; combine data in central clusters; low architectural SN design; optimal routing configuration [27, 34]; vary the sampling rate and the rest (duty cycle) in which the system switches between the active and idle states [27]. The sensor consumes a large amount of energy to collect data, the sensor's choice must be considered. Sensors manufactured using MEMS technology are preferred due to their very low power consumption. A solution to change the sampling frequency is also used. Sensors are also stratified, in which sensors with a large power consumption only operate when the SN detects a specific event [22]. In addition to the grouping solution, SN also needs to set up an appropriate sampling algorithm and schedule to limit energy consumption. Different solutions can be combined to extend network lifetime. The solutions are a trade-off between SN lifetime and application requirements, including processing capacity, speed, and data transmission.

Processing data at the sensor node or in the central cluster helps reduce data transmission energy while also reducing congestion in the network as the number of sensor nodes in the network increases. A popularly applied direction is to use technology and techniques to optimize the sensor node's operation and reduce the amount of data transmitted. The principles that have been applied and presented in the document include data compression and duty circle.

WSN Customization and Reliability Issues WSN is typically deployed in a variable environment. Button positions can be predictable or random, fixed, or mobile. The SN quantity is customizable and extensible. SN has limited energy, computing power, storage capacity, and communication bandwidth. The WSN must also satisfy the SN's scalability, independent operability condition if another SN goes wrong. Therefore, the design should consider common issues such as data arrangement, positioning, node grouping, routing, scheduling, anomaly detection, and error. For optimal routing, the SN needs to know the location. The solution used can either use GPS to determine the absolute position or estimate the reference position by calculating the reference point's propagation time.

Data Processing Problem (Congestion Reduction) in WSN Network WSN includes many SNs and tends to increase, data are collected in large quantities, and operation time is extended. Information needs to be processed before transmission to reduce congestion. The purpose of data processing at the source is to reduce the amount of SN data to be transmitted. Data processing is essential in reducing latency, reducing congestion, reducing transmission power, and increasing SNs in the network. The basis for data processing is based on the characteristic that the data obtained at MEMS sensors are not very accurate compared to large measuring equipment. On the other hand, the time and spatial correlation data between the SNs are arranged close together.

The distribution processing model at SN is studied to solve the problem of data processing in WSN networks. Distributed data processing at SN is used very limitedly with simple decisions. The reason is due to SN limitations in processing speed, memory capacity, and power. Furthermore, the node's data processing does not promote data correlation between the SNs, which is the WSN network's strength. The time correlation between data obtained in the past cannot be exploited due to memory capacity limitations. The implementation algorithm must have low complexity consistent with the limited capabilities of SN [32, 55]. Decision accuracy is limited only by the computational power of SN. The advantage of distributed processing is exploiting the computing power of SN, reducing the amount of data to be transmitted in the network.

The centralized data processing model at the central station or central cluster is also deployed. A commonly used solution is to divide the SN group according to the spatial deployment relationship or measurement data object correlation. Within each group, there is a central cluster. The center cluster can be fixed or alternately selected according to different criteria, for example, based on the remaining energy at each SN. The SNs send the data to the central cluster. In the central cluster, the data is processed by discarding redundant data, sorting it, and sending it to the central station. Because the SN's data accuracy is not high, they need to be synthesized at the central cluster to find the data's correlation to make a general decision. Assuming that the energy, computation, and memory resources at the central cluster are higher than that of SN, this model supports a more complex and powerful algorithm than performing distributed computation at SN.

On the other hand, due to obtaining information from many SNs, the model of environmental information exploitation is more extensive. Data mining and development trends in the spatial and time scale are predicted [59]. The grouping also reduces energy because the SN does not have to transmit/receive data directly with the central station but through the central cluster and acts as a routing function. Furthermore, transmitting data directly to the central station will require large bandwidth and energy consumption at SN. Concentrating data to the central cluster and sorting and pre-processing will reduce the communication bandwidth between the central cluster and the central station while reducing SN's energy consumption.

Data prediction solution. SN predicts received data to reduce the amount of data to be transmitted. In the case the obtained data are different from the predicted data, the newly acquired data are sent. The predictive method is based on data series measured in the past or on the correlation of data obtained at SN close together.

Synchronization Issue in WSN Synchronization in the WSN network is necessary to ensure smooth coordination between nodes, the relationship of the information obtained at the nodes over time is shown [9]. For example, to save energy, each button can put itself in sleep mode (sleep mode or idle mode) but must switch to active mode at the right time so as not to miss information. The center station has to know when each node has acquired information to coordinate communication between these nodes. The synchronous solution must take into account the limited energy problem of the WSN. Solve the problem of density and the increasing number of nodes in the network. Accuracy depends on the application. The solution must also ensure reliability in the event of some node failure.

Anomaly Detection Network security is also a significant problem with WSN. Due to wireless transmission, various types of data retrieval and hijacking attacks have been performed. Many proposed solutions are proposed, such as data encryption and decoding, anomaly detection algorithms. However, this solution also contributes to greater computation volume for SN.

Quality of Service (QoS)

- Ability of extension.
- Energy usage is limited by battery sources.
- Resources in SN are limited: processing speed, memory capacity, battery power.
- Ability to operate when buttons do not work properly.
- Scope of supervision.

Positioning Problem in WSN Positioning in WSN to determine the position of SN, from there can detect wrong SN location, where abnormality happens, etc.

For the application using WSN, the above-mentioned problems should be considered. However, for a particular application, some issues are considered acceptable, while others need evaluation.

6 Conclusion

This chapter presents systems for monitoring and early warning of landslides due to rain applied on a slope scale using wireless sensor networks. We discuss the slope surface monitoring solutions using accelerometers, pore pressure sensors, rain gage, soil parameters, rain information, etc. Next, wireless sensor networks are proposed for use in surveillance and alarm systems due to the advantages of deployment capacity, flexibility, low energy consumption, etc. Besides, challenges and constraints when applying wireless sensor networks in landslide monitoring systems.

References

1. S. Ahmed, S. Gupta, A. Suri, S. Sharma, Adaptive energy efficient fuzzy: An adaptive and energy efficient fuzzy clustering algorithm for wireless sensor network-based landslide detection system. IET Network **10**(1), 1–12 (2021)
2. G. Anastasi, M. Conti, M. Di Francesco, A. Passarella, Energy conservation in wireless sensor networks: A survey. Ad Hoc Netw. **7**, 537–568 (2009)
3. M.-G. Angeli, A. Pasuto, S. Silvano, A critical review of landslide monitoring experiences. Eng. Geol. **55**, 133–147 (2000)
4. G. Antonello, N. Casagli, P. Farina, D. Leva, G. Nico, A. Sieber, et al., Ground-based SAR interferometry for monitoring mass movements. Landslides **1**, 21–28 (2004)
5. C. Arnhardt, K. Asch, R. Azzam, R. Bill, T. Fernandez-Steeger, S. Homfeld, et al., Sensor based landslide early warning system-SLEWS. Development of a geoservice infrastructure as basis for early warning systems for landslides by integration of real-time sensors. Geotechnologien Sci. Rep. **10**, 75–88 (2007)
6. S. Asano, H. Ochiai, H.D. Vinh, TXT-tool 4.081-8.1: landslide monitoring for early warning in the Hai Van Station landslide in Vietnam, in *Landslide Dynamics: ISDR-ICL Landslide Interactive Teaching Tools*, (Springer, 2018), pp. 785–792
7. M. Barla, F. Antolini, An integrated methodology for landslides' early warning systems. Landslides **13**, 215–228 (2015)
8. P. Baronti, P. Pillai, V.W. Chook, S. Chessa, A. Gotta, Y.F. Hu, Wireless sensor networks: A survey on the state of the art and the 802.15. 4 and ZigBee standards. Comput. Commun. **30**, 1655–1695 (2007)
9. R.L. Baum, J.W. Godt, Early warning of rainfall-induced shallow landslides and debris flows in the USA. Landslides **7**, 259–272 (2010)
10. M. Berti, M. Martina, S. Franceschini, S. Pignone, A. Simoni, M. Pizziolo, Probabilistic rainfall thresholds for landslide occurrence using a Bayesian approach. J. Geophys. Res. Earth Surf. **117** (2012)

11. C. Buratti, A. Conti, D. Dardari, R. Verdone, An overview on wireless sensor networks technology and evolution. Sensors **9**, 6869–6896 (2009)
12. G. Capparelli, P. Versace, FLaIR and SUSHI: Two mathematical models for early warning of landslides induced by rainfall. Landslides **8**, 67–79 (2010)
13. N. Casagli, S. Morelli, W. Frodella, E. Intrieri, V. Tofani, TXT-tool 2.039-3.2 ground-based remote sensing techniques for landslides mapping, monitoring and early warning, in *Landslide Dynamics: ISDR-ICL Landslide Interactive Teaching Tools*, (Springer, 2018), pp. 255–274
14. M. Castillo-Effer, D.H. Quintela, W. Moreno, R. Jordan, W. Westhoff, Wireless sensor networks for flash-flood alerting, in *Devices, Circuits and Systems*, (Proceedings of the Fifth IEEE International Caracas Conference on, 2004, 2004), pp. 142–146
15. B.-G. Chae, M.-I. Kim, Suggestion of a method for landslide early warning using the change in the volumetric water content gradient due to rainfall infiltration. Environ. Earth Sci. **66**, 1973–1986 (2011)
16. K. Chintalapudi, T. Fu, J. Paek, N. Kothari, S. Rangwala, J. Caffrey, et al., Monitoring civil structures with a wireless sensor network. IEEE Internet Comput. **10**, 26–34 (2006)
17. G.M. Dias, B. Bellalta, S. Oechsner, A survey about prediction-based data reduction in wireless sensor networks. ACM Comput. Surv. (CSUR) **49**, 58 (2016)
18. M.J. Dong, K.G. Yung, W.J. Kaiser, *Low Power Signal Processing Architectures for Network Microsensors* (Proceedings of the 1997 International Symposium on Low Power Electronics and Design, 1997), pp. 173–177
19. C. Fosalau, C. Zet, D. Petrisor, Implementation of a Landslide Monitoring System as a Wireless Sensor Network, in *Ubiquitous Computing, Electronics & Mobile Communication Conference (UEMCON)*, (IEEE Annual, 2016), pp. 1–6
20. A. Gian Quoc, C. Nguyen Dinh, N. Tran Duc, T. Tran Duc, S. Kumbesan, Wireless technology for monitoring site-specific landslide in Vietnam. Int. J. Electr. Comput. Eng. **8**(6), 4448–4455 (2018)
21. Q.A. Gian, D.C. Nguyen, D.N. Tran, D.T. Tran, Monitoring of landslides in mountainous regions based on FEM modelling and rain gauge measurements. Int. J. Electric. Comput. Eng. **6**(5), 2106 (2016)
22. Q.A. Gian, D.T. Tran, D.C. Nguyen, V.H. Nhu, D. Tien Bui, Design and implementation of site-specific rainfall-induced landslide early warning and monitoring system: A case study at Nam Dan landslide (Vietnam). Geomatic. Nat. Hazards Risk **8**(2), 1978–1996 (2017)
23. J.A. Gili, J. Corominas, J. Rius, Using global positioning system techniques in landslide monitoring. Eng. Geol. **55**, 167–192 (2000)
24. P. Giri, K. Ng, W. Phillips, *Wireless Sensor Network System for Landslide Monitoring and Warning* (IEEE Transactions on Instrumentation and Measurement, 2018), pp. 1–11
25. J. Goswami, A. Saha, IoT sensor network based implementation for rainfall induced landslide monitoring, in *International Conference on Computational Intelligence, Security and Internet of Things*, (Springer, Cham, 2020), pp. 304–316
26. R. Greco, A. Guida, E. Damiano, L. Olivares, Soil water content and suction monitoring in model slopes for shallow flowslides early warning applications. Phys. Chem. Earth, Parts A/B/C **35**, 127–136 (2010)
27. J.A. Gutierrez, M. Naeve, E. Callaway, M. Bourgeois, V. Mitter, B. Heile, IEEE 802.15. 4: A developing standard for low-power low-cost wireless personal area networks. IEEE Netw. **15**, 12–19 (2001)
28. M. Hons, R. Stewart, D. Lawton, M. Bertram, G. Hauer, Field data comparisons of MEMS accelerometers and analog geophones. Lead. Edge **27**, 896–903 (2008)
29. http://www.safeland-fp7.eu
30. C. Huggel, N. Khabarov, M. Obersteiner, J.M. Ramírez, Implementation and integrated numerical modeling of a landslide early warning system: A pilot study in Colombia. Nat. Hazards **52**, 501–518 (2010)
31. E. Intrieri, G. Gigli, F. Mugnai, R. Fanti, N. Casagli, Design and implementation of a landslide early warning system. Eng. Geol. **147–148**, 124–136 (2012)

32. B. Kerkez, S.D. Glaser, R.C. Bales, M.W. Meadows, Design and performance of a wireless sensor network for catchment-scale snow and soil moisture measurements. Water Resour. Res. **48** (2012)
33. S. Kumar, S. Duttagupta, V.P. Rangan, M.V. Ramesh, Reliable network connectivity in wireless sensor networks for remote monitoring of landslides. Wirel. Netw **26**(3), 2137–2152 (2020)
34. D. Lagomarsino, S. Segoni, R. Fanti, F. Catani, Updating and tuning a regional-scale landslide early warning system. Landslides **10**, 91–97 (2013)
35. J. Landes, J. Begley, G. Clarke, American society for testing and materials. STP **590**, 128–148 (1976)
36. M. Li, Y. Liu, *Underground Structure Monitoring with Wireless Sensor Networks* (Proceedings of the 6th International Conference on Information Processing in Sensor Networks, 2007), pp. 69–78
37. Li, Y. Liu, Underground coal mine monitoring with wireless sensor networks. ACM Trans. Sensor Network (TOSN) **5**, 10 (2009)
38. Z. Liao, Y. Hong, J. Wang, H. Fukuoka, K. Sassa, D. Karnawati, et al., Prototyping an experimental early warning system for rainfall-induced landslides in Indonesia using satellite remote sensing and geospatial datasets. Landslides **7**, 317–324 (2010)
39. R. Macciotta, C.D. Martin, N.R. Morgenstern, D.M. Cruden, Quantitative risk assessment of slope hazards along a section of railway in the Canadian Cordillera—A methodology considering the uncertainty in the results. Landslides **13**, 115–127 (2016)
40. A. Manconi, D. Giordan, Landslide early warning based on failure forecast models: The example of the Mt. de La Saxe rockslide, northern Italy. Nat. Hazards Earth Syst. Sci. **15**, 1639–1644 (2015)
41. J. Mathew, D.G. Babu, S. Kundu, K.V. Kumar, C. Pant, Integrating intensity–duration-based rainfall threshold and antecedent rainfall-based probability estimate towards generating early warning for rainfall-induced landslides in parts of the Garhwal Himalaya, India. Landslides **11**, 575–588 (2014)
42. A. Menció, M. Galán, D. Boix, J. Mas-Pla, Analysis of stream–aquifer relationships: A comparison between mass balance and Darcy's law approaches. J. Hydrol. **517**, 157–172 (2014)
43. D.C. Nguyen, D.N. Tran, N.H. Le, D.T. Ta, A.T. Pham, D.T. Tran, Multi-sensors integration for landslide monitoring application. VNU J. Sci. **30**(6S-B), 202–210 (2014)
44. C.D. Nguyen, T.D. Tran, N.D. Tran, T.H. Huynh, D.T. Nguyen, Flexible and efficient wireless sensor networks for detecting rainfall-induced landslides. Int. J. Distrib. Sens. Netw. **2015**, 235954 (2015a)
45. D.C. Nguyen, T. Duc-Tan, D.N. Tran, Application of compressed sensing in effective power consumption of WSN for landslide scenario, in *Asia Pacific Conference on Multimedia and Broadcasting*, (IEEE, 2015b), pp. 1–5
46. M. Papa, V. Medina, F. Ciervo, A. Bateman, Derivation of critical rainfall thresholds for shallow landslides as a tool for debris flow early warning systems. Hydrol. Earth Syst. Sci. **17**, 4095–4107 (2013)
47. Y. Peng, Z. Li, W. Zhang, D. Qiao, *Prolonging Sensor Network Lifetime Through Wireless Charging* (IEEE Real-Time Systems Symposium, 2010), pp. 129–139
48. L. Piciullo, S.L. Gariano, M. Melillo, M.T. Brunetti, S. Peruccacci, F. Guzzetti, et al., Definition and performance of a threshold-based regional early warning model for rainfall-induced landslides. Landslides **14**, 995–1008 (2016)
49. M.V. Ramesh, Design, development, and deployment of a wireless sensor network for detection of landslides. Ad Hoc Netw. **13**, 2–18 (2014)
50. P. Rawat, K.D. Singh, H. Chaouchi, J.M. Bonnin, Wireless sensor networks: A survey on recent developments and potential synergies. J. Supercomput. **68**, 1–48 (2014)
51. S. Segoni, L. Piciullo, S.L. Gariano, A review of the recent literature on rainfall thresholds for landslide occurrence. Landslides **15**, 1–19 (2018)
52. A. Sheth, K. Tejaswi, P. Mehta, C. Parekh, R. Bansal, S. Merchant, et al., *Senslide: A Sensor Network Based Landslide Prediction System* (Proceedings of the 3rd International Conference on Embedded Networked Sensor Systems, 2005), pp. 280–281

53. A. Terzis, A. Anandarajah, K. Moore, I. Wang, *Slip Surface Localization in Wireless Sensor Networks for Landslide Prediction* (Proceedings of the 5th International Conference on Information Processing in Sensor Networks, 2006), pp. 109–116
54. B. Thiebes, R. Bell, T. Glade, S. Jäger, J. Mayer, M. Anderson, et al., Integration of a limit-equilibrium model into a landslide early warning system. Landslides **11**, 859–875 (2013)
55. H. Thirugnanam, M.V. Ramesh, V.P. Rangan, Enhancing the reliability of landslide early warning systems by machine learning. Landslides **17**, 2231–2246 (2020)
56. I. Towhata, T. Uchimura, C. Gallage, On early detection and warning against rainfall-induced landslides (m129), in *Landslides*, (Springer, 2005), pp. 133–139
57. D.T. Tran, D.C. Nguyen, D.N. Tran, D.T. Ta, Development of a rainfall-triggered landslide system using wireless accelerometer network. Int. J. Adv. Comput. Technol. **7**(5), 14 (2015)
58. UN-ISDR, *Developing Early Warning Systems: A Checklist* (Third International Conference on Early Warning (EWC III), Bonn, 2006)
59. L. Xiang, J. Luo, C. Rosenberg, Compressed data aggregation: Energy-efficient and high-fidelity data collection. IEEE/ACM Trans. Network (TON) **21**, 1722–1735 (2013)
60. Y. Yin, H. Wang, Y. Gao, X. Li, Real-time monitoring and early warning of landslides at relocated Wushan town, the three Gorges reservoir, China. Landslides **7**, 339–349 (2010)
61. X. Yu, P. Wu, W. Han, Z. Zhang, A survey on wireless sensor network infrastructure for agriculture. Comput. Stand. Interfaces **35**, 59–64 (2013)
62. X. Zhu, Q. Xu, M. Tang, W. Nie, S. Ma, Z. Xu, Comparison of two optimized machine learning models for predicting displacement of rainfall-induced landslide: A case study in Sichuan Province, China. Eng. Geol. **218**, 213–222 (2017)