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Monitoring System Using Internet of Things For Potential Landslides

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Abstract

The North-Western RIF of Morocco is considered as one of the most mountainous zone in the Middle East and North Africa. This area is more serious in the corridor faults region, where the recent reactivation of those tectonic layering may greatly contribute to the triggering of landslides. The consequences of this phenomenon can be enormous property damage and human casualties. Furthermore, this disaster can disrupt progress and destroy developmental efforts of government, and often pushing nations back by many years. In our previous works of Tetouan-Ras-Mazari region, we identified the areas that are prone to landslides by different methods like Weights of Evidence (WofE) and Logistic Regression (LR). In fact, these zones are built and susceptible. Undoubtedly, the challenge to save human lives is vital. For this reason, we develop a robust monitoring model as part of an alert system to evacuate populations in case of imminent danger risks. This model is ground-based remote monitoring system consist of more than just field sensors; they employ data acquisition units to record sensor measurements, automated data processing, and display of current conditions usually via the Internet of Things (IoT). To sum up, this paper outlines a new approach of monitoring to detect when hillslopes are primed for sliding and can provide early indications of rapid and catastrophic movement. It reports also continuous information from up-to-the-minute or real-time monitoring, provides prompt notification of landslide activities, advances our understanding of landslide behaviors, and enables more effective engineering and planning efforts.

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Keywords: Landslides; Internet of Things; Lambda Architecture; Risk Monitoring

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1. Introduction

Detecting and outlining possible indications of rapid landslide events require high frequency monitoring and very high precision of measurements [1]. This paper aims to build a monitoring system for a better follow up before and while the occurrences of landslides in the study area of Tetouan-Ras-Mazari and Ceuta city (Northern of Morocco).

1.1. Landslide

Landslide is considered as a geological phenomenon to describe a wide variety of processes that result in the perceptible downward and outward movement of soil, rock, and vegetation under the influence of gravity. A landslide hazard is defined, according to Vanes in 1978 [2], as 'the probability of a landslide occurrence within a specified time and within a given area of potentially damaging phenomenon'.

Table 1. Types of landslides. Abbreviated version of Varnes' classification of slope movements.

Type of Movement	Type of Material		
	BedRock	Soils Kinematics	
		Predominantly coarse	Predominantly fine
Falls	Rock fall	Debris fall	Earth fall
Topples	Rock topple	Debris topple	Earth topple
Rotational Translational	Rock slide	Debris slide	Earth slide
Lateral Spreads	Rock spread	Debris spread	
Flows	Rock flow	Debris	Earth flow

Landslides are classified depending on several criteria such as movement, materials, amount of fluids, geotechnical properties of rocks [2] and [3]. The movement of landslides can occur in many ways. It can be a fall, topple, slide, spread or flow. The velocity of the movement may range from very slow to rapid. Although landslides are primarily associated with mountainous regions, they can also occur in areas of generally low relief. In low-relief areas, landslides occur as cut and fill failures (roadway and building excavations), river bluff failures, lateral spreading landslides, collapse of mine-waste piles (especially coal), and a wide variety of slope failures associated with quarries and open-pit mining (Landslides in focus). The most common types of landslides are described as follow and are illustrated in Table 1.

As it has been mentioned on the table above, landslides are classified depending on several criteria such as movement, materials, amount of fluids, geotechnical properties of rocks [3]. The movement of landslides can occur in many ways. It can be a fall, topple, slide, spread or flow. The velocity of the movement may range from very slow to rapid. The type of landslides encountered in the study area of this research paper are rockfalls, block landslides, landslides. Rockfalls and landslides are genetically and spatially connected to each other. The main difference between them is that landslide remain attached to the slope; however, rockfalls lose their link with it. Both of them may have similar factors of triggering. When rock is falling, very seldom only one rock block is moving downwards. A block slide is a single unit or a few closely related units of rocks that move downslope as a relatively coherent mass following different types of movement either by sliding, rolling and/or bouncing of single block. More information about the different types of landslides can be found here [5].

In the previous works of Elmoulat and At Brahim [6], the types of landslides encountered in the study area of this research paper are rockfalls, block landslides and landslides.

Landslides can be caused by natural effect or human activities. First of all, there a number of natural factors that can trigger slope failure, we would like to mention the geological, morphological and climatological causes [7]. For the geological causes, we come across weak or sensitive materials, weathering which is the deterioration of rock by natural process which weaken the components of the lithological materials and sheared, jointed, or fissured materials etc. Concerning the morphological causes, we can find the erosion caused by continuous runoff over a slope. The removal of the toe and lateral support of a soil mass by the flow of water in streams, rivers, wave action, etc. There is also the volcanic activity in areas where there is an existing volcano, volcanic deposits are prone to erosion and subjected to mudflows due to intense rainfall. In addition, landslides are also caused by some climatological factors, like important changes in the climate that have a significant impact on the slope stability. A decrease in precipitation lowers the water sheet that results in lessening of the weight of the soil mass.

Secondly, man-made activities triggering landslides are mainly associated to human activities on slopes such as construction done without proper engineering inputs Farming practices. Removal of vegetation cover and deforestation, etc. These activities may cause increase in slope gradient or significant change in surface and ground water regimes adding to the instability of slopes.

As mentioned by Elmoulat and Aït Brahim [6], the main factors triggering landslides on the case study are climatic (Precipitation, Water resources which lower the mechanical characteristics of the marlstone of the Tangier Unit and Flysch layers), anthropogenic (Unstable roads, rapid urban expansion, etc) and Seismic (very active neighboring seismic zones (Alboran and Acores).

Landslides result in several losses. They can result in death and injury of people and animals. The mass moving can bury people and animals under debris. In addition to the loss of property and assets the velocity of rocks, mud or earth mass generated due to mass movement may destroy houses, buildings and other properties on its way. Moreover, these phenomena cause loss of infrastructure and lifeline facilities (roads, railway, bridges, telecommunication, electrical supply lines, etc). Reduction in quality of life due to the deaths of family members and the destruction of personal belongings, which may also have great sentimental value and impact the emotional well-being of people and affecting their feelings, thoughts, actions, and relationships. These catastrophic events can put tremendous psychological pressure on a person, often even the capability to function at the time of the crisis.

1.2. Tetouan-Ras-Mazari by Weight of Evidence (WoE)

In the first of paper of Elmoulat et al. in 2018 [6], we established a model to identify the zones susceptible to landslides using the weight of evidence method. Many authors utilized WofE in some region of Northern Morocco [8], [9] and [10]. It consisted of the following steps: first, we identified six predictor factors that control landslide occurrence such as lithology, distance to fault, distance to drainage, slope, aspect and hillshade. Those parameters have been derived from remote sensing data and applications of GIS to enable geo-processing and mapping the variables that are mandatory for the landslide assessment. Second, we investigated the relationship between landslide and conditioning factors for the Tetouan-Ras Mazari area using the weights of evidence approach.

1.3. Tetouan-Ras-Mazari by Logistic Regression (LR)

In the second paper, the authors [11], have developed a procedure to detect zones that have been prone to landslides using the six independent variables (lithology, distance to fault, distance to drainage, slope, aspect and hypsometry) as the input factors and the 63 landslide points as a dependent variable using the Logistic Regression tool implemented in The ArcGIS along with SDM utilities. An investigation of the susceptibility map highlights a high probability of landslides where mudstones and conglomerates outcrop. The susceptibility maps show also that the landslide is more prone in highly elevated areas greater than 57° with the Northeast, West and South-east-facing slopes. This map reveals that landslides preferentially occur close to drainage lines and high altitudes.

The combination of susceptibility zones with the challenges established on these zones where downstream from its zones makes it possible to evaluate the places requiring a particular follow-up either because the economic issues are important, and/or the human lives are concerned. The use of sensors distributed on the high-risk zones allow a better follow-up of their evolution on time. According to [12], a follow-up of landslide as a new landslide that happens inside a previous landslide, or partly overlaps or touches it.

1.4. Our contribution

In this paper, we propose on one hand a network of sensors for the follow-up of the evolution of these zones in order to keep an eye on a wide variety of hillslopes prone to hazardous landslides, and on the other hand an architecture cloud for the real-time treatment of the data. Our proposition uses more robust transmission protocol to interferences from climate and difficult environment more particularly important temperature and air humidity variation. Furthermore, the failure of one or more nodes does not call into question the operation of the entire monitoring system. Moreover, it will save human lives by providing real time notification in case of an imminent danger.

2. Literature Review

The principal purpose of monitoring landslides is to protect the population and infrastructures. The roads and habitat in hill and mountain areas are priority issues. Different follow-up methods of landslides evolution are cited in the literature such as using of the electrical resistivity (ER) measurement [13], geolocalized sensor data with GPS [14], the following at high precision of characteristic points [1], 3D representation from LiDAR [15] [16] or remote sensing imagery [16].

Geophysical properties such as soil type, pore structure, degree of saturation, stress state and anterior history affect the strength and deformation behavior. Several authors have used electrical resistivity tomography (ERT) to define morphology and depth landslides, lithologic interfaces and moisture state. The advantage of this technique is to provide a detailed 3D representation of ER information. Another approach followed by several authors use remote sensing and imaging technic such LiDAR and InSAR imagery to create a 3D representation landslide and measure their evolution at the time. But these technics are adapted for slow landslides and cannot allow create a near-real-time monitoring of high risk landslides or instantaneous landslides. Traditional field observations cannot detect changes at the moment when they occur. A near-real time monitoring is necessary to follow the changes of the key factors for forecast purpose and rapidly identify the susceptibility of instantaneous landslides. Indeed, this kind of landslide is usually triggered after plentiful rainfall where the groundwater is already impacted by previous conditions. Wireless sensor network (WSN) is widely used to monitor environmental conditions by mean of a variety of sensors such as accelerometer, thermometer, soil moisture, precipitation, ground water pressure, sound sensor and GPS device [17] [18].

High-precision Global Positioning System (GPS) is able to detect tiny movements of the rockslide. The measurements of rainfall and soil moisture are compared with a threshold that can originate several landslides. The monitoring of groundwater pressure allows to detect the destabilization that drives the slide movement. The monitoring of the acceleration provides early indication of catastrophic movement. Indeed, the gradual evolution of the acceleration is a warning signs of rapid movement [18]. Authors of [14] propose the using of a network of GPS low-cost place at different place on the landslide. The low-cost GPS allow also the acquisition of time stamped data from complementary sensors. The identification of precursors of rapid landslide events need acquisition of data with a high precision at a high sampling rate [14].

Data acquired by sensors are used to elaborate geomechanical models of slope including parameters such as temperature, soil moisture, water flow, movement speed. The detection and the prediction of instantaneous landslides characterized by sudden changes of the mountain slope is crucial to make decisions about safety [17] [18]. Furthermore, near-real-time monitoring enables land managers to adapt quickly to safety alert levels for inhabitants. Moreover, the acquisition of a large amount of data coming from of various kinds of landslides localized in different environments are stored. Moreover, data stored in big data hosted in the cloud constitute the base of the enhance of the comprehension of dynamic of their formation and the behavior of landslides. This big data is a corner-stone for the development of better model of landslide behavior elaborate and validate on large amount of data.

3. Proposed Architecture

The proposed Architecture is based on two kinds of nodes. The first one is a micro meteorological node base which acquires temperature, relative humidity, wind vane, wind speed, rainfall. The second one is a ground node which measure the soil moisture at different depth.

Both types of nodes uses a data transmission multi protocol microcontroller LoPy, but others more recent model such LoPy4[1] and FiPy[2] can also be used. These microcontrollers do not cost much money, easily programmable

[1] https://pycom.io/product/lopy4/
[2] https://pycom.io/product/fipy/

in micro python and embed natively several protocols where other microcontrollers such as Waspmote[3] or need an extension board to add the support of supplementary protocols. The principal characteristics are given in Table 2.

Table 2. Principal characteristics of PyCom microcontrollers.

Characteristics	WiPy 3.0	LoPy 1.0	SiPy 1.0	LoPy4	GiPy 1.0	FiPy 1.0
Support of WiFi/Bluetooth	Yes / Yes	Yes / Yes	Yes / Yes	Yes / Yes	Yes / Yes	Yes / Yes
Support of LoRaWan/Sigfox	No / No	Yes / No	No / Yes	Yes / Yes	No / No	Yes / Yes
Support of LTE (cat 1/NbIoT)	No	No	No	No	Yes	Yes
ADC 12 bits/DAC 8 bits/GPIO	8 / 0 / 24	8 / 0 / 24	8 / 0 / 24	8 / 0 / 24	8 / 2 / 22	8 / 2 / 22
Ram/External flash	4Mb / 8Mb	512Kb / 4Mb	512Kb / 4Mb	4Mb / 8Mb	4Mb / 8Mb	4Mb / 8Mb
Price HTVA out of port	19.95€	29.95€	34.95€	34.95€	44.00€	54.00€

These microcontrollers are equipped by a Dual Processor Espressif ESP32 chipset, a hardware floating point acceleration, support hash/encryption SHA, MD5, DES, AES and is provided of 2 UART, SPI, 2 I^2C, I^2S, micro SD card and a Real Time Controller (RTC) at 32.768Hz. The deep sleep mode consumption is only of 10 μA and the hibernation mode 1μA. Furthermore, all these microcontrollers weigh only 7g and support SSL/TLS and WPA enterprise.

LoPy4 and LoPy microcontrollers make it possible to adapt to the main networks of the Internet of Things according to their availability. The meteorological station transmit data each minute by one of the four IoT protocols. In case of using Sigfox, available with LoPy4, FiPy and SiPy, due to a protocol limitation to 140 messages sent by day, the data can only transmit every ten minutes.

The two nodes which have been develop during this research, are presented in Fig. 1.

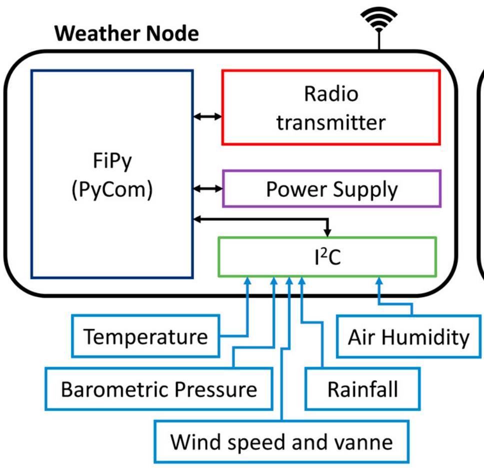

Fig. 1. Architecture of developed nodes

The meteorological node is equipped with a FiPy microcontroller, a LiPo battery of 4400 mAh, a solar panel of 10W. This kind of nodes measures the temperature and relative humidity of the air by mean of a AM2315 (Aosong) sensors I^2C (address 05C) with a high accuracy providing an error of ±0.1°C for temperature and ±2% for relative humidity. The meteorological node is also equipped with a barometric sensor BMP 280 (Bosch) and a weather meter SparkFun to measure wind speed, wind direction and rainfall. The system uses IP67 enclosure which guarantees reliable performance in a dusty environment and protection against the effects of immersion up to 1 meter deep.

The ground node uses also a FiPy with a LiPo battery of 4400 mAh, a solar panel of 10W. An MPU9250 (TDK IvenSense) accelerometer, gyroscope and compass measure movements of the landslide. While soil moisture humidity

[3] http://www.libelium.com/products/waspmote/

sensor place at different depth measure the amount of water present in the different layers of soil by means of soil moisture sensors model 200SS (Watermark). The GPS module is a LEA-M8T (u-blox). This GPS module allows to receive GPS/QZSS L1 C/A, GLONASS L10F, BeiDou B1, SBAS L1 C/A: WAAS, EGNOS, MSAS, GAGAN, Galileo E1B/C signals.

Data from network of ground nodes and weather nodes are sent using LoRa frequency modulation to one or more LoRa gateway available in the area which transfer data to the Things Network (Free LoRaWan Network). Then, data are forwarded from The Things Network to own cloud architecture. The LoRa/LoRaWan protocol is a robust to interference protocol using the spreading factor, double AES 128 bits encryption. This protocol also allows to connect more thousands of nodes on a unique gateway which are distributed in a perimeter up to 15 km around the gateway. This protocol uses ISM Frequency band and offers the possibility to send a payload up to 242 octets. The system uses IP67 enclosure which guarantees reliable performance in a dusty environment and protection against the effects of immersion up to 1 meter deep. The power consumptions of sensors and microcontroller is done in Table 3.

Table 3. Power consumption according to manufacturers data and interface of connection

Component	Interface	Operation mode	Supply Current (Max)	Voltage
AM2315	I^2C	Sleep / Measuring / Average	1.5 μA / 1 mA / 28 μA	5 Vdc
BMP280	I^2C	Average / Maximum	7.02 μA / 10.5 μA	3.3 Vdc
LEA-M8T	I^2C	Typical / Max	28 mA / 67 mA	3.3 Vdc
MPU9250	I^2C	Idle mode / Typical	8 μA / 3.7 mA	3.3 Vdc
FiPy		On / Deep sleep / Hibernation	156 mA / 24 μA / 1 μA	5 Vdc

The proposed cloud architecture consists of two parts: First, a lambda architecture which is able to collect and store different kinds of data and keep the structure easily adaptable [19]; second, a hosting platform which shares data applications and models between all the research teams. The use of containers and virtualization technologies makes it easy to deploy different versions of the same model and validate them on a wide range of data. Moreover, the technology of containerization also allows a continuous integration of change made on the model and a rapid deployment. In this architecture, proprietary and real-time data are treated by streaming processing. Event and time related data are treated by batch processing which consists of data verification (complete and consistent data). If data are incomplete or erroneous, they can be corrected, and erroneous or missing data must also be interpolated. Each corrected or interpolated data is specifically tagged “corrected” or “generated data” in order to differentiate them from the original data. This architecture is adaptable to many cases and has already been tested by Debauche et al. in 2017 for the cattle behavior [20], the digital phenotyping [21], the pivot-center irrigation [22], the bee health monitoring [23], the animal’ behavior [24]. The proposed architecture is illustrated in Fig 2.

In the lambda architecture, Apache Kafka provides a message bus between nodes and Apache Samza. Yarn containers run Apache Samza to preprocess data by eliminating erroneous or incomplete data that improve by ten the speed of data ingestion by Druid. Druid is a distributed fault tolerant column-oriented database which is composed of four types of nodes designed to ingesting and explore large amount of times-stamped data. The unit of storage in Druid is “segment” composed of 5 to 10 million times-stamped data compressed with LZ4 and covering a time period. In our architecture, Druid uses a PostgreSQL database to store metadata of segments. A quorum of Zookeeper monitors the four kinds of Druid nodes present in the cluster. These four nodes respectively coordinate, broke, store in real-time or archived data on HDFS.

Real-times nodes provide functionality to ingest, query, index event streams for small time range. Indexes are maintained in-memory to be directly queryable. A background task merges indexes together and build immutable blocks with ingested data from real-time nodes. Segments are then uploaded to HDFS. Historical nodes contain functionalities to load and serve the immutable block of data created by real-time nodes. Brokers nodes route incoming queries to historical or real-time nodes and return a final consolidated result to the applicant. Brokers nodes contain a caching system with a LRU[4] invalidation strategy and using Redis to store key-value. Finally, Coordinators nodes are in charge of data management and distribution on Historical nodes: loading, dropping, replication and moving of

[4] Least Recently Used

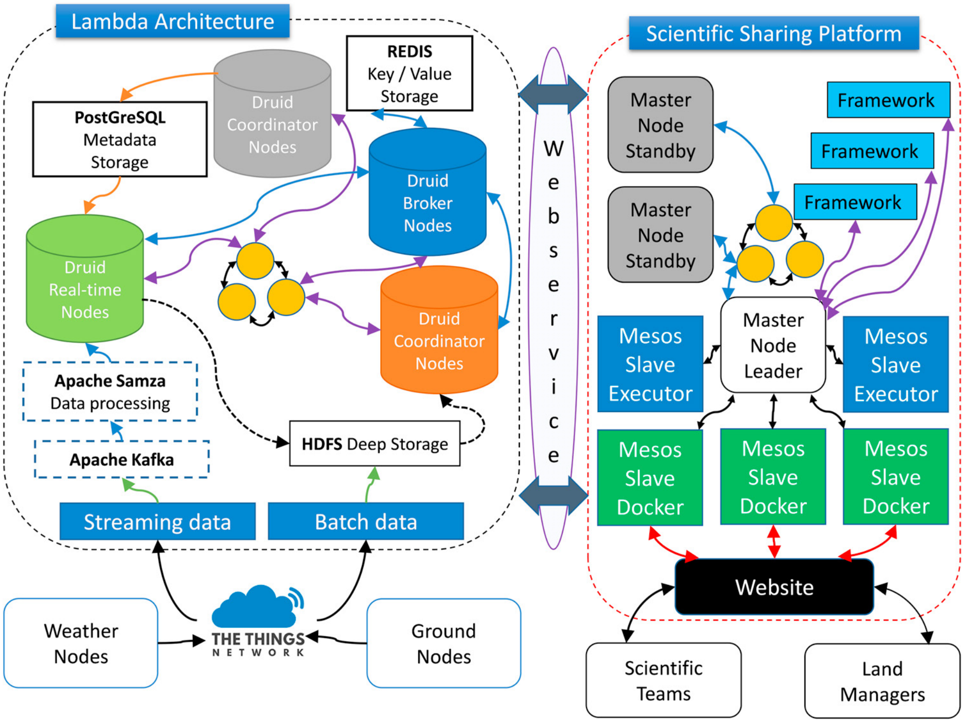

Fig. 2. Proposed Cloud Architecture

data. No timestamped data are treated by means of Hadoop and MapReduce framework. This batch processing treats sound, images and video and complete the batch processing of timestamped data of Druid.

The scientific sharing platform uses Apache Mesos and Docker containers to isolate and host applications. Mesos keeps the structure easily adaptable to various framework while proposing isolation and fine-grained resources of the cluster. Mesos isolation is better than Docker but we have mixed both for compatibility reasons. A quorum of Zookeeper: one master node and two master standby nodes ensures fault tolerance in the cluster. Apache Mesos offers several pluggable frameworks.

Each framework sends tasks to the master node which transfer them to Apache Mesos slave executor available. When the task is executed the result is send to node master which forward them to the framework. Each framework that run on the top of Apache Mesos use a job scheduler registered to the master node and ask resources while an executor process is on slave nodes to run tasks of the framework.

A Docker slave node can host external application which are not initially developed to work on frameworks plugged on Apache Mesos. They can nevertheless be hosted with container technology offered by Docker.

A webservice ensures the communication between the lambda architecture and the hosting and sharing platform and provides authentication, anonymization, access control and using data traceability.

Finally, a website allows users to upload owns applications and uses applications hosted on the platform.

4. Experimental Results

In the experiments related to this case-study, the impact of data local treatment at the sensor level was measured. Data compression consisted in eliminating the redundant data for each parameter presented in Table 4 and recorded each second. In the present case-study, all data must be conserved so replacement of redundant data by a time interval during which the value remains constant was applied in order to preserve data integrity.

The implementation of the lambda architecture and edge computing on FiPy allows the reduction in the amount of data that must be transmitted to cloud and bandwidth used. The compression algorithm proposed in this paper improves storage efficiency in the distributed database hosted in the cloud. The results are obtained for 10 days of data treated locally on FiPy and transmitted on the lambda cloud architecture to be post treated. In the actual configuration the cloud architecture collects and treats 150,000 events by second.

Table 4 shows the different compression rates obtained on raw data by redundancy elimination without loss of data.

Table 4. Compression rate obtained for each category of data collected on 10 days

Type of data	Variable number	Data treated	Data size (Mb)	Compression rate [%]
Wind (Speed, Direction)	2	1,728,000	6.592	87.12
Air Temperature	1	864,000	3.296	84.56
Air Humidity	1	864,000	3.296	84.56
Barometric Pressure	1	864,000	3.296	84.25
Rainfall	1	864,000	3.296	68.72
Soil Moisture (at 3 levels)	3	2,592,000	9.887	92.87
GPS	3	2,592,000	9.887	12.78
Accelerometer	3	2,592,000	9.887	12.78
Gyroscope	3	2,592,000	9.887	48.26
Compass	3	2,592,000	9.887	60.79

The analysis of compression rate shows that all kinds of data are compressible, but GPS and accelerometer data are weakly compressible in comparison with other data because these parameters are more susceptible and by consequence change more easily.

The compression of the data allowed a reduction of the bandwidth consumed for their transmission to the cloud by 45% on average. The transmission of the float data at 1Hz corresponds to 80 bytes of data. By eliminating redundancies, the amount of data transmitted every second was reduced to 45 bytes per second.

5. Conclusion and future work

In this paper, we propose a complete solution to monitor areas with a high probability of landslides. This system includes a new data storage architecture dedicated to scientific research and a network of sensors nodes. The lambda architecture is able to ingest a large variety of data at high frequency such as images, videos, sound, punctual data and time series data, etc. In this configuration, the proposed lambda architecture is able to ingest and treat up to 150,000 events by second.

The main novelty of this architecture offered by this platform remains in its capacity to normalize, share and exchange data between group of researchers. Moreover, the increasingly wide availability of Internet of Things protocols such as LoRaWan, Sigfox, allows to transfer, at low cost, wide range of data from many different sources. The scientific sharing platform allows to scientists to access to large amount of data to develop and validate more accurate models.

The platform using Apache Mesos keeps the structure easily adaptable to various framework while proposing isolation and fine-grained resources of the cluster. In the future, the platform will also allow to host a set up an alert system to warn populations and security services of imminent danger of landslides. On basis of collected data on a wide range of landslide better models will be elaborate to have an earlier detection of situations that is dangerous for people.

In future works, we will implement the NB-IoT protocol which depend of cellular network, propose a better throughput which will allow the transmission of more parameters, uses existing cellular infrastructures and does not require the deployment of a specific technological network like the LoRaWan or SigFox

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References

[1] Malet, Jean-Pierre, Maquaire Olivier and E. Calais. (2002) "The use of Global Positioning System for the continuous monitoring of landslides. Application to the Super-Sauze earthflow (Alpes-de-Haute-Provence, France)." *Geomorphology* **43** (1-2): 33–54.

[2] Varnes, David J. (1978) "Slope movement types and processes.", in R.L. Schuster and R.J., Krizek (eds) *Landslides, analysis and control*

[3] WP/WLI. (1994) "A suggested method for reporting landslides causes." *Bulletin of the International Association of Engineering Geology* **50** (1): 71–74.

[4] *Landslides in focus*, (2000) National Building Research Organization.

[5] Poisel, Rainer, Preh, Alexander. (2011) "ROCK FALL DETACHMENT MECHANISMS."', in *Interdisciplinary Rockfall Workshop 2011*, Innsbruck-Igls, Autrichia.

[6] Elmoulat, Meryem and Lahsen Aï, Brahim. (2018) "Landslides Susceptibility Mapping Using GIS and Weights of Evidence Model in Tetouan-Ras-Mazari Area (Northern Morocco)." *Geomatics, Natural Hazards and Risk*.

[7] Alexander, David. (1992) "On the causes of landslides: Human activities, perception, and natural processes." *Environmental Geology and Water Sciences* **20** (3): 165-179.

[8] Mastere, Mohamed, Van Vliet Lanoë, Brigitte and Lahsen Ait, Brahim. (2013) "Land use mapping and its relation to mass wasting and gullying in NorthWestern Rif (Morocco)." *Geomorphology* bf 3: 335–352.

[9] Mastere, Mohamed, Van Vliet Lanoë, Brigitte, Brahim, Lahsen Ait and Meryem Elmoulat. (2015) "A linear indexing approach to mass movements susceptibility mapping: The case of the Chefchaouen province (Morocco)." *Revue internationale de géomatique* **25** (2): 245–265.

[10] El Moulat, Meryem, Brahim, Lahsen Aït, Mastere, Mohamed and Anouar Ilham, Jemmah. (2015) "Mapping of Mass Movements Susceptibility in the Zoumi Region Using Satellite Image and GIS Technology (Moroccan Rif)." *International Journal of Scientific & Engineering Research* **6** (2): 210–217.

[11] Elmoulat, Meryem and Lahsen Aït, Brahim. (2017) "Application Of Logistic Regression Method To Produce Landslide Susceptibility Map: A Case Study Of Tetouan Mazari, Morocco.", in *The International Symposium on Computer Sciences and Applications (ISCSA2017)*, Errachidia, Morocco.

[12] Samia, Jala, Temme, Arnaud, Bregt, Arnold, Wallinga, Jakob, Guzzetti, Fausto, Ardizzone, Francesca and Mauro Rossi. (2017) "Do landslides follow landslides? Insights in path dependency from a multi-temporal landslide inventory." *Landslides* **14** (2): 547-558.

[13] Crawford, Matthew M. and L. Sebastian, Bryson. (2018) "Assessment of active landslides using field electrical measurements." *Engineering Geology* **233**: 146–159.

[14] Benoit, L., Martin, O., Thom, C., Malet J-P and P. Ulrich. (2015) "Monitoring landslide displacements with the Geocube wireless network of low-cost GPS." *Engineering Geology* **195**: 111–121.

[15] Travelletti, Julien, Malet, Jean-Pierre and Christophe Delacourt. (2014) "Image-based correlation of laser scanning point cloud time series for landslide monitoring." *International Journal of Applied Earth Observation and Geoinformation* **32**: 1–18.

[16] Janboyedeff, Michel, Oppikofer, Thierry, Abellán, Antonio, Derron, Marc-Henri, Loye, Alex, Metzger, Richard and Andrea Pedrazzini. (2012) "Use of LiDAR in landslide investigation." *Natural Hazards* **61** (1): 5–28. doi: 10.1007/s11069-010-9634-2

[17] Khoa, Vu Van and Shigeru, Takayama, "Wireless sensor network in landslide monitoring system with remote data management." *Measurement* **118**: 214–229.

[18] Reid, Mark E., LaHusen, Richard, Baum, Rex L., Kean, Jason W., Schulz William H. and Lynn M., Highland. (2012) "Real-Time Monitoring of Landslides." *Fact Sheet 2012-3008* USGS.

[19] Diáz, Manuel, Martin Christian and Bartholomé Rubio. (2016) "State-of-the art, challenges, and open issues in the integration of Internet of things and cloud computing." *Journal of Network and Computer Applications* **67**: 99–117.

[20] Debauche, Olivier, Mahmoudi, Saïd, Andriamandroso, A.L.H., Manneback, Pierre, Bindelle Jérôme and Frédéric Lebeau. (2017) "Web-based cattle behaviour service for researchers based on the smartphone inertial central." *Procedia Computer Science* **110**: 110–116. doi: 10.1016/j.procs.2017.06.127

[21] Debauche, Olivier, Mahmoudi, Saïd, Manneback, Pierre, Massinon, Mathieu, Tadrist, Nassima, Lebeau Frédéric and Sidi Ahmed, Mahmoudi. (2018) "Cloud Architecture for Digital Phenotyping And Automation." in *3rd International Conference on Cloud Computing Technologies and Applications (CloudTech17)*, Rabat, Morocco. doi: 10.1109/CloudTech.2017.8284718

[22] Debauche, Olivier, Elmoulat, Meryem, Mahmoudi, Saïd, Boukraa, Slimane, Manneback, Pierre and Frédéric Lebeau. (2018) "Web Monitoring of Bee Health for Researchers and Beekeepers Based on the Internet of Things." in *The 8th International Symposium on Frontiers in Ambient and Mobile Systems (FAMS 2018)*, Porto, Portugal. *Procedia Computer Science* **130**: 991-998. doi: 10.1016/j.procs.2018.04.103

[23] Debauche, Olivier, Elmoulat, Meryem, Mahmoudi, Saïd, Manneback, Pierre and Frédéric Lebeau. (2018) "Irrigation pivot-center connected at low cost for the reduction of crop water requirements." in *2018 International Conference on Advanced Communication Technologies and Networking (CommNet)*, Marrakech, Morocco, pp. 1-9. doi: 10.1109/COMMNET.2018.8360259

[24] Debauche, Olivier, Mahmoudi, Saïd, Andriamandroso, A.L.H., Manneback, Pierre, Bindelle Jérôme and Frédéric Lebeau. (2018) "Cloud services integration for farm animals behavior studies based on smartphones as activity sensors." *Journal of Ambient Intelligence and Humanized Computing*. 1–12. doi: 10.1007/s12652-018-0845-9