Long-term Monitoring of Soil Surface Deformation with RFID

Arthur Charléty, Mathieu Le Breton, Laurent Baillet, Eric Larose

Long-term Monitoring of Soil Surface Deformation with RFID

Arthur Charléty
arthur.charlety@univ-grenoble-alpes.fr
Univ. Grenoble Alpes, Univ. Savoie Mont Blanc, CNRS, IRD, Univ. Gustave Eiffel, ISTerre, 38000 Grenoble, France

Mathieu Le Breton
Géolithe
Crolles, France

Laurent Baillet
Univ. Grenoble Alpes, Univ. Savoie Mont Blanc, CNRS, IRD, Univ. Gustave Eiffel, ISTerre, 38000 Grenoble, France

Eric Larose
Univ. Grenoble Alpes, Univ. Savoie Mont Blanc, CNRS, IRD, Univ. Gustave Eiffel, ISTerre, 38000 Grenoble, France

***Abstract*—Passive Radio-Frequency Identification (RFID) has been used to monitor landslide displacement since approximately 5 years. This method allows soil displacement estimation at a high spatio-temporal resolution, and at a relatively low cost. In perspective of the previous years, this paper proposes to summarize the various challenges encountered with the long-term outdoor RFID localization method, and presents solutions that were implemented to overcome these challenges. Finally, displacement results from three monitored sites are shown in order to validate the implemented solutions.**

***Index Terms*—Phase localization, landslides, RFID, remote sensing, early warning**

I. Introduction

Radio-Frequency Identification (RFID) has recently drawn the attention of the Earth Sciences community [1], notably for environment remote sensing at low cost. RFID tag localization has been a growing research topic in the past years [2], with multiple localization methods [3], [4] and applications [5], [6].

In this paper we propose to discuss the recent advances in soil surface monitoring using RFID, with data and experience from the past years on several instrumented sites.

Other techniques already exist for landslide monitoring, such as optical approaches [7], radar interferometry [8] or GPS [9]. Despite their simplicity, optical methods are sensitive to obstruction by obstacles, fog or heavy rain. Radiofrequency methods are much less sensitive to these obstacles, but they require more complex and expensive systems, and usually rely on active sensors. Compared to these classical methods, RFID monitoring offers a lower-cost alternative in terms of installation and maintenance, because the tags are passive. Additionally, RFID provides dense measurements both in space and time with easy reflector identification, that are little sensitive to obstruction (vegetation, snow cover, fog). This is a great advantage in an all-seasons long-term monitoring approach. The method has shown robust results in outdoor scenarios [10] with centimetric precision [11], [12].

This short paper will present the tracking method as applied on different monitored sites, and discuss the different challenges that the method poses as well as the proposed and implemented solutions. These recent advances are then validated by comparing on-site displacement estimation to reference measurements.

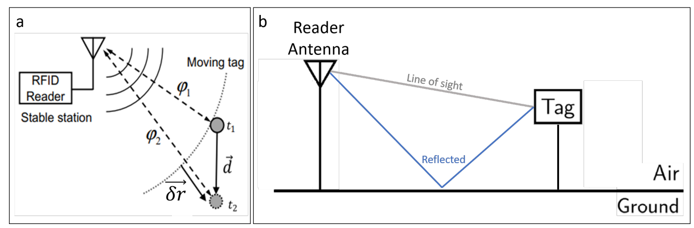

Fig. 1. Schematic principle of all RFID monitoring sites. (a) The principle of relative TD-PD localization : the phase variation between two measurements is linked to the projected radial distance variation (see Equation 1). (b) The tags are placed on stakes (metallic or fiberglass) about 1m above ground, which can generate multipath interference as shown by two rays : line of sight and reflected on ground.

II. Equipment and localization method

A. RFID Instrumentation

In this study we investigate the RFID data from 3 landslides and a prone-to-fall boulder, that all share the same measurement scheme. Several RFID tags (Confidex Survivor) are continuously read by an acquisition system consisting of an interrogator (Impinj SR420 or equivalent) and at least two reader antennas. A micro-computer and a modem ensure continuous data acquisition and uploading.

The measurement rate depends on the site and the available power : autonomous stations relying on solar/wind energy cannot read continuously for example. On average the available data gives a minimum of 100 data points per day. Both the Phase of Arrival (PoA) and the Received Signal Strength (RSSI) are measured, in order to estimate the quality of the signal of the received phase. All measurements are performed at four different carrier frequencies : 865.7, 866.9, 866.9 and 867.5 MHz.

B. RFID Relative localization scheme

Among various RFID localization schemes, phase-based methods have shown the best results in outdoor scenarios [10].

In particular we will use the Time-Domain Phase-Difference (TD-PD) method [2] for its robustness and high precision. A schematic of this method is presented in Figure 1a.

TD-PD is a relative ranging technique based on a phase variation $\delta\phi = \phi_1 - \phi_0$ between two measurements at different points in time. $\delta\phi$ is related to the radial distance variation $\delta r = r_1 - r_0$ between tag and reader antenna, by the following equation:

$$\delta r = -\frac{c}{4\pi f}\delta\phi \tag{1}$$

where f is the frequency of the electromagnetic wave (see values above) and c is the speed of light in the propagation medium. It is important to note that (1) is only valid for displacements smaller than $\lambda/4 \approx 8cm$ between two phase measurements because of phase ambiguity. In the present case this condition is generally fulfilled as the incremental displacements are small compared to the wavelength (usually less than 1 cm between two successive acquisitions). In the case where the phase is correctly unwrapped, (1) is valid for any unwrapped phase variation. Phase unwrapping is a crucial step in recovering true tag displacement, as we will see below (section III-D).

C. RFID 1-bit displacement sensor

We also present a trigger RFID sensing application, using the simplest 1-bit sensor to detect millimetric motion of unstable rocks [13]. The application required designing custom RFID tags adapted for outdoor usage at long range, adapting the data acquisition of an existing tag microcircuit, and designing a sensor that triggers when displacement exceeds a few millimetres, with a threshold value that can be adapted for each sensor. The monitoring principle is described in Figure 2. The main advantage of this method is the robustness of RFID chips, as well as the ability to place the reader antenna in an accessible spot (down the monitored cliff for example). This makes for an easier maintenance, as the power source does not have to be placed close to the sensor, in potentially hazardous situations.

D. Monitored sites

This paper will focus on monitoring results from 4 sites located in France and Switzerland (see Fig. 4). All sites grossly correspond to the typical setup presented in Figure 1b, with a group of tags facing the antennas, all placed on fiber glass stakes at an elevation of approximately 1m above ground.

- The Harmalière landslide (Sinard, France) is located near Grenoble in the western Pre-Alps, and is a slow moving landslide currently active and investigated by many research projects . The RFID setup, installed in 2020, is described in [12] and consists of 4 reader antennas and 32 tags spread in a 30m by 30m investigated zone.
- The Pont-Bourquin landslide is located in the western Pre-Alps near Lausanne in Switzerland. The setup described in [11] was installed in 2017, and consists of 2 reader antennas and 20 tags. An extensometer located near the installation is used as a 1D-reference for surface displacement.
- The Villa Itxas Gaïna landslide is located in the coastal city of Bidart in the south-east of France. It has been under observation by the Bureau de recherches géologiques et minières (BRGM) and Geolithe, for more than 3 years. The RFID setup was installed in 2022 and consists of 2 reader antennas and about 30 tags.
- The Graufthal boulder was equipped with a 1-bit RFID system, as an early warning system predicting a catastrophic rock fall.

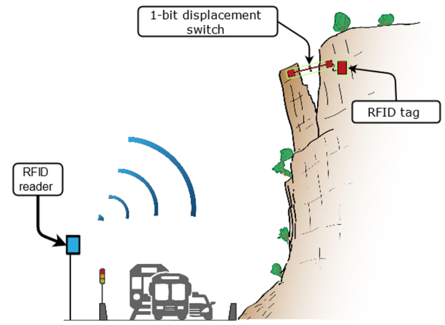

Fig. 2. Depiction of a 1-bit RFID displacement sensor. Only the reader is connected to power supply and telecom channels, which is installed down the cliff. From [13].

The selection of sites presented above cover a wide variety of topographies, weather conditions and monitored stakes, highlighting the versatility of the presented technique.

III. Main challenges for robust monitoring

This section will present and discuss the various challenges encountered with the RFID-phase monitoring technique. The challenges are listed in an operational perspective.

A. Reducing environment influence on tag antenna

Environmental conditions can have a strong influence on RFID-phase measurements. Phase random fluctuations can imply centimeter value errors in localization, as studied in [10]. This kind of measurement artifact is caused by environmental variations including tag and cable temperature, water layers over the antennas, and air refractive index. Such measurement artifacts decrease the trueness of the measurement. An extensive study of these issues and implemented solutions are presented in [10].

B. Mitigating multipath interference

Measurement trueness is also sensitive to multipath interference, which is related to terrain topography, system geometry, but also to soil humidity and snow cover. As studied in [12], multipath generates both a measurement bias and a higher random error. On most sites, two tags have been mounted on each stake, at a short distance from one another (about 20-50cm). Additionally, multiple antennas often read the same tag, providing data redundancy. This alone can mitigate several problems : the stake tilt can be estimated and corrected, the multipath-induced artifacts can be detected and compensated.

C. Correcting for mechanical rotation

The tags are approximately 1m above ground in order to be optimally readable by antennas located a few meters above ground too. The stakes supporting the tags and the infrastructure supporting the reader antennas are prone to movement over time. A tilt of the stakes generates a true displacement that does not correspond to a ground deformation. This can also happen with snow creep, that bends the stakes progressively during winter, returning to the initial position when the snow melts. This was observed in the Pont-Bourquin landslide and caused important unwrapping errors on several tags (Fig.3). On sites prone to snow creep the stakes supporting the tags were replaced by stiffer metallic stakes that do not bend with snow nor tilt with time. This reduces the occurrence of displacement artifacts over the years, but it increases the risk of multipath interference.

D. Avoid unwrapping errors due to data gaps

Data continuity over long periods of time is a key challenge in order to correctly estimate tag displacement. In the TD-PD relative localization scheme, the maximum readable displacement between two measurements is limited to a few centimeters. When a data gap coincides with a rapid displacement higher than the unwrapping ambiguity, this localization scheme alone does not allow true displacement estimation. Such data gaps can be cause by various phenomena such as hardware failures, multipath shading, harsh environmental conditions. The data continuity and availability issues are mitigated via a signal processing data-fusion approach, notably by taking advantage of the information redundancy provided by a dense network of tags, as well as the multi-frequency and multi-antenna measurements. After computing a fused multi-frequency measurement for every tag/antenna couple, groups of tags are selected based on their spatial proximity and observed correlation in their displacements : two tags on the same stake will be fused together (Fig.3), and tags close together will be mutual guides for unwrapping. The data of each group is then fused in order to guide the unwrapping of every tag, and to validate the correlation (see Fig.4). In addition to the previous method, when a reference measurement is available it can be used to unwrap (or validate) the fused data from a group of tags. In long-term monitoring, such reference measurements can allow yearly calibration, in order to keep track of the displacements on long periods of time (see Fig. 4c).

E. Increase data availability

The availability of data at all times is a crucial element in the context of early warning systems, and especially at the start of a soil surface movement. Furthermore, the quality of the signal is usually worse during strong precipitation events, when the risk of landslide activation is generally higher [14]. This is why optimizing data availability is an important issue. The experience showed that RFID phase availability is heavily dependent on tag/antenna orientation and multipath shading. These aspects should not be overlooked when designing a new

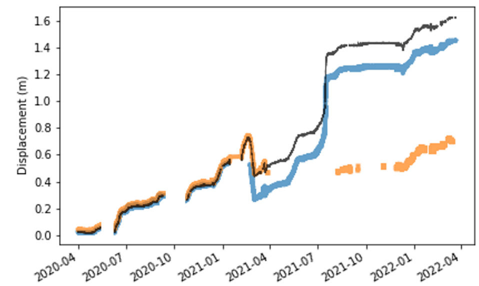

Fig. 3. Typical example of an unwrapping error corrected using a data fusion approach. The phase from two tags on the same support (blue and yellow lines) present different data gaps, that generate unwrapping errors. Combining the two datasets (black line) in phase space allows a better reconstruction of the final surface displacement. The steep variation occurring around March 2021 corresponds to snow creep. An unwrapping error remains in the presented data (June 2020).

RFID monitoring setup. The previously mentioned implementation, based on data fusion (multi-frequency, multi-antennas, multi-tag) greatly increase data availability.

F. Reduce station infrastructure

Amongst other factors, data gaps are often related to the power supply failure of RFID stations. Most stations need to be electrically autonomous due to their location, and this implies the use of in-situ power sources : wind turbines or solar panels. Reducing the electrical consumption of the RFID infrastructure would thus decrease the cost and maintenance of the stations, as well as improve data availability. As of now, the measurement scheme has been adapted depending on the power source of each station : the autonomous in Harmalière was set to a lower measurement frequency that the Pont-Bourquin station, which is connected to the Swiss power grid.

G. Address wider areas

To conclude this section, a notable limitation to a spatial up-scaling of the method is the tag reading range. The current method cannot read the Survivor RFID tags past a 60m maximum distance, which limits the size of the monitored field. The reader antennas directivity can also limit the angular range, both horizontally and vertically. In order to increase the size of the monitored areas, long-range tags were installed along with a more sensitive reader (Impinj R700). For even wider areas, new methods are developped based on Unmaned Aerial Vehicle (UAV), as described in [1], [15].

IV. Field results

Figure 4 shows RFID-phase displacement results over various time periods and sites. Most observed sites show alternating periods of acceleration and periods of rest, often correlated with seasonality. Indeed, landslides are usually more active after prolonged strong precipitation events [14].

- Pont Bourquin landslide : this site shows the longest monitoring time, with several features to interpret. The RFID measurements are prone to snow-creep which generates

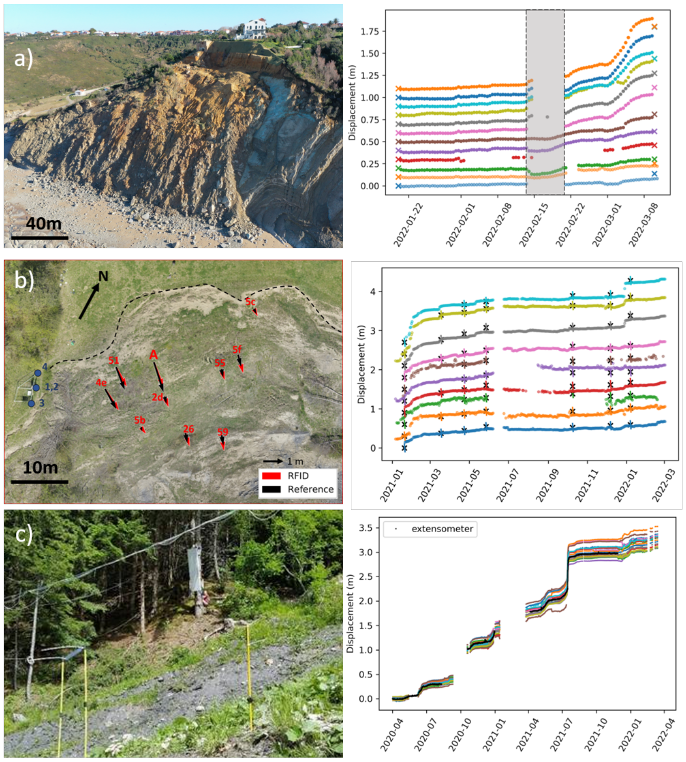

Fig. 4. (Left) Monitored site photographs and (Right) displacement data computed from RFID-phase measurements for all monitored tags. (a) Villa Itxas Gaïna coastal landslide, (b) The Harmalière vector map is from [12], and the vectors are not at scale. The absence of data correspond to either strong meteorological events (storms, long periods without sun, snow creep) or to hardware failure.

artifacts, especially during snow melt. An extensometer measurement provides partial but absolute reference measurements, that are used to guide the phase unwrapping (see III-D).

- Villa Itxas Gaïna landslide : this coastal landlide has shown activity since its recent instrumentation. The absence of data is due to a strong storm. For this dataset, a reference measurement was computed by fusing the data from groups of tags, as described in section III-D.
- Harmalière landslide : although the Harmalière station was setup in 2020, continuous exploitable monitoring only started in January 2021. The total 2D-displacement norm is presented and corresponds to tacheometer reference measurements.

V. Conclusion

Earth surface displacement monitoring with RFID has proven to be a viable solution, with three equipped sites across France and Switzerland. The method achieves centimeter-precision displacement monitoring over long time periods, and is robust to snow, vegetation cover but also to coastal weather (strong rainfall and winds). Several hardware and software solutions were proposed to improve the method, such as data-fusion algorithms, tag and antenna data redundancy. New localization schemes can also be investigated, such as mobile-antenna approaches.

VI. Acknowledgements

We would like to express special thanks to the BRGM, the INTERREG SUDOE (2019-2022) project RISK COAST and Geolithe, for allowing us to present their data. This work was partially funded by the ANR LABCOM GEO3ILAB, Geolithe and by the Region Auvergne Rhone-Alpes RISKID project.

References

[1] M. L. Breton, F. Liébault, L. Baillet, A. Charléty, Éric Larose, and S. Tedjini, "Dense and longdterm monitoring of earth surface processes with passive rfid – a review," 2021.

[2] P. V. Nikitin, R. Martinez, S. Ramamurthy, H. Leland, G. Spiess, and K. Rao, "Phase based spatial identification of uhf rfid tags," in *2010 IEEE International Conference on RFID (IEEE RFID 2010)*, pp. 102–109, IEEE, 2010.

[3] M. Scherhäufl, M. Pichler, and A. Stelzer, "Uhf rfid localization based on evaluation of backscattered tag signals," *IEEE Transactions on Instrumentation and Measurement*, vol. 64, no. 11, pp. 2889–2899, 2015.

[4] N. D. Rohmat Rose, T. J. Low, and M. Ahmad, "3d trilateration localization using rssi in indoor environment," *International Journal of Advanced Computer Science and Applications*, vol. 11, no. 2, pp. 385–391, 2020.

[5] L. Vojtech, M. Nerada, J. Hrad, and R. Bortel, "Outdoor localization technique using active rfid technology aimed for security and disaster management applications," in *Proceedings of the 2015 16th International Carpathian Control Conference (ICCC)*, pp. 586–589, IEEE, 2015.

[6] A. Buffi, P. Nepa, and F. Lombardini, "A phase-based technique for localization of uhf-rfid tags moving on a conveyor belt: Performance analysis and test-case measurements," *IEEE Sensors Journal*, vol. 15, no. 1, pp. 387–396, 2014.

[7] M. Jaboyedoff, T. Oppikofer, A. Abellán, M.-H. Derron, A. Loye, R. Metzger, and A. Pedrazzini, "Use of lidar in landslide investigations: a review," *Natural hazards*, vol. 61, no. 1, pp. 5–28, 2012.

[8] O. Monserrat, M. Crosetto, and G. Luzi, "A review of ground-based sar interferometry for deformation measurement," *ISPRS Journal of Photogrammetry and Remote Sensing*, vol. 93, pp. 40–48, 2014.

[9] J. A. Gili, J. Corominas, and J. Rius, "Using global positioning system techniques in landslide monitoring," *Engineering geology*, vol. 55, no. 3, pp. 167–192, 2000.

[10] M. Le Breton, L. Baillet, E. Larose, E. Rey, P. Benech, D. Jongmans, and F. Guyoton, "Outdoor uhf rfid: Phase stabilization for real-world applications," *IEEE Journal of Radio Frequency Identification*, vol. 1, no. 4, pp. 279–290, 2017.

[11] M. Le Breton, L. Baillet, E. Larose, E. Rey, P. Benech, D. Jongmans, F. Guyoton, and M. Jaboyedoff, "Passive radio-frequency identification ranging, a dense and weather-robust technique for landslide displacement monitoring," *Engineering geology*, vol. 250, pp. 1–10, 2019.

[12] A. Charléty, E. Larose, M. Le Breton, L. Baillet, and A. Helmstetter, "2d phase-based rfid localization for on-site landslide monitoring," 2022.

[13] M. Le Breton, N. Grunbaum, L. Baillet, and É. Larose, "Monitoring rock displacement threshold with 1-bit sensing passive rfid tag," in *EGU General Assembly Conference Abstracts*, pp. EGU21–15305, 2021.

[14] F. Guzzetti, S. Peruccacci, M. Rossi, and C. P. Stark, "Rainfall thresholds for the initiation of landslides in central and southern europe," *Meteorology and atmospheric physics*, vol. 98, no. 3, pp. 239–267, 2007.

[15] A. Buffi, A. Motroni, P. Nepa, B. Tellini, and R. Cioni, "A sar-based measurement method for passive-tag positioning with a flying uhf-rfid reader," *IEEE Transactions on Instrumentation and Measurement*, vol. 68, no. 3, pp. 845–853, 2018.