Nat. Hazards Earth Syst. Sci., 17, 881–885, 2017
https://doi.org/10.5194/nhess-17-881-2017

Natural Hazards and Earth System Sciences
Open Access

Brief Communication: A low-cost Arduino®-based wire extensometer for earth flow monitoring

Luigi Guerriero[1], Giovanni Guerriero[2], Gerardo Grelle[1], Francesco M. Guadagno[1], and Paola Revellino[1]

[1]Department of Science and Technology, University of Sannio, 11 Port'Arsa street, 82100, Benevento, Italy
[2]Independent researcher, 5 Accesso alla Nazionale street, 83010, Capriglia Irpina, Avellino, Italy

Correspondence to: Luigi Guerriero (luigi.guerriero@unisannio.it)

Received: 20 February 2017 – Discussion started: 22 February 2017
Revised: 8 May 2017 – Accepted: 16 May 2017 – Published: 14 June 2017

Abstract. Continuous monitoring of earth flow displacement is essential for the understanding of the dynamic of the process, its ongoing evolution and designing mitigation measures. Despite its importance, it is not always applied due to its expense and the need for integration with additional sensors to monitor factors controlling movement. To overcome these problems, we developed and tested a low-cost Arduino-based wire-rail extensometer integrating a data logger, a power system and multiple digital and analog inputs. The system is equipped with a high-precision position transducer that in the test configuration offers a measuring range of 1023 mm and an associated accuracy of ±1 mm, and integrates an operating temperature sensor that should allow potential thermal drift that typically affects this kind of systems to be identified and corrected. A field test, conducted at the Pietrafitta earth flow where additional monitoring systems had been installed, indicates a high reliability of the measurement and a high monitoring stability without visible thermal drift.

1 Introduction

Earth flow activity alternates between long periods of slow and/or localized movements and surging events (e.g. Guerriero et al., 2015). Slow movement is normally concentrated along lateral-slip surfaces (Fleming and Johnson, 1989; Gomberg et al., 1995; Coe et al., 2003; Guerriero et al., 2016) which consist of fault-like segments (e.g. Segall and Pollard, 1980) locally associated with cracks arranged in en echelon sets (Fleming and Johnson, 1989). Movement velocity is controlled by hydrologic forcing, and seasonal acceleration and deceleration are induced by variation of the pore-water pressure (e.g. Iverson, 2005; Grelle et al., 2014). Thus, most earth flows move faster during periods of high precipitation or snowmelt than during drier periods, and the correlation between precipitation and velocity is normally complex (Coe et al., 2003; Schulz et al., 2009). Earth flow surges can occur when prolonged rainfalls are associated with the loss of efficient drainage pathways (Handwerger et al., 2013) and new sediment becomes available in the source zone through retrogression of the upper boundary (e.g., Guerriero et al., 2014). In these conditions, the earth flow material can fluidize and fail catastrophically.

Each different kinematic behavior materializes a specific hazard level that needs to be quantified on the basis of monitoring data. An accurate identification of hazard also includes the understanding of factors controlling earth flow movement (Schulz et al., 2009). In this way, a continuous record of earth flow displacement and its environmental drivers is essential in defining the dynamic of the process (e.g. Corominas et al., 2000). Additionally, for earth flow involving human infrastructures (e.g. roads and railroads) displacement monitoring is crucial for understanding the ongoing evolution and designing mitigation measures.

Displacement monitoring can be completed with a variety of instrumentations (e.g. rTPS, GPS), but most of them (i) do not allow nearly continuous monitoring, (ii) imply time-consuming and expensive monitoring campaigns and/or (iii) cannot be integrated with additional sensors (Corominas et al., 2000). Wire extensometers are particularly suitable for continuous monitoring, especially when it is concentrated along well-defined shear surfaces, and can be easily integrated in multisensor monitoring systems. Major dis-

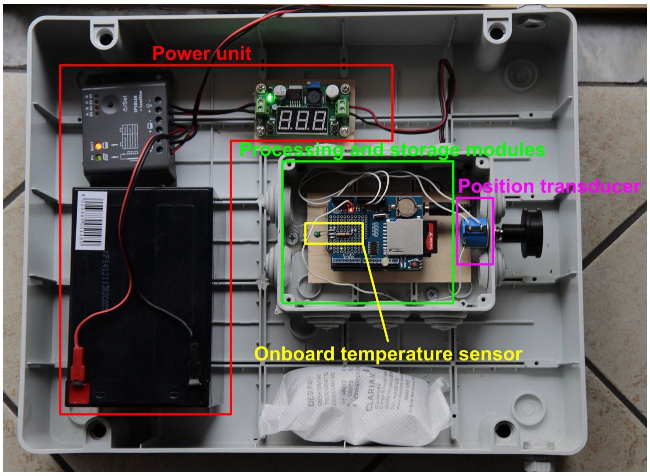

Figure 1. The Arduino-based extensometer after the assemblage. Major electronic components are labeled.

advantages of extensometers are their cost (a single-point high-performance sensor is sold at ∼ EUR 1000) and their sensitivity to temperature is also a function of the characteristics of cabling systems. In this paper, we present a new Arduino®-based wire-rail extensometer specifically developed for monitoring earth flow movement. We chose the Arduino board because it has been successfully used for the development of monitoring systems for different applications (e.g. Bitella et al., 2014; Di Gennaro et al., 2014; Lockridge et al., 2016). The system integrates a power unit, a data logger and an operating temperature sensor, has a very low cost (∼ EUR 200), is configurable with different measurement ranges and accuracy and has the potential to work with additional sensors. We test extensometer performance at the Pietrafitta earth flow in southern Italy and compare its measurements with those derived by successive GPS surveys and discrete rTPS measurements.

2 Extensometer components, structure, and code logic

The extensometer is composed of (i) processing and storage modules, (ii) an on-board operating temperature sensor, (iii) a linear position transducer, and (iv) a power unit (Fig. 1; a simplified assemblage guide is reported in the Supplement). The processing and storage modules are an Arduino Uno board and a XD-05 data logging shield, respectively. The Arduino Uno board is a user-friendly version of an integrated microcontroller circuit that uses an ATmega238p low-power CMOS 8-bit microcontroller. It has 14 digital input/output pins, 6 analog inputs, a 16 MHz quartz crystal, a USB connection, a power jack, an ICSP header and a reset button (https://www.arduino.cc). The presence of multiple digital and analog inputs make this platform ready for reading multiple sensors. The data logging shield integrates a SD card read/write slot, a Real Time Clock

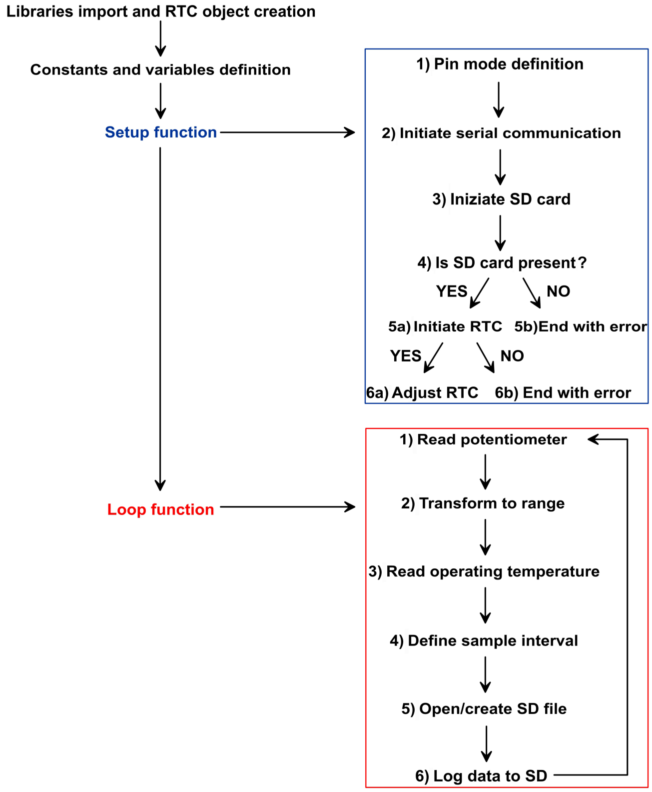

Figure 2. Flow chart showing acquisition and storage logic.

(RTC) module with coin cell battery backup and a prototyping area. In this way, monitoring data are logged in a SD card at a predefined interval and a date/time is associated. To choose this shield, we considered the presence of the RTC module and its cost. We chose the cheapest. The operating temperature sensor consists of a 10 K thermistor characterized by a tolerance of ±5 %. It is installed with a reference resistor of 10 K in the prototyping area of the logging shield (see wiring schematic in the code attached as supporting material). For our test, the thermistor was calibrated between −10 and 40 °C and obtained Steinhart–Hart coefficients were used for temperature estimation. Steinhart–Hart coefficients were calculated using a SRS Thermistor Calculator (http://www.thinksrs.com/downloads/programs/ThermCalc/NTCCalibrator/NTCcalculator.htm). We estimated temperature error by comparing thermistor measurements with a precision thermometer (accuracy ±0.05 °C) in laboratory controlled conditions. The RMSE calculated on the basis of 40 observations (between −5 and 35 °C) was ∼ 1 °C. The linear position transducer is responsible for measuring cumulated displacement and consists of a 1Kohms Bourns 3540S-1-102L precision potentiometer equipped with a 3-D printed pulley. For our development and test we used a pulley of 33 mm in diameter made of ABS (acrylonitrile butadiene styrene) plastic, the design files of which (.obj and .skp) are reported in the Supplement. This

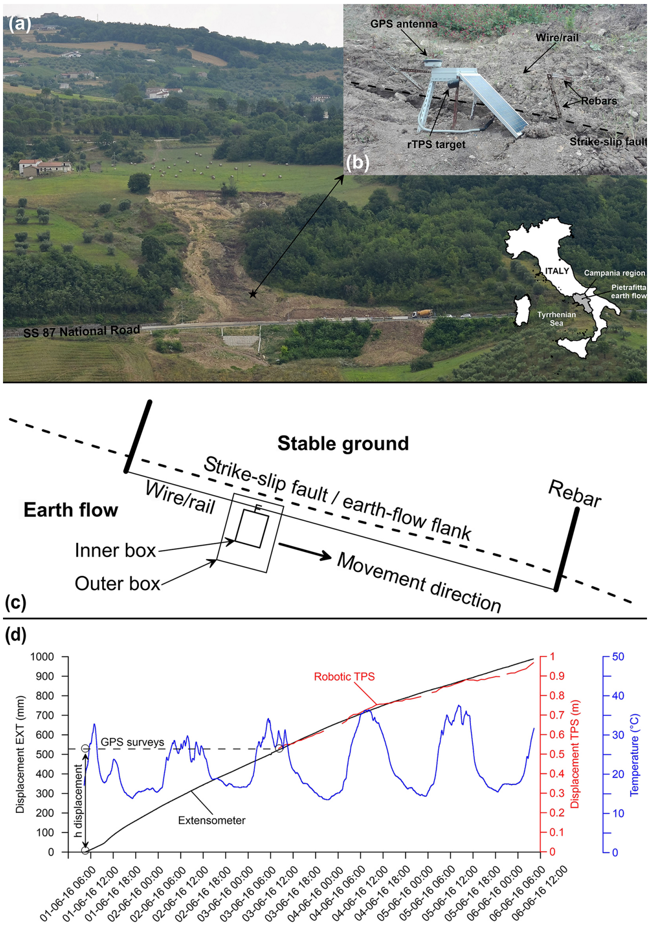

Figure 3. **(a)** The Pietrafitta earth flow in the Appenine mountains of southern Italy, Campania region. The black star indicates the position of the extensometer during the field test. **(b)** Installation configuration and monitoring equipment for comparative analysis. **(c)** Installation scheme. **(d)** Results of displacement monitoring with the extensometer and comparison with GPS derived and rTPS results. Black circles indicate error associated with GPS surveys. Operating temperature measured by the extensometer is also shown.

allows a measurement range of 1023 mm and an associated accuracy of ±1 mm (nominal accuracy of 0.1 %). Such a range can be varied using a pulley with different diameter. A change in range results in a change in accuracy and resolution. The pulley was printed using a 3-D PRN LAB54 printer and an ABS filament of 1.75 mm in diameter (specific density 1488 kg m^{-3}). The filament was extruded at 210 °C with a velocity of 30 mm s^{-1}.

The system is powered using a 50 w solar panel and 12 V, 12 Ah battery. Since the Arduino Uno has a broad power input range (recommended 7–12 V), and in order to avoid overheating of the board connected to the use of a 12 V power input voltage, a DC-DC converter is used to stabilize power voltage to 7.2 V. The processing and storage module, the onboard operating temperature sensor and the linear position

Table 1. Individual cost and seller type of each component of the monitoring system.

Components*	Cost** (EUR)	Seller
Arduino Uno board	22.0	Online
Data logging shield	10.0	Online
Precision potentiometer	18.0	Online
3-D pulley printing	5.0	Local
10 k thermistor + 10 k resistor	2.0	Local
Led	0.5	Local
RTC coin cell battery	2.5	Local
DC-DC converter	10.0	Online
50 W Solar panel + 12 Ah battery + 5 A regulator	60.0	Online
Inner box	8.0	Local
Outer box + cable glands	36.0	Local
Cables + connector	5.0	Local
Wood panel (40 × 50 cm)	7.0	Local
Glue + rivets	10.0	Local
Rebars + screws	25.0	Local
Extensometer cable (steel fishing line)	3.0	Local
Total	224.0	

* Minor components like board supports are not considered in the list because they were already available. ** Online cost does not include shipping fees. Total shipping fees are around EUR 35.

transducer are housed in a 15 × 10 × 7 cm waterproof box that, together with the power system, is housed in a second larger 40 × 30 × 15 cm waterproof box. Such a modular structure is used to protect both electronic and mechanic components from environmental conditions and allow very short cables to be used that, as well as the modular structure, prevent the system from thermal drift.

The code for the extensometer has been developed and compiled using the Arduino IDE environment and open source code-string available online. The logic of the code is reported in Fig. 2 and the code is reported in the Supplement as well as the sensors wiring schematics. The final cost of the extensometer was around EUR 200 including additional installation equipment (see Table 1; e.g. rebars, wire, screw etc. . . .). Additionally, even if it has been developed specifically for earth flows it can be used for all types of landslide that move along well-defined lateral-slip surfaces, and with specific improvements it can also be installed in different position such as at the head of a landslide.

3 Installation and testing at the Pietrafitta earth flow

We test the extensometer performance at the Pietrafitta earth flow (Fig. 3a) in the Apennine mountains of southern Italy (Campania region, Province of Benevento). Since 2006, this earth flow has been periodically active, exhibiting an alternation of slow persistent movements and rapid movement especially localized at the toe of the flow. We chose this earth flow because it is actively moving, its movement occurs largely along a lateral well-defined shear surface (e.g. Gomberg et al., 1995) and is monitored using both discrete GPS surveys and nearly continuous rTPS measurements. We installed our low-cost Arduino-based extensometer along the left flank of the earth flow toe (Fig. 3b). The installation was completed using a 2.5 m long wire supported by several rebars, which forms a rail parallel to the strike-slip fault, materializing the left flank of the flow. In this way, the extensometer is dragged/moves along the flank registering the cumulative displacement (scheme is shown in Fig. 3c) every 30 s. We used available displacement data to make a comparative analysis of the monitored displacement. To compare displacement measured with different systems, we installed a GPS antenna screw mounting and a rTPS target on the wire extensometer (Fig. 3b). Raw data measured with our monitoring systems are shown in the graph of Fig. 3d. In particular, the earth flow toe moved approximately 1 m in 6 days and 6 h. The average velocity calculated on the basis of these data was $\sim 6.6\,\mathrm{mm\,h^{-1}}$. In this part of the flow, the movement was largely dominated by the horizontal component. This makes it possible to compare the displacement measured by the extensometer and the horizontal component of the displacement vectors reconstructed with both the GPS surveys and the rTPS. The comparison of the results indicates that the total displacement measured by our extensometer was approximately the same as that measured by combining GPS and rTPS surveys. The difference between total displacement measured by the combination of GPS surveys and rTPS and the extensometer was around 1.5 cm (1.5 %). Additionally, the displacement time series reconstructed using rTPS data perfectly fits the extensometer time series for the first 4 days of rTPS monitoring, despite a slight thermal drift of the rTPS (see red curve of Fig. 3d). In the successive 2 days the degree of fit seems to decrease and affects the measured total displacement. This was probably also caused by the deformation of the rail induced by the tilting of the ground surface around the extensometer. Despite this drawback, the system exhibits a very high monitoring stability without visible thermal drift, also at operating temperatures higher than 35 °C.

4 Concluding remarks and possible future improvements

The Arduino-based extensometer was developed to provide a low-cost improved platform for continuous earth flow/landslide monitoring. The prototype was developed on the basis of the Arduino Uno board and integrated a data logging RTC shield and an operating temperature sensor. It was equipped with a high-precision position transducer that in the test configuration offers a measuring range of 1023 mm and an associate accuracy of ± 1 mm. The field test indicates a high reliability of the measurement and the importance of the rail setup. In particular, for horizontal displacement monitoring it is important to consider the topography of the surface of the flow and possible surface deformation caused by movement. In this way, periodic inspection of the system needs to be planned. Major advantages of the system are (i) the very low cost, (ii) the presence of an integrated data logger, (iii) the potential to integrate it with additional sensors, (iv) the possibility for use with different types of landslides.

Even though our test indicates the ability of the system to work in real field conditions by providing reliable data, we have to consider that our test was very short, and in only 6 days our extensometer reached the maximum measurable displacement (average velocity of $6.6\,\mathrm{mm\,h^{-1}}$). Thus, for very low velocities and very long monitoring periods it might be useful to use a 12 bit Arduino DUE board that permits an increase of 4 times the resolution and/or the range. The system can be integrated with a data transmission shield that allows near real time data transmission and has the potential to be used in landslide emergency scenarios. To further reduce the cost of the device it would be possible to use the Arduino Pro Mini board that is cheaper than the Arduino Uno and has a lower power consumption that allow to choose also a cheaper power system and smaller housing boxes. Additionally, we have planned to replace the ABS plastic pulley with an aluminium pulley that should ensure a higher durability. This change might increase the cost of the system.

Data availability. Data are available upon request by contacting the corresponding author (luigi.guerriero@unisannio.it).

The Supplement related to this article is available online at https://doi.org/10.5194/nhess-17-881-2017-supplement.

Competing interests. The authors declare that they have no conflict of interest.

Acknowledgements. We thank Rolf Hut and an anonymous reviewer for their constructive reviews of the paper. We thank Remo Pedace of 3-D MAKERS (Avellino, Italy) for his assistance in printing the pulley.

Edited by: T. Bogaard
Reviewed by: R. Hut and one anonymous referee

References

Bitella, G., Rossi, R., Bochicchio, R., Perniola, M., and Amato, M.: A Novel Low-Cost Open-Hardware Platform for Monitoring Soil

Water Content and Multiple Soil-Air-Vegetation Parameter, Sensors, 14, 19639–19659, 2014.

Coe, J. A., Ellis, W. L., Godt, J. W., Savage, W. Z., Savage, J. E., Michael, J. A., Kibler, J. D., Powers, P. S., Lidke, D. J., and Debray, S.: Seasonal movement of the Slumgullion landslide determined from Global Positioning System survey and field instrumentation, July 1998 – March 2002, Eng. Geol., 68, 67–101, 2003.

Corominas, J., Moya, J., Lloret, A., Gili, J. A., Angeli, M. G., Pasuto, A., and Silvano S.: Measurement of landslide displacements using a wire extensometer, Eng. Geol., 55, 149–166, 2000.

Di Gennaro, S. F., Matese, A., Mancin, M., Primicerio, J., and Palliotti, A.: An Open-Source and Low-Cost Monitoring System for Precision Enology, Sensors, 14, 23388–23397, 2014.

Fleming, R. W. and Johnson, A. M.: Structures associated with strike-slip faults that bound landslide elements, Eng. Geol., 27, 39–114, 1989.

Gomberg, J., Bodin, P., Savage, W. Z., and Jackson, M. E.: Landslide faults and tectonic faults, analogs: the Slumgullion earthflow, Colorado, Geology, 23, 41–44, 1995.

Grelle, G., Soriano, M., Revellino, P., Guerriero, L., Anderson, M. G., Diambra, A., Fiorillo, F., Esposito, L., and Guadagno F. M.: Space-time prediction of rainfall-induced shallow landslides through a combined probabilistic/deterministic approach optimized for initial water table condition, B. Eng. Geol. Environ., 73, 877–890, 2014.

Guerriero, L., Coe, J. A., Revellino, P., Grelle, G., Pinto, F., and Guadagno, F. M.: Influence of slip-surface geometry on earth flow deformation, Montaguto earth flow, southern Italy, Geomorphology, 219, 285–305, 2014.

Guerriero, L., Diodato, N., Fiorillo, F., Revellino, P., Grelle, G., and Guadagno, F. M.: Reconstruction of long-term earth-flow activity using a hydro-climatological model, Nat. Hazards, 77, 1–15, 2015.

Guerriero, L., Revellino, P., Luongo, A., Focareta, M., Grelle, G., and Guadagno, F. M.: The Mount Pizzuto earth flow: deformational pattern and recent thrusting evolution, Journal of Maps, 12, 1187–1194, 2016.

Handwerger, A. L., Roering, J. J., and Schmidt, D. A.: Controls on the seasonal deformation of slow-moving landslides, Earth Planet. Sc. Lett., 377–378, 239–247, 2013.

Iverson, R. M.: Regulation of landslide motion by dilatancy and pore pressure feedback, J. Geophys. Res.-Earth, 110, 1–16, 2005.

Lockridge, G., Dzwonkowski, B., Nelson, R., and Powers, S.: Development of a Low-Cost Arduino-Based Sonde for Coastal Applications, Sensors, 16, 1–16, https://doi.org/10.3390/s16040528, 2016.

Schulz, W. H., Mackenna, J. P., Kibler, J. D., and Biavati, G: Relations between hydrology and velocity of a continuously moving landslide – evidence of pore pressure feedback regulating landslide motion?, Landslides, 6, 181–190, 2009.

Segall, P. and Pollard, P. P.: Mechanics of discontinuous faults, J. Geophys. Res.-Sol. Ea., 85, 4337–4350, 1980.