Brief communication: monitoring a soft-rock coastal cliff using webcams and strain sensors

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Abstract. In this brief communication, we describe a case study about monitoring a soft-rock coastal cliff using webcams and a strain sensor, located in the Apulia region (southeastern Italy). In this urban and touristic area, coastal recession is extremely rapid and rockfalls are very frequent. Using low-cost and open source hardware and software, we are monitoring the area, trying to correlate both meteorological information with measures obtained from the crack-meter and webcams, aiming to recognize potential precursor signals that could be triggered by instability phenomena.

1 Introduction

Among the geo-hydrological instability phenomena that affect the Apulia region, the rockfall hazard affecting the coastal areas characterized by high cliffs formed of soft rocks is of high scientific interest, mainly due to the possible interaction with nearby infrastructures and urban areas.

The evolution of these cliffs and their collapse is well known among the scientific community (Sunamura 1992, Adams et al. 2005, Stephenson and Naylor 2010, Sansò et al. 2016, Fazio et al. 2019), but currently there are no consolidated methods concerning the monitoring of these phenomena with a spatial and temporal resolution suitable for prediction and alerting purposes. Along these cliffs, brittle failures are frequent, resulting in entire cliffs sectors that suddenly are involved in rockfalls without any appreciable precursor signal. The main elements that contribute to the collapse are the poor geomechanical properties of the rock materials combined with environmental forcing, such as sea waves, winds, rainfalls and temperature variations (Perrotti et al. 2020; Lollino et al. 2021). In our study, we want to pursue a monitoring approach with two main aims: i) the integration of conventional geotechnical sensors with digital images and videos processing; ii) the detection of potential precursor signals that could occur in case of instability phenomena.

2 Study area

The coastal area of Melendugno, located in the southeastern area of the Apulia region (latitude 40°16'45"N and longitude 18°25'53"E), has been characterized by a large number of rockfall events in the last decades (Lollino et al. 2021). Coastal erosion phenomena are continuously evolving and many sites have reached a high degree of geomorphological hazard, due to the close presence of roads, infrastructures and urban areas. From a geological point of view, the area is characterized by the outcropping of the "Uggiano la Chiesa" Formation, dating back to the upper Pliocene-lower Pleistocene, which is formed of stratified marly calcisiltites and biocalcarenites, of low mechanical strength and highly susceptible to water-induced weakening processes. A specific sector of the local coastline has shown a significant coastal recession in the last years due to recurring rockfalls, with an average retreat rate estimated in approximately 0.10-0.15 m/year as described in Lollino et al. (2021). Moreover, laboratory testing carried out by the authors on rock samples taken from the study area (or of the same typology) has confirmed that even rock of low mechanical strength can exhibit brittle failure (Lollino & Andriani 2017, Perrotti et al. 2020). Therefore, an integrated monitoring system has been specifically designed in order to control the evolution of the coastal sector and the corresponding recession rate.

3 Materials and methods

Automatic monitoring of geo-hydrological phenomena allows high frequency data acquisition that enables advancements in the analysis of the phenomena and their evolution. In particular, due to the reduced temporal delay between sequential measurements, rapidly evolving brittle processes can be even explored and eventually correlated with external variables. To ensure such a frequent monitoring, however, it is necessary to have both software and hardware that are able to adequately support all the activities of the system, in addition to a suitable power supply system (Herrera et al. 2011, Intrieri et al. 2015, Allasia et al. 2020).

In our study, we decided to implement a digital photographic monitoring system that follows these principles (Giordan et al. 2016, Dematteis et al. 2021) and that is based mostly on open source hardware and software, ensuring a flexible and low-cost system. In particular, we choose a Raspberry Pi Zero W (https://www.raspberrypi.org/) as the main control unit. This single board computer is connected wirelessly to two webcams: a main camera (a commercial 2 Mpixel PTZ Foscam - https://www.foscam.it/) and a secondary one (a 2 Mpixel bullet-model Foscam). Moreover, it integrates an additional 8 Mpixel webcam cabled directly to its Camera Serial Interface: the Raspberry Camera Module. All these optical sensors constantly monitor the area 24 hours a day also thanks to the IR capability, storing videos in full-HD and photos. In particular, webcams continuously record videos and take shots every few seconds, while the Raspberry Camera Module takes only shots at timed interval. The periodically acquired images are analyzed and, in case of a possible rockfall between two consecutive photos, we analyze the corresponding videos, to obtain further details. This can be achieved either manually or using artificial intelligence techniques (i.e. Image Change Detection), leading to an automated and smart system.

The two webcams are mounted on two different poles distant approximately 50 meters, watching each other and looking at different sides of the cliff (see top of fig. 1). Each camera (that is around 5 meters from the cliff) has its own solar panel, charge controller and 12V battery; on the main camera pole, there is also a 4G wireless router with an IP voltmeter and a relay. Thanks to the router, it is possible to connect remotely to the Raspberry (i.e. via SSH) to have a complete control, in addition to changing webcams configuration and orientation. Moreover, the IP voltmeter let us know in real time the system voltage, while the relay allows turning on/off any device (router, Raspberry or webcam). Finally, it is possible to obtain all the data by uploading photographs and videos automatically and periodically to a FTP server, in real time. This system has been installed at the end of May 2019, while on 12 February 2020 we added an electric crack-meter on the most evident fracture present on the cliff (see bottom of fig. 1). This crack-meter has an accuracy of $0.1 \div 0.3$ mm and is remotely connected with the FTP server. In addition to photos, videos and crack-meter measurements, we constantly download data from a neighboring weather station managed by the Civil Protection, in order to correlate the information logged from the cameras and the crack-meter with the meteorological variables such as temperature, rainfall rate, wind speed and direction. The analysis is carried out using a code written in R language (R Core Team 2021).

4 Results

In these two years of activity, the monitoring system recorded several events. The first remarkable event occurred between 12 November 2019 (after h09:00) and 14 November 2019 (before h08:30) when a collapse of a large part of the cliff took place (see fig. 2). Unfortunately, when the failure occurred, the instrumentation was inactive due to the lack of energy caused by the severe rainstorm that struck the area for few days; moreover, no crack-meter was still available (see bottom of fig. 1). Despite these issues, both images and videos just before and after the collapse were available. Based on such information and the application of Image Change Detection techniques, we estimated a volume of the collapse equal to 300 m^3 $\pm$ 30% following the methods described in Giordan et al. (2020).

Two other rockfall events took place on 23 June 2020, around h17.05 (bottom of fig. 1, green area), and on 28 June 2020, approximately between h9.00 and h11.00. In the latter event, the cameras, despite the area being under restricted access, also detected the presence of a passer-by; this anthropogenic disturbance interfered with the crack-meter measurements. This event confirmed that crack-meter devices alone cannot be used to monitor areas like the examined one and an optical system is fundamental to have an additional control on the global factors acting on the site.

The last recorded event is related to the rockfall that occurred on 7 December 2020 h04.15. In this case, crack-meter data starting from July 2020 show a slight trend of the monitored fissure, which is seen to gradually enlarge, up to the time of failure (bottom of fig. 1, red area). Unfortunately, at that time, the optical instrumentation was off due to the lack of power caused by the adverse weather conditions: in the previous 96 hours, a rather intense rainfall event occurred, which reached a peak of 24h-cumulative precipitation of 80 mm. Despite this issue, however, the images and videos obtained before and after the event are consistent with what was detected by the sudden deviation in the data of the crack-meter. The fracture monitored by the

instrument was not directly affected by the collapse, since the collapse involved a rock block not far from it, while the crack-
meter itself recorded, at the time of failure, a contraction of approximately 1 mm. In this case, following the same approach, it
was possible to estimate the volume of the collapse, which resulted to be about 20 m^3 ± 30%. Based on the data acquired by
the secondary camera, we have also observed that the collapse itself occurred in two stages: the most conspicuous part, as
already mentioned, collapsed around h04.15, while a second detachment, considerably smaller, occurred between h11.00 and
h16.30 on the same day, without affecting the crack-meter measurements (see fig. 3).

5 Concluding remarks

An optical monitoring system (integrated by conventional strain measurement devices) for the control of a coastal rock cliff
has been presented in this paper and the data acquired through the last two years have been briefly discussed. The data indicate
that the combination of frequently acquired digital images with local displacement measurements can provide useful
information regarding the evolution of the rock cliff. In particular, digital images can give information on the rock volumes
progressively subjected to detachment and collapse, thus providing clear indications on the evolution of the cliff recession and
the areas highly susceptible to instability, as well as on the correlation of the failure events with potential triggering factors.
Strain sensors, instead, can offer detailed information on the local enlargement or closure behavior of single fractures and
joints, to be related to the information obtained from the optical images.

In all the events described above, adverse conditions (i.e. severe storms, battery outage and human disturbance) prevented us
to obtain direct optical information on the collapse itself and to detect potential precursory signs of the failure. However, the
data acquired show that, even in such adverse cases, the monitoring system is capable of giving valuable information, even
using only shots that are antecedent and subsequent to the failure event.

The choice of using a single strain sensor is only due to the fact that we are experimenting a very low-cost monitoring system;
in other cases, this system can be extended with as many crack-meters as needed.

Moreover, despite being a low-cost solution, this system demonstrated a lot of potential, especially in flexibility and
adaptability, since it allows to readily estimate the volume of the fallen blocks as well as the evolving failure mechanism of
the examined coastal sector and, as such, the potential evolution of the coast retreat. As a consequence, it could be easily
applied to the monitoring of different coastal areas subject to rockfalls.

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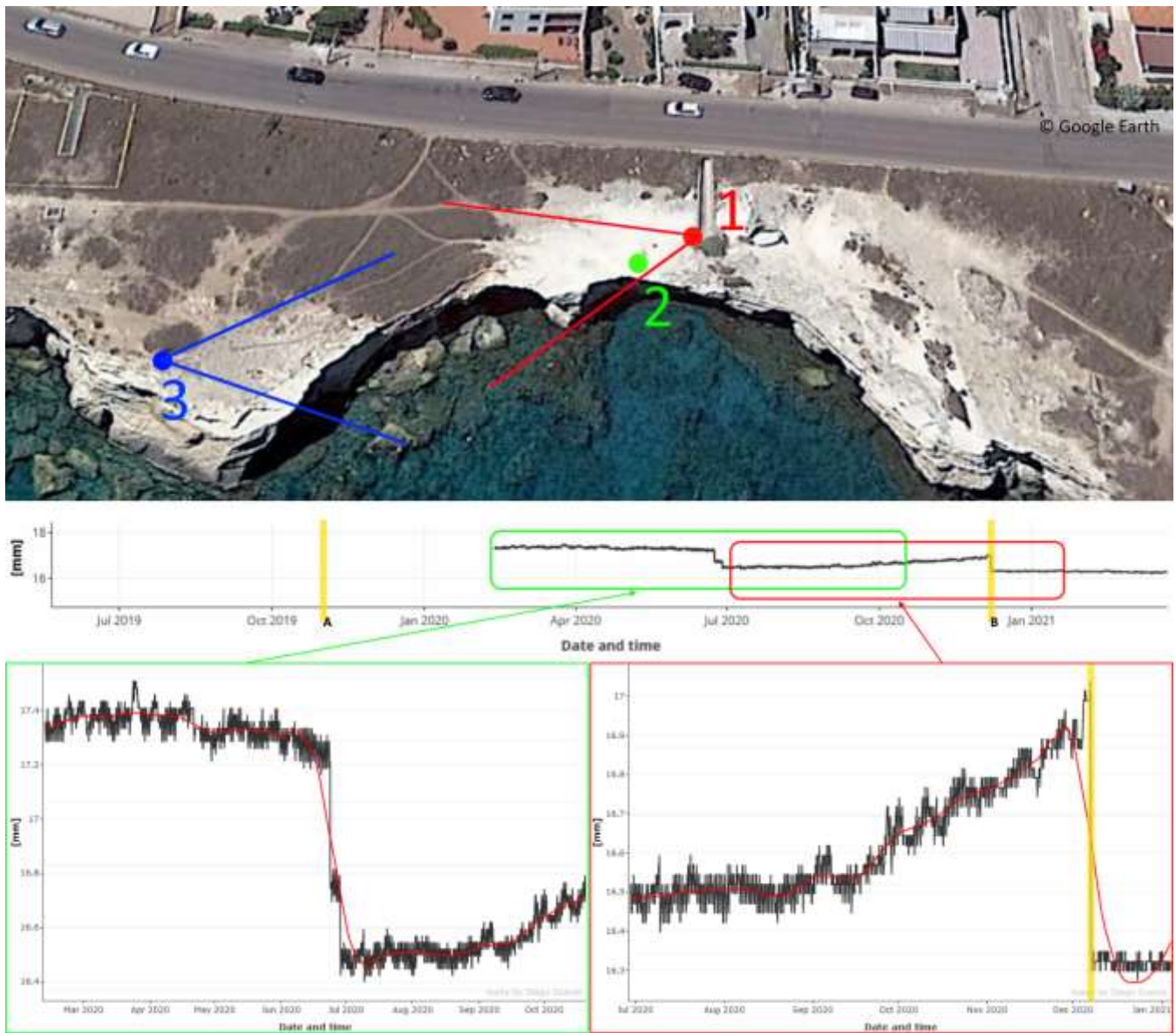


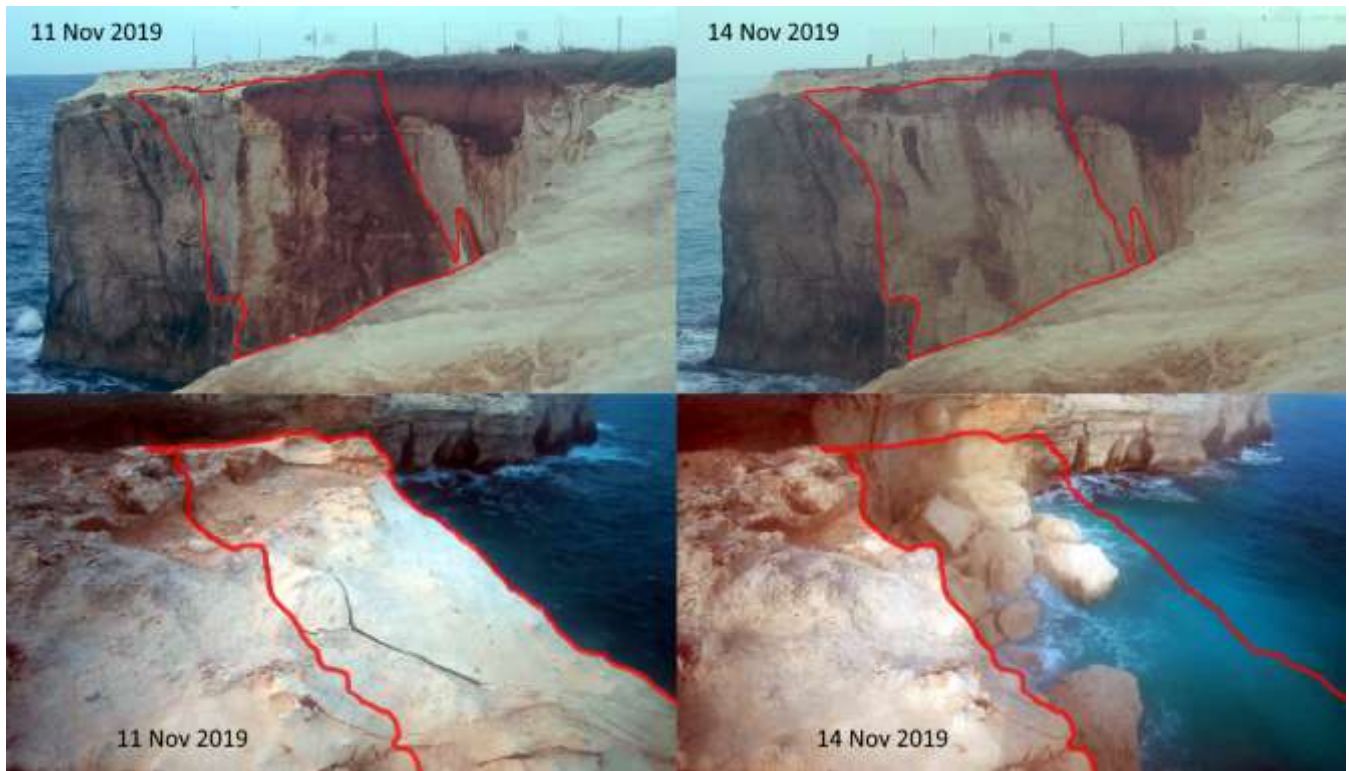
Figure 1: on top, plan of the monitored cliff area (taken from Google Earth) – In red (marked with "1"), the main camera position and the Raspberry Camera Module field of view; in blue (marked with "3") the secondary camera; the green dot marked with "2" is the position of the crack-meter. On bottom, the crack-meter data – In the green box the first period of data obtained using the automatic crack-meter (from 12 February 2020 up to 20 October 2020). In the red box the second period of data of the same crack-meter (going from 29 June 2020 to 04 January 2021). Two main rockfalls have been noticed in this period and have been marked with the "A" and "B" yellow lines.

170   **Figure 2: the first rockfall (marked with "A" on fig. 1) – Top left image shows the cliff as it was on 11 November 2019 and the top right image shows as it was 3 days later (both images are taken from the Raspberry Camera Module – see fig. 1 for the position). Bottom images shows the same event but from a different point of view (the secondary camera – see fig. 1 for the position): on the left, a picture taken before the collapse and on the right, a picture taken on 14 November 2019.**

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Figure 3: the second rockfall (marked with "B" on fig. 1) – Top left image shows the cliff as it was on 4 December 2020 and the top right image shows as it was on the morning of the 7 December 2020, after the main collapse (marked by the thick red line). Bottom right images shows the cliff as it was on the 8 December 2020, after a minor rockfall (marked by the thin red line). Those three images are taken from the secondary camera (see fig. 1 for the position). On the bottom left part, two smaller images that shows the
180 **collapse from another point of view (the main camera, that could also be seen in the top left image, highlighted in green – see fig. 1 for the position) both before the rockfall (on the left) and after it (on the right). On those images, the newly installed automatic crack-meter is also visible.**