Autonomous Remote Monitoring System for Landslides

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ABSTRACT

There is a general tendency in systems for environmental monitoring towards ever more automatic and autonomous operation. Moreover, technologies and instruments are available to reliably interconnect distributed, disparate components. This allows the measurement, logging, data processing and interpretation activities to be carried out by separate units at different locations in near real-time.

Building on the results of a previous research and development project at SUPSI, which focused on movement monitoring with GPS, the system has been generalized to accommodate a range of other sensors, thus rendering it even more interesting for geotechnical applications. In particular a laser distance meter and a robotized theodolite have been integrated. First results confirm an expected increase in robustness of the combined measurement network, which is particularly important in unfavorable stand-alone GPS reception conditions. Due to the modular architecture of the system, other sensor types, ranging from simple analog or digital sensors to complex measuring instruments may be supported with minimal effort.

Measurements are transmitted via cellular or point-to-point radio links to a control station, which provides for post-processing and system management. The control station may be remotely accessed via an Internet connection. The system takes advantage of a standard and flexible database structure which has been tailored to measurement and monitoring projects using different sensors.

The system represents an architecture for remote monitoring tasks requiring a high degree of autonomy, reliability and automation. The solution can be advantageously applied to remote, near real-time measurements of low dynamics movements.

Keywords: GPS, satellite, structural monitoring, movement monitoring, landslide, laser distance meter

1. INTRODUCTION

Is has been shown that Global Positioning System technology can provide differential position information with sub-centimeter level accuracy in structural and land monitoring applications. The system described in [3] operates a network of GPS receivers autonomously, and is connected by means of a wireless data link. In good sky visibility conditions, the system consistently achieves sub-centimeter accuracy and is independent of meteorological influences.

This novel approach is in contrast with commonly favored monitoring techniques which foresee measurement campaigns at regular intervals (usually months) and work by determining angles and distances between points using traditional optical instruments as theodolites or distance meters. The achievable level of precision with these instruments is generally high.

It is believed that in the field of permanent and continuous geotechnical monitoring, the integration of GPS with other traditional sensors allows a better interpretation of the measured data, in that movement phenomena or dynamics not measurable by one sensor can become apparent by using an additional sensor based on different principles.

Looking closely at the respective characteristics of the two methods, we can say that although traditional techniques exhibit a slightly higher degree of precision, when considering them for continuous monitoring tasks they are flawed by several important disadvantages:

- The precision of traditional optical methods is heavily dependent on environmental and meteorological conditions (day/night, temperature, pressure, rain and fog).
- With traditional methods, intervisibility and distance between measured points are fundamental requirements, while with GPS-based measuring methods these are by no means relevant issues.
- Traditional equipment exhibits difficulties inherent in setting up the instruments for unattended automatic operation over extended periods of time, brought about by the high cost of the equipment as well as the limited suitability for outdoors operation.

The respective advantages and disadvantages of the two measurement principles are summarized in the following table:

	Carrier Phase GPS with postprocessing	**Traditional optical sensors**
Dependency on temperature and pressure	low	high
Dependency on atmospheric conditions (day/night, rain, fog)	low	high
Measurement frequency	tens of minutes	seconds, minutes
Intervisibility between points	not required	required
Outdoor applications	yes	with limitations
Single measurement accuracy	< 10 mm	< 4 mm

Table 1: comparison between GPS and traditional sensors

Integrating additional sensors serves not only to increase the usefulness of the system in terms of measurement precision. In fact, when observing movements with slow dynamics as a large structure, often there is a need or interest in correlating the movements with other factors such as temperature, air humidity or solar irradiation.

2. MOTIVATION AND OBJECTIVES

The system is based on the results of a research project that has been carried out at the University of Applied Sciences of Southern Switzerland as a multidisciplinary collaboration between the University's Institute for Computer Integrated Manufacturing, ICIMSI, the Soil Mechanics Laboratory of EPFL, Lausanne and GEODEV SA.

Having demonstrated the technical and commercial feasibility of using self-contained, low-cost single-frequency GPS receivers to solve a class of movement monitoring problems with reasonably high accuracy, a first functional prototype of the system has been designed and developed. Its architecture was defined so that it could form the basis of a product line for structural and geotechnical monitoring. During the course of the project, the prototype has been extensively tested and improved, and subsequently a series of pre-production units have been built incorporating an additional sensor unit.

As noted in [3], a general requirement for such a monitoring system is that it must guarantee autonomous operation in extreme climatic conditions. Also, the set up of the measuring stations must be facilitated and the system must be remotely accessible for both configuration and measurement downloading activities. A further general requirement of such a system is its modular architecture, both for the hardware and the software components. This modularity allows flexibility and ease in adapting to new situations.

System requirements	Sensor requirements
modular architecture	compact size
ease of installation, configuration and maintenance	robustness and resistance to extreme environmental conditions
remote connectivity	autonomy from power supply
integration with other sensors	freedom from maintenance and on-site intervention

Table 2: System and sensors requirements

3. SYSTEM ARCHITECTURE

The system consists of a number of small mobile measuring stations including a GPS receiver unit installed on the object to be monitored, plus one or more mobile reference stations installed at fixed, possibly surveyed locations around the object. The reference stations units are identical to the mobile station units in every respect. Depending on the application, remote units are individually linked to a base station by a cable, a radio link or a cellular modem. The control station provides for data collection, monitoring for correct operation of the network. It is remotely accessible through a dedicated communication channel, including an internet dial-up connection.

The slow dynamics associated with geotechnical movements (mm/year to cm/day) do not impose high acquisition frequencies. For these applications, intervals between measurements of 15 to 30 minutes are more than adequate if the goal is to observe possible land movements or trends. On the other hand, single frequency GPS static measurements require the collection of about 10-20 minutes of measurement data, to be post-processed before yielding the final positional measurement. For this reason, using this kind of low-cost receiver is perfectly in line with the application requirements. Every measuring station will thus collect GPS observation data for a sufficient amount of time, and the data will be transmitted to the control station for post-processing.

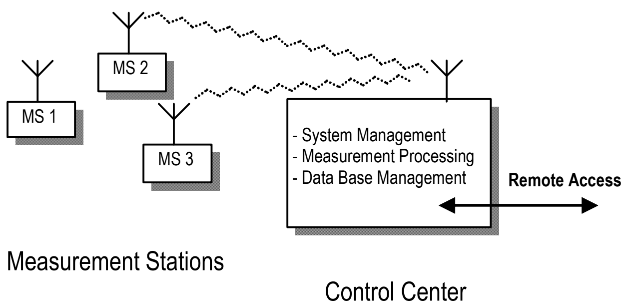


Figure 1: System architecture

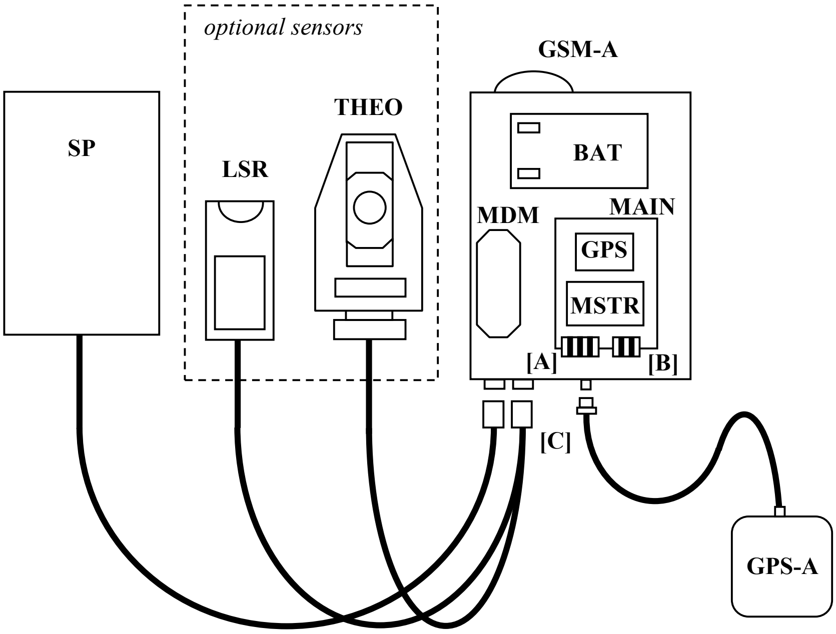
Figure 2: Mobile measuring station

The control station has the task of collecting the data from all receivers in the network while overseeing the single stations for correct operation. The GPS data will be processed together, and the result will consist of the relative position of the various mobile measuring stations with respect to the reference stations.

The operation of additional sensors connected to the remote stations is also managed by the control station, be it for the data acquisition or for the data transmission phases. Acquisition and transmission of additional sensor data may be carried out asynchronously to GPS receiver cycles.

4. REMOTE SENSORS

A remote sensor consists of GPS receiver, a communication transceiver, an ancillary data acquisition unit, and a power supply management unit. A central processing unit oversees overall operation and schedules measurement and communication tasks. Figure 3 shows a block diagram of the sensor unit. All electronic subsystems are mounted in an environmentally sealed enclosure.



Legend:

SP:	solar panel
LSR:	laser distance meter
THEO:	theodolite
GSM-A:	GMS antenna
MDM:	GSM / radio modem
GPS-A:	GPS antenna
GPS:	GPS receiver
BAT:	battery
MAIN:	mainboard
MSTR:	master
[A]:	3 analog input ports
[B]:	2 digital input ports
[C]:	RS-232 serial port

Figure 3: Sensor unit block diagram

The GPS receiver is a single-frequency receiver module characterized by low power consumption and good sensitivity. Since the stability of the local receiver reference clock is a factor influencing the precision of the carrier phase measurement, a high-quality clock source has been selected.

Ancillary sensors may be added to the single stations where desired. To this purpose, the unit is equipped with three additional analog input ports and two digital input ports. As part of the initial station configuration, these additional measurement channels may be defined in terms of measurement interval, scale and resolution. When the equipment is in use, measurements from the ancillary sensors can be asynchronously logged and transmitted to the base station on demand. A spare RS-232 serial port is also provided for connection to an "intelligent" external sensor. Presently, a laser distance meter and a motorized theodolite have been successfully connected.

A CPU runs a real-time operating system and a multi-task program written in standard "C". The program oversees the operation of the whole sensor, manages the data acquisition and implements the communication protocols. Activation and deactivation of the single subsystems is sequenced according to the configuration. Care has been exerted in developing the program to reduce power consumption of the sensor unit to a minimum. The CPU spends most of the time in a "doze" state with very low power consumption, and periodically wakes up to attend to measurement or communication tasks.

An important requirement is the ability for the measuring units to operate for extended intervals in total autonomy and without requiring on-site human intervention. Fitting each station with an accumulator and a solar panel enables autonomous operation over extended periods of time, while the unit itself is essentially maintenance-free.

5. EXTERNAL SENSORS

Figure 4: Integrated laser distance meter

In the field of geotechnical movement monitoring, additional sensors are useful mainly to increase the precision and robustness of positional measurements from the main sensor. In our system, an additional sensor generally serves to compensate one or more shortcomings inherent in the GPS measurement. A typical example is when a sensor must be installed in a location with limited visibility of the sky. A good sky visibility is important for the precision and quality of GPS measurements. In such a case, the GPS sensor can be supplemented by e.g. a laser distance meter measuring the distance between the point in question and another one. This arrangement allows the first point to be integrated in the measurement network, compensating the loss of measurement precision and quality due to the non-ideal conditions for GPS.

Figure 4 shows the integrated laser distance meter developed by the Soil Mechanics Laboratory of EPFL, Lausanne.

The following table compares the performance of GPS with that of a typical laser distance meter.

	L1 Phase GPS with postprocessing	**Laser distance meter**
Max. baseline length	10 – 15 Km	500-600 m (with reflector)
Max. acquisition rate	2-4 meas. / hour	Up to 30-40 meas. / minute
Accuracy on single measurement	± 5.. 10 mm	± 1.5 mm + 3ppm
Dependency on P and T	weak	strong
Dependency on day / night	weak	strong

Table 3: GPS and laser distance meter performance comparison

The following plots show the strong dependency of the laser distance measurements on temperature and light conditions.

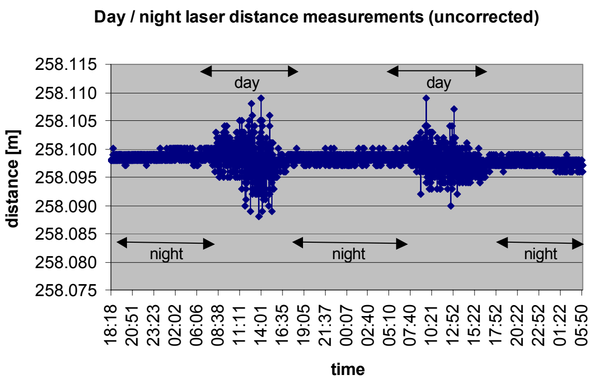


Table 4: Day / night laser distance meter measurements

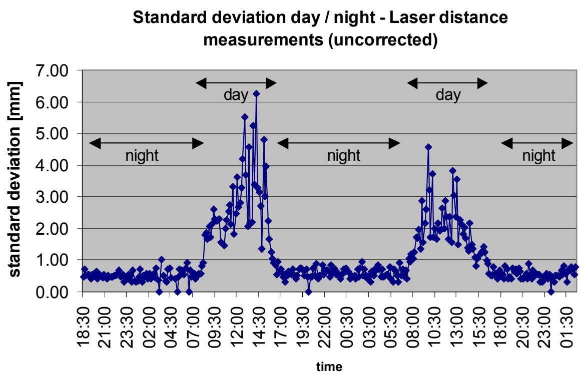


Table 5: Day / night laser distance meter standard deviations

6. CONCLUSIONS AND FUTURE WORK

A remote multi-sensor movement monitoring system has been described. It has been shown that Carrier Frequency GPS measurements can be effectively used for measuring small movements in the structural and geotechnical monitoring fields. The integration of traditional measuring instruments such as a laser distance meter or a robotized theodolite can be of help in unfavourable GPS reception situations. Also, the combination can show movement phenomena or dynamics not measurable by either sensor alone. This ultimately results in a better interpretation of measurement data.
The resulting movement measuring system is characterized by flexibility, robustness and a high degree of connectivity, making it ideal for use in remotely monitored measurement networks. The simplicity of installation and configuration is another relevant characteristic.

While the described system is suitable for solving a range of remote movement monitoring tasks at a relatively low cost, the underlying hardware, software and communications architecture can be effective in a wider range of remote monitoring applications. We intend to pursue this further development, seen as a generalization of the present work.

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REFERENCES

1. Leick, Alfred (1995). *GPS Satellite Surveying*. John Wiley and Sons, Inc., New York, 2nd edition.
2. Manetti, L., Knecht, A. *Permanente und autonome Erdrutschüberwachung mit GPS*, Mensuration, Photogrammetrie, Génie Rural, N° 7, 2000, Switzerland
3. Knecht, A., Manetti, L. (3.2001): Using GPS in structural health monitoring, Proceedings of the SPIE's 8th Annual International Symposium on Smart Structures and Materials, Newport Beach (CA), USA, [4328-12]

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