A Self-adaptive Data Acquisition Technique and Its Application in Landslide Monitoring

Xing Zhu, Qiang Xu, Xing Qi, and Hanxiang Liu

Abstract

With aim to deal with a continuously environmental change that may be unknown at design-time, we have proposed a novel self-adaptive data acquisition method for slope instability monitoring. The developed device can automatically adjust its data output rate from very low frequency to high one to capture the high-speed process when the physical variable sensed is dramatically changing. Such technique has the potential to reduce the energy consumption, bandwidth resources and data transmission burden in some practical energy conservation monitoring applications. A preliminary application of the proposed method was successfully carried out in one slope monitoring engineering in China. Application results indicate that the suggested solution can save much more energy consumed, while maintaining the data quality of crucial information.

Keywords

Self-adaptive data acquisition technique • Energy conservation • Landslide monitoring

Introduction

In the conventional signal sampling and processing techniques, we normally used uniform sampling frequency that was determined by the highest expected spectral frequency of the objective signal (Dieter et al. 2005; Tsividis 2010). However, the input signal properties are random and un-stationary corresponding to continuously environmental change that may be unknown at design time. When the input signal is more low frequency content or long periods of silence, the fixed high-frequency sampling and data communication simply waste power (Dorf et al. 1962; Mark and Todd 1981). When the input analog signal is of high frequency or paroxysmal changing, the fixed low-frequency sampling may not capture the crucial information in time. Therefore, it is very important to find some way to balance the power consumption and data quality in some practical applications.

In field landslide monitoring, sensor nodes are, generally, solar battery powered. The battery has limited capacity and often cannot be replaced, due to environmental or cost constraints. The design of any component in the sensor should address minimization of the energy consumption. Energy conservation techniques for sensor networks typically rely on the assumption that data sensing and processing consume considerably less energy than communication. As the wireless radio component of sensor mainly account for energy consumption, many energy management techniques, such as data compression (Tang and Raghavendra 2004; Sadler and Martonosi 2006) and aggregation (Madden et al. 2002; Boulis et al. 2003), predictive monitoring (Goel et al. 2001), adaptive duty cycle (Ganesan et al. 2004), have been proposed to minimize the radio activity. All the above

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techniques, however, require very complicated embedded software programming in a microcontroller unit (MCU) chip.

In this paper, we present a self-adaptive data acquisition method with electrical crack gauge for landslide monitoring applications. Here, we propose a cost-effective way at sensor board level to develop an improved crack gauge for monitoring paroxysmal instability of landslide in long term. Even if we focus the attention on crack gauge to make the presentation easy to follow, the methodology is quite general and simple, and can be applied possibly with minor adaptation to any other landslide monitoring device. The basic idea is to find an optimal data output rate compatible with the target signal. When landslide is in long periods of silence, the displacement of crack can just be measured in several hours or days interval to notify the state of sensor node to remote control center. While landslide exists in quick cracking or collapse phase, the displacement of crack can be monitored in up to hundreds of samples per second to capture the crucial information for early-warning of landslide. Hence, the amount of data to be transmitted and the energy consumed by the wireless communication can be reduced significantly. In other words, the long-term stability of monitoring system can be guaranteed and improved.

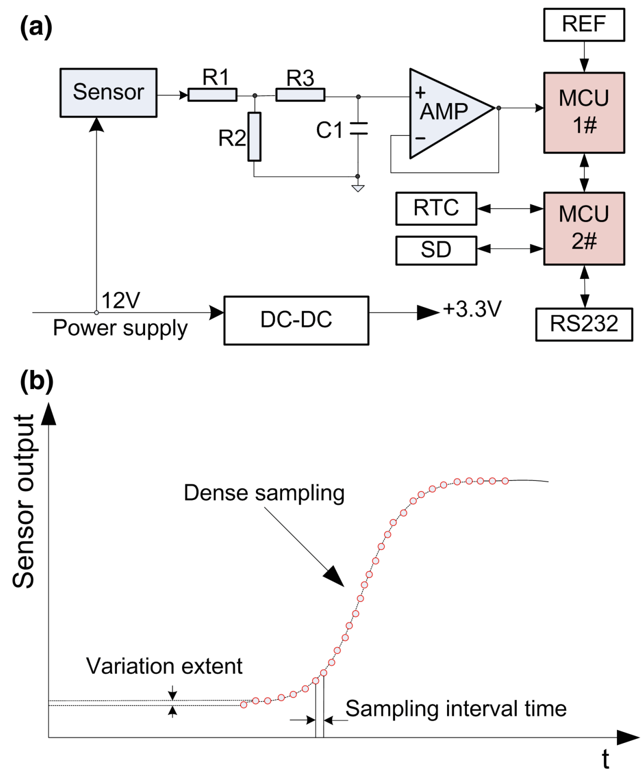

Fig. 1 **a** Hardware architecture of adaptive data acquisition system. **b** Adaptive data acquisition mechanism

Methodology

In landslide monitoring, the challenge is to represent an accurate process of the changes in the physical variables (e.g. displacement, pore pressure, etc.). This can only be achieved if the physical variable is sensed or sampled from the environment at a fixed rate (as shown in Fig. 1b). Meanwhile, with aim to reduce the energy consumed by transmitting data and to maintain the crucial data in the changing process, a self-adaptive data acquisition method should be proposed to reduce the amount of data transmitted while guarantee the data density for the crucial information. In this paper, the novel data acquisition device will be developed in cost-effective hardware architecture companied with adaptive software programming.

Double MCUs Based Hardware Architecture

Figure 1a shows the hardware architecture of the proposed data acquisition method. Firstly, the physical signal is transformed into an analogy voltage signal by the sensor. The analog signal is adjusted by Resistors (R1 and R2) to a suitable range that is compatible with the input dynamic range of Analog-to-Digital Convertor (ADC), and the random noise is removed through a simple low-pass filter constructed with R3 and C1. To provide proper performance and impedance matching, an analog signal follower constructed with one amplifier is necessary before the ADC. A micro-power and low dropout voltage reference chip REF192 (indicated REF in Fig. 1a) provides a precision voltage reference to the embedded 24 bit ADC in MCU (1#). Figure 1b shows the self-adaptive data acquisition mechanism. Essentially, the signal is sampled densely and obtained only when the sensor output changes significantly and rapidly.

The filtered analog signal is converted into digital signal through a 24 bit ADC embedded in the first MCU (1#). C8051F350 device is an integrated mixed-signal System-on-a-ship MCU and it is chosen as the first MCU in this system. There are many multi-function resources on this single MCU chip, which contains high-speed (up to 50 MIPS) pipelined 8051 compatible microcontroller core,

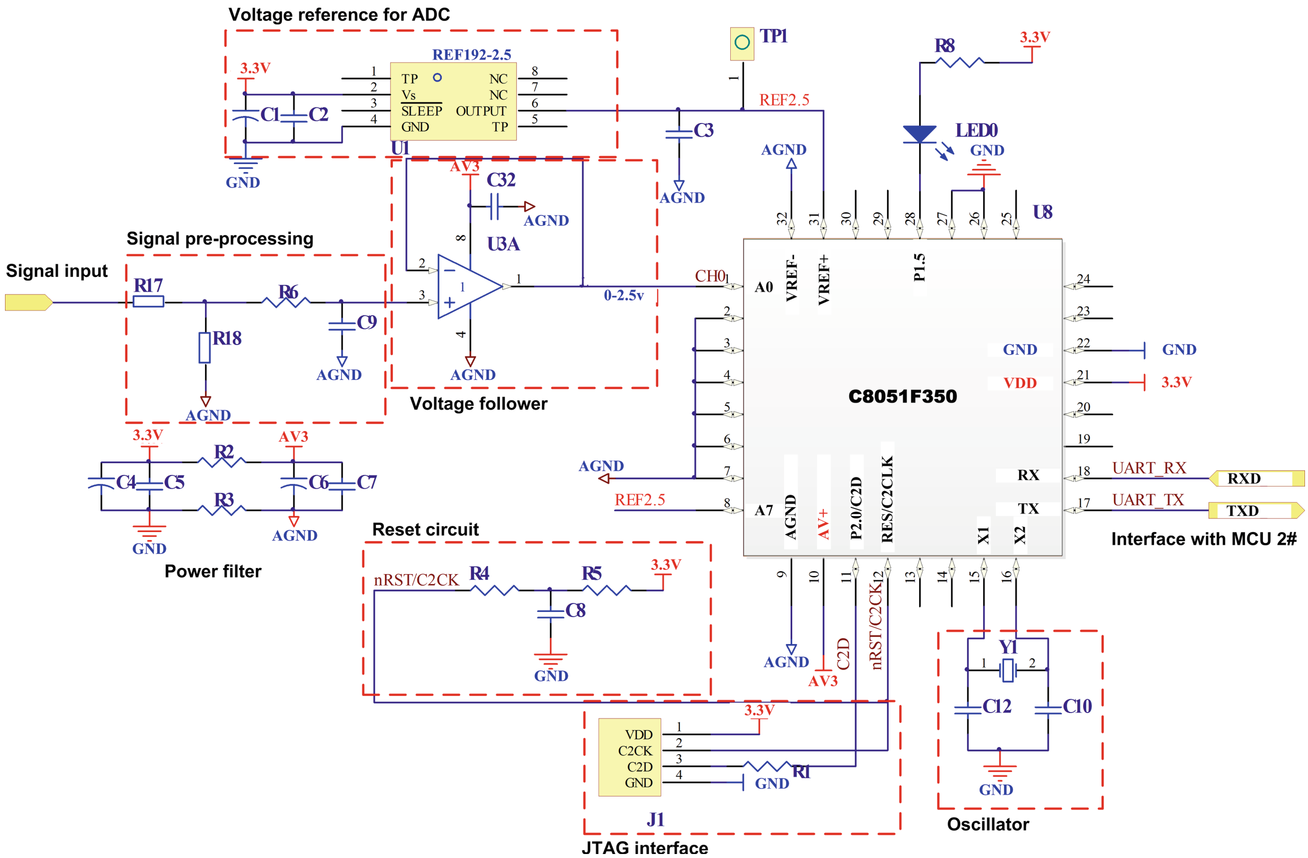

Fig. 2 Cost-effective MCU based ADC functional circuit design

24 bit single-ended/differential ADC with 0.0015% nonlinearity, and multi-functional interfaces implemented in hardware, etc. Furthermore, being low-cost and low-power are the hot features of this chip (Silicon Labs 2016). Figure 2 shows the ADC functional circuit design. Embedded software programming in this chip will be introduced in Section "Embedded Software Implementation" to intelligently control the 24 bit ADC's operation and digital data pre-processing. Hence, such simple and cost-effective design based on this chip constructs a high-precision, low-power and dynamical data acquisition module. ADC's output data are generated densely only when the input changes enough to cross a small delta level, thus saving dynamic power of the chip and the following hardware. In addition, bandwidth resources can also be saved when no data or low-frequency data are converted.

The first MCU is used in signal sampling and data pre-processing, and the second MCU (2#) is designed to work cooperatively in a concurrent manner with MCU 1#. Similarly, low-power MCU chip C8051F340 is chosen as the second control unit (MCU 2#) to manage sampled data. It changes from stop mode (low power consumption) to active mode only at the arrival of the output data from MCU 1#. Meanwhile, the sampling interval time and the delta level value can also be controlled by commanding to MCU 1# from MCU 2#. Sampled data is locally written into text file in the SD card and synchronously transmitted to remote monitoring center via RS232 interface compatible communication manners (e.g. wireless GPRS module, ZigBee module, etc.). Design of the local storage into SD card is to maintain the crucial information when wireless communication malfunctions.

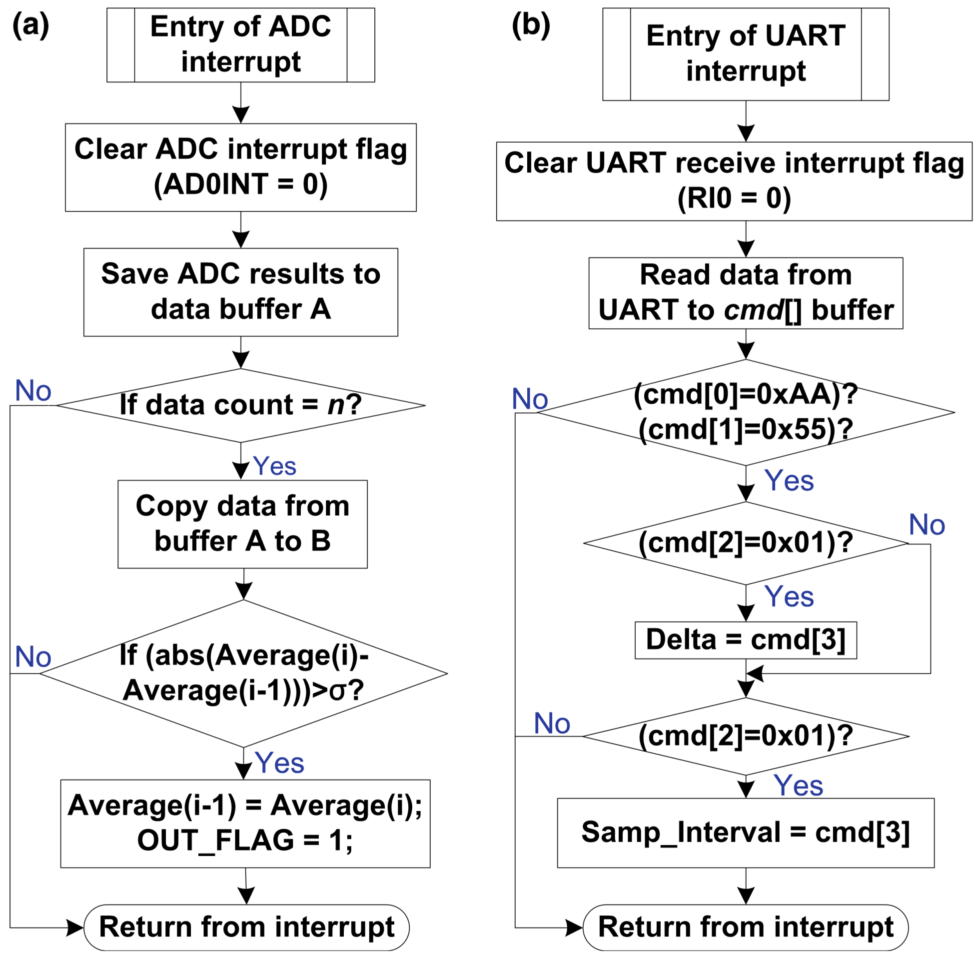

Fig. 3 Detail work flow chart of MCU 1# (C8051F350). **a** Interrupt routine of ADC conversion complete. **b** Interrupt routine of serial port UART0

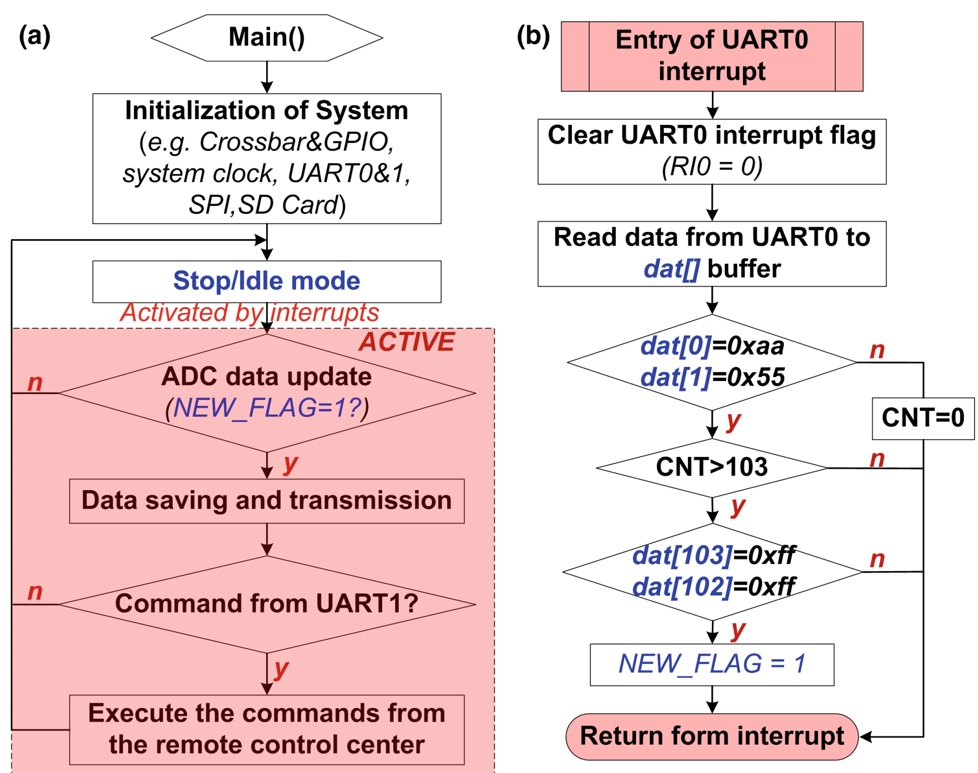

Fig. 4 Detail work flow chart of MCU 2# (C8051F340). **a** Main program routine. **b** Interrupt routine of UART0, CNT is the count of data in buffer

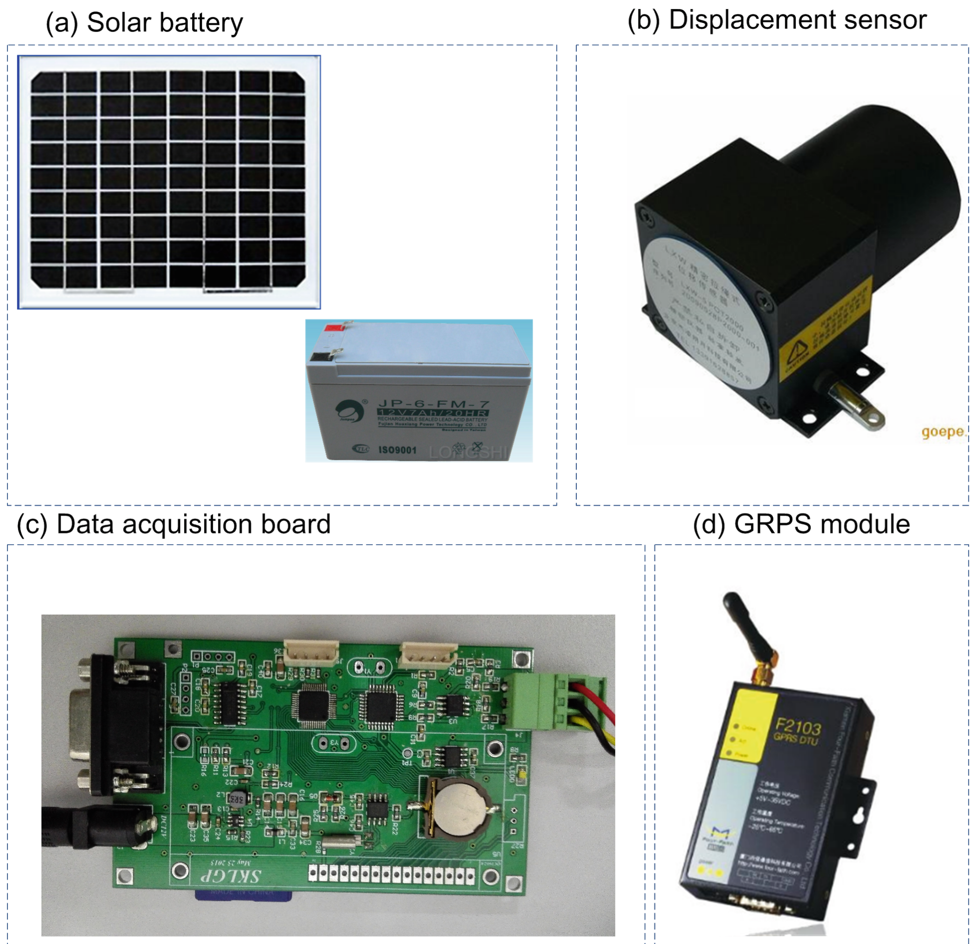

Fig. 5 Components of the improved crack gauge

Embedded Software Implementation

To conserve power, two MCUs normally work in Stop/Idle mode that can be activated by interrupt events. Figure 3 shows the interrupts work flow chart of MCU 1# (C8051F350). The system resources, such as system clock, GPIO, ADC, are initialized firstly in main routine. The ADC data output flag (OUT_FLAG) generated by ADC conversion interrupt routine is checked continuously in the main routine to send the effective ADC data packet to MCU 2# only when the average changes per n data points enough to cross a small delta level, that is, the actual noise level. Hence, there are n data points per effective data packet transmitted. Number n should be smaller than the half of sampling rate f to implement quick response of the system. The small delta level (δ) can be determined by the maximum noise value of the sensor. It can also be experimentally defined by the user.

$$w_{i+1} - w_i > \delta, w_i = \sum_{j=1}^{n} d_j / n \qquad (1)$$

where, w_i is the average value of the ith sampling window, n is the length of data in the sampling window.

Two parameters (sampling interval τ and crucial threshold delta δ) can be set flexibly through commands from MCU 2# (C8051F340) via UART (Universal Asynchronous Receiver/Transmitter) connection. Similarly, Fig. 4 shows

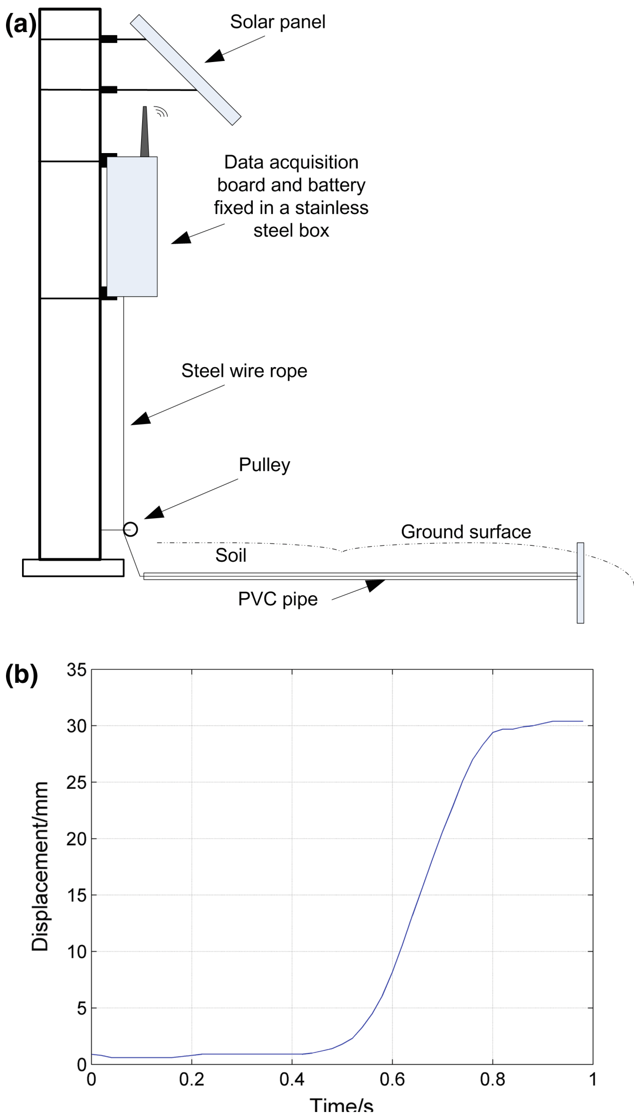

Fig. 6 **a** Installation of crack gauge. **b** Manual pull test result

the programming routines in MCU 2# (C8051F340). The MCU chip works in stop/idle mode when no new ADC data updated and/or no commands from remote control center to save system power. However, it can be activated immediately by two interrupt sources, UART0 and UART1. UART0 routine is designed to obtain the effective ADC output data packet. Every data packet includes packet head (0xAA, 0x55), data section, and end flag (0xFF, 0xFF). Additionally, UART1 routine is simply designed to build the data link between the sensor node and the remote control center.

Improved Crack Gauge and Its Landslide Monitoring Application

Crack Gauge with Self-adaptive Data Acquisition Mode

Accordingly, we developed a novel crack gauge for monitoring the abrupt instability of loess landslide in northern China. The developed crack gauge is composed of four components: draw-wire displacement sensor, solar panel with chargeable battery, data acquisition board, and GPRS data transmission module (Fig. 5).

Figure 6a shows installation of the crack gauge and manual pull test result. To avoid the external disturbances, we buried the steel wire rope in the soil. Then, we manually tested the timely response of crack gauge to quick displacement. Figure 6b indicates that the crack gauge can adaptively record the displacement time series only when the input of sensor changes dramatically, in which the maximum velocity reaches up to 75 mm/s. The sampling interval time τ and crucial threshold delta δ are set to 20 ms and 0.8 mm, respectively. The energy consumption of the crack gauge is about 100 mW, while average power consumption of crack gauge with 100 Hz signal sampling rate is about 800 mW. Therefore, the improved crack gauge can reduce power consumption and extend battery life mostly.

Preliminary Application in Landslide Monitoring

Figure 7 shows the preliminary application of the proposed crack gauge in a loess landslide monitoring. The crack gauge was deployed cross some horizontal cracks on April 20th, 2015. The fixed sampling rate was set to 10 Hz, and

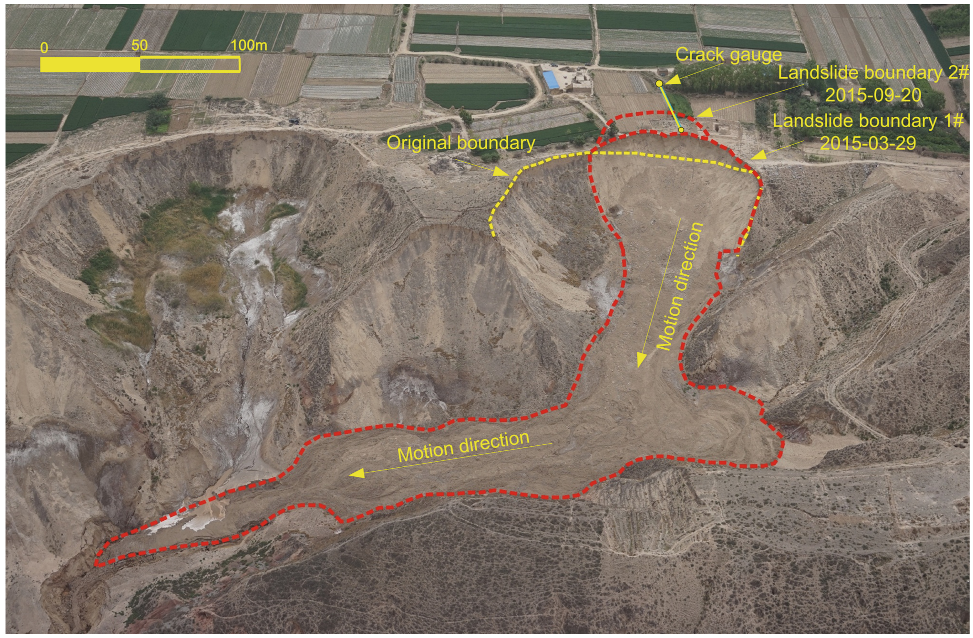

Fig. 7 Preliminary application of the developed crack gauge in loess landslide monitoring

δ = 1.0 mm. Meanwhile, the average sampling values every 15 s were stored and transmitted to monitor the state of the devices in the preliminary study. The loess landslide is located on the northeast edge of Heifangtai terrace, the arid loess area in Gansu Province, northwest of China. The previous loess slide occurred in March 2015 with long run-out distance, and the failure resulted in dense distribution of cracks due to lateral unloading. Then, a crack gauge was deployed to monitor the subsequent failure of this landslide. As shown in Fig. 8, the latest sudden slope failure that occurred on September 20th 2015 was timely captured by this deployed crack gauge. It indicates that the developed crack gauge can helpfully provide a good data quality for monitoring the paroxysmal instability of landslide, meanwhile, it can mostly save power of the device when no significant displacement changes to maintain its long term reliability.

Conclusion and Future Work

In this paper, we propose a self-adaptive data acquisition method to dynamically adjust the output rate of sensor to reduce the amount of data to be transmitted and processed and to reduce the power consumption of sensor node. The method has been implemented in both hardware and software embedded of a crack gauge for landslide monitoring applications. The preliminary application outcome indicates that

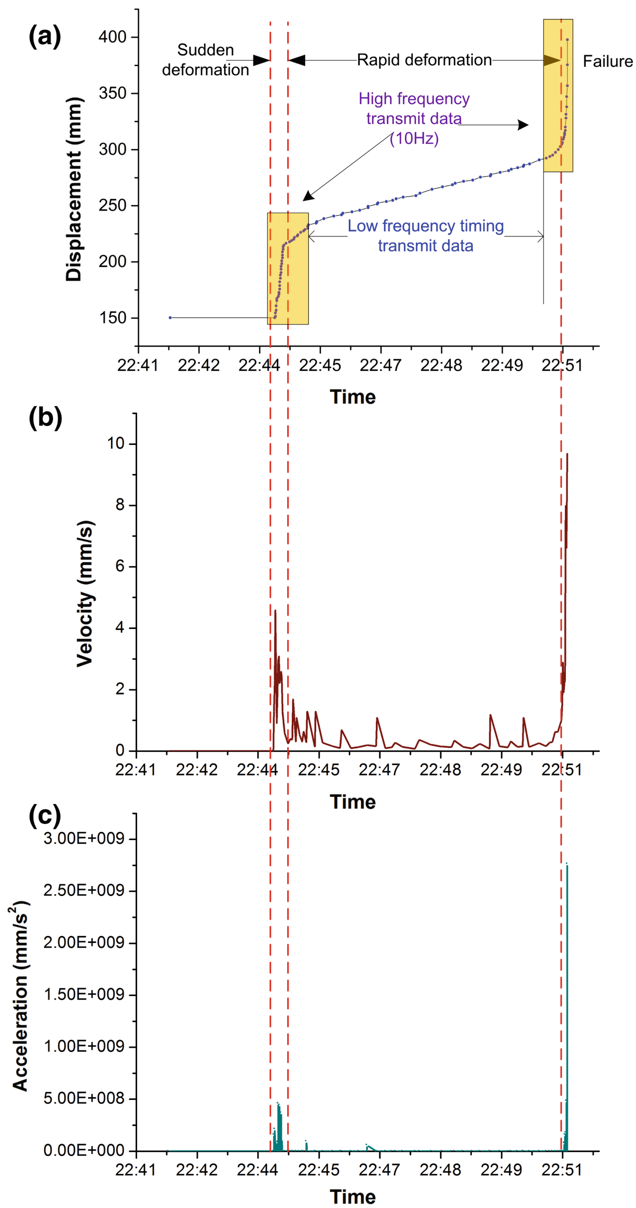

Fig. 8 Outcome of the developed crack gauge for monitoring a loess landslide from 22:41 to 22:51 in Sep. 20, 2015. **a** Monitored displacement, **b** velocity and **c** acceleration of landslide

the proposed self-adaptive data acquisition method can effectively capture crucial data changed suddenly and significantly. Meanwhile, it can reduce the power consumption significantly compared to the traditional data acquisition method with the same fixed sampling and data output rate.

In this paper, we have analyzed and implemented our proposal in a single sensor input scenario. The next step will include exploring multi-sensory input scenarios.

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