Wireless sensors as a tool to explore avalanche internal dynamics: experiments at the Weissfluhjoch Snow Chute

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ABSTRACT: Specially designed wireless accelerometers units were used in a series of experiments at the snow chute operated by the SLF at Weissflühjoch (Switzerland) during two consecutive winters. The purpose of the experiment was to evaluate the best design and the performance of these innovative instruments to provide information on the internal dynamics of flowing snow.
The wireless accelerometers were placed in the snow chute starting zone prior to the experiments and traveled within the flow when the avalanche was released. The characteristics of the units (size and density) allow them to evolve like active particle tracers. Acceleration readings obtained at 85 Hz for the different experiments where analyzed. The analysis methods used include Empirical Mode Decomposition, Kalman Filtering techniques and inertial navigation signal processing techniques. The developed methodologies were used to obtain reliable speed and position values from the single 2D acceleration measurements. The obtained results were compared to independent measurements of speed and position of the sensors. The results show to be in agreement with that obtained from independent speed measurements from optical sensors and Video Images and open a new perspective for future avalanche research. The extracted information could provide valuable data related to internal dynamics of the avalanche. Small-scale chutes are the ideal scenario to test these new technologies. Moreover, we consider this sites essential to develop and test new instrumentation (to be deployed), in the future, in full-scale experiments. In addition, the experiments performed show for the first time the potential of the wireless technologies and wireless sensors to study snow avalanches.

KEYWORDS: Snow Avalanches, Wireless Sensor Networks, Accelerometers, Snow chute, Avalanche dynamics.

1 INTRODUCTION

Over the last 80 years, avalanche-dynamics models have been increasingly used in land-use planning and for the design of protecting structures that are able to resist avalanche impact. These models have been improved by taking more and more processes into account to better describe snow avalanche motion. To keep on refining these models and develop more robust avalanche physical description it is essential to obtain more information on avalanche dynamics.

In the last decades the measuring equipment of the main test sites in Europe were renovated (Ammann,K 1999, Lied et al., 2002). Test sites were equipped with monitoring systems to get new insights on the avalanche features (e.g., velocity, flow depth, mass balance). However, acquiring data on high-speed phenomena still remains a challenge. Moreover, the description of the avalanche behavior needs to be supported by physical observations measured during chute and full-scale experiments. Classic methods such as image processing techniques give useful information on the shape and velocity of the avalanche, but cannot track the internal structure. Non-intrusive methods (e.g., Doppler radar) give access to it but their signals are difficult to interpret. Static sensors for measuring impact pressure or snow density are also of common use but they yield information at fixed places and their interpretation needs supplementary information (velocity measurements, density (Gauer et al., 2007)). In the last decade, a new generation of instruments has been used to study snow avalanches. Radar techniques have been improved to yield more accurate speed estimates (Gauer et al., 2007 and Rammer et al., 2007). Development of commercially available Laser Scanner systems allowed to obtain accurate measurements on avalanche mass balance (Sailer et al.,2008) which was inconceivable some years ago. Ground Based SAR radars have been successfully used to monitor avalanche activity (Martinez, A. and Fortuny, J., 2005). In addition, small scale experiments in laboratory chutes have become increasingly popular and a large number of experiments have been carried out in the past years (Issler, 2003). It is obvious that experiment under controllable and reproducible conditions become the ideal background for developing new measuring techniques especially for snow avalanche research. For example, the usage of high-speed cameras has been popularized in chute experiments. Their measurements combined with new data processing methodologies brought to successful results related to avalanche dynamics (Biancardi et al., 2005).

Emerging technologies have the potential to provide environmental information in an unprecedented scale. For example, the Sensor networks have been studied and deployed for decades; their wireless extension, additionally, has witnessed a tremendous increase in recent years. This is mainly attributed to the unprecedented operating conditions of wireless sensor networks (WSNs). Sensor networks were developed for military purposes (Warneke et al., 2001). However, their specific characteristics: low power, low cost, wireless communications made them also very attractive for exploring snow avalanche internal dynamics.

The University of Barcelona (UB) Avalanche Group in collaboration with the Distributed Systems and Computer Networks at the Open University of Catalonia (UOC) are developing a new type of sensors that will overcome the current limitations imposed by avalanche nature. The basic idea for the next future is to seed the snow cover with tennis ball sized sensors provided with accelerometers and other complementary sensors (temperature, magnetic…) before the avalanche is released. The main objective is to track the motion of each sensor and to measure complementary properties (temperature, density) as if they were snow clods.

It is obvious that such an ambitious goal requires a clear road map and previous experimentations under more controlled conditions. In this sense, the large snow chute of the Swiss Federal Institute of Snow and Avalanche Research (SLF) located at the Weissflühjoch 2670 m.a.s.l. near Davos, Switzerland becomes an ideal scenario for testing this technology.

In this paper we present an experiment at the snow chute where specifically designed WSN nodes were released inside the avalanche flow. Specifically, we focus on the determination of the position of the sensors as a function of time when they travel in the flow. To do that, we used 2D and 3D accelerometers connected to a wireless micro-device as a first attempt to use this technology for snow avalanche dynamics studies in a series of experiments carried out at the Weissflühjoch snow chute in Davos.

2 SITE, INSTRUMENTS & EXPERIMENTS

The large snow chute of the Swiss Federal Institute of Snow and Avalanche Research SLF is located at the Weissfluhjoch 2670 m.a.s.l. near Davos, Switzerland. The chute is equipped with different type of sensors including optoelectronic sensor arrays, load cells, high-speed camera, and ultrasonic sensor. A schematic picture of the chute is provided in Figure 1.

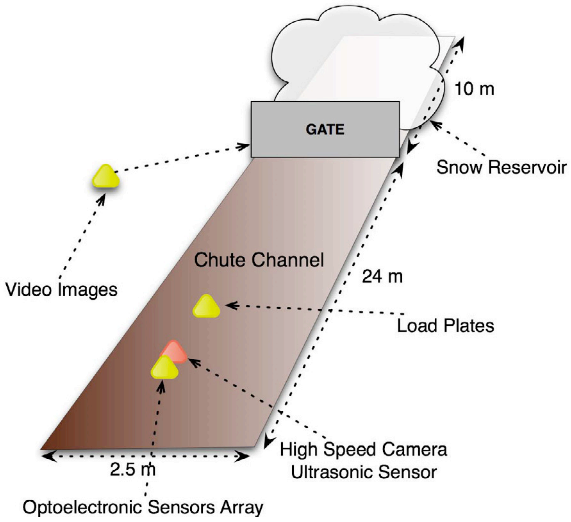

Figure 1. Scheme showing snow chute geometry and position of the available sensors.

The chute is 34 m long and 2.5 m wide. The uppermost 10 m of the chute are used as a snow reservoir separated from the rest of the chute by a release gate which can be opened electrically to release up to 25 m^3 of snow. The sliding part of the chute has a variable inclination between 35º and 45º.

A high spatial resolution array of sensors behind a half-wedge at the centreline of the chute was installed. The positions of the different sensors are also indicated in Figure 1. They were located at the 32º part of the chute, where the flow is assumed to have reached a steady state (Tiefenbacher and Kern 2004).

The reservoir part of the chute was filled up by direct shovelling the surrounding snow. The snow was released by activating manually the hydraulic system that opens the gate.

The wireless units used in this work are based on a commercial development platform for wireless sensor networks applications. Specifially, the core of each wireless sensor node is based on the telosb platform (Polastre et al, 2005). The telosb is used as a node on the wireless sensor network. It features a Texas Instruments MSP430 microcontroller, 48 Kbytes of program memory, 10 Kbytes of static RAM, 1Mbyte of external flash memory, and a 2.4-GHz Chipcon CC2420 IEEE 802.15.4 radio. The telosb was designed to run TinyOS (www.TinyOs.net). The election of the telosb platform is justified because the MSP430 microprocessor provides several configurable ports that easily support external devices. The large amount of flash memory available in that device, was useful for buffering the collected data.

In order to monitor accelerations the accelerometer (MMA6260Q, http://www.freescale.com/) was used. It is a 2 axis capacitive micromachined accelerometer featuring signal conditioning, a 1-pole low pass filter and temperature compensation. This sensor has a linear output with good signal to noise ratio, low power consumption and high sensitivity. It has a typical sensitivity of 800 mV/g with a typical acceleration range of ±1.5 g.

The accelerometer used is capable of measuring accelerations over a bandwidth of 1.5 kHz for all axes. The output is analog and it is sampled using the microcontrollers embedded 12 bit A/D converter.

A single sensor node was constituted by the sensor board the interface board and battery holder with two AA batteries. These parts, were housed inside a rugged PVC weatherproof and watertight case as presented in Figure 2

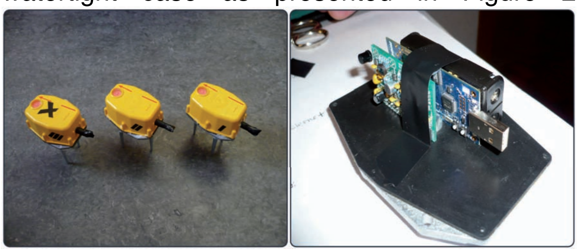

Figure 2. Waterproof packaging and Sensor node.

The whole software was developed using TinyOS 2.x (TinyOs) operating system. TinyOS is a wireless sensor networks specific operating system which follows an event-driven programming model. The programming language is nesC which is an extension of C that adds the concept of components and bidirectional interfaces. Components allow programmers to encapsulate the behavior of the different parts of the program independently. The communication between the components is achieved by the use of bidirectional interfaces. This approach makes collaboration between different programmers easier, ensures cleaner code, and facilitates reutilization.

Four different experiments were carried out during the period 02/02/2008 and 04/02/2008. In each of the experiments, after filling up the reservoir and tilting up the chute to its maximum inclination (42º), the sensors were placed over the snow surface, 1.5 m uphill the gate. Once the gate was opened the sensors released with the flow travelling downhill as particle clods.

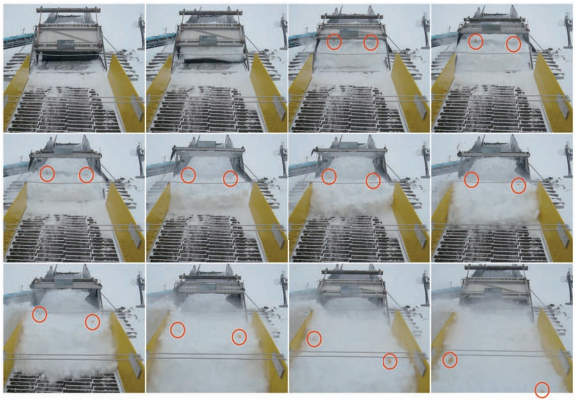

Figure 3. Snapshots of the first instants of one experiment. Red circles indicate the deployed sensors.

Three sensors were released in each experiment. The sensors data were time stamped to have a common base of time to facilitate comparison between the different sensors.

Four successful experiments were carried out during the 2008 winter. However, for sake of brevity, only one experiment is presented here. Apart of the data from the available sensors, Video images were recorded during the experiments; Figure 3 shows snapshots of the small scale dry-mixed avalanche released on the 04/02/2008. Red circles indicate the position of the 3 deployed sensors.

3 DATA ANALYSIS AND RESULTS

Acceleration readings from the two axis accelerometers are analyzed to obtain the velocity and position of the sensor inside the avalanche flow. It is well known that accelerometers are very good to provide local accelerations. However, they are inaccurate to furnish velocity and position estimates through direct numerical integration (Britting, K.R, 1971). Accelerometers measure the force per unit of mass acting on a body along a specific sensing direction. The vector sum of this force per unit of mass and the gravity, is the inertial acceleration of the body, which is the value of our interest. In Figure 4, normal and tangential accelerations obtained during the experiment are presented. The initial (approx) 5.5 seconds of data show normal and tangential gravity component that corresponds to the sensors laying on the snow surface before the experiment. Note that slope angle, θ, can be recovered from these readings assuming that $a_t = g \cdot \cos\theta$ (because inertial acceleration is 0). After opening the gate, a sudden decrease of the force per unit of mass is observed in the time series (arrow Figure 4). It corresponds, as expected, to an increase of the inertial acceleration. During first 2 s of motion the sensors traveled in straight line in the flow (observed from video images). In that period the motion of the sensor shows an erratic shifting between acceleration and deceleration phases. The mean retarding acceleration, however, is rather constant as also observed by Gauer et al., (2007) for full-scale avalanches based on Doppler radar measurements. In the next few seconds, the acceleration becomes even more erratic due to impacts of the sensors with the chute, snow clods, sensor rotation etc… These effects must be filtered using appropriate signal-processing techniques in order to recover the velocity and position of the units.

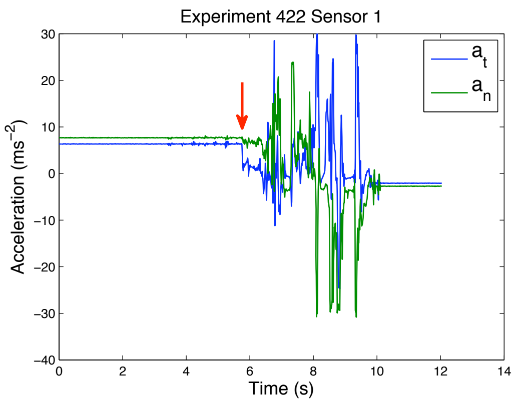

Figure 4. Normal (green), tangential (blue) acceleration readings from experiment released on 04/02/2008. Arrow shows instant of avalanche release.

To this end we developed a methodology based on the Empirical Mode Decomposition (Huang et al.,1998), and Kalman filtering (Kalman, R.E., 1960) to estimate the velocity and position of the sensors along the path minimizing gravity component effects, numerical integration errors, and random errors from sensor collisions with surrounding snow clods and chute walls.

Specifically, Empirical Mode Decomposition (EMD) was used to subtract the gravity component from the acceleration readings. Essentially, this methodology allows to decompose any data set into a finite number of intrinsic mode functions (IMF's) which constitute the empirically determined basis for our data.

Each IMF represents a simple oscillatory mode similar to a component in the Fourier-based methodology. The EMD explores temporal variations in the characteristic time scale of the data and thus it is adaptive to nonlinear and nonstationary data processes like the inclination of the snow surface running downhill the chute. Once gravity component was removed from the data, Kalman filtering based on a ballistic model (Kalman, R. E., 1960) was used to estimate velocity and position of the sensors. We used the acceleration readings as a driver for the Kalman filtering technique.

In Figure 5, the velocity (dashed line) and position (continuous line) estimates of two sensors released with the avalanche on the 04/02/2008 are presented. Raw position estimates are also depicted in red doted lines. For comparison purposes, position estimates from simultaneously obtained video images are also presented (squares and triangles, Figure 5). Results show significant agreement between the two independent estimates.

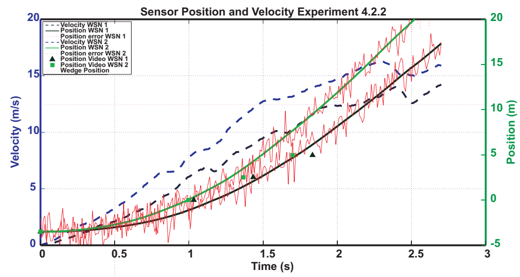

Figure 5. Velocity (dashed lines), Velocity error (red dotted lines), Position (Continuous lines), position estimates obtained from video images processing of two sensors released in the avalanche 04/02/2008.

4 CONCLUSIONS

Specially designed wireless accelerometers were used in a series of experiments at the snow chute operated by the SLF at Weissflühjoch (Switzerland). The main goal was to evaluate their capability to provide information on the internal dynamics of flowing snow.

Data from 4 different experiments was obtained. A methodology based on the Empirical Mode Decomposition (Huang et al., 1998) and Kalman Filtering was developed to determine position and velocity of the sensors travelling inside the flow from acceleration readings.

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