Cold Regions Science and Technology 65 (2011) 242–250

Contents lists available at ScienceDirect

Cold Regions Science and Technology

journal homepage: www.elsevier.com/locate/coldregions

Wireless sensors as a tool to explore avalanche internal dynamics: Experiments at the Weissflühjoch Snow Chute

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ARTICLE INFO

Article history:
Received 23 February 2010
Accepted 28 September 2010

Keywords:
Snow avalanche
Wireless sensors
Accelerometer
Speed

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 2008–2009 winter. 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 measurements obtained at 85 Hz in the different experiments were analyzed. The analysis methods used include Empirical Mode Decomposition and Kalman filtering 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 speed and position measurements. The results show to be in agreement with that obtained from independent speed measurements from optoelectronic sensor arrays 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 these 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.

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 and USA were renovated (Ammann, 1999), (Lied et al., 2002), (Dent et al., 1998). Test sites were equipped with monitoring systems to get new insights on the avalanche physical parameters (e.g., front velocity, flow depth, mass balance, and density).

However, acquiring data on high-speed phenomena still remains a challenge. The description of the avalanche behavior needs to be supported by physical observations measured during chute and full-scale experiments (Dent et al., 1998). Classical methods such as image processing techniques give useful information on the shape and velocity of the avalanche, but they cannot track the internal structure. Non-intrusive methods (e.g., Doppler radar) give access to the internal structure of an avalanche but the obtained signals are difficult to interpret (Issler, 2003). Static sensors for measuring the impact pressure or snow density are also of common use but they only 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. Louge et al. (1997) have developed a capacitance probe that can be calibrated to measure snow density. 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.,

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0165-232X/$ – see front matter © 2010 Elsevier B.V. All rights reserved.
doi:10.1016/j.coldregions.2010.09.011

2008) which was inconceivable some years ago. Ground Based SAR radars have also been successfully used to monitor avalanche activity (Martínez-Vázquez and Fortuny-Guasch, 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), (Dent et al., 1998). It is obvious that experiments under controllable and reproducible conditions become the ideal scenery for developing new measuring techniques especially for snow avalanche research. As an example, the usage of high-speed cameras has been popularized in chute experiments. Their measurements combined with new data processing methodologies brought successful results related to avalanche dynamics (McElwaine and Nishimura, 2001), (Biancardi et al., 2005).

There is also a unique approach to nonintrusively track a particle in the avalanche flow that was presented in a series of two papers by Dave and Bukiet (1998) and Dave et al. (1998). Specifically, they proposed a system, which is based on the principle of magnetic induction coupling and consists of small transmitters mounted inside the particle being tracked and a set of receiving antennae surrounding the experimental apparatus. In Part I of the sequence of two papers, they focus on the theoretical aspects, in particular, on developing a computational technique to solve the inverse problem of finding the three-dimensional position as well as orientation of the particle from the voltages induced in the antennae. In the second part (Dave et al., 1998) they focus on the system development, including all hardware and data acquisition aspects. In that work, (Dave and Bukiet, 1998) they demonstrate the wide applicability of the system due to its non-intrusive nature, especially when optical tracking techniques are not feasible. However, the system presents also some drawbacks. Mainly the requirement of using multiple receiving antennae limits the applicability to chute experiments where antennae could be easily installed.

Nowadays, emerging technologies have the potential to provide environmental information in an unprecedented scale. For example, the wireless sensor networks which were developed for military purposes (Warneke et al., 2001) have presented a tremendous increase of application in many fields due to their specific characteristics: low power, low cost and wireless communications. These characteristics are what also made them very "attractive" for exploring natural phenomena. In this work this technology will be used to obtain information from the internal dynamics of snow avalanches.

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 main objective is to track the motion of each sensor while flowing in the avalanche body as if they were snow clods and in addition, to measure complementary properties (temperature, density). 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 WSL Swiss Federal Institute of Snow and Avalanche Research (SLF) located at Weissflühjoch, Switzerland becomes an ideal scenario for testing this technology.

In this paper we present a series of experiments at the Weissflühjoch 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. 2D accelerometers connected to a wireless micro-device were employed as a first attempt to use wireless technology for snow avalanche dynamics studies.

2. Instruments and experimental site

The large snow chute located at Weissflühjoch 2670 M.A.S.L. is equipped with different type of sensors including optoelectronic sensor arrays, load cells, high-speed camera, and ultrasonic sensor (Tiefenbacher & Kern, 2004). The SLF Snow Chute is described in more detail in Tiefenbacher and Kern (2004). A schematic picture of the chute is provided in Fig. 1. The chute consists of a 10 m long reservoir, a 10 m long acceleration section followed by a 4 m long measurement section and, finally, a 6 m long run-out zone. In the experiments the slope of the two uppermost moveable sections of the chute was set to 45°. The slope of the measurement section was 40° and in the run-out zone was 8°. In the acceleration section and the measurement section rubber mats cover and roughen the smooth running surface of the chute. The rubber mats have a width of 6 cm and a stream wise spacing of 2.5 cm. In the experiments snow stuck in the void spaces and sliding conditions similar to natural avalanches were produced. Up to 15 m^3 of snow was released from the storage part by opening a shutter door forming artificial avalanches. The front velocities of the test avalanches were in the range of 6 m/s to 14 m/s obtained from optoelectronic sensors and video images and flow heights up to 1 m were generated depending on the filling volume and snow properties. The snow chute reservoir was filled with considerable effort of manpower: snow surrounding the chute was shoveled in by hand. Before each experiment the snow density and snow temperature inside the reservoir were measured and grain sizes and forms were determined. The air temperature was measured as well. The wireless units used in this experiment are based on a commercial development platform for wireless sensor network applications. Specifically, 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, 1 Mbyte of external flash memory, and a 2.4-GHz Chipcon CC2420 IEEE 802.15.4 radio. The telosb was designed to run TinyOS (TinyOs: Operating System, web page http://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 each unit the sensor used was an accelerometer MMA6260Q (http://www.freescale.com/). It is a 2 axis capacitive micro-machined accelerometer featuring signal conditioning, a 1-pole low pass filter and temperature compensation. This sensor has a linear output with high signal to noise ratio, low power consumption and high sensitivity. The typical sensitivity is 800 mV/g with a characteristic acceleration range of $\pm 1.5g$. The accelerometer used is capable of measuring accelerations over a

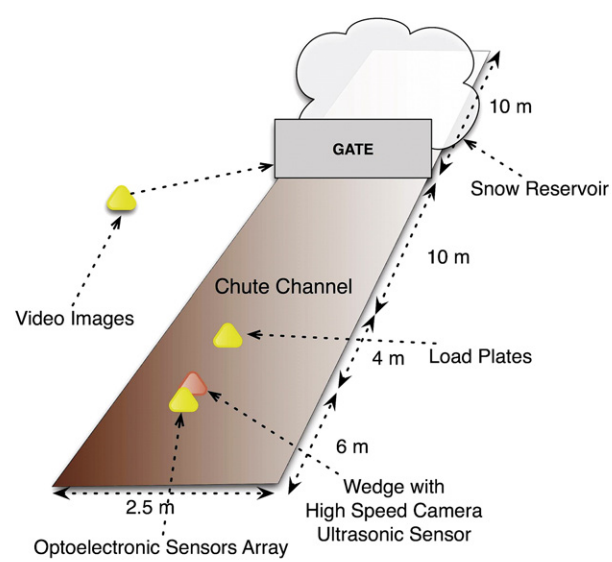

Fig. 1. Scheme showing the snow chute geometry and position of the available sensors.