The PermaSense Remote Monitoring Infrastructure

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ABSTRACT: The PermaSense project, a joint computer science and geoscience project, investigates the influence of climate change on permafrost and specifically the stability of steep rock walls in alpine regions and future natural hazard scenarios due to global warming. Current practice only allows to make observations in the mountain cryosphere using limited field studies; larger-scale and longer-term measurements are very difficult. To this extent we develop autonomous, wireless sensors that allow the collection, transmission and analysis of data online with reliable and high-quality measurement systems for extreme environmental conditions. The main goal of PermaSense is to provide long-term high-quality sensing in harsh environments, to obtain better quality data more effectively and make measurements that have previously been impossible. The system makes use of state-of-the-art ultra-low power wireless sensor nodes that can live off of a single battery for 3-5 years and survive the harsh environmental conditions in high-alpine regions. A base station is responsible of relaying data to a server using a long-haul wireless link, e.g. GSM/GPRS or WLAN with low latency on the order of seconds. Online data analysis allows to assess the state of a field site quickly and to adapt algorithms and analysis methods when necessary. We are currently operating sensor networks delivering online data on both the Jungfraujoch and the Matterhorn at 3500m a.s.l. In this paper we describe the technology currently used in PermaSense and explain how this can be adapted for other cases of environmental monitoring.

KEYWORDS: Permafrost, Remote Sensing, Wireless Sensors, Natural Hazard Early Warning

1 INTRODUCTION

In a joint computer science and geoscience project we have built and deployed a wireless sensor network for measuring permafrost related parameters. The project PermaSense aims at developing and demonstrating a flexible, distributed wireless sensor network (WSN) adapted to geophysical sensors with reliable and high-quality measurement systems for extreme environmental conditions. For this purpose, a WSN is used as the core of a novel monitoring infrastructure to investigate the physical processes ongoing in the mountain cryosphere. More specifically it is investigated how the warming and thawing of permafrost in steep alpine bedrock can affect slope stability, lead to natural hazards and complicate the operation of man-made infrastructure. In order to develop the necessary theoretical models for temperature simulation and hazard assessment, continuous and reliable data of the physical parameters involved and extracted from diverse topological settings, i.e. slope angle, elevation, orientation, are required. At present, only limited measurement data exist for selected locations, but no large-scale measurement series are available. This is partly due to the lack of inexpensive, easy to deploy and reliable measurement systems and dangerous and time consuming data collection in steep and inaccessible terrain.

The PermaSense wireless system architecture aims to provide a long-term, high-quality wireless sensing and data recovery solution in extremely harsh environments with near complete recovery and near real-time delivery of the data. The observation periods targeted in conjunction with higher quality data than was previously feasible is expected to provide the relevant information for research and decision making, pioneering next generation early natural hazard warning systems. When using a sensor network as a scientific instrument for data gathering, the quality of data is of utmost importance. In PermaSense this is exacerbated by difficult access to the area under investigation and the labor intensive installation and maintenance of any sensing solution, wired or wireless.

2 PERMASENSE SYSTEM DESIGN

The technological challenges posed in PermaSense here are chiefly w.r.t the extremes of the environment and the long system life-time targeted. The system architecture consists of

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low-power sensor node running the Dozer protocol [Burri2007], a solar powered base station and a server based data backend.

2.1 Key Architectural Requirements

- About 25 nodes per site; spacing 10-150 m
- Minimum 3 years unattended lifetime
- Survival in harsh, high-alpine environment (rock fall, avalanches, snow, ice, rime, lightning, storm)
- Ambient operating range -40 to +65°C, with max. 5°C per minute change rate
- Capable of sensing basic environmental parameters (temperature, electric conductivity, crack motion, ice stress, water pressure)
- ADC resolution >12 bits with 50ppm/°C
- 1 to 60 min adjustable sampling interval
- 99% data yield with max. 10 consecutive samples being lost
- Time synchronization to 1 sec/UTC
- 6 months autonomous storage capability
- No physical repairs or exchange of components during measurement campaign
- No infrastructure support necessary

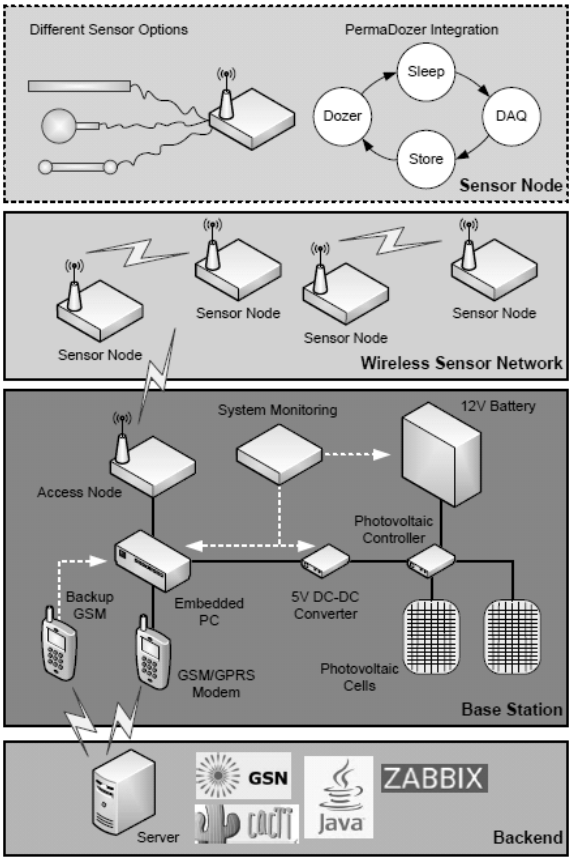

Figure 1. The PermaSense system architecture is made of a low-power wireless sensor network, a solar powered base station and a powerful data backend aggregating and managing all online data sources.

2.2 Wireless Sensor Nodes

The custom built sensor nodes constitute the heart of the PermaSense system. They are based on state-of-the-art wireless sensor network technology [Karl2005] and consist of a small, microcontroller and radio platform (Shockfish TinyNode) running an ultra low power communication protocol (Dozer) [Burri2007]. This communication infrastructure uses a very low duty cycle to save power and relay all sensor values acquired in a multihop network to a central data sink, the base station. The sensor nodes use a specialized sensor interface board (SIB) for connecting to and reading out various kinds of sensors. This SIB contains all data acquisition circuitry, reference voltages, capabilities to interface to multiplexers and digital sensors, protective circuitry and power management functions. The system is fed from a single, non-rechargeable SAFT LSH-20 Li-$SOCl_2$ battery rated at 13 Ah. With an approximate average power consumption of 148 uA this supply is expected to last at least the three years specified, even under very adverse conditions. While achieving this ultra-low power envelope is one of the main goals pursued by the engineering and computer science research in the project, the long-term reliability of the sensor nodes are equally important. Probably, from an application perspective the reliability is of a higher concern rather than the ultimate size and bulk of a sensor node, should a significant increase in stability and reliability necessitate a power source of twice the capacity.

All components are housed inside an IP68 die-cast aluminium enclosure that is inserted into a further stainless steel "protective shoe" and mounted upside down on a rock wall. This upside down mounting allows the antenna to radiate freely, while being shielded from rockfall and avalanches coming from above. Also, the ingress of water is minimized by allowing openings (connector, antenna) on the bottom side only.

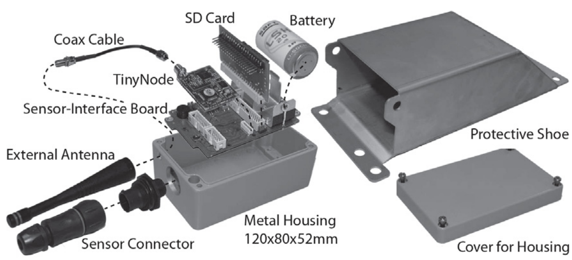

Figure 2. The low-power sensor nodes form the heart of the PermaSense data acquisition system. They are housed in stainless steel housing and contain the measurement electronics, a wireless transmitter and a battery.

2.2 Sensor Data Gathering and the Base Station

The data gathered by the low-power sensor nodes is collected at a sink node, the base station. Here, a global timestamp is added and the actual time of the data acquisition at the sensor nodes is computed, based on the accumulated network transit time that is contained in every network packet. The base station further administers a local data repository, that allows to gather data without loss from the sensor network while being disconnected on the long distance data link. The base station can be connected to an infrastructure network using different link technologies: GSM/GPRS, UMTS, Wireless LAN or for even more remote locations satellite links. Apart from the pure choice of technology, it is important to note that the PermaSense base station relies on redundant long-distance data links. In our case we use a combination of Wireless LAN (primary) and GSM/GPRS (secondary) to link the base station on the mountain to the Internet and in the following to our servers.

Figure 3. PermaSense base station including a solar power system and a Linux mini-computer located at 3500 m a.s.l. on the Hörnliridge, Matterhorn, Switzerland.

Apart from the wireless networking and computing resources, every base station is equipped with a solar power system, a webcam to get a concrete view of the equipment on the mountain and the general weather situation and a weather station (Vaisala WXT520).

2.3 Testbed Infrastructure

For realistic testing, we have built an exact replica of the system installed on the mountain on the rooftop of the university building in Zurich. Apart from this we use sophisticated methods and tools for power and functional testing, validation and temperature cycling. Especially the latter one has proven extremely helpful in validating correct software operation under the influence of the elements, predominantly the extreme effect of fast cooling and heating such as is the case when the sun comes over the horizon and warms sensor nodes on the mountain.

2.4 Data Backend and Data Management Infrastructure

The PermaSense project uses the “Global Sensor Network” for data collection, storage and data management [Aberer2006]. This is a system that is designed to accommodate a number of streaming data sources, also at different rates. It is further connected to a wiki-based metadata repository that is jointly developed with the Swiss-Experiment. Data evaluation is taking place using specialized and domain specific tools. By using a generic backplane for data management and specialized tools at the frontend it is warranted that every scientific domain is capable of dealing with its portion of the data gathered in an optimal way. Furthermore, for the control and operation of the network a number of commercial tools, mainly stemming from the network management domain, are used.

3 FIELD SITES AND FIRST SENSED DATA

Currently, the project has two field sites deployed and equipped with the PermaSense remote monitoring system. Both sites are located at 3500 m a.s.l. in the Swiss Alps. They are easily accessible, by either train (Jungfraujoch) or within reach of a heliport (Matterhorn) which make logistics in setting up and test driving this novel technology for environmental sciences much easier. Both field sites have specific characteristics that make them interesting for geoscience, especially w.r.t permafrost in steep bedrock. Also, both sites have been under investigation for various studies and related topics in the past.

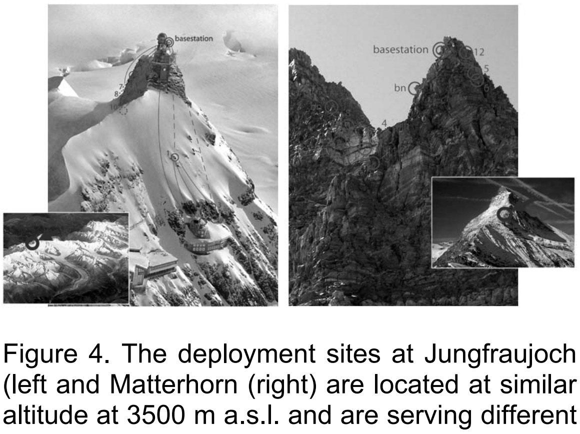

Figure 4. The deployment sites at Jungfraujoch (left and Matterhorn (right) are located at similar altitude at 3500 m a.s.l. and are serving different observation objectives. Jungfraujoch is primarily devoted to detailed temperature profiling while the Matterhorn field site investigates the causes of crack movement and increased instability.

3.1 Sensors and Preliminary Data Acquired

The main scientific research goal pursued within PermaSense is the understanding of heat transport in frozen rock walls and its influence on the stability. For this purpose a custom “sensor rod” has been designed that allows to measure temperature and resistivity at different depths. This sensor rod is connected to a sensor node that is mounted on the outside of the rock minimizing the impact of the sensor itself on the thermal regime of the location under investigation.

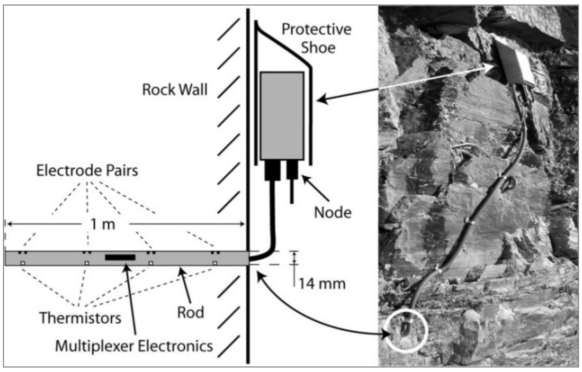

Figure 5. A custom sensor developed for the PermaSense project is the sensor rod. It contains temperature sensors and electrode pairs at different depth that allow to measure temperature profiles in rock surfaces up to a depth of one meter.

Some sample data from such a sensor rod is shown in Figure 6. The plots shown are the values for temperatures an resistivity taken at different depth over a period in the first half of 2009. This data is currently being analyzed and will serve as an input to calibrate larger models of permafrost in alpine regions.

A further sensor used is the crack meter. This is a commercial extension analog sensor that is used in conjunction with thermistors mounted to a PermaSense sensor node. A crack meter mounted on site at Matterhorn is shown in Figure 7. Sample data showing the influence of the daily and weather induced temperature cycles on the crack movement is shown for a sample crack in Figure 8.

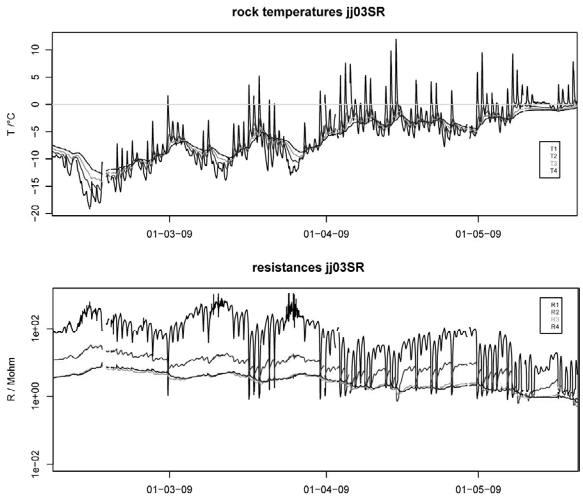

Figure 6. Sample data from a sensor rod shows the significant impact of the daily temperature cycles at the surface with gradual decrease of the effect with increasing depth inside the rock wall.

Figure 7. A crack meter is mounted under a protective hood in conjunction with other thermo measurements.

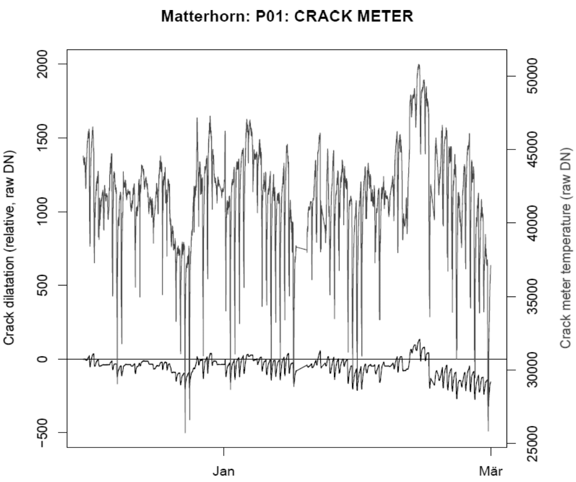

Figure 8. The rock surface temperature is plotted on the top with the corresponding crack dilatation signal on the bottom. The correlation to the daily temperature cycle is visible in this sample data from early 2009.

5 CONCLUSION AND OUTLOOK

The PermaSense project has been a compelling and very successful collaboration between engineering sciences and geoscience over the last three years. Apart from solving a number on unanticipated technological issues, the project has evolved from a technological prototype into full-fledged environmental monitoring campaign. This would not have been possible without the cross-fertilization and constant learning that has been going on between the different disciplines involved.

Today, after three years of engineering and two years of deployments we are starting the analysis that will hopefully yield interesting results on both sides involved. So far, it has been assured that the data quality of the acquired sensor data is of very high quality, far more than was required by the geoscience partners. Also, the developments made for the PermaSense remote monitoring system work; not only in the lab, but also in the field where we have constantly been generating sensor data since July 2008. However it shows that it is still very hard to give guarantees on the uptime and achieve a data yield as anticipated. Narrowing down these sources of uncertainty and generating the necessary tools for the analysis of online, streaming data will be the focus of the next phase in the project. Especially the continuous, but not perfect streaming data sources necessitate novel approaches, not commonly found in geosciences today. Also, the application of this data in adequate models and the extraction of information for the detection of natural hazard scenarios will be a major effort of the future. The system architecture and wireless sensing technology designed in PermaSense have large potential for other application areas, predominantly in outdoor, environmental monitoring

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