High-Resolution Imaging for Environmental Monitoring Applications

Matthias Keller[1,*], Mustafa Yücel[1] and Jan Beutel[1]
[1]Computer Engineering and Networks Lab, ETH Zurich, Switzerland

ABSTRACT: The PermaSense project strives to collect long-term geophysical data for permafrost research in Switzerland. By now, we have successfully established two installations at Jungfraujoch and Matterhorn measuring temperature profiles, crack dilatation, pressures and conductivity in the alpine extremes at 3.500m a.s.l. The data is sampled continuously and relayed to a datacenter in real-time with low latency. While the currently measured quantities are rather simple measurements we are also investigating possibilities to measure using more complex methods and devices. In this work we present a novel optical sensor designed for application in high-alpine locations allowing for very-high fidelity image acquisition, e.g. to measure the variability of snow cover or detailed rock movement. For this purpose, a Nikon D300 DSLR camera (12 Megapixel) has been adapted for unattended operation at extreme conditions, including a suitable power supply, optically corrected lens port, lens heating system and wireless data link. In order to support a high image quality and facilitate application in diverse scenarios different lens options are supported (telephoto, wide angle, infrared). The system presented can support any kind of digital SLR camera and lens system depending on the actual application requirements. Designed with a very low overall power profile, the system is suited for long-term operation from either a fixed battery or an optional solar charging facility. In this work we present the system design as well as live data from our field site at 3500m a.s.l. On the Matterhorn Hörnliridge, Switzerland and ongoing analysis work using spatial reconstruction techniques.

KEYWORDS: Imaging, Permafrost, Remote Sensing, Wireless Camera

1 INTRODUCTION

The PermaSense project [Hasler2008] strives for collecting geophysical data in the high-altitude environment of the Swiss Alps with an autonomous and long-lived wireless sensor network (WSN). To this day, a WSN consisting of one base station and 15 respectively 20 motes have been successfully deployed at 3.500 m a.s.l. on Matterhorn and Jungfraujoch, Switzerland. In this deployment, simple analog and digital sensors representing properties such as temperature, humidity or electrical resistivity are sampled every few minutes. While this sensor data constitutes the core input to the geophysical research pursued in this project, there are contexts that require more complex data, e.g. with fidelity and data rates two or three orders of magnitudes higher than the current set of simple sensors. To this extent, we present a novel, high-precision wireless image sensor based on a commercial digital SLR camera suitable for detecting spatial distributions, e.g. snow cover [Kaufmann2008] or temporal behavior, e.g. permafrost creep and rock glacier dynamics [Haeberli2006] with great detail and fidelity.

Corresponding author address: Matthias Keller, Computer Engineering and Networks Laboratory, ETH Zürich, Switzerland; tel: +41 44 6327041; email: matthias.keller@tik.ee.ethz.ch

2 SCIENTIFIC OBJECTIVE AND RELATED WORK

In order to assess detailed temporal and spatial patterns of glacier movement and rock falls imaging has been frequently used. In most cases this has been limited to time-consuming field campaigns with infrequently taken images often at large intervals and only when conditions allowed to access the scene, i.e. once a year in the summer months. In other cases, simple, low-fidelity cameras have been instrumented with a cell-phone link for automated imaging at regular, pre-defined intervals. All these methods described have deficiencies and are thus limiting in their applicability to a detailed understanding of our environment.

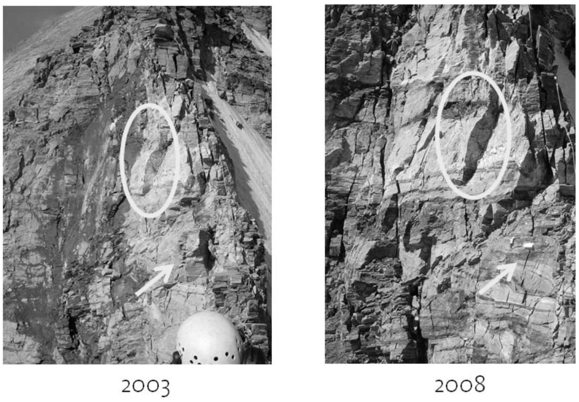

Figure 1. An example of studying long-term dynamics of permafrost: The site of the rockfall

from 2003 on the Matterhorn Hörnliridge, Switzerland shows significant change in the following five years. The surface ice has vanished as well as some rock outcrops have broken off. Details, such as the temporal and/or spatial patterns have not been observed.

Figure 2. An example of instability in steep permafrost such as is under investigation in PermaSense in Valais, Switzerland. The MountainView camera system is used to assess the detailed surface patterns, velocity and movement trajectories as well as their magnitudes.

The MountainView system presented here tries to follow a similar path at greatly enhanced fidelity and quality of the images acquired. Key here are an adaptive software and communication framework, high-quality lens and camera as well as means for calibration and integration with sophisticated spatial reconstruction techniques.

3 SYSTEM DESCRIPTION

For the application of advanced image processing algorithms and a meaningful analysis of the image data gathered from the environment, the fidelity and optical precision are of the utmost importance. In order to adapt to different locations, lighting conditions and imaging requirements (near – far) a generic, high quality imaging solution is required. This is even exacerbated when taking into account, that often enough in the outdoors it is hard or even impossible to place a camera in an optimal angle or field of view of the scene under investigation. Apart from the high fidelity required and resilience to the harsh environment at high altitude a relative autonomy from infrastructure elements or specific location requirements are key concerns for the applicability of such a camera in a real monitoring scenario in high-alpine environment. A main concern here is a low power consumption footprint to reduce the necessity for excessively large solar panels, and thus reducing the risk of snow cover, riming and damage due to rockfall. A further, more project specific requirement is the seamless integration with the existing PermaSense wireless sensor network infrastructure [Beutel2009]. The adaptation of the imaging system presented here in another setting, possibly with another networking resource should be straightforward.

The system is designed, based on a commercial digital SLR camera, mounted in a ruggedized housing. The housing includes an optically corrected lens port adapted from a scuba diving housing, a heating system with temperature control used primarily as lens port defogging/deicing system, system supervision and power supply. The standard power supply is a 12V solar system, but in scenarios where there is no direct sunlight in the vicinity of the camera, it is also feasible to use a larger 12V lead-acid battery (e.g. from a truck) and plan for a limited amount of photographs only.

Apart from some engineering effort, the main challenges are reliability concerns, issues concerning the power efficiency and optimizations in the operation based on the available energy supply, data throughput and image quality. The system design is optimized to operate on a very low duty cycle, i.e. with a few pictures per day, but fast image acquisition or even movies are also feasible, should a scenario require such operating modes. Especially for this adaptivity for future use cases, a somewhat modular and scalable architecture, with enough headroom for exploration and ample resources was conceived for the MountainView camera system.

3.1 MountainView System Implementation

The main platform used is an embedded PC with an attached digital SLR camera – in our case a NIKON D300 with a 12 Megapixel image sensor and capable of mounting the most commercial lens systems. The Gumstix embedded PC platform is running Linux and uses a Wireless LAN interface to connect to either a local WLAN cell at the deployment site, or using directional antennas to a distant access point. For increased performance and ease of integration with our other infrastructure an external Mikrotik WLAN router platform is used instead of a Gumstix built-in Wireless LAN here. The setup is similar to that of the PermaSense base station described in [Beutel2009].

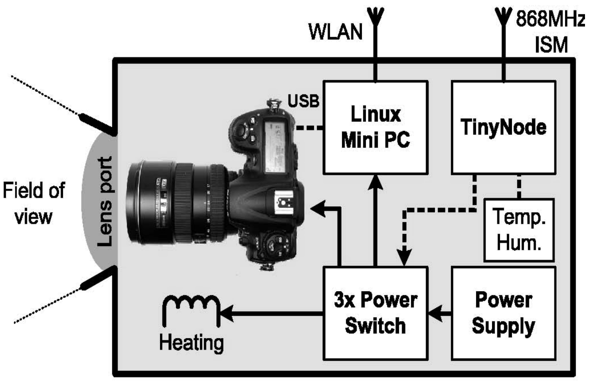

Figure 3. Schematic overview of the MountainView camera and components.

All components are integrated into an IP68 diecast aluminum enclosure (L 125 x W 80 x H 57 mm). The system has a net weight of 25 kilograms excluding mounting equipment.

3.1 Low-power Network Integration

Operating a camera, a PC platform and a WLAN router constantly consumes considerable energy on the order of tens of watts – not a resource readily available in remote high-alpine environments. Therefore the system architecture makes use of aggressive duty cycling techniques and uses the concept of a "wakeup-radio" [Shih2003]. Using a second, low-power radio for the control of the operation of the main and power-hungry system components allows building a reactive system while saving large amounts of energy. A different approach, not considered here, would be to use a timer for regular wakeups, say once or twice a day at the drawback of no real interaction and adaptivity of the system according to user needs. Such timer-based cameras have been designed and used in the past but their applicability in a changing mountain environment is limited. If for example, a user realizes that at his location there are often clouds at midday, or that at a different time of the year the shading of the environment has changed and is impacting image quality, nothing can be done to adapt the imaging process to the local circumstances.

Therefore the MountainView camera uses a low-power sensor node that communicates with the PermaSense wireless sensor network to receive a user-initiated wakeup. Upon arrival of such a wakeup message, the sensor node powers on the embedded PC that then takes over control of the system, enabling power for the WLAN router, camera and heating/defogging system as well as starting the image acquisition processes. The wakeup messages are designed to transport not only a simple wakeup call, but also parameters that determine whether the system takes only one image, sends it over the wireless link and goes back to sleep, or rather stays active longer awaiting more complex user interaction. Using this system architecture, it is possible to adapt the system according to a users (=environmental scientist) needs with camera being installed on a field site.

In the current implementation, it takes up to 30 seconds until the user-initiated wakeup dis-

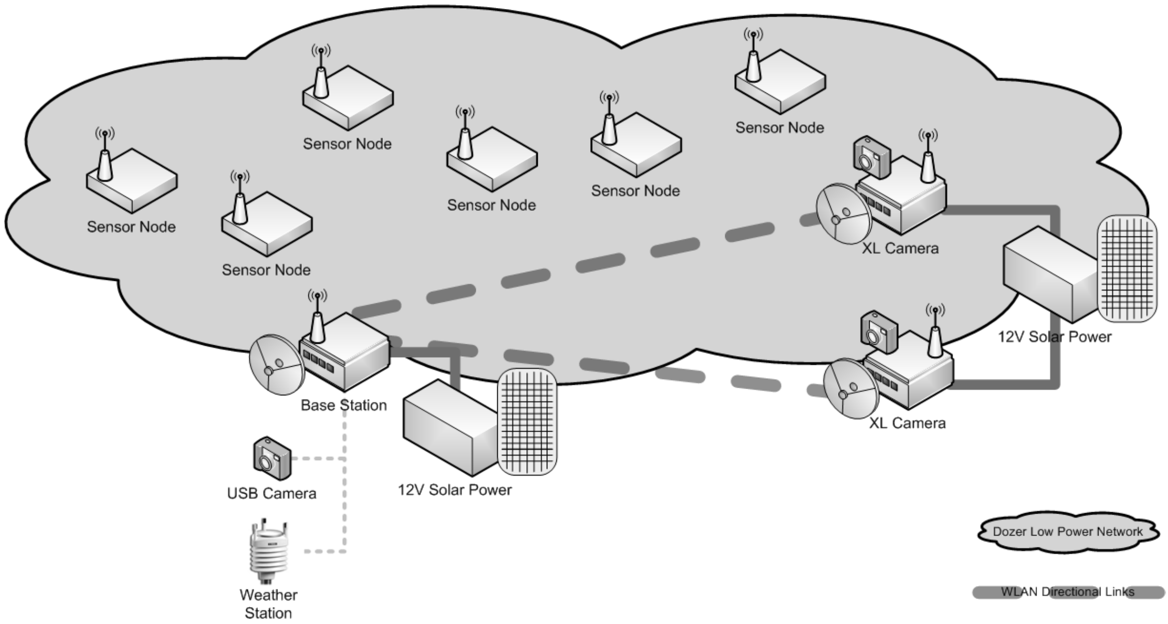

Figure 3. The integration with the PermaSense wireless sensor network is based on a wakeup using a low-power network of sensor nodes and a high-throughput link to control the camera and download images.

seminates through the network. An image is taken about 60 seconds after the arrival of the wakeup request has arrived. After image acquisition, 30 sec are necessary for image download before the system returns to sleep mode.

During the active phase, the system consumes an average current of 0.36 A from a 12 V power supply. In turn, only 3 mA are drawn during sleep. Assuming one image captured per day and disregarding long-term effects such as self-discharge, a battery with a capacity of 10 Ah lasts for approximately 150 days of operation. Thus it is feasible to use the camera in a non-solar powered setting.

Apart from having to send wakeup messages, the user only has to learn and understand how to control a camera over a remote internet connection. The user perception is simply a resource that is temporarily (un-)available and that is controlled using standard, off-the-shelf internet based tools. Additionally, the integration with the same hard- and software as is being used for the PermaSense sensor network base station, alleviates users from learning, maintaining and operating yet another, often complicated platform.

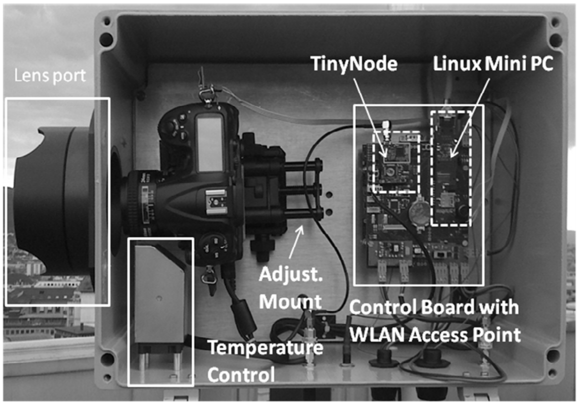

Figure 4. The camera components are assembled inside a sturdy, die-cast aluminum housing. The camera is mounted on an adjustable mount allowing moving the lens into the center independent of lens and camera size used.

4 EXPERIENCE AND FIELD TRIALS

The work on the MountainView imager is still ongoing. However, important steps have been made in different field trials that allowed learning from experience and gradually refining the camera platform. It is expected that the camera will be mounted on its designated outdoor location in the next couple of weeks as of the writing of this paper. The efforts discussed here shall make clear the necessity and the large effort necessary to test such a system prior to deployment in a high-alpine setting.

4.1 Testbed Operation

In a first step the camera was tested on our rooftop testbed at the university, primarily to have a longer-term operation in an outdoor setting. This testbed is an exact replica of the network in the Matterhorn field site, with the exception of the increases altitude and exposure to the elements. In excess to the outdoor tests, a number of specific test runs, testing the power consumption in all operating modes, wireless performance, connectivity breakdowns as well as temperature cycling in a controlled temperature and humidity chamber.

Figure 5. Rooftop testbed with base station, solar power system and long-range WLAN link (left). Camera is mounted in on a separate pole (right).

4.1 Data Management Integration

Permasense uses the “Global Sensor Network” (GSN) for data management and centralized storage to a database [Aberer2006]. This is a tool that allows to integrate various data sources such as temperature and humidity, but also more complex data sources such as images. All images derived from the camera are transferred to GSN, where they can be retrieved and/or put into context with other sensor data from the field site. Images are stored both in thumbnails (reduced image data) and full resolution.

4.1 Field Site Preparation – Current Deployment Work

Currently the field site is being prepared for the camera installation. This mainly involves finding a suitable mounting position and installing a Wireless LAN link from Klein Matterhorn to the field site on the Hörnliridge. Additionally a solar power system for the camera is also being prepared.

Figure 6. Three example pictures taken at hourly intervals with the MountainView camera when testing on a rooftop in Zurich, Switzerland.

5 CONCLUSION

In this paper we have presented a novel, high-precision image sensor for outdoor, environmental monitoring applications. It is geared at different imaging scenarios in remote areas and can be fitted with different cameras/lenses as needed.

A first deployment in the field will help to further refine the system setup. Further steps include work concerning the post-processing of the images as well as the deployment of multiple cameras.

6 *ACKNOWLEDGMENT*

The work presented was supported by NCCR-MICS, a center supported by the Swiss National Science Foundation under grant number 5005-67322.

7 REFERENCES

Hasler, A., Talzi, I., Beutel, J., Tschudin, C. and Gruber, S., 2008. Wireless sensor networks in permafrost research - concept, requirements, implementation and challenges. Proc. 9th Int'l Conf. on Permafrost (NICOP 2008), vol. 1, pp. 669–674, June 2008.

Kaufmann, V. and Ladstädter, R., 2008. Application of Terrestrial Photogrammetry for Glacier Monitoring in Alpine Environments. International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, vol. XXXVII, part B8, Beijing 2008.

Häberli, W., Hallet, B., Arenson, L., Elconin, R., Humlum, O., Kääb, A., Kaufmann, V., Ladanyi, B., Matsuoka, N., Springman, S. and Vonder Muehll, D. , 2006. Permafrost Creep and Rock Glacier Dynamics. Permafrost and Periglacial Processes, 17: 189-214.

Harris, C., et al., Permafrost and climate in Europe: Monitoring and modelling thermal, geomorphological and geotechnical responses, Earth-Science Reviews (2009), doi:10.1016/j.earscirev.2008.12.002

Beutel, J., Gruber, S., Hasler, A., Lim, R., Meier, A., Plessl, C., Talzi, I., Thiele, L., Tschudin, C., Woehrle, M. and Yuecel, M., 2009. PermaDAQ: A Scientific Instrument for Precision Sensing and Data Recovery under Extreme Conditions. Proc. 8th ACM/IEEE Int'l Conf. on Information Processing in Sensor Networks (IPSN/SPOTS '09), pp. 265-276, April 2009.

Shih, E., Bahl, P., and Sinclair, M. J. 2002. Wake on wireless: an event driven energy saving strategy for battery operated devices. In Proc. 8th Annual Int'l Conf. on Mobile Computing and Networking MobiCom '02. ACM, New York, NY, 160-171.

Aberer, K., Hauswirth, M. and Salehi, A. 2006. A middleware forfast and flexible sensor network deployment. In Proc. 32nd Int'l Conf. Very Large Data Bases (VLDB '06), pages 1199–1202. ACM Press, New York, 2006.