Deploying a Wireless Sensor Network in Iceland

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Abstract. A wireless sensor network deployment on a glacier in Iceland is described. The system uses power management as well as power harvesting to provide long-term environment sensing. Advances in base station and sensor node design as well as initial results are described.

1 The Glacsweb Project

The Glacsweb project [1] aimed to study glacier dynamics through the use of wireless sensor networks. It replaced wired instruments which had previously been used with radio-linked subglacial *probes* which contained many sensors. The base of a glacier has a significant effect on a glacier's response to climate change and there is a growing need to study it in order to build better models of their behaviour. Several generations of systems were deployed in Briksdalsbreen, an outlet of the Jostedal icecap in Norway. As a multi-disciplinary research project it involved people from many domains: electronics, computer science, glaciology, electrical engineering, mechanical engineering and GIS.

Initial deployments had to solve the mechanical design of the probe cases and the unknown radio communication issues. The solutions involved craft as much as science and engineering but the key success has been to create data which had not existed before [2,3,4,5] while advancing our knowledge of sensor network deployments. Hot water drills are used in order to produce holes which reach the glacier bed. Most probes are placed 10-30cm under the ice while some are placed within the ice. Due to the relatively slowly changing environment the probe sense rate is normally set to once every four hours, although an adaptive sampling algorithm has been developed in the lab [6] which would optimise this sampling rate.

2 Iceland Deployment

Skalafellsjökull is a part of the large Vatnajökull icecap in Iceland and our site was chosen at (64°15'27.09"N, 15°50'37.68"W) around 800m altitude near an access road. Although there was no local internet connection there was a mobile phone signal which we used for the main internet link. The glacier is deep enough to test beyond 100m depth in the future (we used 60-80m).

Due to the nature of the team and time available a few key topics were chosen for the developments for the Iceland deployment. One main area was to improve the basestation

N. Trigoni, A. Markham, and S. Nawaz (Eds.): GSN 2009, LNCS 5659, pp. 131–137, 2009.

design through the use of a Gumstix processor. This would provide a better development environment and easier package management. The probes would maintain the PIC18 microcontroller but would gain an improved power supply and simplified code. In terms of sensors, a high resolution temperature sensor was required to sense small changes. A light reflectance sensor was also on the list of items to be tested in order to provide more information on the nature of the material surrounding the probes. A simple star network was used rather than our more complex TDMA-based protocol [7] in order to simplify debugging.

The disintegration of the ice front in Briksdalsbreen [8] meant that we lost our previous basestation infrastructure. This coupled with the higher altitude of the Iceland site (approximately 800m) led us to build a strong physical structure based on the previous pyramid design, to support antennas and the wind generator.

3 Probes

The sensor probe was developed around a low voltage version of a PIC18 microcontroller employing rigorous power management techniques, as shown in [9]. Power is supplied by three Lithium Thionyl Chloride cells chosen for their high energy density and wired in parallel. These cells constantly supply power to the real-time clock (RTC) and the 5V DC-DC converter. Three voltage regulators are used to significantly reduce power-rail noise due to the DC-DC converter, and increase the power supply rejection ratio (PSRR) between the digital and analogue circuits of the system.

The microcontroller is only powered when the RTC's alarm is triggered. The PIC controls the supply to the sensors and the wireless transceiver to avoid wastage of energy when they are not needed. A low drift (1ppm/°C) RTC was used to minimize the necessary synchronization window when the probes awaken each day for communication.

The sensor probes were configured to gather readings hourly. Apart from one reading, it powers off immediately after the sensors are read and the RTC's alarm is configured for the following wake up time. The sensor probe enables its transceiver after one daily reading at noon and remains powered for up to one minute to allow communication. A simple potential divider and opamp configuration used for the battery sensor allowed it to monitor the energy available to allow automatic schedule tuning. This rigorous power management scheme has been successfully employed in all versions of our sub glacial monitoring system, with the current design having a sleep current of 6μA (at 3.6V), and a daily consumption of approximately 550μWH.

The sensor probe uses the conductivity sensor to determine the presence of water within its immediate surrounding, and together with the reflectivity sensor to determine the presence of ice; we are able to infer the surrounding medium of the sensor probe: whether embedded it is in dry or wet till, or stuck in the bore hole. The strain gauge and pressure sensor measure the structural and hydrostatic (or atmospheric) pressure applied by the glacier, which themselves had been used in the past to infer the probe's surrounding medium.

The tilt sensors are integrated in a single micro-electro-mechanical system (MEMS) integrated circuit capable of measuring static acceleration in all orthogonal directions. This data is converted to the tilt/roll of the probe. The case strain is measured using strain gauges glued inside the case.

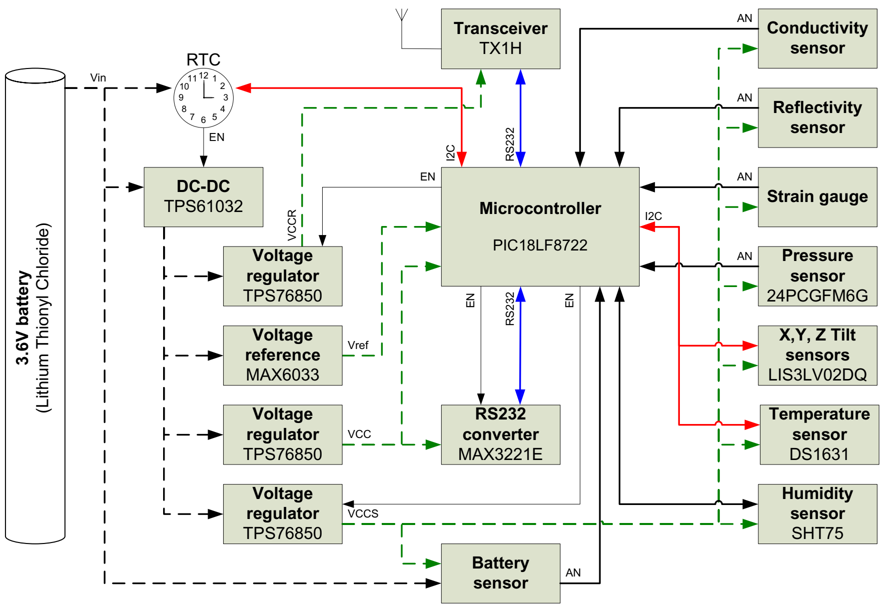

Fig. 1. Block diagram of a probe

The radio transceiver used was the BiM1-173.250-10 from Radiometrix which was tested in Norway. 173MHz was used rather than the more usual 433MHz, 868Mhz or 2.4GHz ISM bands due to the significant attenuation and reflections at higher frequencies. The antenna was a custom 1/4 wave helical design made from a 24 s.w.g. wire specifically tuned for transmissions through ice.

Each sensor probe has the provision for an RS232 level converter allowing it to be used as a "wired probe". In this mode of operation, the sensor probe acts as a distant transceiver which was embedded 10m within the glacier for improved communication range, particularly during the summer. The light sensor was a simple LED and photodiode configured with till/ice in the lab.

Calibration data for each probe is held on the basestation and the raw data is stored alongside a converted set of readings. This saves some effort by the probes and requires very little processing by the more powerful basestation. Twelve probes were deployed in the summer of 2008.

4 Base Station

Gateways or base stations are often a single point of failure in sensor networks. We have continually improved and redesigned a basestation every year since the first Norway deployment in 2001. The earliest were highly specialized and could not easily be reprogrammed remotely. The reality of deployments means that enhancements are often required after leaving the site. It is also very useful to be able to run experimental configurations for short periods of time. The 2008 basestation used research from the lab into combining a powerful processor running Linux with a low power microcontroller [6]. A small ARM-based platform produced by Gumstix provides easy programming, networking and management. In Norway we had decided that the main control code should be in an easily read/edited script language, with core code frozen (and generally written in C). The Gumstix platform made the use of the Python language simple and this was a major advance over Csh scripts previously used.

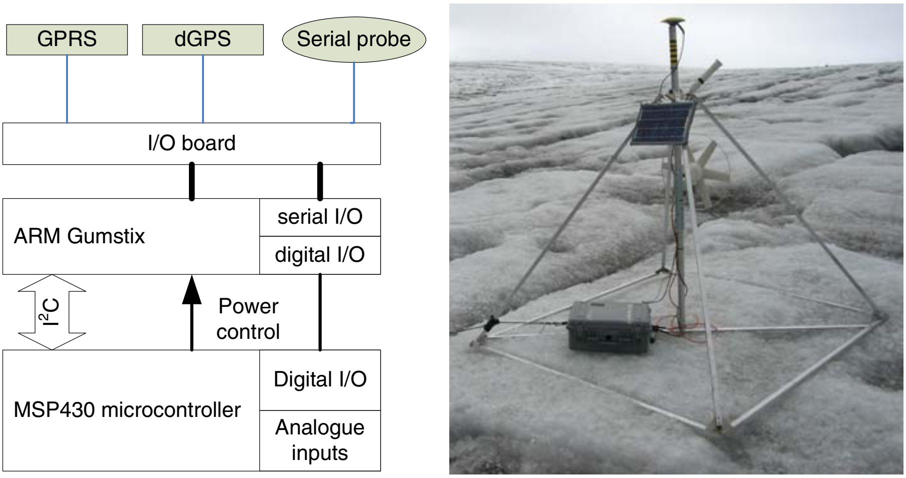

Fig. 2. Base station schematic and photograph of the installation

However one of the weaknesses shown by our previous ARM-linux component (Bitsy) was its high sleep current. The Gumstix (Connex) was not much better so the decision was made to power-off the ARM completely between uses and use the microcontroller (MSP430) to power it up. This "cold-boot" takes much longer than a standby wake-up but uses almost zero power. The energy wasted by booting for twenty seconds is compensated for by over 23hours in off-mode. This is made possible by the low frequency of basestation wake-ups we typically use – one per day. Clearly if such a system is woken too frequently the power saving benefits are lost. The microcontroller has a negligible sleep current (given that we operate from lead acid batteries) and can wake to carry out basestation sensing such as battery voltage, temperature etc.

As can be seen in Fig. 2, the base station structure is not anchored to the ice but has cutting edges and the weight of the base station "pelican" case is used to stabilise it. The Topcon dGPS antenna can be seen on the very top next to the slanted GPRS antenna. The wind generator is placed in a fixed position low down in order to increase stability. This was found to be a good compromise in Norway – as the wind tends to come down glacier and having a mobile generator would create stability problems. Figure 3 shows the case design – with its aluminium strengthening structure, which also separates the batteries in case of severe impacts. An internal case is always used in order to allow work when the weather is poor. It also allows the complete control unit to be removed easily. Large MIL-spec connectors are used on the outside of the Pelican case. A small round piezo sounder can be seen inside the internal case which

Fig. 3. Base station case showing major components

is used for debugging beeps. A USB network connection is used to connect a laptop in order to log into the Gumstix and upload/edit files or software. A compact flash card is used to create an archive of all data and logs. The compact flash card was one of the few components to survive falling into the lake in Norway (along with the Topcon GPS).

5 Initial Results and Analysis

In terms of system monitoring the solar and wind power worked well as shown by consistently high battery voltage readings. While it was known that the solar power would become negligible in winter the snow effects on the wind generator were unpredictable. The low power needed for the basestation meant we could compensate for this unknown by installing plenty of lead-acid battery capacity to maintain it through the winter (36AH). Sadly because of the GPRS loss in November we will have to wait to obtain the winter data. A problem with the wired probe's radio also

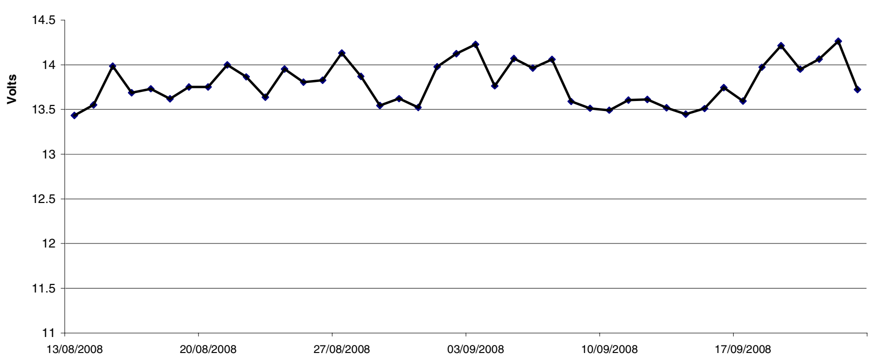

Fig. 4. Battery voltage of the base station showing consistently high charge after deployment

meant that after leaving the site no probe communications were possible. In Norway we had switched to four wired probes to remove this single point of failure. A "rescue mission" in 2009 will replace it as well as install other upgrades.

The base station computer was found to use 7µW in sleep mode, 52mW when taking sensor readings with the Gumstix off and 900mW when fully on (without GPRS or dGPS). It is the extremely low power in sleep mode which makes this the most frugal system we have produced.

The GPRS communications worked well even though the signal strength was not good and some of the daily files reached 110 kbytes. It was not possible to "tunnel" back into the system from the UK so the backup control of writing a "special" script which was fetched and executed daily worked well. This appears to be a weakness of using GPRS as an international network solution.

The data from the wired probe 12 shown in Fig. 5 shows that the light reflectance sensor is showing a change as the borehole closes around the probe. The temperature reading is a typical value for ice and the case strain (primary axis) is varying due to the ice closing around the case.

The dGPS was configured to record for five minutes once per week and these files would be correlated with those available from a national reference system in Höfn in order to measure ice velocity. While this leads to less accuracy due to the long baseline it saved us a task installing our own second dGPS. Long recordings were found to have an accuracy of 4mm because of the large numbers of satellites available. External data such as weather and a webcam image of the area are downloaded automatically by the server in the UK.

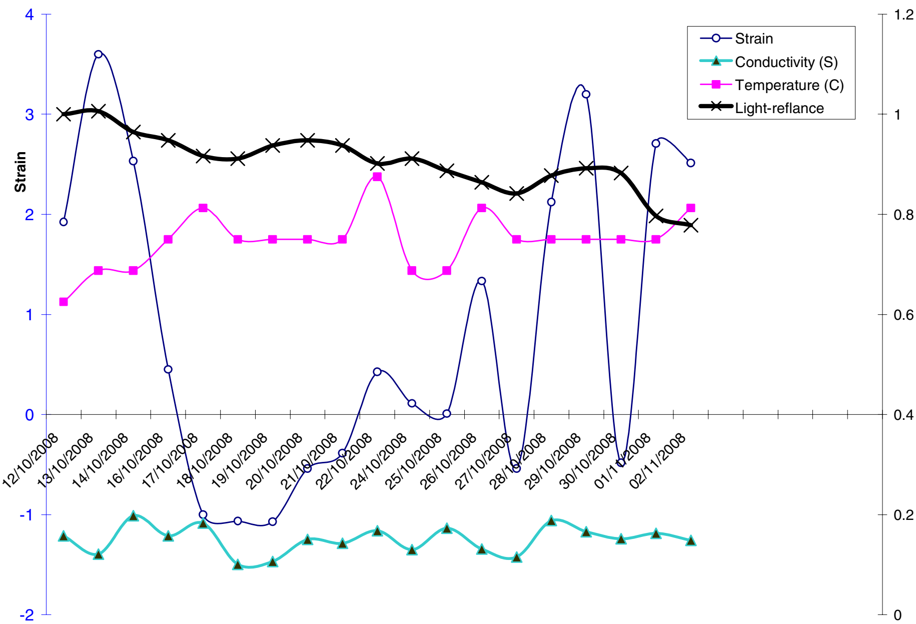

Fig. 5. Sample probe data (case strain left axis – others right Y axis)

6 Discussion and Conclusions

Every deployment has its own characteristics and issues which are only discovered once in the field. We built, programmed and deployed this system within four months, which is a record for us and was only possible through carefully cutting down the complexity of the system and because the team was technically extremely capable. The single point of failure in the wired probe turned out to be a weak point but we expect the probes to be still running, so gathering their stored data and re-establishing the network is still possible. The new base station architecture has proven a success, not only is it easier to develop with and uses less power but is also cheaper than our previous platform.

Future improvements will include adaptive GPS recording, so that in times of high power availability longer (hence more accurate) readings can be taken. A backup internet link is also needed, using long range modems to the nearest building.

Acknowledgements

The authors would like to thank the Glacsweb team for their dedicated efforts: Kathryn Rose, Jeff Gough, Robert Spanton, Tom Bennellick, Stuart Rimmer and James Cheshire. This research was funded by the EPSRC.

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