Using Sensor Technology to Protect an Endangered Species: A Case Study

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***Abstract*—A lot of applications for wireless sensor networks have been proposed in the last years. Only a few of them have led to real, non-academic deployments, partially due to the differences between end user needs and academic assumptions. In this paper we discuss a real world problem arising from an ecological question (protection of an endangered species) and the theoretical solution as well as the deployed solution that actually works.**

I. Introduction

In recent years, lots of applications for wireless sensor networks have been proposed by research groups around the world. These range from military applications like vehicle tracking [1] to civilian applications like water quality monitoring [2] and precision agriculture [3]. Even though there are some real world applications like those described above, most developed algorithms have not found their way into real word applications outside academic testbeds. Typical requirements presented by the end-users are often very different from those envisioned by the researchers. In this paper we present an example from ecology, in which wireless sensor nodes are used to gain vital knowledge about an endangered species, the hermit beetle.

This paper is structured as follows: Information about the observed hermit beetles and some of the reasons for monitoring them are given in Section II, the way information about the hermit beetles is gathered is discussed in Section III. The means (hard- and software) used to achieve the wishes of the end-user as well as some preliminary results are described in Section IV. We finish with a conclusion in Section V.

II. The Hermit Beetle (*Osmoderma eremita*)

Osmoderma eremita is a large scarab beetle, often more than 30 mm long. This saproxylic (living within wood) beetle lives in open caverns inside old hollow trees. It is associated with both, living trees and dead ones, the status of different tree species, and different positions in trees. It also interacts with special fungi. Therefore, the hermit beetle is a good "indicator" for the status of a whole forest. The main long-term threat has been identified as habitat loss due to lack of veteran trees. Especially the historical continuity of suitable veteran trees is no longer given. Basically there are not enough trees older than 150 years due to intensive forestry. Also, road side trees are often cut down early for safety reasons, before the beetle can settle inside the cave. The hermit beetle species is endemic to (only living in) Europe. Especially Germany has been requested to protect its entire population of this species. Therefore the federal states of Germany, for example Mecklenburg-Vorpommern, have organized a systematic monitoring for this beetle [4].

For all these reasons, *O. eremita* is listed as priority species in annex II and IV of the European unions habitat directive (see also [5]). In the IUCN red list of threatened species (see www.iucnredlist.org) we can find the beetle as near threatened species. In many European countries the species is also on the red lists.

III. The Problem Statement

Although many gaps in knowledge could be filled in the last decade, research requirements with respect to the habitat claims [5] remain. For example the reasons why the hermit beetle chooses one tree above another are still unknown. An important criterion seems to be the state of the duff (a degradation product of blight fungi). Moisture and temperature are considered to be its most important characteristic. One basic assumption made about hermit beetles is that the temperature and humidity within the duff they settled are basically constant throughout the year, resulting in optimal growth rates for the larvae of the hermit beetles.

To confirm or disprove this assumption, temperature and humidity must be evaluated regularly. The previous way of achieving this was to drive into the woods on a regular basis, carrying the measurement equipment along. Taking a single sample requires a lot of time and is very expensive. Therefore, it was previously only possible to take one sample value every week due to personal and budget constraints.

During talks between academics and user we found that an increase in sampling frequency and of course ease of use were all the improvements wished for. Contrary to the wishes often assumed by researchers the increased sampling rate was not envisioned as once every second or even once every minute. Once every day would be sufficient, everything better would be a bonus. We proposed sampling every hour.

A. Theory

As we listened to the report from the intended user, we thought that this application would be an ideal use case for wireless sensor networks. The similarities to the great duck island experiment [6] seemed obvious. We would be monitoring the natural habitat of beetles instead of birds, but this only meant a different deployment site. Sensor nodes would be deployed throughout the forest into each tree that contained a hermit beetle, forming a classic sensor network with many sampling nodes. These nodes would then transmit the gathered data to a central sink, which contains an uplink to mobile broadband. The sink itself would then forward the aggregated information once a day, enabling the user to access the data from his desk.

B. Practice

Then we all went on a field trip to see the beetles and trees for ourselves. We were quite surprised by the actual circumstances we would be dealing with:

In the forest, mobile broadband was basically not available, making an automatic upload impossible. But even if it had been possible, the risk of theft would have been high, as the forest was no private property and anyone might stumble upon the equipment. Our assumption that the nodes used to collect sensor data could be used to form a network was also proven invalid. We found that inside the forest, the used hardware (see Section IV-A) was not able to communicate for even 15 meters without line of sight. But as we learned, the beetle inhabited trees are often a few hundred meters distant, which would require many relay nodes in between. Also, the measurements were meant to be conducted for a whole year, and data loss was intolerable. Therefore, energy constraints had to be weighted against data safety.

IV. Introducing Sensor "Networks" into Ecology

In the end we settled for a simple data logging application, which fulfills the requirements of the user while keeping the hardware costs within the given budget. After deducting the memory consumption of the operating system and application, enough flash memory remained for 960 data sets consisting of a timestamp (date, hour) and 4 raw sensor values (temperature and humidity for both, cave and duff). With a sampling rate of once every hour, enough flash memory would be available on the nodes to store the data of 7 weeks.

Due to the fact that the senor nodes only need to communicate when the data is retrieved, the radio module can be turned of most of the time. But how can the nodes decide when they should turn their radio on? Once again there are different theoretical approaches, but the simplest and therefore chosen way is to use a button on the sensor node, that the user presses when he wants to download the data.

Two standard AA batteries are used to power the sensor node. Depending on the quality of the batteries, the sensor nodes would have been able to work for years, but had to be accessed by the biologist at least every 7 weeks because by then they ran out of memory to store the sampled data in. Also, the gathered data is too important to risk losing it due to a set of bad batteries. Therefore, the batteries were changed with every data download, just to be on the safe side.

A. Hardware

In search of a usable hardware platform we found the eZ430-Chronos from Texas Instruments [7], an inexpensive evaluation platform for the CC430. It is a MSP430 microcontroller with integrated CC1100 sub-gigahertz communication module [8] . The evaluation board is delivered as a compact sports watch containing several sensors, e.g. a three-axis accelerometer, and 5 buttons which are connected through general purpose I/O pins. We removed the board from the watch casing and attached two temperature/humidity sensors of type SHT 71 from Sensirion (http://www.sensirion.com) to the I/O pins instead of the buttons.

The access point which is delivered with the eZ430 is connected to a laptop and used to download the sampled data and free the memory on the sensor node.

To keep the hardware dry even when it is raining, we enclosed it in an airtight box. The temperature/humidity sensors were connected with long cables through a hole in the side of the box, with was then resealed using hot glue. Silica gel was also enclosed, it removes any moisture that might get into the packaging during battery change. A sensor node with its packaging before deployment can be seen in figure 1.

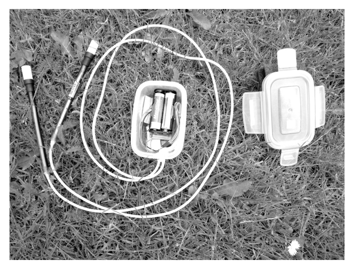

Fig. 1. The used hardware

B. Software

As the eZ430-Chronos is not delivered with a sensor network operating system, we ported our own operating system REFLEX [9] for the microcontroller. REFLEX is an event driven operating system for deeply embedded systems and sensor nodes, which enables the programmer to write sensor network applications in C++.

The application itself has two main duties: sampling and delivering the sampled data. Therefore, the sensor node could remain in a low power sleep mode most of the time. Switching into the appropriate sleep mode is done automatically by REFLEX, as described in [10]. Every hour the sensors take a sample, initiated by the real-time clock. The sampled values are stored in the flash memory, together with the current timestamp. Note that in absence of external memory, program code and sampled data must share the 32 kb internal flash. Apart from discriminating the sampled values, the timestamp

(a) The sensors are deployed inside the duff

(b) Ants investigating the Sensor Node

(c) Hermits Beetles investigating the Sensor Node

Fig. 2. Sensor node deployment

is also used to recover from resets. If the node suffers a reset for any reason, it finds the last timestamp in the flash and uses it to set the real-time clock. This can lead to clock skew of course, but the precious values sampled before the reset are preserved. The clock skew of up to one hour is completely within the tolerance parameters.

The download of the data was initialized by pressing a button on the node, which caused the application to turn on the radio module for 10 seconds and try to connect to the access point. Once connected, the software on the laptop sets the real-time clock to the current time to remove clock skew. After this, it is used to either download the gathered data or erase the downloaded values from the node. Note that these two functions could theoretically be combined, but two different programs were used on the laptop none-the-less. This is once again done due to the importance of the gathered data. If downloading the values would automatically erase the data and an error occurred, the data could be lost. Therefore, the erasure program is started only after it has been confirmed that the data has been received successfully.

C. Deployment

The nodes are deployed on three locations in eastern Germany. The first deployment area is located near Tauer in the federal state of Brandenburg, were old oaks can be found. A second deployment site is located near Löcknitz in the state of Mecklenburg-Vorpommern, where old oaks are common as well. The third deployment site is near Burg/Spreewald in the federal state of Brandenburg, where some trees that house the hermit beetle have been relocated due to mining requirements.

Figure 2(a) shows the combined temperature and humidity sensors placed within the duff. The left one is facing down, measuring inside the duff, while the right one is facing up with its sensing end protruding from the duff to evaluate the surrounding air.

On the first deployment site, we placed the sensor box on the outside of a tree with cables leading into the tree to the actual sensors and moved a few meters away in order to test the connectivity as described above. As we returned only three minutes later, the whole box was swarming with ants (figure 2(b)). No one had thought about this possibility, but luckily the airtight packaging also kept the sensor node bug free.

Figure 2(c) shows the sensor node inside its water, bug and beetle proof packaging deployed in a different tree. On the figure, three adult hermit beetles can be seen. Altogether nine imagos (adult beetles) of the beetle were seen at the time this picture was taken, which is quite a high number. Sightings of adult hermit beetles outside of the inhabited duff are rare, often only single imagos or none at all are observed.

D. Results

The sensor nodes have been in deployment on the three sites mentioned above for a year, sampling the temperature and humidity of duff and cave each hour. To the best of the authors' knowledge, this is the first continuous measurement of the environment of the hermit beetles over such a long time. A first evaluation of the gathered temperature values confirms the assumptions made about the duff: it dampens the variations in temperature. As an example, the values gathered in Löcknitz in the state of Mecklenburg-Vorpommern on 40 days in the summer (figure 3) and 40 days in the winter (figure 4) are shown here.

Figure 3 visualizes the temperature values of the cave and the duff it contains measured between June 24th and August 2nd in 2010. The figure shows that even though the temperature within the cave rose drastically during daytime and dropped equally drastic at night, the duffs temperature remained fairly stable. It only increased in the course of many days. This is due to the high amount of water stored within the duff (80% relative humidity, sometimes even more).

The temperature values gathered in the same cave during winter are shown in figure 4. There, the differences between the temperature in the cave and that in the duff are even more drastic. Even though the outside temperature was below minus five degree Celsius most of the time and even dropped to minus 14,75, the duff did not drop below minus 3,26 degree Celsius. The high amount of water stored within the duff means once again that temperature changes affect the duff much less than the air surrounding it. Also, when the temperature drops to negative values over a longer period of time, only the outer regions of the duff freeze, insulating the core. This seems to indicate that a certain size of duff is required to keep the beetles alive during winter.

Sadly, the humidity sensors failed to deliver results time and again. In retrospective the choice of sensing hardware was wrong, because the chosen sensors could not cope with nearly 100% humidity over long periods of time. Also, during winter, when the temperature dropped below 0 degree Celsius, snow and ice proved to be a big problem for the humidity sensors: They simply froze.

V. Conclusion

In this paper we have presented our work with the hermit beetle, an endangered species living in Europe. We have shown how sensor nodes can be used to fill the gaps in the knowledge about the hermit beetles, and described three deployments in which the nodes are currently used. A first evaluation of the gathered data confirms assumptions about the role of the duff in which the hermits reside, but further evaluation is needed to answer open questions like why hermit beetles choose one tree above the other.

We have also shown the differences between the first idea, in which we wanted to use whole sensor networks with multi hop routing, and the actual solution which consists of isolated sensor nodes.

As the energy consumption of sensor nodes is mostly dictated by their need to communicate, that is turning the radio on, a solution which does not transmit the gathered data to a central sink but only stores it inside the sensor nodes themselves can be operational much longer with a given amount of energy. If the gathered data is not time critical and can be downloaded anytime later, it pays to consider delivering the data only when a human has to be near the nodes anyway.

In conclusion it can be said that there is a definite need for improvement on communication between researchers and possible end users, as both sides assumed knowledge and/or facts about the other one that simply were not there.

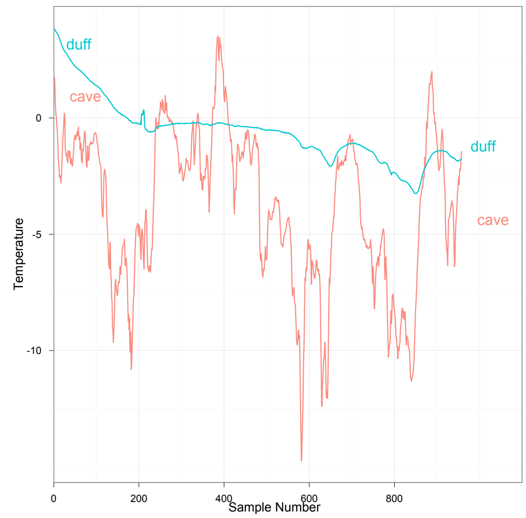

Fig. 4. Temperature Values gathered in 40 winter days (November 25th, 1PM to January 4th, 11am)

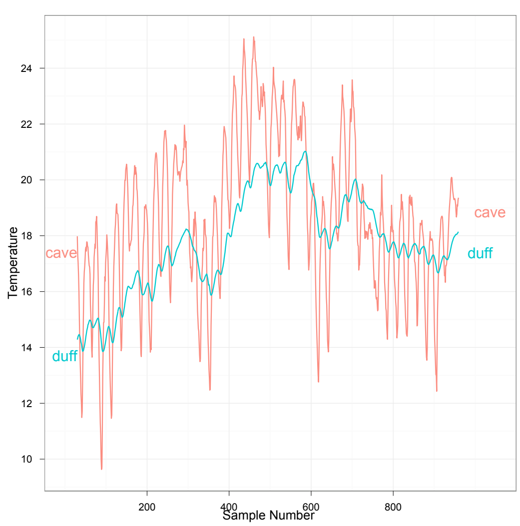

Fig. 3. Temperature Values gathered in 40 summer days (June 24th, 5PM to August 2nd, 11am)

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