Krill: An Exploration in Underwater Sensor Networks

I Vasilescu, K Kotay, D Rus
MIT Computer Science and Artificial Intelligence Laboratory
Cambridge MA 02139

L Overs, P Sikka, M Dunbabin, P Chen, P Corke
CSIRO ICT Centre
P. O. Box 883, Kenmore QLD 4069, AUSTRALIA

1. Introduction

While sensor networks have now become very popular on land, the underwater environment still poses some difficult problems. Communication is one of the difficult challenges under water. There are two options: optical and acoustic. We have designed an optical communication board that allows the Fleck's to communicate optically. We have tested the resulting underwater sensor nodes in two different applications.

2. Design

Figure 1 shows the construction of an underwater sensor node. The basic building block is a Fleck1 [2]. It is interfaced to a special optical communications board through 2 digital IO pins. One of these pins is used to turn a LED on or off, while the other is used to sense the output from a matched photo-diode. A special interface board contains all the analog electronics required to drive/sense the photodiodes. The Fleck is also interfaced with a sensor board to measure temperature and pressure. All these boards are connected in a stack using stack-through connectors.

The components are all packed into an "Otter" box that is water-tight to a depth of about 30m. The box has been modified to allow for mounting the LED, the diode and sensors.

The underwater Flecks have a range of about 2.2m in clear water that reduces to about 1.2m in highly turbid water. The maximum possible transmission rate is 320 kbit/s.

3. TinyOS Integration

Information over the optical channel is encoded in the width of a transmitted pulse. For example, a 200 μs pulse encodes a '0', while a 400 μs pulse encodes a '1'.

Our initial approach was to take the existing radio stack for the Fleck [2] and wire in a different component to provide the RadioData interface to the stack. This interface provides the input and output byte streams to the radio stack. The approach worked well in that it allowed us to quickly prototype applications. However, the problem with this approach was the band-width, which was theoretically limited to about 3000 bytes/s since we could not reliably reduce the pulse widths any more. The limitation was caused by the use of timers to control pulse widths.

We were able to achieve greater bandwidth by using an alternative implementation to provide the RadioData interface. In this implementation, interrupts are completely disabled during packet transmission and reception (and this is bad). However, the pulse widths are now 250 μs, so throughput is significantly enhanced to a maximum possible rate of 40000 bytes/s. This approach was acceptable in our case since communication is occasional and all other activity can be suspended during communication.

4. Applications

The primary aim for building these sensor nodes was some experiments in sensor-robot interaction. Once the experiments were complete we used these nodes for other underwater sensor network applications, an example of which is provided below.

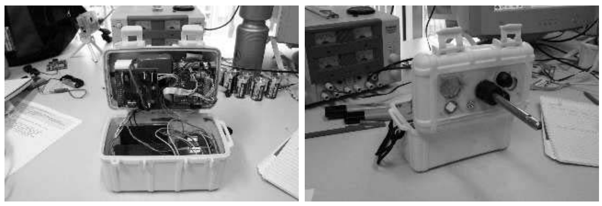

Figure 1. The underwater Fleck. (a) Inside view, and (b) outside view.

Figure 2. A small AUV interacting with the underwater Flecks in a “simulated ocean”.

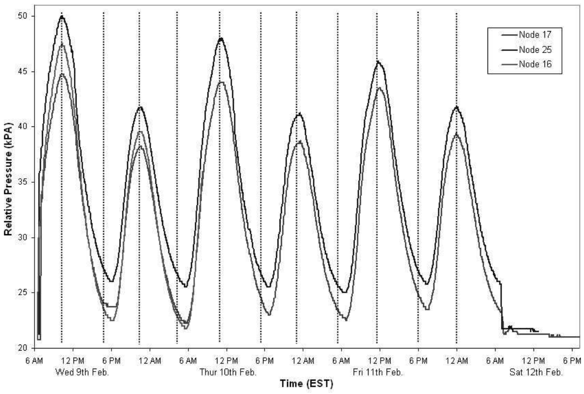

Figure 3. The pressure data collected from the three underwater Flecks.

4.1. Autonomous Underwater Vehicle

The main goal for the underwater Flecks was to conduct some experiments in sensor network — robot interactions. In the simplest case, the underwater Flecks can log useful data (temperature, pressure in this case) and the AUV [1] can be used as a data mule that goes around and uploads the data from the Flecks. In more sophisticated situations, the Flecks can also be used to guide the robot and the robot can act as smart data mule that can carry information between sensor nodes. Figure 2 shows an underwater Fleck in a swimming pool interacting with a small AUV.

4.2. Creek monitoring

Three underwater Flecks were deployed in Tingalpa Creek, Brisbane. These particular sensor nodes were capable of logging water temperature and water pressure. Each sensor node was deployed approximately one kilometre apart and for three days. After the sensor nodes were retrieved, the logged data was downloaded via an optical-based communications link and then analyzed. The acquired pressure data are in agreement with the expected tidal shifts published in a tide guide for this area.

The sensor node deployment at Tingalpa Creek was completed to verify the ability of sensor nodes to record water pressure and temperature data accurately. Software developed for the sensor nodes was written in nesC in a TinyOS environment. A file system recently developed at CSIRO was used to save data to the on-board flash memory. The sensor nodes were programmed to log water pressure and temperature every 150 seconds. The file system was initialized such it could hold seven days worth of data. Approximately 110 KB of the 500 KB on-board flash memory was used.

The data sets acquired from the pressure sensors are displayed in Figure 3. This data correlates well with known tidal conditions. The high tide and low tide times are marked on the graph with broken lines. As can be seen on the graph, there is good agreement between the observed and expected high tide times. There is an approximately one hour lag between the expected and observed low tide times. This is due to the dynamics of the water flowing in and out of a creek from the ocean. It is also important to note that the tide guide provides information about a certain position in Brisbane. An average offset is then provided for secondary locations such as Tingalpa Creek. As a result, it is reasonable to assume that there may be a small variance between the expected and real times for high and low tides.

5. Conclusion

We have developed underwater sensor nodes that communicate via optical means. We have successfully deployed these nodes in two applications: experiments in underwater sensor network — robot interaction, and creek monitoring.

References

[1] M. Dunbabin, J. Roberts, K. Usher, G. Winstanley, and P. Corke. A hybrid auv design for shallow water reef navigation. In *International Conference on Robotics and Automation*, 2005.

[2] P. Sikka, P. Corke, and L. Overs. Wireless sensor devices for animal tracking and control. In *First IEEE Workshop on Embedded Networked Sensors in 29th Conference on Local Computer Networks*, pages 446–454, 2004.