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Field Trials of Screen-Printed Chloride Sensors for Environmental Sensing: Fluvarium Tests

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Abstract

This paper reports on a trial of 21 low-cost, robust and reliable chloride sensors, networked and tested in a fluvarium (stream simulator). Initial test results reported here have shown that the sensors are able to monitor real time changes in chloride flux, and track its progress through the fluvarium. We report on results from both surface flow as well as from sensors at a depth of a few mm in the fluvarium sediment, and differences and trends between the two are discussed. It is shown that for the flow regime and sediment type tested, penetration of surface chloride into the river bed is unexpectedly slow and raises questions regarding the dynamics of pollutants in such systems. We conclude that the sensors offer a new paradigm in hydrologic monitoring and will enable new science to be investigated.

Keywords: sensing; wireless;chloride;environmental;hydrology

1. Introduction

Wireless Sensor Networks (WSNs) have received a significant amount of research attention recently, and are finding favour in agricultural and environmental applications [1]. One issue that is affecting their uptake is the availability of suitable sensors. If a network is going to be usefully deployed, then it is a requirement that it can sense the measurand of importance. In addition it is necessary that the sensor is low cost (as many are going to be used), is accurate enough to be useful, and has a lifetime that is commensurate with the monitoring task at hand.

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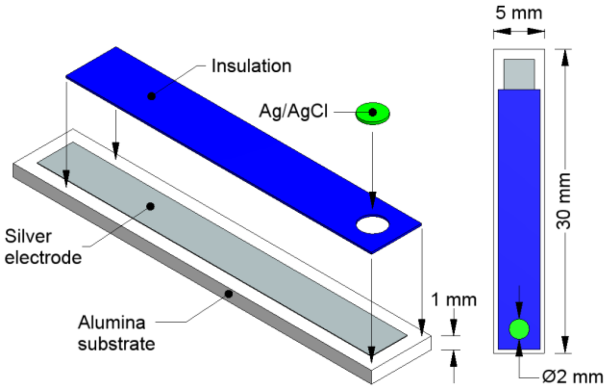

Fig. 1: Schematic of screen printed chloride sensor.

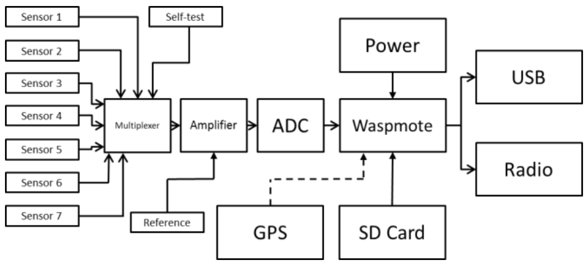

Fig. 2: Sensor system diagram.

This paper illustrates an attempt to address the sensors issue by reporting on the field use of a screen printed chloride sensor. The sensor system (consisting of the sensors themselves and some bespoke data collection electronics) was deployed in a fluvarium containing an experimental river bed, and the fluvarium flow was managed under different conditions. Known amounts of chloride solution were added and the results monitored.

The sensors are based on those previously reported in [2]. The sensors themselves are silver electrodes screen printed onto an alumina substrate. A dielectric insulation layer is added to mask off the active area which is then chloridised electrochemically to create a layer of silver chloride on top of the electrode. Since the sensors are potentiometric, they need to be measured against a standard. Accordingly, all measurements were made with respect to a commercial Ag/AgCl reference electrode (VWR GelPlas, 3.5 M KCl).

2. Sensor electronics

The logging electronics were custom built for the sensors. The system consists of an analog processing board, a digital board, and a robust housing. The analog processing board allows up to 8 individual sensors to be connected and measured against a single reference. Each sensor is measured individually and sequentially through an analog multiplexer. The signal is then amplified by a gain factor which can be varied to allow for different expected ranges of chloride, to allow the full range of the following analog to digital converter to be used.

The digital board in this case is based on a Waspmote sensor node [3]. This is a commercially available microprocessor platform based on an Atmel microcontroller. It has interfaces already defined for common radio systems such as 802.15.4 or GSM, and also has an SD card interface. It is possible to send this module to sleep with very low power consumption, which is advantageous for extended battery life. Programming is done via a USB connection to a PC. Data is digitized from the analog board using the on-board ADC which has a 10 bit resolution. This data is then scaled, time stamped and then either assembled into a data packet for radio transmission or stored on the SD card. For multiple data loggers operating at the same time, it is necessary to synchronise the clocks of the loggers. This is achieved by running a separate program that extracts the time from a GPS module that is temporarily installed into each logger. This is used to set a real-time clock. Finally the electronics are housed in a water resistant box, with the sensors grommetted though the casing. The sensors are on 1 meter cables and so the sensing points can be up to +/-1 m away from the logger.

The fluvarium consisted of a long channel (20m) which had previously been filled with an example river bed. This was used as a representative environment. The slope of the fluvarium was adjustable, and the flow rate could be controlled and measured at the outflow. Figure 2 shows a representative photo of the fluvarium along its length. The sensors can be seen inserted into the river bed at this location. For the experiment reported here the sensors were placed at 30cm intervals. Two sets of sensors (14 sensors) were used to give lateral measurements. A third set of sensors were co-located with the downstream sensors, but located in the surface flow rather than embedded in the bed. The embedded sensors were inserted to a depth of 20mm.

Fig. 3: Photograph of fluvarium showing sensor positions.

Fig. 4: Photograph showing the inlet pool and the first embedded sensor. The surface flow sensor is not installed at this time.

3. Methodology

The fluvarium was allowed to soak overnight. At the inlet end 100ml of 100mM salt solution was added with no flow into the fluvarium and this pooled at the inlet. Sensor 2 in fig 5 was placed near the downstream end of this pool as a reference, and it can be seen that the added solution was diluted by the water already in the fluvarium to give a reading of about 52mM. The other sensors shown in figure 5 are sensors located in the river bed, moving downstream. All of these show very low levels of chloride, except for sensor 1 (shown in fig.4) which was located very near the inlet pool and this shows that there has been some diffusion of chloride though the bed, probably from previous experiments. At about 50 minutes, the gradient of the fluvarium was increased, to encourage a slow drain flow away from the inlet. Periodically samples of tap water were added to the inlet pool to provide impetus. These events are listed in table 1.

Table 1. Chronography of fluvarium events.

Event	Time (mins)	Description	Event	Time (mins)	Description
1	54	Fluvarium tilted	5	139	400 ml water added
2	107	200 ml water added	6	164	600 ml water added
3	114	200 ml water added	7	185	1,000 ml water added
4	129	200 ml water added	8	204	Flume turned on

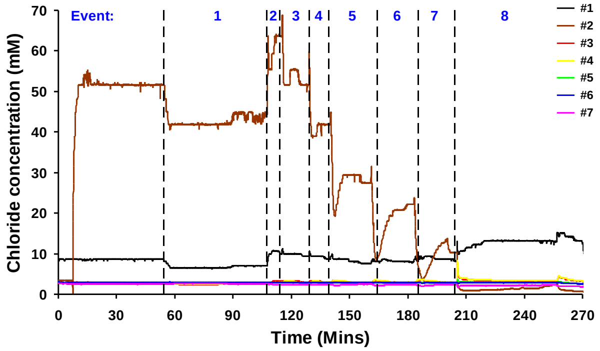

Fig. 5: Results from embedded sensors. Sensor 2 is in the inlet pool

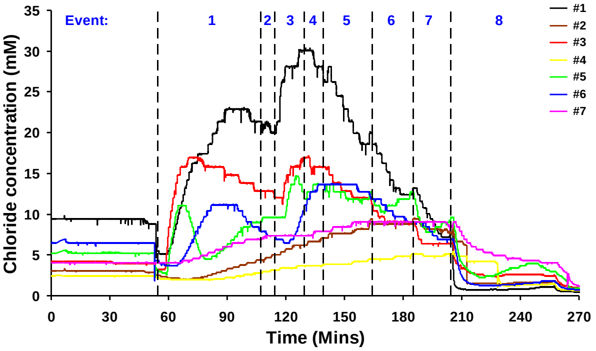

Fig. 6: Results for surface flow sensors

4. Discussion

All these events are marked in fig. 5 and it can be seen that the sensor in the inlet pool responds very quickly. Sensor 1 (embedded, but nearest the inlet) also shows a small response. There is a response as the fluvarium is tilted and sensors 1 and 2 show an increase in concentration. This is due to the relatively poorly mixed inlet solution starting to move towards the outlet and move downstream. This effect is emphasised as the first water is added at 107 minutes. The addition of the water pushes the higher concentration further down the fluvarium as is shown by sensor 2. Other additions are then seen to indicate a reduced concentration as the salt slug is replaced by a more dilute solution. When the fluvarium is turned on at about 200 minutes a steady flow of water establishes itself after a few minutes and sensor 2 then shows a similar reading to the other sensors, indicating that the salt pool has been flushed. Sensor 1 continues to rise as salt is pushed through the river bed, but starts to fall as the experiment finishes.

Figure 6 shows the surface flow sensors located further down the fluvarium. The dotted lines show the events of table 1. The picture is less clear here . There is evidence that sensors 1, 3 and 6 are responding similarly, showing an increase in chloride concentration with time, before tailing off. This is commensurate with the intial salt pulse moving down through the surface flow of the fluvarium, being intially driven by the tilting and establishing a concentration gradient, as the sensors peak in inverse order of distance between 60 and 100 minutes. Later responses are driven by the water events with a time delay. The other sensors respond slowly. Visual inspection of the sensors showed that a preferred meandering flow path was being established in the fluvarium and that sensors 1, 3 and 5 were positioned in that flow. Other sensors were not in the obvious preferred flow path and so were seeing different driving functions. A third set of co-located sensors were also measured, with these being embedded 20mm deep in the river bed. All these sensors showed no variation from baseline over the time of the experiment, similar to sensors 3 to 7 in figure 5, and these results are not shown here for reasons of space.

5. Conclusions

These initial trials of chloride sensors in a fluvarium environment allow some interesting observations to be noted. First we conclused that the sensors are useable in such an environment and allow real time measurements of chloride concentration in both fluid environments and also wet soil environments. Secondly, the simple experiment shown here illustrates the care needed in interpreting spot measurements in a distributed environment. Even sensors positioned a few centimetres away from a preferred flow path will give results significantly different from those in the preferred flow. Thirdly, in this system, although surface flows exhibited significant chloride concentrations, this is not necessarily evidenced even at low depths of 20mm in the river bed, except very near the source of chloride in this case.

Thus we conclude that these chloride sensors and associated electronics offer an opportunity to measure and track short term chloride events in flowing water, and also offer the opportunity to log the same positions for longer periods of time, rather than the alternative of grab sampling. The need for distributed sensors across a wide area is established and the dangers of extrapolating measurements from a point measurement are illustrated. Thus it is concluded that sensor networks can provide very useful and new scientific evidence for natural system processes, but care must be taken in interpreting results.

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[3] Libelium http://www.libelium.com/products/waspmote/