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Low-cost sensor networks to quantify the dynamics of suspended sediment yields in peri-urban areas

Des réseaux de capteurs à faible coût pour quantifier la dynamique des apports de sédiments en suspension dans les zones périurbaines

P. V. R. M. Silva^{1,2,3^}, K. L. Russell², T. D. Fletcher², F. Cherqui^{1,2,4}, O. Navratil³, and E. Cossart¹.

¹ University of Lyon, INSA Lyon, DEEP, EA7429, 69621 Villeurbanne, France.

² WERG, SEFS, The University of Melbourne, Burnley, VIC 3121, Australia.

³ University of Lyon, CNRS UMR 5600 Environment Ville et Société, Lyon, France.

⁴ University of Lyon, Université Claude Bernard Lyon-1, F-69622 Villeurbanne, France.

pribeiomarq@student.unimelb.edu.au; kathryn.russell@unimelb.edu.au; timf@unimelb.edu.au; fcherqui@gmail.com; oldrich.navratil@univ-lyon2.fr; etienne.cossart@univ-lyon3.fr

RÉSUMÉ

Les sédiments en suspension représentent une source de pollution importante pour les cours d'eau périurbains. Toutefois, les principales sources de production de ces sédiments et la variabilité spatio-temporelle de leurs transferts dans le réseau hydrographique demeurent encore mal connues. Une métrologie de terrain adaptée est alors essentielle pour quantifier la contribution des différentes sources (urbaines ou non) aux flux de sédiments dans les cours d'eau. Cette quantification est cependant actuellement techniquement et financièrement difficilement généralisable. L'utilisation de capteurs à faible coût et *open-source* pourrait faciliter la mise en œuvre d'une observation de terrain avec une densité spatiale importante et à un prix abordable. Ce réseau de suivi donnerait alors la capacité de représenter la variabilité spatio-temporelle des flux de sédiments à l'échelle du bassin versant et à une résolution spatiale fine. Notre recherche vise donc à utiliser un capteur de turbidité à faible coût (modèle TST-10) dans le cadre de stations de surveillance (télé-relevées à un serveur central) pour une surveillance en continue des flux de sédiments dans les petits cours d'eau péri-urbains. De plus, des unités mobiles de capteurs de turbidité sont en cours de développement pour identifier et quantifier les contributions de diverses sources à la production globale de sédiments au cours des processus d'urbanisation. Des expériences en laboratoire avec ce capteur de turbidité ont montré des résultats prometteurs (pour une gamme de turbidité variant de 0-4000 FNU). La compensation de température et le contrôle de la lumière ambiante sont des étapes essentielles pour une bonne précision des mesures sur site. Ils sont assurés en mesurant la température de l'eau avec les mesures de turbidité et en effectuant les mesures de turbidité dans un boîtier totalement opaque.

ABSTRACT

Suspended sediment is an important pollutant in peri-urban streams, yet its main sources and their spatial and temporal variability are not well understood in these complex landscapes. Field measurements are essential to identify and monitor sediment load from different sources at fine spatial scale, i.e., at many locations, but doing so is technically and financially challenging. The use of low-cost sensors, with open-source code, facilitates their cost-effective implementation in different locations simultaneously in a range of field conditions. This research aims to use a low-cost turbidity sensor (TST-10) with an innovative design to be deployed in field telemetry stations for continuous monitoring, to estimate sediment loads in small streams in real time. Furthermore, mobile turbidity sensor units are being developed in order to make it possible to identify and quantify the contributions of various sources to the overall production of sediments during urbanization processes. Laboratory experiments with the low-cost turbidity sensor, in a controlled environment, showed promising results in estimating the turbidity values of water samples for turbidity between 0 and about 4000 FNU (Formazin Nephelometric Unit). Temperature-compensation and control of ambient light are important for accuracy and are addressed by measuring the water temperature simultaneously with turbidity measurements and providing a dark environment for the low-cost turbidity sensor.

KEYWORDS

Low-cost sensor networks, monitoring, peri-urban streams, suspended sediment, turbidity levels.

1 INTRODUCTION

Land use has a major effect on streams, resulting in impacts on their morphology and dynamics, and significantly altering the production and transport of sediment (Russell et al., 2019). Although sediment yields in urbanizing areas are complex and our understanding remains limited, urban development has the potential to produce significant amounts of fine sediment, both during construction and after urban areas are established (Russell et al., 2017). Suspended sediment is an important pollutant in peri-urban streams and an effort must therefore be made to better understand the processes of sediment production in areas undergoing urban expansion to maintain and improve the health of water bodies.

Field measurements are essential to identify and monitor suspended sediment loads from different sources at fine spatial scale, i.e., at many locations, but doing so is technically and financially challenging. Commercial water quality sensors prioritise accuracy, reliability and usability in environmental measurements and are currently widely used in field measurements. However, their high cost can be a limiting factor for studies that require continuous measurements of water quality, such as turbidity levels, at different points of interest in streams (Murphy et al., 2015).

To address this limitation, this research aims to develop and implement low-cost turbidity sensors at telemetered monitoring stations for continuous monitoring, to estimate sediment loads in small streams in real time. Mobile turbidity sensor units are also being developed to identify and quantify the contributions of various sources to the overall production of sediments during urbanization processes. The use of low-cost sensors, with open-source code, facilitates their cost-effective implementation in different locations simultaneously in a range of field conditions. This solution allows measurements to cover a large area with a high spatial resolution, and provide real-time data, which permits continuous monitoring and evaluation of environmental parameters of interest prior to, during, and after rainfall events.

2 METHODS

2.1 Laboratory experiments

2.1.1 Experiment setup

The experiment was carried out in a closed loop system with a peristaltic pump to run the water sample through the turbidity and temperature sensors (Figure 1). As the turbidity sensor (TST-10) has high sensitivity to ambient light, it was placed in a dark environment. The temperature sensor was inserted inside the pipe, through the tee, in order to measure the water temperature. Both sensors were connected to an Arduino board, so that measurements of voltage (mV) and water temperature (°C) could be recorded every 1.5 seconds simultaneously. The system also had a hot water container to heat the water sample by thermal conduction. A total of thirteen samples were used in the experiment, with a turbidity of 0, 46, 94, 140, 194, 330, 817, 1263, 1392, 1825, 2133, 3167, and 3617 FNU. Samples were prepared with bentonite and tap water, filtered through a 63 μm sieve, and their turbidity was measured using a YSI probe.

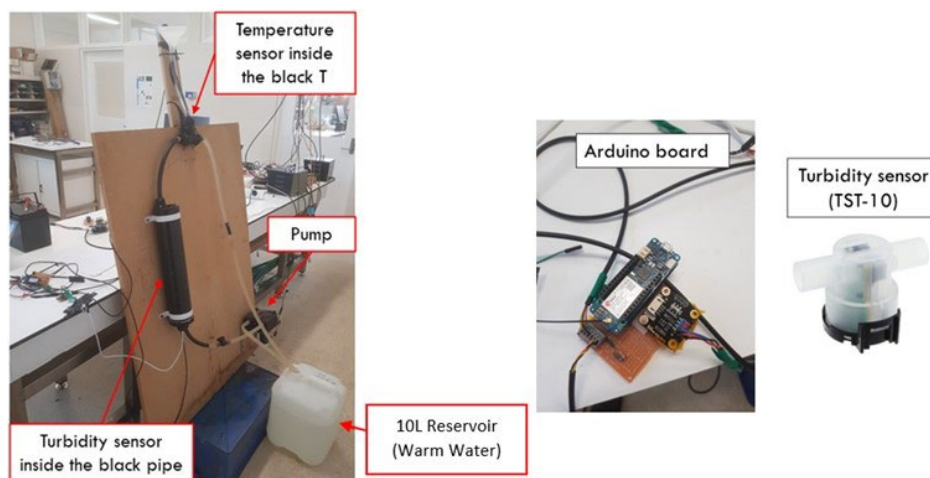


Figure 1 - Experiment setup.

2.1.2 Experimental results

Thirteen experiments, one with each sample, were performed with an average for approximately 30 minutes each, which gave an average of 1200 voltage and water temperature measurements for each sample. Each experiment was started with a sample at low temperature (stored in a refrigerator), and the temperature of the sample increased throughout the experiments due to friction, pump operation, and the warm water container, which enabled voltage measurements for a wide range of temperatures. A linear regression model was developed to estimate turbidity (T_u) from voltage (V) and water temperature (T_e) measurements as shown below.

$$T_u = 44228.22 * V^{-0.2} - 4.02 * T_e - 8376.82 \quad \therefore \quad R^2 = 0.9986$$

Laboratory experiments with the low-cost turbidity sensor, in a controlled environment, showed promising results in estimating the turbidity values of water samples for turbidity between 0 and about 4000 FNU. Figure 2 shows the comparison between the measurements made by the YSI probe and estimated by the low-cost turbidity sensor through the regression model.

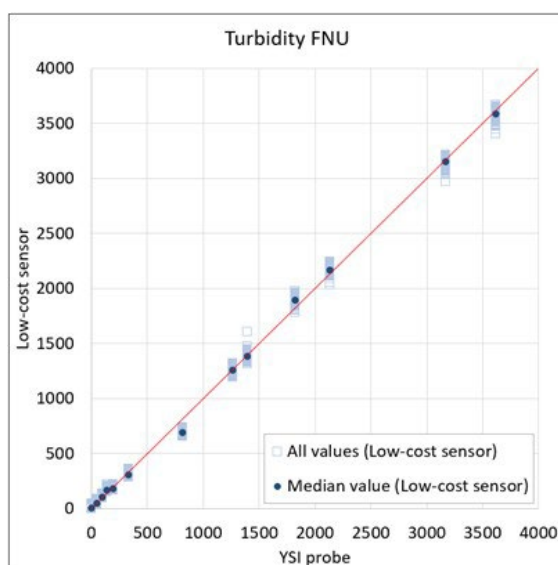


Figure 2 - Turbidity values measured by YSI probe and estimated by the low-cost turbidity sensor.

2.2 Study area

The study area is located in the outer eastern suburbs of Melbourne, Australia. My focus is on the intensive development areas in Officer and Pakenham, located in the Western Port catchment. Most of the urban development is occurring on alluvial deposits of sand, gravel, silt, and clay. Development in this location can generate high loads of fine sediments, which can be harmful to seagrass in Western Port. Western Port is a shallow tidal bay containing a variety of habitats (e.g. mangrove, saltmarsh, rocky reefs, and seagrass meadows), which support diverse species including marine invertebrates, fish and mammals (Cuddy et al., 2019).

2.3 Monitoring station

To monitor sediment loads and river hydraulic parameters in Officer and Pakenham, we installed two monitoring stations on Officer Creek and three monitoring stations on Quirks Creek. Two stations are located on the edge of the urban growth area (upstream of construction sites), and three stations are located downstream of the construction sites. The five stations have similar characteristics. They are automatic stations, with a telemetry system/remote control via SMS. Each one has an autosampler, a solar panel, a charge regulator, a battery, an OTT PLS pressure sensor, a gauge board, a thin plate weir, and an Arduino board. Real-time data is sent every six minutes to a dashboard. A low-cost turbidity sensor (TST-10) was installed at one of our stations in a dark environment with a pump-purge cycle designed to minimise biofouling, to continuously measure stream turbidity values. A humidity sensor was installed within the turbidity sensor housing in order to identify possible condensation during voltage measurements. It is intended to instal the same turbidity sensor at the other stations. Figure 3 illustrate the monitoring station we have already installed the low-cost turbidity sensor (on the left), and the mobile turbidity sensor unit that is being developed (on the right). The mobile unit has the same components

that were used during the lab experiments.

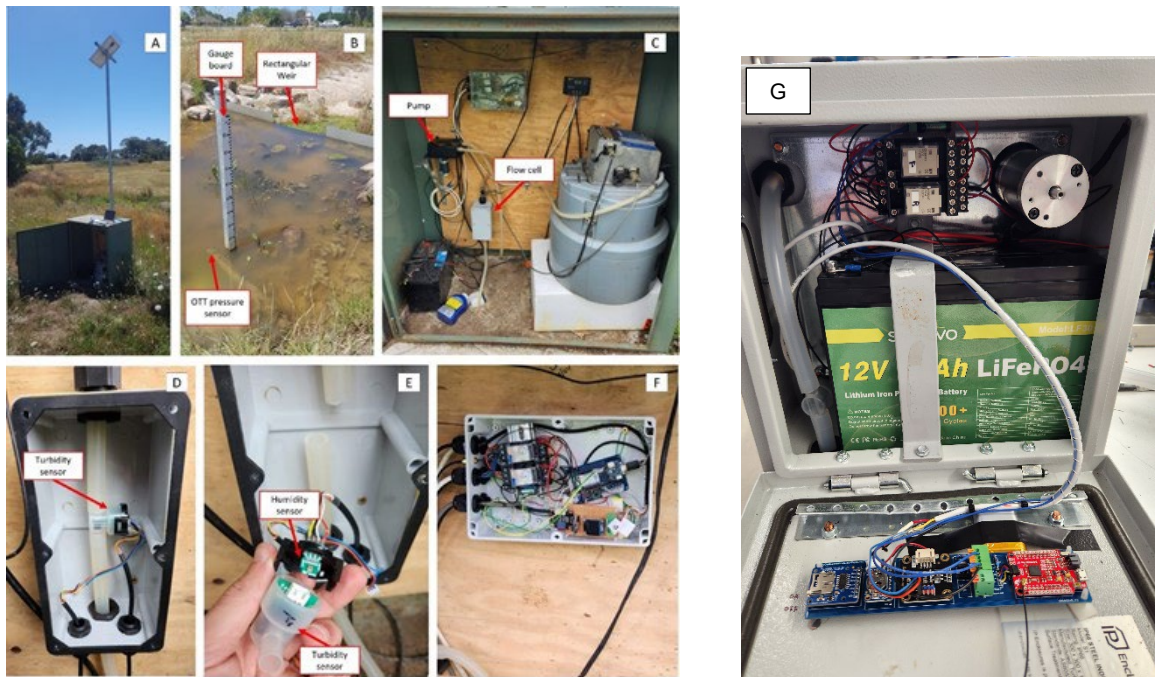


Figure 3 - Monitoring Station (ORD0003) (on the left), and mobile turbidity sensor unit (on the right). A) cabinet solar panel; B) gauge board, OTT pressure sensor and weir; C) charge regulator, battery, autosampler, flow cell and pump; D) turbidity sensor (TST-10) in the flow cell; E) Humidity sensor and turbidity sensor within the sensor housing; F) Arduino board (logger and control system); G) mobile turbidity sensor unit.

3 CONCLUSIONS AND EXPECTATIONS

The results of laboratory testing illustrate that the influence of external factors on turbidity measurements with the TST-10 sensor can be mitigated or avoided. Temperature compensation and innovative design approaches were developed to minimise ambient light and potential for biofouling. A linear relationship between voltage and water temperature was found, making a reliable and efficient calibration feasible. Furthermore, turbidity could be reliably calculated through a relationship with voltage (with power of -0.2) and water temperature (linear).

The results of this research build confidence in low-cost monitoring methods. The design and specifications used in the laboratory test platform and deployed in the field monitoring stations can be replicated and implemented by others. We expect that this work can identify and quantify the contributions of the various sources in the overall production of fine sediments during and after urbanisation processes in peri-urban areas. It is also expected that this work can significantly contribute to the global effort to monitor the production and transport of fine sediments in hydrographic basins.

Furthermore, the results of this work could help catchment managers and policy makers on priorities for erosion and sediment control and may provide indications to inform improvements in sediment control regulations.

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