# An Innovative Low-cost Turbidity Sensor for Long-term Turbidity Monitoring in the Urban Water System

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## Highlights

- This innovative turbidity sensor is a low-cost device (less than AUD25).
- It can be used for field monitoring in the urban water system.
- The sensor provides results that are comparable to high-end sensors.

## Introduction

The urban water system plays a very important role in the environment. To better understand pollutant variation and mitigate pollutant inputs to the urban water system, water monitoring becomes increasingly important to reveal the sources of pollutants and contamination (Osman et al., 2018). Turbidity, the optical clarity or cloudless of the water (Liu et al., 2018), is a relative indicator related to total suspended solids (TSS) and suspended sediment concentration (SSC) in the water column (Omar & MatJafri, 2009). Other substances such as microorganisms can also be reflected by turbidity (Farrell et al., 2018; Romero et al., 2020). Therefore, turbidity is an important indicator of water quality hence monitoring turbidity is a significant aspect of urban water system protection.

The conventional methods for turbidity monitoring in the urban water system involve either measuring the turbidity of the water samples in the lab or installing high-end turbidity sensors in the field that provide high-frequency measurements. However, both methods have drawbacks. Measuring the turbidity of samples limits understanding of temporal variation in the urban water system, making accurate estimates of pollutant conditions difficult. While monitoring continuous turbidity with high-end sensors allows the collection of more comprehensive turbidity data, the use of these sensors is limited by their high price. Therefore, it is necessary to develop a low-cost turbidity sensor that is able to conduct long-term turbidity monitoring in the field.

## Methodology

**Sensor development**

The mechanism of the turbidity is optically based sensing techniques -the most reliable method for measuring turbidity (Samah et al., 2018) which are based on reflectance (Omar & MatJafri, 2009). In this method, light from an emitter reflected by particles in the water is received by a photodetector. The more particles present in the water, the more reflected light is received by the photodetector.

The main parts of the sensor are a light emitter (VSLY5850 LED), a photodetector (BPW77NB phototransistor) (Wang et al., 2018) and a microcontroller (ATmega328). The reading of the innovative sensor is the analogue reading converted from the voltage drop of the phototransistor. Some other electrical components such as voltage regulator and NPN transistor are also included to make the circuit work well. The program can be edited to customize the interval between measurements (i.e. the sensing frequency). The circuit of the turbidity sensor is shown in Figure 1a. The Printed Circuit Board (PCB) of the turbidity sensor is designed based on the circuit diagram (Figure 1b). LED and Phototransistor is facing each other at a 90-degree angle, the distance between the two diodes is 22mm (centre to centre), and both of them are placed in a 3Dprinted housing. A transparent epoxy board is fixed in front of the LED and phototransistor to mitigate the impact of air bubbles in the water (Figure 1c). A 3D printed cover was designed (Figure 1d) to prevent sources of noise such as sunlight from being detected by the

phototransistor. The potting compound gel was injected into the 3D printed house to make sure the sensor is waterproofed (Shi et al., 2021).
The total cost of an individual innovative sensor is less than AUD25, shown in Table 1.

**Table 1.** Detailed cost of the innovative turbidity sensor

| Parts | Cost in USD | Cost in AUD |
|---|---|---|
| LED | 1.2 | 2.7 |
| Phototransistor | 3.18 | 4.68 |
| PCB | 6.5 | 8 |
| Potting compound | 1 | 2.5 |
| Epoxy cover | 0.1 | 1.6 |
| 3D printing house | 3 | 4.5 |
| **Price In total** | **14.98** | **23.98** |

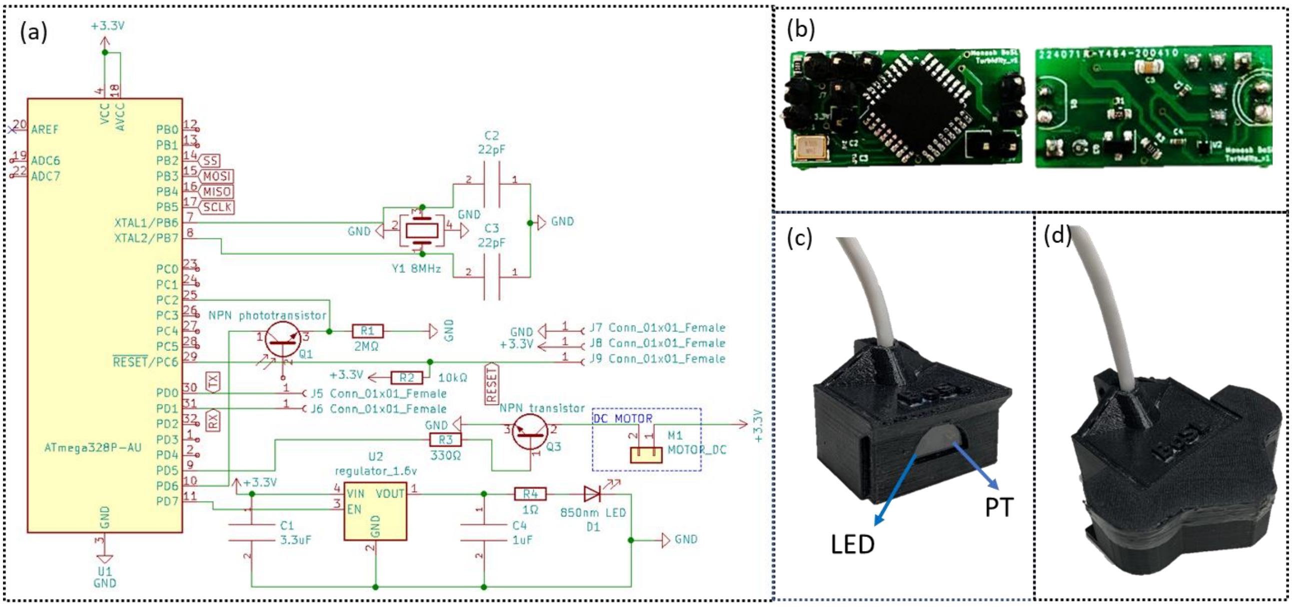


**Figure 1** (a) circuit diagram of the innovative turbidity sensor, (b) PCB of the turbidity sensor (left for front side, right for back side), (c) assembled innovative turbidity sensor, (d) turbidity sensor with cover

**Lab validation and calibration**

The turbidity of different dilutions of standard turbidity solution was measured with a Thermo Scientific AQ4500 Turbidimeter, were assumed to provide accurate turbidity measurements. Measurements of the turbidity solutions were also made with the innovative low-cost turbidity sensor to see if a reasonable regression relationship could be established with the measurements of the more costly sensor. This relationship can be used as a calibration curve for further measurement.

**Field test and comparison**

The low-cost sensor and a high-end sensor (Greenspan TS1000 Turbidity sensor) were installed in the field (Troups Creek Wetland, Narre Warren, Victoria) to allow a comparison of the monitoring results. The sensors are installed at the same location in the wetland approximately 30cm apart from each other. The scanning interval of each sensor is 6 minutes, the Greenspan monitoring data is stored in Campbell CR1000 datalogger while the monitoring data of the low-cost sensor is uploaded to a website.

## Results and discussion

Three innovative sensors were tested in the lab, the readings of all the sensors forming a linear regression relationship with the accurate turbidity (Figure 2). R squared of the three relationships is 0.9993, 0.9986 and 0.9982 respectively, indicating that for turbidity between 0NTU and 250NTU, the reading of the innovative sensor will follow a good linear calibration curve. The calibration curve of each sensor is not identical due to differences in manufacturing, meaning that each sensor requires a specific calibration curve to provide an accurate result.

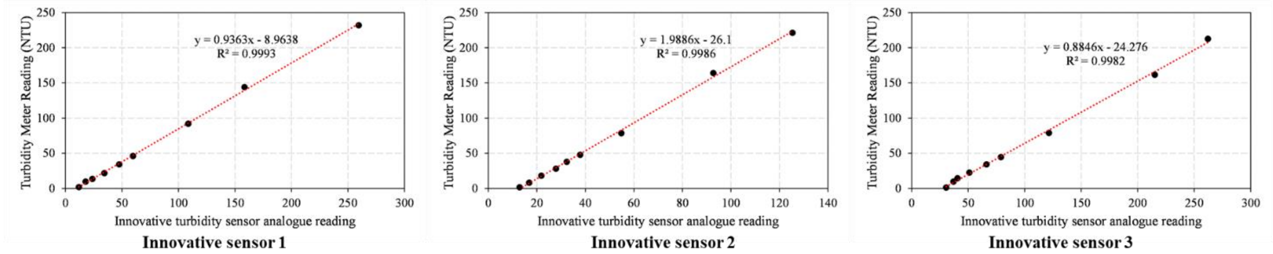


**Figure 2.** Linear regression of accurate turbidity and innovative turbidity sensor reading results

The field monitoring results for the Greenspan sensor and the innovative turbidity sensors are compared in Figure 3. The sensors display almost the same pattern. Both sensors show some outliers which may be caused by litter coving the probes. Apart from the outliers, the differences between the two sensor results are within 10NTU, which indicating that the innovative sensor is able to provide comparable results to the high-end sensor.

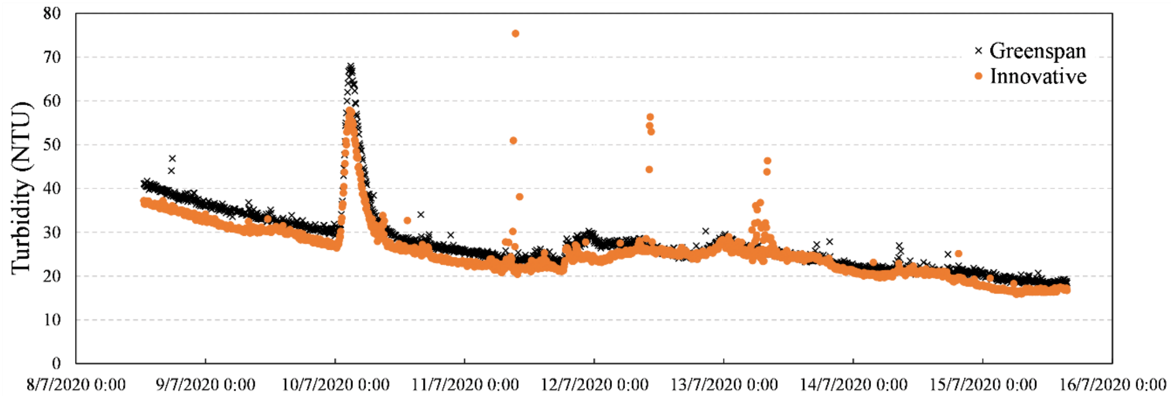


**Figure 3.** Monitoring results comparison between Greenspan turbidity sensor and Innovative turbidity sensor

# Conclusions and future work

In conclusion, the innovative turbidity sensor is a cost-effective device that can be used for long-term turbidity monitoring in the field and can provide comparable results to a high-end sensor. As innovative sensors can provide reliable results, more sensors could be deployed to get a better understanding of the turbidity variation in the urban water system.

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