Development of a low-cost radar velocity and depth sensor for urban water systems

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Highlights

- • A sensor for depth and velocity metering is described and tested with a cost <40AUD.
- • 3D printing builds radar lens into enclosure, accelerometer for self-measuring of install angle.
- • Low cost and power usage allow for wide-scale deployment with low maintenance.

Introduction

Stormwater monitoring is crucial to the assessment and improvement of the health of urban waterways. This is of increased importance in light of the effects of urbanisation and climate change. Water depth and flow rate are quantities which are commonly used in the understanding of urban water quality. The high spatial and temporal variability of these waterways calls for higher spatial and temporal measurement resolutions (Kerkez, et al., 2016) (Shi, et al., 2019). A major issue with current measurement solutions such as the HACH AV sensor (HACH, 2021) is their cost and difficulty to install and maintain. This makes wide scale deployment infeasible on limited budgets. New low-cost sensing technologies promise to allow for feasible high-resolution monitoring schemes. Thus, development of a low-cost velocity and depth sensor is of interest for urban water management schemes. The integration of a water depth and velocity sensor into one device is of particular interest as from these quantities the volumetric flow rate in a channel may be determined.

Non-contact measurement via radar has seen significant development in recent years. The feasibility of low-cost velocity and depth measurement using radar is demonstrated by Ma (2020) and a continuous wave doppler sensor based on Arduino and custom radar front end to deliver velocity measurements of rivers is shown by Alimenti, et al. (2020).

While significant progress has been made in miniaturising and lowering the price point of these technologies, there has been more limited work in the design of sensors ready for highly scalable field deployment with most focus on proof of concept testing or developing sensors not easily reproducible by an intended user. This paper aims to design a low-cost radar sensor for non-contact measurement of water depth and velocity in stormwater systems. A characterisation of the sensor's measurement principal will then be performed to determine the feasibility of the sensor.

Methodology

Sensor Design

The proposed sensor design consists of an XM132 radar sensing module, a KXTJ3-1057 accelerometer, and an ATmega328PB microcontroller. These components are integrated onto a single PCB. The microcontroller is able to communicate with dataloggers via UART and manages the power state of the device by shutting off devices when not needed. It also runs a DSP (digital signal processing) algorithm developed to process the radar data. The radar sensing module transmits a 60 GHz radar signal and records the reflected power, it performs some pre-processing on this to return a time series of measurements of reflected power at multiple distance bins away from the sensor. This data is used by the DSP algorithm to extract the velocity and distance of the water surface. The accelerometer is used to determine the direction of gravity, this can be used to calculate the angle between the water flow and the sensor which is needed to correct the distance and velocity readings. The benefit of having an onboard accelerometer is that the sensor angle does not need to be measured by other means manually at installation. The sensor is enclosed in a 3D printed housing

displayed in **Figure *1***. The front of the casing also acts as a radar lens, increasing the radar sensitivity by 70%. The sensor interfaces to a datalogger via UART and requires a 3.3V supply voltage.
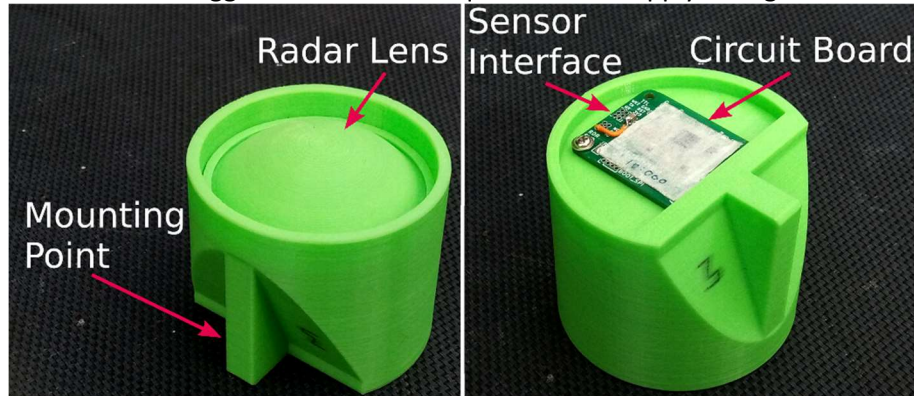

Figure 1. Left: front of radar sensor enclosure displaying radar lens and mounting point. Right: back of radar sensor with back cover removed. This displays the circuit board and sensor interfaces to which cable can be soldered to connect the sensor to a datalogger. The sensor measures 60 mm in diameter and 50 mm in height.

Lab Testing

The XM132 radar module was tested in conjunction with the developed DSP algorithm to measure its ability to deliver reliable velocity readouts. In the test, readings from the radar sensor were compared against a theoretical velocity as calculated from Manning's formula,

$$v = \frac{1}{n} R^{\frac{2}{3}} S^{\frac{1}{2}} \tag{1}$$

where v is the average velocity, n the Manning's coefficient, R the hydraulic radius, and S approximated as the slope of the channel (Keaton, 2018). Figure 2 displays a diagram of the setup used to test the radar module. A hosepipe was used to provide an open channel flow of water down a PVC pipe which was inclined relative to the ground by a height H. The radar module, which was elevated a distance h above the pipe and at an angle θ relative to the pipe, was used to stream radar data back to a computer running the DSP algorithm. A radar lens was placed in front of the radar module. For each height H, the velocity displayed by the DSP algorithm and the width of the flow in the pipe were recorded. From these measurements and supplementary quantities, the angle corrected velocity measured, and the velocity predicted from Manning's formula could be determined.
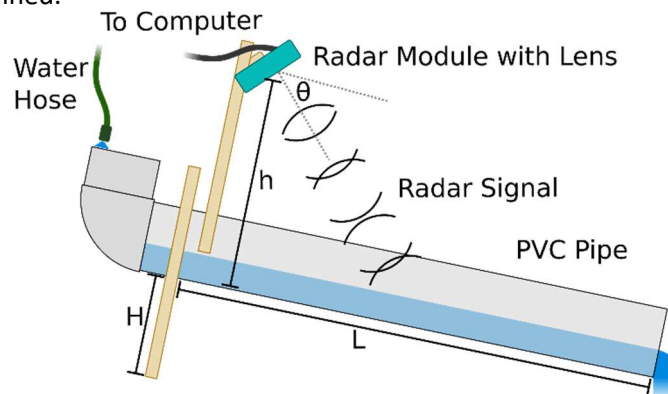

Figure 2. Lab testing setup for measurement of velocity readout. The value h was set to 400mm, θ to 53°, and L was 1500 mm. Water was supplied at a flow rate of 60 mL/s. The pipe's diameter is 103 mm.

Results and discussion

The data recorded in the lab test is displayed as a correlation plot in Figure 3. An R^2 value of 0.996 for the line of best fit indicates that there is a strong linear correlation between the recorded radar velocity and the velocity calculated with Manning's formula. This linear correlation is further supported by the linear fit lying within the errors for each data point. The graph's gradient of 0.73 and y-intercept of -0.11 m/s are not near the values of 1 and 0 m/s as desired for a velocity readout. The deviation of the gradient from 1 is likely due to the error in the Manning's roughness coefficient. This coefficient was retrieved from Bishop (1978) rather than measured for the surface of the pipe, and hence factors such as inherent material differences, small flows, and surface wear are not accounted for in the coefficient. This is likely to explain the majority of the

error in the gradient. Differences in y-intercept may be partly attributable to the initial velocity of the water as it is injected into the pipe because the water may not have reached the Manning's steady state before the measurement point. Regardless of the causes for the gradient and intercept deviation. The linearity of the sensor's reading allows a linear calibration curve to be used to correct these deviations and deliver an accurate velocity readout.
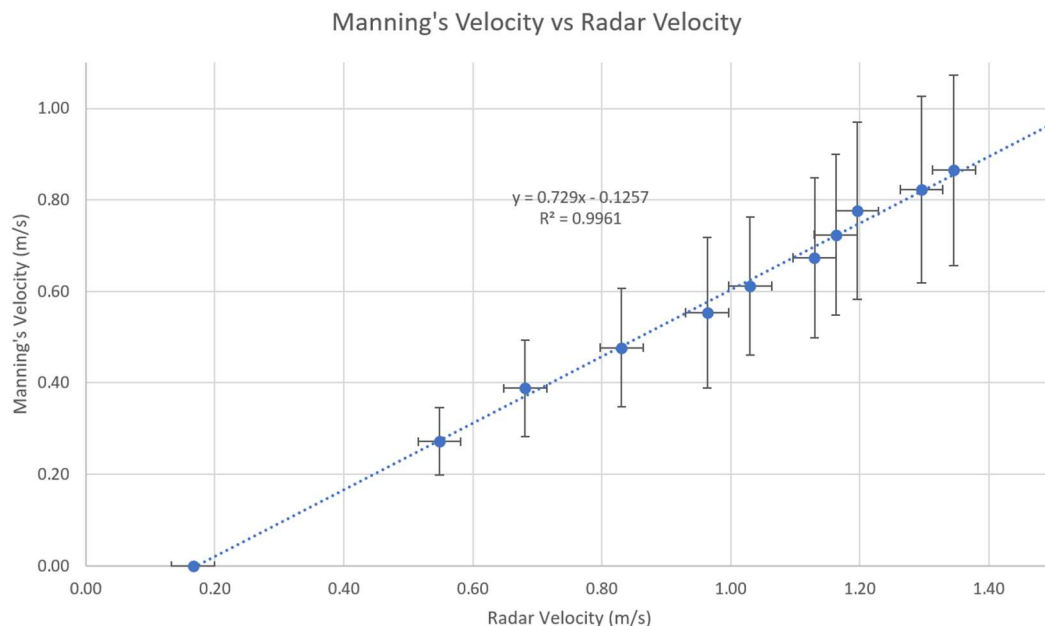

Figure 3. Graph of measured radar velocity vs theoretical velocity as calculated by Manning's formula from lab test. Line of best fit displayed as blue dotted line with parameters of fit displayed above in plot area. The error in Manning's roughness is not considered in the calculation of vertical error bars.

Conclusions and future work

A brief description of an architecture for an integrated water velocity and depth sensor at a <40 AUD price point was described. Novel features of the sensor include use of an accelerometer for installation angle determination and 3D printing a radar lenses into the housing for additional gain. Laboratory tests indicated that the architecture's radar module is able to accurately measure water velocities once a linear calibration is introduced. Future works necessary before a 'installation-ready' sensor is developed are the verification of the sensor's depth measurements and full in-field verification.

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