Using a ROS-Based Low-Cost System for Bathymetric Surveys

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SUMMARY

Much of the world's oceans is uncharted. Crowd-sourced bathymetry has the potential to improve our knowledge of the oceans and to provide opensource bathymetric charts for the public. Installing bathymetric measurement equipment aboard a large number of vessels, such as commercial and pleasure craft, requires a low-cost, accurate and easy-to-use bathymetric measurement system. The goal of this project was to design and test such a system.
In addition to crowd-sourced bathymetry, this MSS may be useful for hydrographic organisations with modest budgets, such as educational organisations and the national agencies of developping countries.

Using low-cost sensors and a software framework based on Robot Operating System (ROS) software, a low-cost Multi-Sensor System (MSS) was developed and tested. The system was successful in producing geo-referenced depth estimations.

Vessel attitude is determined using a temperature-compensated MPU-9250 Micro-electromechanical System (MEMS) array. Timestamps are based on a PPS (Pulse Per Second) signal from a GNSS module, which uses atomic clocks on satellites as a reference.

Depth is determined based on water temperature, salinity and the time taken for an acoustic pulse to travel from the vessel transducer to the sea floor and back.

All sensor data can be recorded and played back using ROS software. A bathymetric map can be produced and visualized in 3D during a survey. The Raspberry Pi 3 used for this task is susceptible to freezing if 3D visualization is done during a survey due to insufficient processing power. Therefore, as an alternative, it is possible to record sensor data during a survey and process this data after concluding the survey. It was found that survey data could be collected non-stop for 34 days before an SD card (128 Gigabyte) swap was required.
Further tests should be carried out to determine the system's accuracy.

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1. INTRODUCTION

Bringing down the cost of hydrographic sensors and software has been the focus of research at the HCU's department of Geodesy and Geomatics in Hamburg in recent years.

The applications of such a low-cost system include crowd-sourced bathymetry and use by hobbyists. In addition, universities and governmental agencies in developing countries would benefit from having access to hydrographic survey equipment at a fraction of the cost of current commercially available systems.

With low-cost surveying systems, the frequency and extent of hydrographic surveys could be increased. This is of obvious benefit in modelling and understanding water circulation in coastal areas, estuaries and inland waterways.

The low-cost hydrographic system presented in this paper makes use of open-source software and low-cost sensors. It has been designed to allow for additional sensors to be easily integrated. The ROS software framework used is popular in the field of robotics. It could be adapted for use with robotic vehicles. This fits the current trend of automation and artificial intelligence.

Educating future generations of hydrographers requires providing students with practical experience. This is best done using low-cost sensors whose loss or damage by inexperienced operators would not be a major financial blow to educational establishments. Open-source software that can be accessed and modified by students is also advantageous compared to proprietary software.

Only a small fraction of the earth's oceans and seas have been sampled for depth, greatly limiting our understanding and knowledge of the ocean. Mapping the ocean using hydrographic vessels is a costly and time-consuming endeavor. Specialized hydrographic vessels only represent a tiny fraction of the total number of seagoing vessels. A much larger number of vessels are equipped with Single Beam Echo Sounders (SBESs) for navigational and safety purposes. If these SBESs could be used to gather depth data, our knowledge of the seas and oceans could be much increased. Crowd-sourced bathymetry has the potential to multiply worldwide depth sampling.

The Nippon Foundation—GEBCO Seabed 2030 Project aims to chart 100% of the oceans by 2030 and has cited crowd-sourced bathymetry as an option to help achieve this (Mayer et al., 2018). The IHO (International Hydrographic Organisation) Inter-Regional Coordinating Committee has established a Crowdsourced Bathymetry Working Group (CSBWG).

OpenSeaMap aims to make crowd-sourced bathymetry available to the public (OpenSeaMap, 2019).

2. COMPONENTS

In selecting components, importance was placed on keeping down component purchasing costs. Also, components were to be assembled without the use of expensive workshop equipment. Finally, components were to function as much as possible with the use of open-source software.

Fig. 1 Main components

Figure 1 shows the main components. Figure 2 shows component costs. Total cost is 985 Euros. For testing, the system was initially mounted on a rented 'Kanadier' type canoe and subsequently on an inflatable canoe which cost 80 Euros.

2.1 Sensors

The sensors used include a single beam echosounder, a GNSS module and a MARG (Magnetic Angular Rate and Gravity) array.

The echosounder was an Airmar Echorange SS510 which operates on a frequency of 200kHz. With a cost of 616 Euros, it is the most expensive single component. It outputs standard NMEA messages and could thus be substituted by any other NMEA echosounder. The echosounder outputs time of return and water temperature at the transducer head.

The GNSS module used was a NEO-6M which uses SBAS (Satellite Based Augmentation System). It was set-up to output position at a rate of 5Hz with a navigation engine optimized for use on a vessel.

The MARG array used was the MPU-9250, which has tri-axial accelerometers, gyroscopes and magnetometers. Its performance is enhanced by the use of temperature- compensation for bias and scale factor. Commercially available higher-end MARG arrays are calibrated with the use of a turntable and thermal chamber. Such equipment may not be available to users of a low-cost system. Therefore, a simplified calibration procedure was carried out with the use of bubble levels and a hair dryer to manipulate temperature. Accelerometers and magnetometers are calibrated for bias and scale factor whereas gyroscopes are only calibrated for bias so as to negate the need for a turntable. Magnetometer scale factor calibration is done by sampling the earth's magnetic field with all three magnetometer and taking the average of the three as the true amplitude of the earth's magnetic field.

2.2 Timestamping

Timestamps for the MARG array are based on a PPS (Pulse Per Second) signal from the EZ-0048 GNSS module, which uses atomic clocks on satellites as a reference. In case of loss of GNSS signal, a DS3231 real time clock is used to timestamp MARG array data. This real time clock is synchronized with GNSS time. The timestamps for the NEO-6M position are also based on atomic clocks. Echosounder data is timestamped using the DS3231 real time clock. A single DS3231 communicates with both the Teensy microcontroller and the Raspberry Pi 3 single board computer via its I2C connection.

Component	Cost (€)
Teensy 3.6	38.00
Raspberry Pi 3	34.45
Waveshare 5 Inch Resistive Touch Screen LCD(B)	39.99
GY-NEO6MV2 GNSS module	10.99
EZ 0048 GNSS module	30.99
MPU-9250 MARG array	5.99
DS3231 real time clock	4.87
RS-422 to USB converter	29.55
Serial Adapter DB9 female to terminal bloc	13.48
Airmar SS510 Echosounder	616.47
Fan and case for Raspberry Pi	8.99
Wireless keyboard and mouse	18.99
UPSPack Power module	18.99
RAVPower 20000mAh Power Bank	26.99
LC-R127R2PG 12V batteries	15.94
USB to TTL Serial Cable	3.54
Electronics supplies	20.00
Cadiz Storage Box	3.99
Cadiz Storage Box lid	1.99
Vaccum storage bag	5.99
Construction supplies	35.00
Total	985.19

Fig 2. Component costs

2.3 Processing

For processing, a Teensy 3.6 microcontroller and a Raspberry Pi 3 single board computer are used. The microcontroller runs a Madgwick algorithm to compute attitude at a rate of around 900 iterations per second while also performing timestamping and temperature compensation. The Raspberry Pi 3 runs ROS Kinetic on an Ubuntu Xenial operating system. Using a Raspberry Pi 3 eliminates the need for a Linux laptop or desktop computer as bathymetric pointclouds can be produced directly on the Raspberry although acquired data may be transferred to such a computer for post-processing.

3. SYSTEM DESIGN AND OPERATION

To fuse data from multiple sensors, the Madgwick (Madgwick, 2010) algorithm and the Extended Kalman Filter contained in the Robot Localization ROS package (Moore and Stouch, 2016). were used. Figure 3 shows an overview of the system. GNSS data is converted to UTM and the surface of the water is modelled as a flat plane.

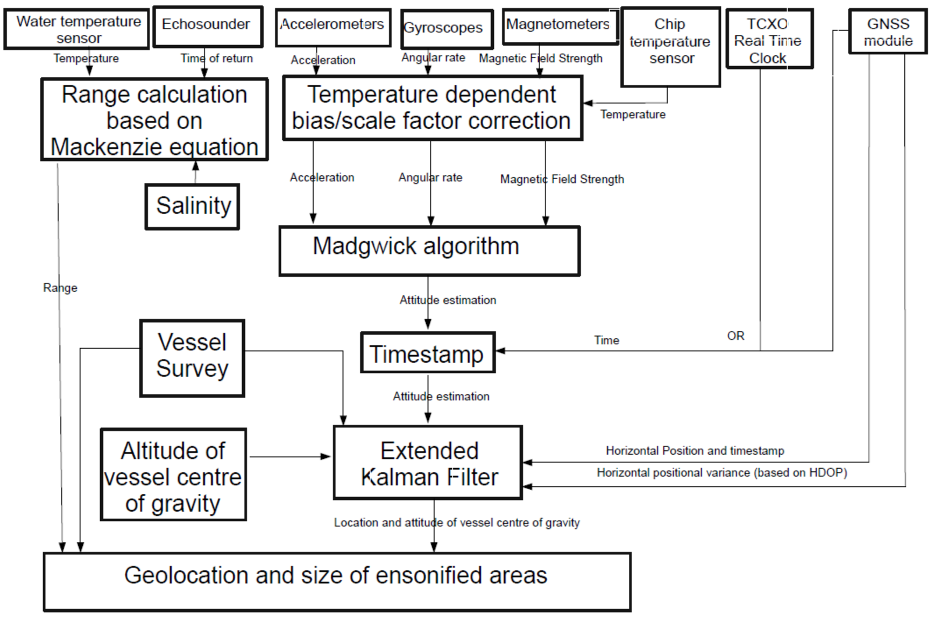

Fig. 3 System overview

3.1 Filter tuning

The Madgwick algorithm's two filter gains of beta and zeta were adjusted. Zeta was set to zero as no gyroscope drift was detected for the MPU-9250. Beta was set to 0.6, a value larger than the 0.041 used in the original Madgwick study (Makiello, 2019). This decreases the time needed for the filter to initially converge.

The Extended Kalman Filter adjustable parameters were tuned as follows: For the measurement noise covariance matrix R, sensor variances for attitude were set according to error estimations from static testing. The variance for horizontal position from the GNSS module was set dynamically according to the HDOP (horizontal dilution of precision) messages contained in the NMEA strings from the sensor. The process noise covariance matrix Q was tuned with the help of a test performed on land, with the system carried around a course measured on the ground that served as 'ground truth'.

3.2 Water Depth Calculation

Depth is determined based on water temperature, salinity and the time taken for an acoustic pulse to travel from the vessel transducer to the sea floor and back. The Mackenzie equation (Mackenzie, 1981) is used for computation. Water temperature is measured at the echosounder head throughout the survey.

TESTING AND RESULT

Two tests were carried out: A first test in the Jaffe-Davids canal, an urban canal in Hamburg and a second test in Eichbaumsee lake. Figures 4 and 5 show the canal test. Figure 4 shows the view in Rviz (Gossow et al., 2011), a robotics vizualisation package, which produces a 3D view of the survey. Positions of sensors and sensor data as well as the motion of the vessel can be observed both during a survey and in post-processing. Figure 5 shows a triangular interpolated network (TIN) overlayed onto satellite imagery of the canal.

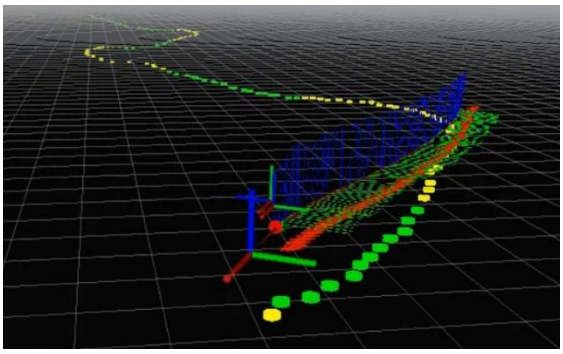

Figure 4: Canal survey, Rviz view. Grid: 1 metre squares on the water surface. Yellow and green circles: ensonified areas. Red translucent arrows: GNSS horizontal position. Thick axes: positions of the echosounder head, centre of gravity, MARG array and GNSS antenna (from bottom to top). Thin long axes: position and attitude estimates of vessel centre of gravity produced by EKF

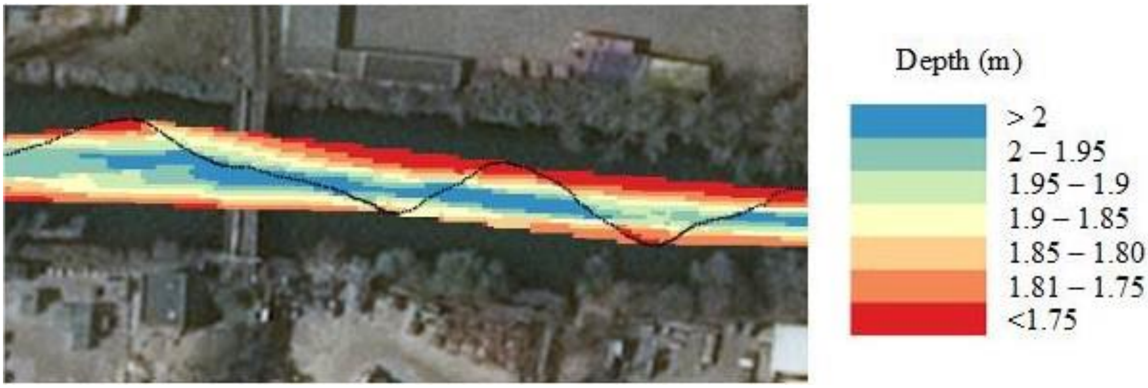

Figure 5: Canal survey. Triangular Interpolated Network (TIN), 1 metre raster. Black dots: centres of ensonified areas.

To evaluate accuracy, cross line tests were performed. Examining the cross line tests, we found ten pairs of points with horizontal distances within 30 cm. The difference in depth between the two points in a pair was always less than 10 cm and usually only a few centimetres.

Figures 6 and 7 show the survey conducted on the Eichbaumsee lake near Hamburg. Figure 6 shows the Rviz view. A custom ROS node allows bathymetry to be displayed using markers of different colours depending on depth. The diameter of the markers is three times the ensonified area, which varies depending on depth.

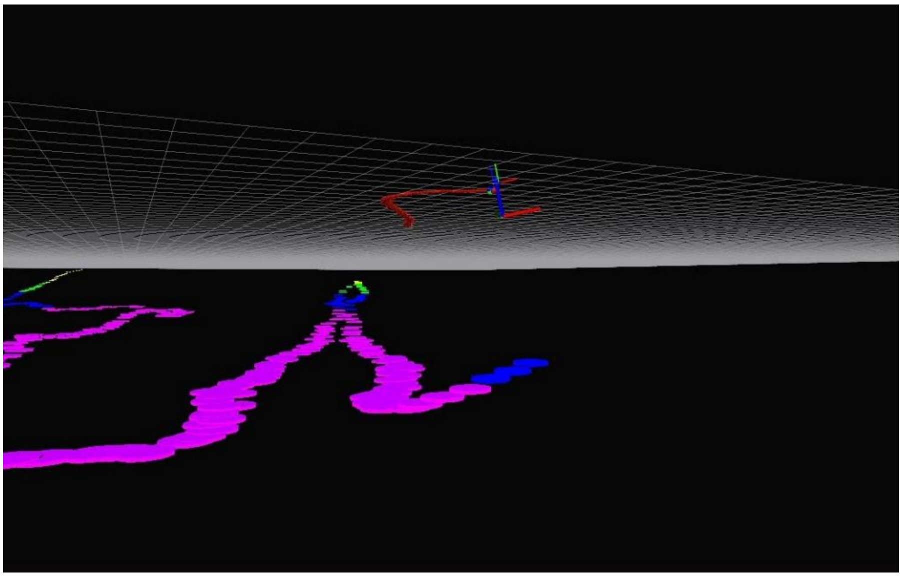

Figure 6: Rviz view of Eichbaumsee survey. Grid: 1 metre squares on the water surface. The survey is viewed from underwater. The circular markers show the ensonified areas.

Figure 7 Eichbaumsee survey

The Raspberry Pi 3 used to run Rviz is susceptible to freezing if 3D visualization is done during a survey due to insufficient processing power. Therefore, as an alternative, it is possible to record sensor data during a survey with processing and visualisation done after concluding the survey. Data acquisition can be monitored during a survey by viewing sensor data streams using the 'rostopic' package. It was found that survey data could be collected non-stop for 34 days before an SD card (128 Gigabyte) swap was required.

4. OUTLOOK

Integrating tide gage data would allow for surveys to be carried out in tidal zones. The same feature could be used to convert depth relative to the water surface to absolute depths relative to a global datum.

Use of a sound velocity profile could, if available, increase accuracy of bathymetric data.

Visual odometry or Visual-inertial odometry may be performed with low-cost sensors and would improve vessel positioning in GNSS-compromised areas.

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BIOGRAPHICAL NOTES

Louis Makiello is a MSc graduate in Geomatics with specialization in Hydrography from Hafencity University and a BSc in Physics from Bristol University. His interests include visual-inertial odometry, low-cost sensors, Kalman filters and multi-sensor system design.

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