Building a ROS Node for a NMEA Depth and Temperature Sensor

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Abstract: Although many commercially available robots ship with a version of ROS this is not as true for many external sensors. There is a lack of ROS support for many devices and sensors one might use to extend the capabilities of a robot. As robots are deployed in more complex environments there is the need for more specialized sensors. In particular in the aquatic domain there is the need for support for depth sounders. This paper describes the design and construction process for building a ROS node for a NMEA 0183 compliant depth and temperature transducer and a strategy for extending this design to other NMEA devices.

1 INTRODUCTION

Although the vast majority of autonomous systems are designed to operate on the ground (ground-contact robots) there is considerable interest in the development of devices that operate in the air, under the water, and on its surface. As devices move off of solid ground it becomes necessary to develop and deploy sensor systems that can deal with these novel environments. To make this task more concrete, consider the problem associated with operating a device such as the Clearpath Kingfisher robot shown in Figure-1. This device is essentially an aquatic differential drive vehicle powered by two propellors mounted in parallel. Similar to traditional differential drive vehicles operated on land, choosing different thrusts from the two motors produces different motion trajectories on the water's surface.

As shipped, the Kingfisher comes equipped with limited onboard computation, differential GPS and wireless communication to an external operator. Control of the vehicle is provided through a ROS-based (Quigley et al., 2009) software infrastructure. We have augmented the stock vehicle in a number of ways, including through the addition of additional onboard computation and a range of different sensor systems including the system described here.

Although monitoring events occurring above the surface is vital for an autonomous surface vehicle, it is also critically important that such devices are able to sense properties of the environment below the water's surface. Underwater obstructions and shallowing of the water associated with the shoreline are important features of the environment that must be monitored. Of critical importance here is ensuring vehicle safety. Striking an underwater obstruction or beaching the robot can be disastrous. Although sensing for such a task can be performed at least in part through the use of vision and similar sensors mounted on the vehicle, it is essential that the vehicle be aware of the depth of the water column beneath it. Although vision and similar sensors can play some role in this, vision may fail when the water turbidity prevents a good view of underwater obstacles or if environmental conditions prevents the sensor from observing obstacles that protrude from the water's surface. An obvious approach here is to augment the robot with one or more depth sensors that measure the depth of the water column directly. A depth sensor does not suffer from many of the shortcomings associated with surface sensors, and if properly designed can be easily integrated into the existing sensor suite mounted on the vehicle. Depth sensors are routinely deployed in the marine environment where standard packaging, power and communication infrastructures have been developed. Unfortunately the standards prevalent in the marine environment are not directly compatible with research robot infrastructure. This paper describes the process of adapting a commercial NMEA 0183-compliant depth sensor for autonomous vehicle use. Specifically, we demonstrate how such a device can be exposed to an autonomous system as a ROS node.

The Robot Operating System (ROS) (Quigley et al., 2009) has included support for National Marine Electronics Association (NMEA) 0183 (Associa-

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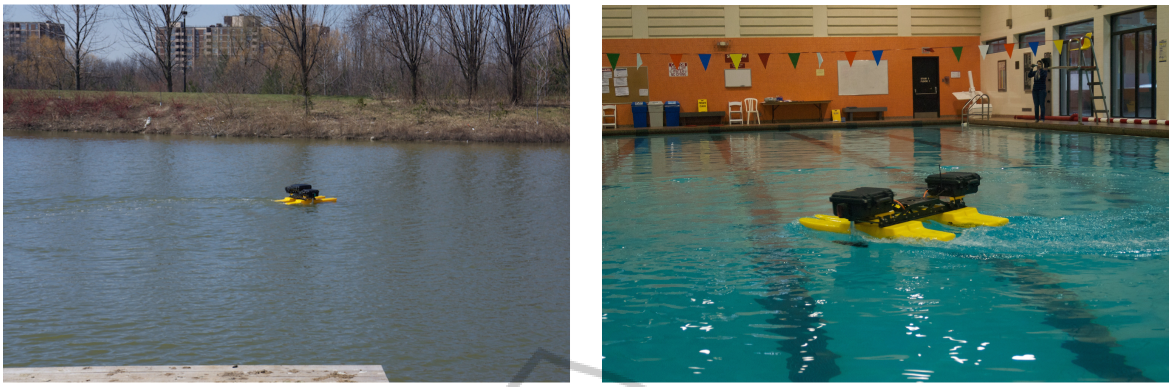


(a) Kingfisher operating on a pond.

(b) Closeup of the Kingfisher.

Figure 1: The Kingfisher operating on a pond on the campus and in the campus pool. The device is essentially a differential drive vehicle.

tion et al., 2003) compliant GPS devices for a number of releases (Perko and Martin, 2012), however there is a tremendous lack of support for the wide variety of other devices supported by the NMEA protocol. NMEA evolved as a standard to enable a wide range of marine sensors and systems to be integrated within a common framework and although this framework includes GPS sensors, GPS is not the only marine technology sensor that can be repurposed for autonomous systems. Many marine vessels are outfitted with electronic depth sensors. Apart from basic navigation tasks, depth sensors are deployed to address many different marine applications. For example, bathymetric maps are an integral part of safe marine navigation in that they help mariners avoid underwater hazards. The OpenSeaMap (OpenSeaMap, 2009) project is a crowdsourcing effort to create a worldwide bathymetric chart, contributions can be made by anyone with a depth sounder and GPS. Apart from navigation these maps are useful in a variety of applications from exploration and planning to the study of underwater volcanoes and earthquakes.

2 BACKGROUND

2.1 Echo Sounders

Echo sounders are sonar devices that are used to determine the depth of water using pulses of sound. A transducer mounted either through the hull or in the bottom of the boat is used to transmit sound pulses into the water column. The transducer also listens for the return pulse. Pulses are produced within the echo sounder using a piezoelectric transducer that contracts when a voltage is applied. This rapid expansion and contraction creates a pressure wave that travels through the water and echoes back after bouncing off the bottom. Upon return, this wave is converted back to an electrical voltage and the travel time is then used to calculate the depth below the transducer. One critical issue here is that the speed of sound in water varies with temperature and thus most depth sounders also monitor water temperature in order to correct for this variation. A second issue is that although the echo pulse may have substantive power in side lobes, to a first order approximation the echo sounder beam can be though of as travelling in a straight line down from the transducer. It is thus critical to know the direction in which the transducer is pointing. This issues becomes particularly acute in the presence of wave action that induces roll and pitch on the vessel.

2.2 NMEA 0183 and NMEA 2000

Although many different communication and control strategies exist for commercial echo sounders two standard protocols have emerged. NMEA 0183 is a simple ASCII communications protocol operating over a 4.8 kbps serial data bus, developed by the National Marine Electronics Association. Unlike serial communications, associated with computers that support the RS232 standard, NMEA 0183 devices utilize the RS422 standard. The RS422 standard differs from RS232 in two fundamental ways: first, the RS422 is a differential protocol and second, the NMEA 0183 does not rely on a 5V reference signal. Many NMEA devices operate at a much higher voltage level than that associated with modern electronics requiring care when connecting them to standard computer hardware. Notwithstanding the electrical differences, the NMEA 0183 protocol is a serial protocol in which talkers – devices that generate sentences – provide data that is transmitted from a single talker to multiple listeners in parallel. The newer NMEA 2000 protocol is slowly being adopted in favour of its predecessor, the NMEA 0183. The NMEA 2000 (Association et al., 2005) is a network protocol built on top of the controller area network bus supporting both multiple talkers and multiple listeners at 250 kbps. Another difference between the NMEA 0183 and NMEA 2000 protocols is a switch from ASCII encoded data sentences to a compact binary format with a proprietary specification (Spitzer et al., 2009).

2.3 From Echo Sounders to ROS

A wide range of devices support the NMEA 0183 protocol. In terms of the robotics community, perhaps the most well integrated of these devices are GPS receivers. Fortunately, a number of researchers have developed software infrastructures that support GPS devices and this investment is easily repurposed for Echo Sounders that support the NMEA 0183 protocol.

ROS has become a de-facto standard for much of the autonomous robot community and its use is especially prevalent in the research community. Within ROS, processes are represented as nodes which communicate through messages within a publisher/subscriber framework. The process of integrating echo sounders within a ROS infrastructure involves providing the necessary power/data connections to the device and then transducing messages received from the echo sounder into corresponding ROS messages.

3 PHYSICAL CONSTRUCTION

A critical aspect in the construction of any component of a field robot, and this is especially true for robots working near water, is ensuring that the device is isolated from its environment. Incidents that are only a minor annoyance for a robot operating indoors can be catastrophic for a field robot. For the echo sounder system described here, water is of particular concern. Although exposure to fresh water might be brushed aside, salt-water or water from chlorine-treated pools can result in permanent damage to electric circuits, and there is always the possibly of complete emersion due to wave and sea action. In order to deal with this issue, we have encased the sensor in a water-proof housing. Two different sensor housings have been built. The first, an experimental housing, is shown in Figure-2(a) while the production housing is shown in Figure-2(b). In both cases the devices are designed to be sealed against the elements.

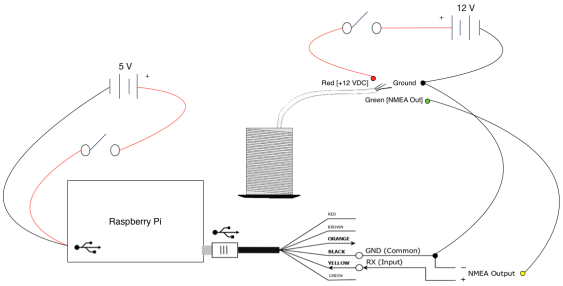


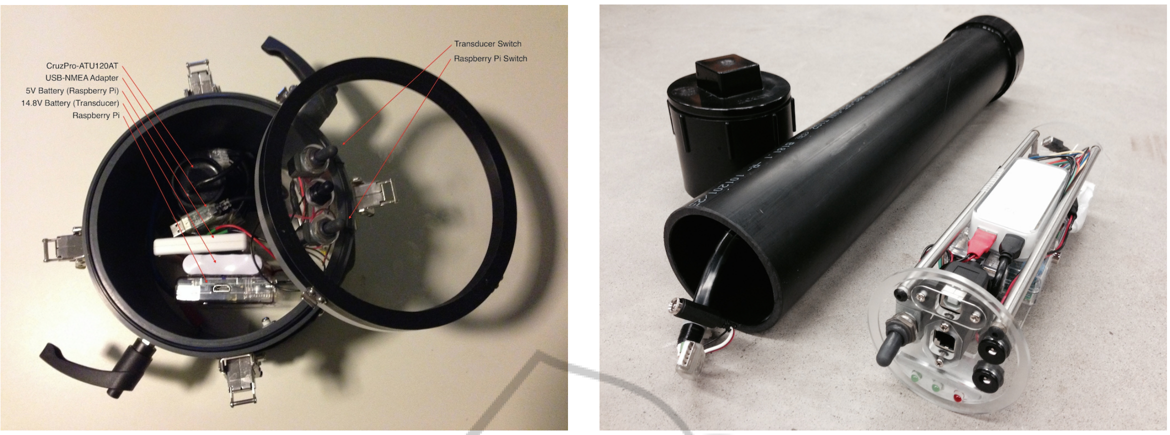
Figure 3: RECHOS wiring diagram.

In the design of any device that will be deployed in harsh environments breaks in the case should be minimized. Switches mounted externally to the case are designed to be waterproof, and the number of cables leaving the device are minimized. The experimental housing was designed to be completely sealed, with communications to and from the device being accomplished via a wireless signal. For the production device we have augmented the wireless capability with the ability to hardwire the device into the ROS network should this prove desirable.

The experimental housing is based on a cylindrical underwater enclosure. Acrylic ports are used to seal the caps of the cylinder. Three toggle switches are mounted to the top port. Two are used to control power to the transducer and onboard electronics. The third is available for use by application software. This configuration allows for pre- and post-deployment testing, and testing of the system out of water using a mobile device or laptop, with the transducer safely powered off. The production housing is based around standard ABS pipe infrastructure and is designed to be more easily mounted on the Kingfisher and other robot platforms. This improved housing also includes additional ports facilitating ethernet connectivity and the recharging of batteries.

The sensor packages are designed to be a self-contained systems so as to enable the device to be fully portable. Although the planned deployment of the production device involves the Kingfisher robot (Figure-1) it is intended that the device will also be deployed on other devices including recreational/commercial vessels. In such deployments it may not be straightforward to provide physical wiring between the sensor and power/data networks.

The ROS echo sounder (RECHOS) is comprised of three major components. The production version includes an additional component to improve the accuracy of sensor readings.



(a) Experimental housing.

(b) Production housing.

Figure 2: RECHOS sensor housing. (a) shows the experimental housing used for field tests to validate the design. (b) shows the production housing designed to be mounted on the Kingfisher platform shown in Figure-1.

- **An Echo Sounder.** The CruzPro-ATU120AT(CruzPro, 1997) is an active depth and temperature transducer requiring 9.5-16.0 VDC at 350 mA that transmits data at 1Hz using the NMEA 0183 communications protocol.
- **Signal Transducer Computer.** The RECHOS uses a Raspberry Pi Model-B Rev-01 for signal processing. This computer is small single-board computer requiring 5VDC at 700 mA.
- **RS422 to USB Converter.** A USB-NMEA 0183 adapter provides bi-directional communication with NMEA compliant devices over a virtual COM port and is used to connect the transducer to the computer.
- **ADXL345 Accelerometer (Production Housing).** A triple-axis accelerometer with digital I2C interface provides tilt information which is used to correct depth readings.

Beyond these major components the RECHOS must also deal with the realities of providing power to the various devices and allowing an operator to start and stop the device. The power requirements of the transducer are unusually high in comparison to the requirements of mobile computing devices like the Raspberry Pi. The transducer was originally developed to be operated off of standard boat power (unregulated 12V) rather than off of the well conditioned power associated with modern computer electronics. This disparity identifies a need to separate and isolate the power supplied to the two devices (Figure-3).

One unfortunate property of the echo sounder used in this project – and this is quite a common property of many such devices – is that they should not be operated out of water. In order to enable software development on the RECHOS a separate power disconnect was provided for the power supply to the echo sounder.

4 SOFTWARE

A Raspberry Pi provides essential on-sensor computation. It transduces messages from the echo sounder and presents them as ROS messages to the ROS system using standard network infrastructure. Messages from the echo sounder appear as serial messages through the USB port on the Raspberry Pi. A ROS node running on the Raspberry Pi parses raw NMEA 0183 sentences from the depth and temperature transducer using the PySerial library (Liechti, 2001) and subsequently publishes this information along with the raw data for further consumption by the system. Additional information about the powered state of the transducer is inferred by the ROS node and published as a latched topic so as to inform all new subscribers about the current state of the device. This is possible because the transducer always outputs NMEA sentences at a rate of 1 Hz while powered on, regardless as to whether it has any depth information to report. Should no messages be received from the echo sounder within 1.5 seconds the device is assumed to have been powered off.

Custom ROS messages corresponding to the depth, temperature, device state, and raw data are defined for the various messages published by the RECHOS device. A custom ROS service is bundled within the node to facilitate the creation of rosbag files for the purposes of data collection. The service only handles one recording request at a time, however this is an acceptable limitation. Further recording can be accomplished using the rosbag command line tool bundled with ROS. The Raspberry Pi is equipped with both wired and wireless Ethernet providing substantive communications connectivity to the ROS network.

The ROS service defines two requests and four responses (generated based on the success of actions taken to fulfill the request and correspond to the current state of the recorder service):

Requests

- start - request to start recording data to a new rosbag file
- stop - request to stop the current recording

Responses

- recording started - response to a successful start request
- already recording - response to a start request when there is already an active recording
- recording stopped - response to a successful stop request
- nothing to stop - response to a stop request when there are no active recordings

This general topic structure can be reused for other types of NMEA 0183 sensors utilizing one-way communication. The general topics (Raw, State and Recorder) carry functionality useful for many sensors. Providing RAW data from the device eases the debugging of sensor malfunctions by facilitating the verification of message integrity and checksum data. The recorder service simplifies the process by which rosbag files can be created in a wireless environment where connectivity to the device cannot be maintained or guaranteed. Without this service it can be difficult to properly shut down the recording of rosbag files which can result in a loss of data. If the state of the device can be accurately inferred such information can be used to stop and start other processes that make use of its data. The data topics (Depth and Temperature) are specific to the type of sensor and others would be required for other classes of NMEA sensors.

4.1 Correcting Depth Readings

A major limitation with the development version of the sensor was due to the lack of inertial data. Accurate depth readings could not be maintain with changes in tilt due to wave action and other forces acting on the surface vessel. For this reason a triple-axis accelerometer was included in the production version of the sensor. Figure-4 shows the geometry of the situation. Let the sensor be mounted at the origin aligned with the z axis (pointing down) and the x-y plane lying in the nominal surface of the water. Wave action will cause the boat to roll and pitch relative to the nominal surface and thus the recovered depth d will not be recorded along the z axis, but rather will recorded along the vector $\hat{d}$. If we encode the recovered depth d as a vector $\vec{d} = d\hat{d}$, then the true depth is $\hat{z} \cdot \vec{d}$, and under the assumption that there are no obstructions between the surface and the bottom then the corresponding surface position p for this depth measurement is given by $(\hat{x} \cdot \vec{d}, \hat{y} \cdot \vec{d})$.

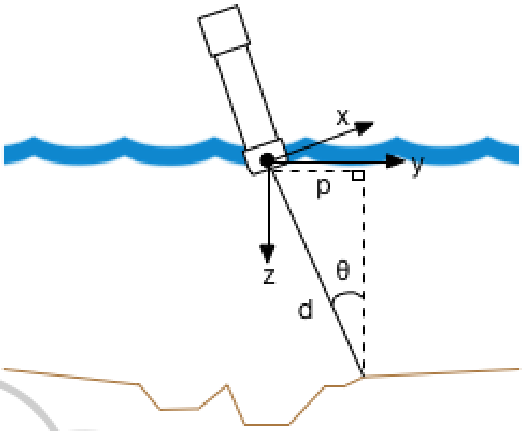


Figure 4: Sensor geometry displaying depth error due to tilt.

5 TESTING

Ensuring that equipment is functioning properly and producing meaningful data is an important part of any testing procedure in the field. Wasting valuable time in the field collecting unusable data or not collecting any data is unacceptable. Due to the limited amount of feedback available from visual checks of the RECHOS apart from a number of status lights – of which only three are of importance (Raspberry Pi power, wifi dongle connection, data transmission from the sensors) – other forms of feedback are necessary to confirm proper functionality. A mobile device can connect to the onboard computer and view console messages and data from the sensor, however parsing these messages for desired information is difficult due to the speed at which they are generated. A more visually pleasing and informative view of the sensor readings is required. In keeping with this requirement an android application was created to wirelessly monitor sensor readings from the system and display them to the user. The application utilizes the android library described in (Speers et al., 2013). The application interfaces with the RosBridge (Crick et al., 2011) suite

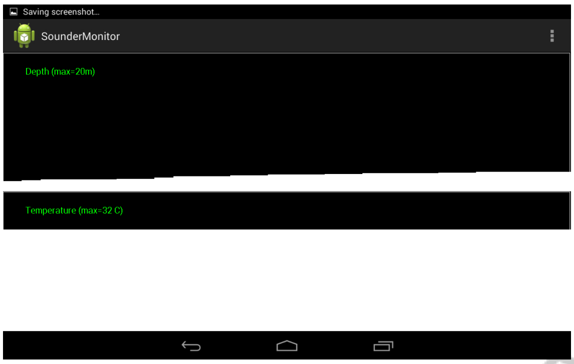


Figure 5: Android Monitor Application.

running on the RECHOS and subscribes to the necessary topics to receive messages for depth and temperature. Figure-5 shows a screenshot from the android application which draws the latest depth and temperature values on two graphs for easy visualization when in wireless communication range of the system.

5.1 Bucket Tests

Testing the sensor on a lab bench risks damaging the piezoceramic transducer in the echo sounder. The rapid expansion and contraction of the piezoceramic material generates considerable heat and without the thermal conductive properties of the water this heat can damage the device. In order to accommodate this requirement initial tests of the transducer were conducted in a lab setting using a large bucket filled with water. These tests were done to acquire knowledge about the transducer which was not included in the specifications provided by the manufacturer. For example, the transducer will continue to function at low voltages, e.g. 4.5 - 9.5 VDC, however depth readings become erroneous and reported temperatures begin to climb well above manufacturer specification for the device (0 °C - 32 °C). As well in some cases the transducer can take up to ten seconds before producing depth readings.

5.2 Field Tests

The sensor was tested during the NCFRN (NSERC Canadian Field Robotics Network) field trails at McGill's Bellairs Research Institute in Holetown, Barbados. A bobbing test was first conducted in shallow water in order to determine the expected variability in depth due to fluctuations in wave height. Following this test two depth profiles were collected, one parallel and one perpendicular to the shore. The map in Figure-6 provides an overview of the testing site and the routes taken which have been colour coded to the test data shown in Figure-7.

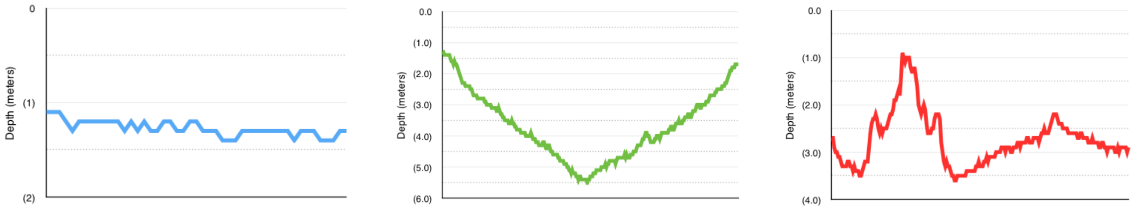
Figure 6: Overview of the testing area for the development housing.

The tracks for both of the perpendicular and parallel shore depth tests were completed both forward and backwards so that reproduction of the depth information could be verified. The perpendicular shore depth test was conducted along a route that lacked underwater coral features so that only the depth profile away from shore could be obtained. The parallel shore depth test was conducted along a route with coral features at either end. The device has also been tested under less desirable environmental conditions. Figure-8 shows the production version of the device being tested in Lake Seneca near Toronto, Canada. Testing here validated the basic construction of the production device. It also identified an issue with battery discharge rates under extreme cold conditions. Based on these results the battery used in the production device has been modified to have a higher capacity than was needed for the tests in Barbados.

6 RESULTS

Figure-7a shows the results from the bobbing test. The sensor was held stationary while it bobbed up and down in the water column, this is far from a comprehensive test case for the study of changing water depths, it does provide a good indication of expected variability of depths recorded by the sensor. The standard deviation of the resulting data is 0.1m, representative of the wave action present during testing.

Since the RECHOS was handled by a swimmer traversing each route there were two factors that influenced the repeatability of the sensor motion data. First, the degree to which sensor velocity could be maintained. Changing velocity of the swimmer could compress or stretch the depth profile. Second, deviations of the swimmer from the original path po-



(a) Bobbing Test. (b) Perpendicular Shore Depth. (c) Parallel Shore Depth.

Figure 7: Experimental results obtained from the RECHOS sensor during field trails at McGill's Bellairs Research Institute in Holetown, Barbados. Graphs are colour coded to routes overlaid on the map in Figure-6.

Figure 8: Testing of the production housing of the sensor.

tentially produce dramatically different results over coral. However, results from both shore depth tests shown in Figures-7b and 7c indicate that sensor data produces similar results when passed repeatedly over the same portion of the seabed.

7 CONCLUSIONS

Depth sensors are a critical sensor for autonomous surface vessels. Commercial echo sounders utilize power and communication protocols that are not consistent with standard robotics power and communication protocols. This paper describes how appropriate electronics and software can be used to convert these NMEA 0183 devices to a standard ROS infrastructure. The approach described here is generalizable and easily adapted to other classes of NMEA 0183 compliant sensors.

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