Development of a GPS-Based Autonomous Water Pollution Monitoring System Using Fish Robots

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Abstract: - We introduce an autonomous water pollution monitoring system that searches the sources of water pollution and makes measurements of relevant data using a fish robot. A fish robot searches and monitors various areas using GPS receivers and directional information. A fish robot has three microcontrollers which provide full functions, for example, motor operations for the swimming of a fish robot, analog sensor data acquisition including temperature and infrared distance sensors, decoding GPS information, counting the time of sonar in ultrasound sensors and a directional sensor, collecting information of water pollution measurement sensors from Vernier Labpro, and communications. A fish robot swims autonomously in predefined areas and collects the water pollution indexes. Collected information by a fish robot is sent to data collecting nodes by USN motes and Bluetooth, and the data are accessible on the Internet by Ethernet devices.

Key-Words: - Fish Robot, Water Pollution, Autonomous Tracking System, Obstacle Avoidance

1 Introduction

Several interesting and unique types of robots have been introduced and developed by the influence of biomimetics for the recent decades. A fishlike underwater robot is one of these categories. Fish in nature move their bodies to generate propulsive power. It is also well known that fish achieve excellent power efficiency and maneuverability that have advantages over conventional propeller-based marine vehicles[1, 2, 3]. Our lab introduced a simple fishlike robot in 2005[4], and improved and added new functions in various manners[5, 6].

The conventional methods of water pollution monitoring collect data by sensors attached on fixed posts. More posts are necessary for large areas. Besides, there are many kinds of locations which are dangerous or have limited accessibility. We introduced fish robots in water pollution monitoring tasks to overcome these problems. Fish robots have a fundamental advantage of mobility over the conventional fixed monitoring posts. Since fish robots can swim while collecting pollution measurements, it is possible to track directions that have higher pollutant densities in real time modes. Practically this kind of real time dynamic monitoring method is very important in the investigation and protection of environmental problems.

In this paper, development of an autonomous dynamic water pollution monitoring in large areas by fish robots is proposed. The basic positional information for navigation is obtained by GPS receivers. The direction data for path planning is calculated using the GPS data. Other than distance sensor data that are necessary to make minor direction changes for obstacle recognition and collision avoidance, the simple GPS data are basic for the autonomous movements of fish robots.

It is fundamental for fish robots to navigate in a given area uniformly without missing areas or repetitive movements in the same tracks for water pollution monitoring. Thus the navigation problem is quite similar to that of cleaning robots and autonomous lawn mowers. Another similar application can be found in the navigation of harvesting tractors for a given large field. Agricultural yield maps[7] which are crop data for given areas provide basic information for better harvest of the following year. Similar navigation methods can be applied to obtain yield maps by harvesting tractors.

A fish robot uses three microcontrollers to reduce calculation loads for the functions of motor operations for swimming, analog sensor data acquisition including temperature and infrared distance sensors, decoding GPS information, counting the time of sonar in ultrasound sensors and directional sensor, collecting information of water pollution measurement sensors from Vernier Labpro, and communications. Collected information from a fish robot is sent to data collecting nodes by USN motes and Bluetooth, and the data are transmitted to a server once per second.

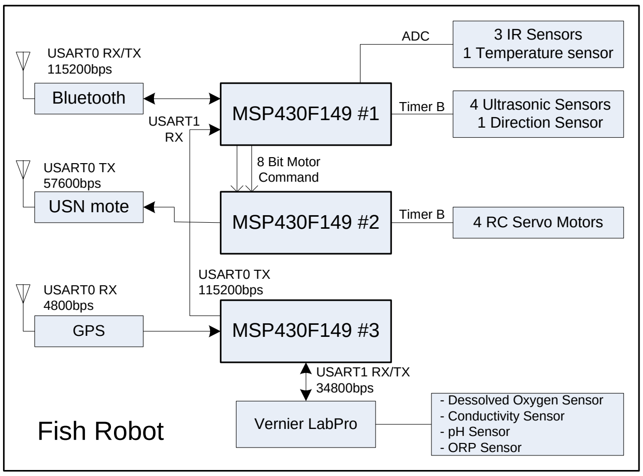
Fish robots with improved functions for autonomous real time water pollution monitoring are described in section 2. The overall system for ubiquitous pollution monitoring and the analysis of monitoring results are explained in section 3. The conclusion is given in section 4.

2 A fish robot for water pollution monitoring system

Several types of fish-shaped underwater robots have been developed and improved in their functions in our lab. The robots with various structures and shapes of real fish imitate the way real fish swim. For instance, four servo motors are used at the caudal fin of the robot for propulsion and horizontal direction control. The fish robot in this paper is improved to get positional information from a GPS receiver, to operate between USN motes for sonar localization, and to collect water pollution indexes from Vernier LabPro sensor tips with a conductivity sensor, DO (Dissolved Oxide) sensor, pH sensor, and ORP (Oxidation Reduction Potential) sensor in real-time.

The most important indexes of water pollution are BOD (Biochemical Oxygen Demand) and COD (Chemical Oxygen Demand). But it takes much time to get the exact values of these indexes. Instead of these two indexes, we can get other indexes for water pollution, for example, DO (Dissolved Oxide), pH, Conductivity, and ORP (Oxidation Reduction Potential) in a real-time mode. These four kinds of sensors are important for water pollution indexes. In addition, they are low cost and easy to operate in experiments.

(a) A fish robot



(b) Block diagram of a fish robot

Fig. 1. Underwater Fish-shape robot

A fish robot has three microcontrollers, MSP430f140 by TI, to reduce the load of processing data. The main microcontroller in Figure 1 reads data from several sensors: 1) reading three IR sensors and one temperature sensor through ADC ports, 2) measuring the time of flight of the ultrasound produced by sonar sensors, 3) reading directional sensor to obtain directional information, and 4) communicating with a server using bidirectional Bluetooth modules to send commands or to get various data. The second microcontroller operates four RC servo motors by producing independent PWM signals to generate necessary swim patterns. This microcontroller is also connected to a USN mote for sonar localization to get more precise positional information compared with the GPS-based method in specific and small areas. The third microcontroller receives positional information from the GPS module and communicates with the Vernier LabPro sensor board which has connections with four different sensor tips. This microcontroller decodes data portion only for time, latitude, longitude, and GPS quality indicator from GPS data in GPGGA sentences by NMEA(National Marine Electronics Association) 0183 protocol, and receives and decodes sensor information from Vernier LabPro. The GPS module has a very low data transmission speed of 4,800bps and LabPro has 34,800bps baud rates. After the third microcontroller gathers all information from the GPS receiver and LabPro, the microcontroller changes the baud rates to 115,200bps and sends all information to the main microcontroller. Then it changes the baud rates to 4,800bps back to receive GPS information. All data of a fish robot are gathered in the main microcontroller where proper motor manipulation actions for navigation and commands for sensor data acquisition and communication are produced. The main microcontroller sends the GPS information and pollutant sensor data to a server by Bluetooth modules. The server relays the information on the Internet by Ethernet modules. Therefore, any user can access all information on the Internet whenever the data are required. Figure 2 shows the sensor configuration on a fish robot. All commands for the motor manipulations are transmitted from the first microcontroller to the second microcontroller.

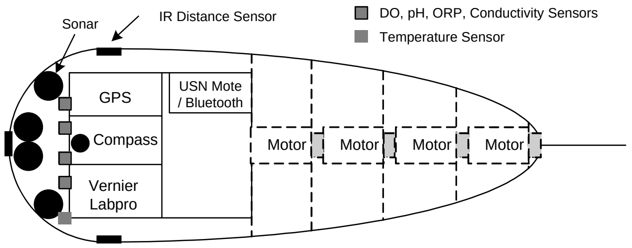


Fig. 2. Sensor configuration on a fish robot

The infrared distance sensors, regardless of obstacle colors, sizes and approaching angles, are generally used to measure distances between a robot and obstacles. Because the detectable ranges of the IR sensors are very short and narrow, while the ranges of sonar sensors are long and wide, two different types of sensors make up for each other. Moreover, when the sizes of obstacles are small or narrow, sonar sensors often miss the detection of obstacles.

Since obstacle detection and avoidance is the most important function of mobile robots whether they are wheel based or not, lots of previous studies have presented a variety of methods and applications[8, 9, 10] for this matter. More detailed specifications of a fish robot are shown in Table 1.

Table 1. Specifications of a fish robot

Item	Specification
Length	78cm
Width	21cm
Height	19cm
Weight	4950g
Length of tail fin	43cm
Maximum angle of tail fin	90°
Minimum rotation radius	42cm
Maximum speed	61cm/sec
Maximum torque of motors	7.4Kg cm at 6V
Angular speed of motors	300°/sec

3 Autonomous monitoring system of water pollution

The overall schematic diagram of the proposed dynamic water pollution monitoring system by an autonomous fish robot is described in Figure 3. The position data, which are basic for this monitoring system, are obtained mainly by a GPS receiver on the fish robot. Since water pollution monitoring routines are done in large open areas, the GPS information is the first choice considering cost and easiness. Due to the dilution characteristics of water, average errors of the GPS positional signals are not practically significant. The method based on sonar localization [8] can be used when more accurate data than those of GPS are required.

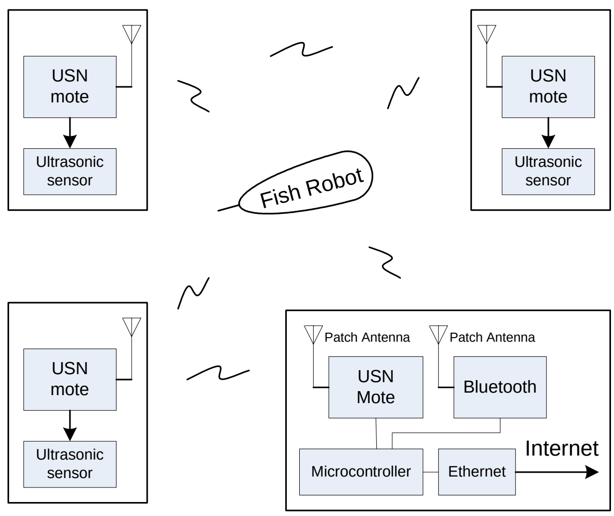


Fig. 3. Water pollution monitoring system

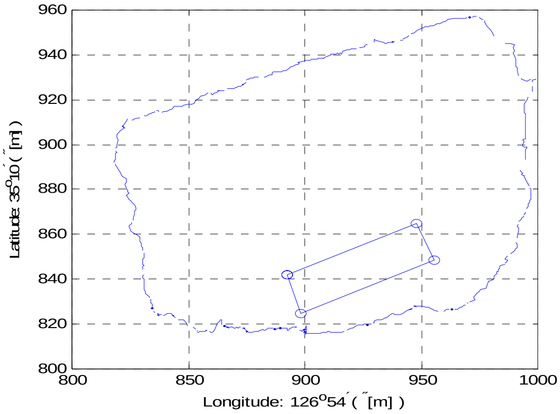
(a) Monitoring fish robot

(b) A large pond on campus

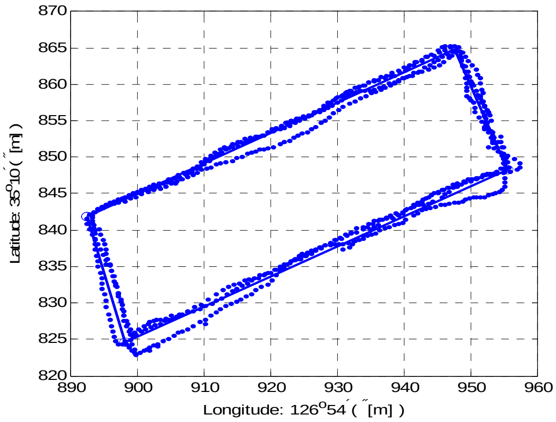
(c) A reservoir near campus

Fig. 4. Test beds for water pollution monitoring

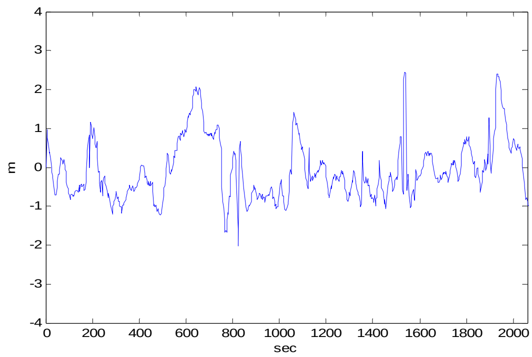
The conventional methods of water pollution monitoring collect data by sensors attached on fixed posts. The proposed method, however, relies on fish robots that have a fundamental advantage of mobility over the conventional fixed monitoring posts. Since fish robots can swim anywhere while collecting pollution measurements, it is possible to track directions that have higher pollutant densities in real time modes. Practically this kind of real time dynamic monitoring method is very important in the investigation and protection of environmental problems.



(a) GPS map of a pond on campus



(b) Tracks of GPS data



(c) Errors of received GPS data

Fig. 5. Trajectory of a fish robot

Since the ideal paths of a monitoring robot are required to be uniform without missing areas or repetitive movements in the same tracks for given areas, the navigation problem is quite similar to that of cleaning robots and autonomous lawn mowers. Another similar application can be found in the navigation of harvesting tractors for given large fields. Agricultural yield maps[7] which are crop data for given areas provide basic information for better harvest of the following years. Similar navigation methods can be applied to obtain yield maps by harvesting tractors.

Figure 4 shows a monitoring fish robot and two test beds, one large pond on campus and one reservoir near campus. A rectangular region is chosen at a pond on campus for a test bed of GPS data as shown in Figure 5(a). The effectiveness of the GPS data for large areas such as pollution monitoring is tested by the repetitive tracking of the same route. Figure 5(b) shows the three tracks that are made of the GPS data received by the monitoring robot. The maximum positional error is about 5 meters between different circulations with a standard deviation of 0.83 m.

The **GGA sentence format of the GPS NMEA 0183 format is as follows:

$GGA,hhmmss.ss,llll.ll,a,yyyyy.yy,**
a,x,xx,x.x,x.x,M,x.x,M,x.x,xxxx*hh

where each field is separated by a comma. $ represents the beginning of a sentence, **hhmmss.ss** represents hours, minutes and seconds in the coordinated universal time(UTC), **llll.ll** represents latitude coordinates with north or south when **a** is N or S, **yyyyy.yy** represents longitude coordinates with east or west when **a** is E or W, and the remaining **x**'s represent GPS quality indicators that verify stable operations of a receiver. In this paper, only the portions of time, latitude, longitude and GPS quality indicators out of full sentences are used.

The microcontroller receives positional data from the GPS module and communicates with the Vernier LabPro sensor board which has connections with four different sensor tips. As shown in Figure 6, the microcontroller decodes data portion for time, latitude, longitude, and GPS quality indicator from GPS data sentences, and receives and decodes sensor information from Vernier LabPro. The GPS module has a very low data transmission speed of 4,800bps and LabPro has 34,800bps baud rates. After the third microcontroller gathers all information from the GPS receiver and LabPro, the microcontroller changes the baud rates to 115,200bps and sends all information to the main microcontroller. Then it changes the baud rates to 4,800bps back to receive the next GPS and sensor data.

A fish robot collects the water pollution indexes while swimming autonomously in predefined areas or in remote controlled modes. Collected information by a fish robot is sent to data collecting nodes by USN motes and Bluetooth, and the data are accessible on the Internet by Ethernet devices.

Figure 7 shows the typical example of measured water pollution indexes. A Vernier LabPro sensor board on a fish robot with conductivity, ORP, DO and pH sensors are used for the measurements.

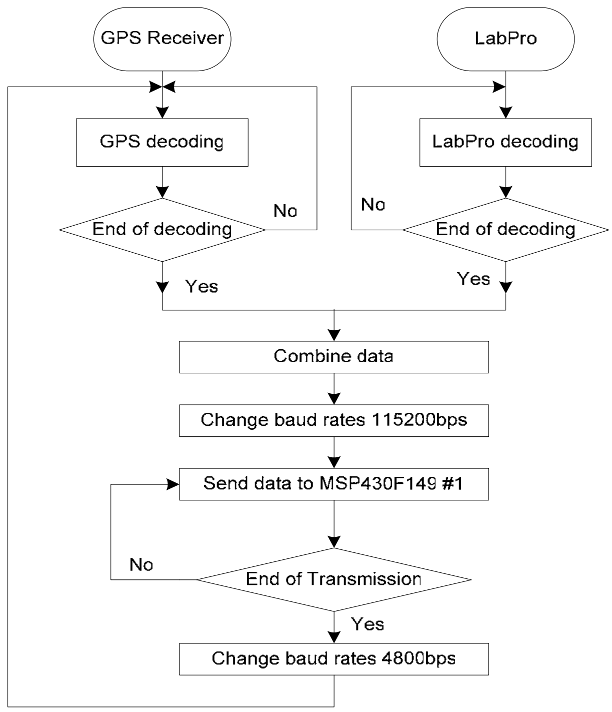


Fig. 6. Decoding and interface of GPS and sensor data

4 Conclusions

Development of an autonomous water pollution monitoring system that searches the sources of water pollution and makes measurements of relevant data using a fish robot is presented. A fish robot searches and monitors various areas using GPS receivers and detection sensors. Several functions including motor operations for the swimming of a fish robot, detection sensor data acquisition, decoding GPS information, counting the time of sonar, collecting information of water pollution measurement sensors from Vernier Labpro, and transmission of data to a server are managed by a control board on a robot. Collected information by a fish robot is sent to data collecting nodes by USN motes and Bluetooth, and the data are accessible ubiquitously on the Internet by Ethernet devices.

Fish robots have a fundamental advantage of mobility over the conventional fixed monitoring posts. Since fish robots can swim while collecting pollution measurements, it is possible to track directions that have higher pollutant densities in real time modes. Practically the real time dynamic monitoring method is very important in the investigation and protection of environmental problems.

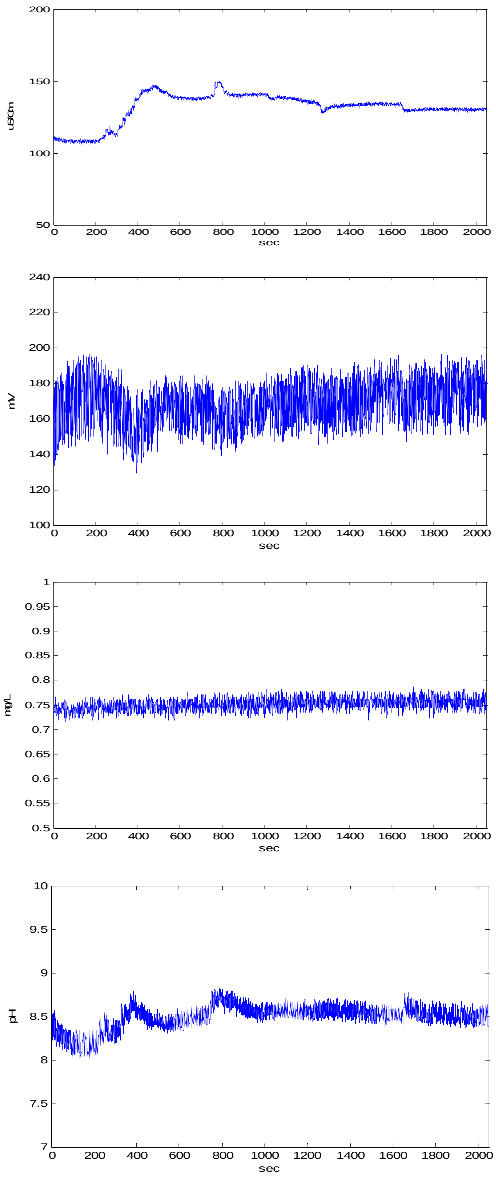


Fig. 7. Measurements of Vernier LabPro sensors (Conductivity, ORP, DO and pH, respectively)

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