Mapping System of Water Pollution by Autonomous Fish Robots

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Abstract: - We propose a water pollution source mapping system based on ubiquitous sensor networks that fish robots search the source of water pollution autonomously. To verify the effectiveness of a water pollution source mapping system, we made a model water pool in which a fish robot pursues infrared measurements of reflection to various colors at the bottom of the pool. The model of water pollution consists of various color maps, an LED emitting infrared, and a photo-transistor sensing the same wave length light. Different color has different reflectivity for the same light source; therefore this simulation model imitates the diffusion of water pollution sources. For real tests, an LED and the photo-transistor can be replaced with particular water pollution sensors. Water pollution maps can be composed based on the known mote location information by identifying motes. To get improved position data between the motes, directional sensors such as magneto-resistive sensors and accelerometers are applied to compensate noise components due to waves and the swing actions of the tail fin. Fish robots obtain simulated pollution data in terms of reflectivity autonomously.

Key-Words: - Fish Robot, Pollution Map, Ubiquitous Sensor Networks, Noise Reduction

1 Introduction

Several different types of small scale fish robots and submersibles were developed and tested in our lab[1]. To confirm their effectiveness, our constructed fish robots have been tested in a small tank for collision avoidance, maneuverability, control performance, posture maintenance, path design, and data communication. Control actions of motors for fins, illumination, communication with a server for monitoring, and data processing, and data acquisition from various sensors are processed based on the MSP430F149 by TI. Various sensors include infrared distance sensors, pressure sensor and acceleration sensors. User commands, sensor data and images are transmitted by Blue-tooth modules between robots and a host notebook PC. Operation is made in autonomous and manual modes in calm water.

We use simple IR type distance sensors instead of a camera or a sonar module for a fish robot's eyes. There are three distance measuring sensors for a general purpose, which are mounted on the foreground and the left and right sides from the fish robot's head. Collision avoidance can be made by detecting simple plane obstacles.

This paper proposes a new method of the water pollution mapping and tracking system by using a fish robot based on ubiquitous sensor networks. We also try to show the effectiveness of the proposed method in the simulation of water pollution in a tank. In the water pool imitating the similar situation such as the diffusion of a real water pollution source, the fish robot searches higher reflected light intensity from the bottom of the tank with different colors to track the highest level position. The water pollution map can be composed based on the known mote location information by identifying motes. Our experimental results show that the fish robot avoids collision while successfully tracking the sources to produce pollution maps.

In section 2, a fish robot for the water pollution tracking system is presented. The simulation of water pollution circumstances is covered in section 3. Tracking control of fish robots and noise reduction are given in section 4. The procedures to acquire location information using USN motes and magneto-resistive direction sensors to compose pollution maps are given in section 5. Experimental results are given in section 6, followed by conclusion.

2 Fish Robots

We have constructed fish-shaped underwater robots in our lab. Our fish robots with various shapes of real fish imitate the way the real fish swims.

2.1 A fish robot

For propulsion and horizontal direction control, four servo motors are used at the caudal fin for the water pollution monitoring robot. Distance sensors, which are mounted at the front and two sides of the head, measure the distance to an obstacle. Every signal is processed based on the MSP430F149 by TI. User commands and sensor data are transmitted between the fish robot and a host notebook PC either by Bluetooth modules of class 1 or by an RF module, which depends on operation depth. A fish robot is shown in Fig. 1.

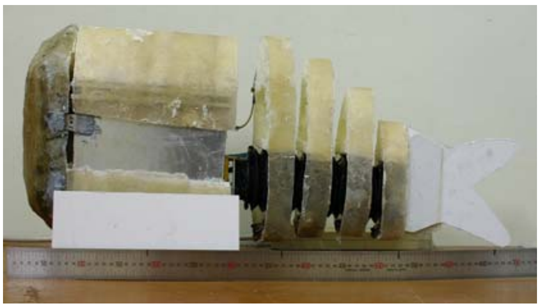


Fig. 1. Implemented fish robot

The infrared distance sensor, regardless of obstacle color, size and angle, is generally used to measure the distance between the robot and an obstacle. Three infrared distance sensors, GP2D12s, are used to measure the distance from the fish robot to the wall or obstacles. The detectable range is reduced to about 12-30cm underwater, though the range is 10-80cm in the air. Using a transparent cover is necessary to keep the focal distance of lens underwater and to make the sensor waterproof.

Three distance sensors are mounted at the frontage and two sides of the head. Direction change is determined by measured distance information. The configuration of the sensors on the fish robot's body is shown in Fig 2.

Since obstacle avoidance is the most important in mobile robot, whether it is wheel based or not, lots of previous studies have presented a variety of methods and applications[2, 3, 4].

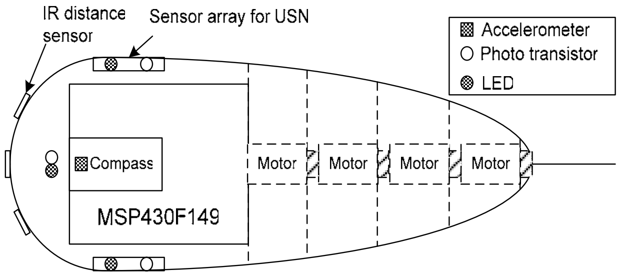


Fig. 2. Sensor configuration on a fish robot

Table 1. Specifications of a fish robot

Item	Specification
Length	73Cm
Width	12.5Cm
Height	22.5Cm
Weight	4950g
Length of tail fin	42Cm
Maximum angle of tail fin	80°
Minimum rotation radius	31Cm
Maximum speed	70Cm/sec
Maximum torque of motors	7.4KgCm at 6V
Angular speed of motors	300°/sec

2.2 Swim patterns

Pectoral fins or ventral fins as well as a caudal fin are used when real fish make a turn. However, we decided on a simple structure of the fish robot, which turns only with a swing of its caudal fin. Since the caudal fin is used for propulsion and turns, the fish robot gets a simpler structure. We assume that there are two turning modes, that is, slow turn and quick turn. The real fish swings its caudal fin to one side slowly for slow turn or quickly for quick turn while turning [5, 6]. Especially when the fish turns slowly, it swings the caudal fin as well as turning it. For a quick turn, the real fish turns quickly. That is, it quickly turns its caudal fin to one side without swinging and then it sustains its caudal fin while turning. We consider slow turn and quick turn the most fundamental and important, since the fish robot imitates real fish's swim and turn. Equation (1) shows general swim function.

$$A_i(t) = K_i Am_i \sin(2\pi ft - \theta_i) + \Delta_i(t) \qquad (1)$$

A_i is the angle of i-th tail motor, K_i is amplitude factor, Am_i is amplitude, f is frequency of caudal fin, θ_i is phase delay of i-th motors, and Δ_i is deflection angle for slow and quick turn. We use 10 degree maximum amplitudes of angle and 35 degree phase delays for general swim. Swim frequency is 0.5Hz. In general, deflection angle Δ_i varies smoothly for slow turn, but varies quickly for quick turn. When the fish robot makes a quick turn, K_i is zero.

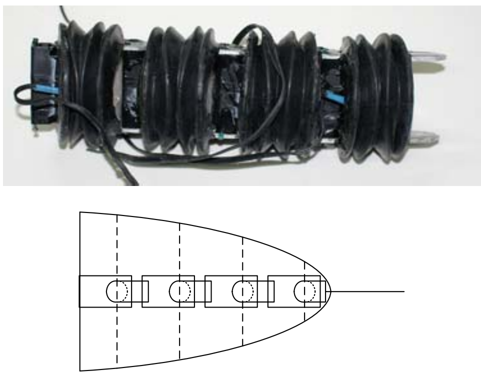


Fig. 3. Lower body and caudal fin of a fish robot

3 Mapping of Water Pollution

A mapping system we propose is that a fish robot tracks the water pollution source autonomously in the real circumstance. BOD (Biochemical Oxygen Demand) and COD (Chemical Oxygen Demand) are the most important indexes of water pollution. However, there is a disadvantage that it takes too much time to get the exact values of these indexes. Furthermore, it is impossible to get the true values of these indexes real-time. Instead of these two indexes, to test the effectiveness of the proposed system, we can get some other indexes for water pollution, for example, DO (Dissolved Oxide), pH, Conductivity, and ORP (Oxidation Reduction Potential) real-time. Though it is very difficult to find or make some contaminated places, we need similar simulation circumstances of water pollution in order to develop a good water pollution tracking system. The pollution source tracking system is shown in Fig. 4.

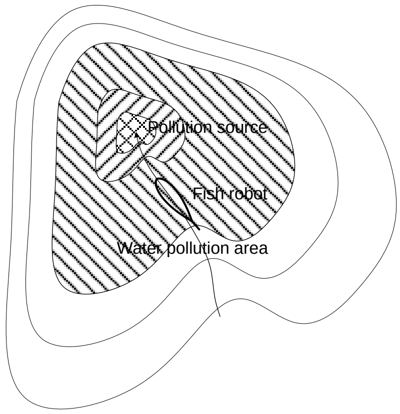


Fig. 4. Autonomous pollution mapping system

We made an artificial model circumstance similar to the real circumstance. It is general that a water pollution source diffuses widely and in a circular pattern at static condition, for example, in the lakes and sea, except the rivers which have streamlines.

A simple model distribution of water pollution was made in a small sized water pool in our lab. We also made a color map which reflects the light source to imitate the water pollution, an LED which produces infrared, and a photo-transistor which reacts in infrared wave length very well. Blue and red are used to make different reflectivity of infrared. The depth of two colors makes smooth gradation at the bottom of the pool. White color which makes the highest reflectivity shows a water pollution source. The artificial circumstance is shown in Fig. 5.

The fish robot can detect higher reflection intensity to infrared among the different colors that are reflected from the bottom to an LED light source. In order to search the place showing higher intensity, we need to make the fish robot's head swing periodically to find a wide area for one period swimming. The basic strategy for tracking is a swing of the body. The robot changes the direction to find higher intensity of reflection to the light source.

Fig. 2 shows the sensor configuration of the fish robot. IR distance sensors, which recognize and avoid obstacles, are mounted at the robot's head and the measurement direction is towards the front. The measurement direction of an LED and a photo-transistor is towards the bottom.

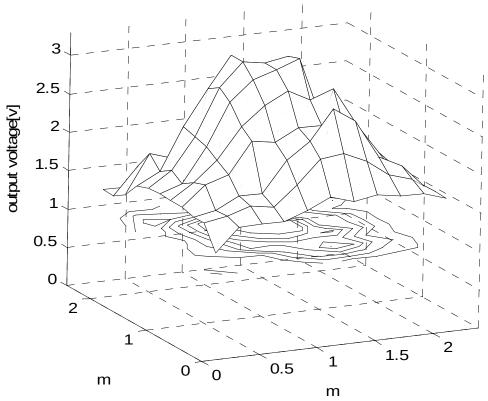


Fig. 5. Light intensity distribution of model water pollution

4 Tracking Control of Fish Robots

The fish robot's ability to search for an increasing measured value in a wide area while swimming is considered as the basic strategy for the water pollution mapping system.

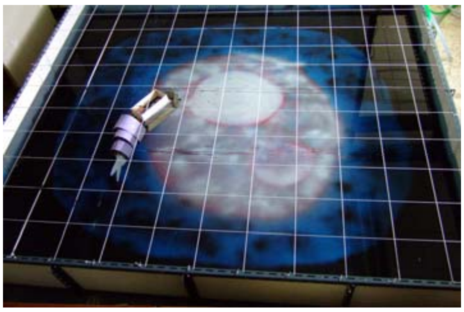


Fig. 6. Model pollution area in a tank

Both the body and the head swing accordingly when the tail fin swings by motors. The intensity of infrared in swing trajectory is measured by the sensor, and the highest intensity is found during the half cycle of each swing. When the highest intensity is found at the right side, the robot must change the direction to the right. Thus, Δ_i in equation (1) must be decreased for direction change to the right, while it must be increased for direction change to the left. The fish robot continuously changes the direction for the place which shows higher reflection intensity to the light source and it can find the highest intensity place. For an autonomous tracking, simple commands are used for direction changes; for example, 'If the intensity of the left side is higher than the right side, then turn left,' 'If the intensity of the right side is higher than the left side, then turn right,' and 'If the intensity of one side is similar to the other side, go straight.' A simple fuzzy logic is applied in our study for easy implementation of the controller.

Direction control of the fish robot uses the fuzzy inference system[7, 8, 9]. The main propulsion for the robot is provided by the tail fin moved by four servo-motors. Thus, a continuous swing action exists at both the head and the tail of the robot. This swinging movement covers some region to recognize the difference of intensity. Control input is one cycle intensity data from the photo-transistor. The fish robot finds the maximum value and the position of the head, and the fuzzy system determines the value of Δ_i for direction change. Very simple and concrete verbal commands are used for direction control. The vagueness of instantaneous sensor noise and ambiguous verbal commands is processed by fuzzy control commands. For example, some commands for the control are shown below:

> "If the intensity of the left side is slightly higher than the right side, then turn left slightly."
> "If the intensity of the left side is much higher than the right side, then turn left much."

Gaussian membership functions are used for input membership functions.

$$F(x) = e^{-\frac{(x-c)^2}{2\sigma^2}} \quad (2)$$

The i-th fuzzy rule for TSK inference is given as

$$R^i : \text{IF } x_1 \text{ is } F_1^i \text{ and } \dots x_k \text{ is } F_k^i \dots, \text{ Then}$$
$$z^i = c_0^i + c_1^i x_1 + \dots + c_K^i x_K \quad (3)$$

where x_k is fuzzy input for the half cycle photo-transistor output, z^i is fuzzy output for change of direction, and F_k^i is a fuzzy membership function.

i = 1, 2,…, I, k = 1, 2,…, K
I : number of fuzzy rules,
K : number of fuzzy inputs,

c^i : linear value of fuzzy output

Fuzzy output is given by

$$z^* = \frac{\sum_{i=1}^{I}\prod_{k=1}^{K} F_k^i(x_k) z^i}{\sum_{i=1}^{I}\prod_{k=1}^{K} F_k^i(x_k)} \quad (4)$$

5 Water Pollution Maps Based on USN Motes

The backbone information for water pollution maps is given by GPS which is the easiest way currently. In this paper, the procedures to obtain more detailed local position information to be added are addressed. Three levels of pollution mapping system based on location acquisition devices are adopted.

- Basic information by GPS receivers
- Intermediate information by checking USN motes
- Detailed information by positional sensors on a fish robot

When a fish robot approaches close to a mote, then the fish robot and the mote recognize each other by sensing a particular source of information. For experiments, an LED and the corresponding photo-transistor are installed on the fish robot and the motes so that a fish robot and a mote can detect each other whenever they are in the range of detection. The mote sends its ID to a fish robot immediately after detection. When a fish robot receives a sensing signal from a mote within a specified short interval of time immediately after it detects a mote, then the fish robot can identify the mote ID and its location. By this way of identification of USN motes that are placed in a given area, a fish robot can recognize a particular USN mote and acquires intermediate location information of step 2 while it is swimming to get water pollution information.

More detailed location information of step 3 between the motes can be acquired using positional sensors on a fish robot such as e-compass, IR distance sensors and acceleration sensors. In experiments, Philips' magneto-resistive sensors of KMZ51 and accelerometers ADXL202 are used. Also for a given set of actuating input data to the motors in a robot, the speed and direction of the fish robot are known by experiments.

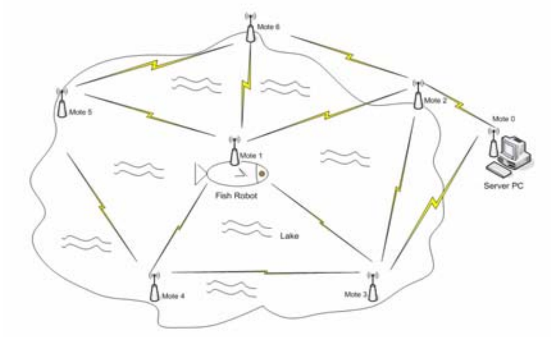


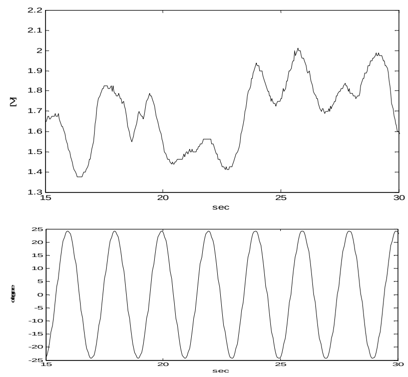
Fig. 7. Typical deployment of USN motes for mapping

6 Experimental results

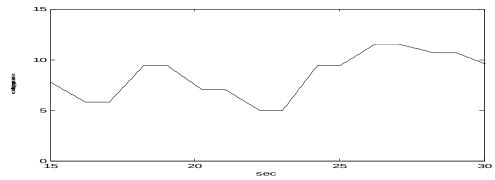
The time interval of a swing due to caudal fin movement is two seconds. The intensity acquisition by a photo-transistor is performed 25 times per second. The following equation

$$\Delta_i(t) = k(I_L(t) - I_R(t))$$

is used to determine the direction of the caudal fin where $\Delta_i(t)$ is the swing direction of $i^{\text{-th}}$ caudal fin, k is a proportional constant, $I_L(t)$ is the left side reflection during three cycles, and $I_R(t)$ is the right side reflection during three cycles.



(a) Typical photo-sensor outputs and periodic head positions



(b) Angle of tail fin for direction changes

Fig. 8. Typical tracking results of a fish robot

The output voltages of the photo-transistor and the head positions of the robot due to caudal fin movement are described in Fig. 8(a). ‘+1’ and ‘-1’ denote the farmost right and left positions of the head, respectively. The calculated angles of the tail fin for direction changes are shown in Fig. 8(b).

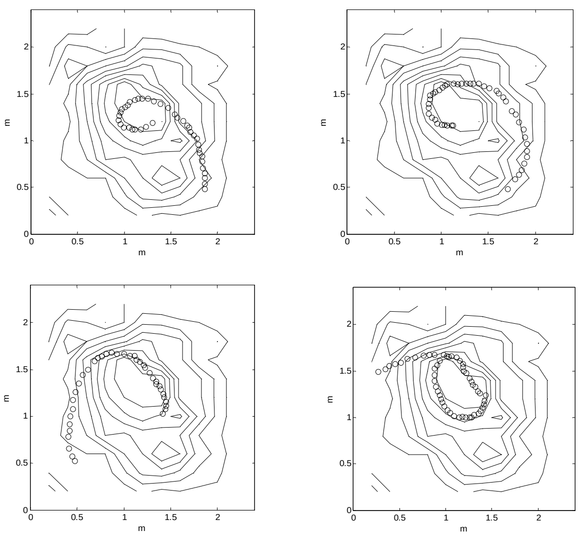


Fig. 9. Examples of autonomous tracking results

7 Conclusion

We presented a new water pollution mapping system by using an autonomous fish robot in this paper. Diffusion of the water pollution source was simulated by a multi-color map at the bottom of a small-sized water pool. Measurement of the pollution is tested using an infrared LED and the corresponding photo-transistor. The successive direction changes of the robot are determined according to the sensor measurements. Three levels of pollution mapping system based on location acquisition devices such as GPS, USN motes, and sensors are adopted. Test results of the mapping fish robot that tracks higher intensity to infrared reflection in a model pool indicate the possibility of the proposed method in real environments.

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