DOI: 10.3745/KIPSTA.2009.16-A.4.255

유비쿼터스 센서 네트워크에 기반한 엔터테인먼트용 수중 로봇의 구현

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요 약

유비쿼터스 센서 네트워크(USN)에 기반한 엔터테인먼트용 자율 돌고래 로봇의 구현에 관하여 소개한다. 일반적으로 수중에서 동작하는 생체모방 로봇에 유비쿼터스 센서 네트워크와 GPS를 적용하는 것은 불가능한 일이다. 본 논문에서 제안된 엔터테인먼트용 돌고래 로봇은 수중이 아닌 수면에서 동작하므로, 사용자와의 상호작용을 중요시하며 제안된 수중 로봇의 네비게이션은 GPS정보와 배치된 USN 모트로부터 얻어진 미세한 위치 정보로부터 수행된다. 본 논문에서는 제안된 돌고래 로봇의 기계적인 구조, 센서와 엑추에이터, 마이크로컨트롤러 보드와 수영 방법, 사용자와의 상호작용의 특징을 기술한다. 엔터테인먼트 돌고래 로봇은 유저에 의한 접촉 센서의 감지 신호를 입력받아 입을 움직이거나, 꼬리를 치고, 물을 뿜어내는 등의 전형적인 응답을 보인다. 로봇의 자율성을 위하여 경로 설정, 장애물 감지 및 회피 등과 같은 로봇의 움직임뿐 아니라 인간과 로봇의 상호작용에 관련된 기능들을 마이크로컨트롤러가 제어한다. 돌고래 로봇의 위치 정보는 배치된 USN 모트의 알려진 위치 정보로부터 주기적으로 교정된다.

키워드 : 엔터테인먼트 수중 로봇, 유비쿼터스 센서 네트워크, 생체모방학

Implementation of Underwater Entertainment Robots Based on Ubiquitous Sensor Networks

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ABSTRACT

We present an autonomous entertainment dolphin robot system based on ubiquitous sensor networks(USN). Generally, It is impossible to apply to USN and GPS in underwater bio-mimetic robots. But An Entertainment dolphin robot which presented in this paper operates on the water not underwater. Navigation of the underwater robot in a given area is based on GPS data and the acquired position information from deployed USN motes with emphasis on user interaction. Body structures, sensors and actuators, governing microcontroller boards, and swimming and interaction features are described for a typical entertainment dolphin robot. Actions of mouth-opening, tail splash or water blow through a spout hole are typical responses of interaction when touch sensors on the body detect users' demand. Dolphin robots should turn towards people who demand to interact with them, while swimming autonomously. The functions that are relevant to human-robot interaction as well as robot movement such as path control, obstacle detection and avoidance are managed by microcontrollers on the robot for autonomy. Distance errors are calibrated periodically by the known position data of the deployed USN motes.

Keywords : Entertainment Underwater Robot, Ubiquitous Sensor Networks, Bio-Memetics

1. Introduction

Several interesting and unique types of robots have been introduced and developed by the influence of bio-mimetics for the recent decades[1, 2]. Particularly, a fishlike underwater robot is one of these categories. Our lab introduced a simple fishlike robot in 2005[3], and has improved and added new functions in various manners[4, 5, 6]. To confirm their effectiveness, our constructed fish robots have been tested in a tank for user interaction as well as collision avoidance, maneuverability, control performance, posture maintenance, path design, and data communication.

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논문접수 : 2009년 1월 16일
수 정 일 : 1차 2009년 6월 19일
심사완료 : 2009년 6월 29일

It is very unusual case to apply ubiquitous sensor networks in underwater bio-mimetic robot, because most of underwater robots operate underwater and there are severe losses of the signal strength for the communications between motes. But we apply USN to entertainment dolphin robot which is operated to show the various operations on the water. Antenna for the communications is disclosed inside of dorsal fins of entertainment dolphin robot.

In this paper, the integration of routines for entertainment dolphin robots based on ubiquitous sensor networks is described. Body and chassis structures, several types of sensors and actuators, governing microcontroller boards and related interfacing circuits, and swimming and interaction features are described as basic modules to construct a dolphin robot. Minimizing the degree of discrepancy compared to real dolphins and maximizing users' satisfaction are the most important criteria in evaluation of the robot performance.

Actions of mouth-opening, tail splash or water blow through a spout hole are typical responses of interaction when touch sensors on the body detect users' demand. In order to improve the entertainment dolphin robot's ability to interact with people, a pair of microphones as the ears of a dolphin robot is used to estimate the peak sound directions from surrounding people. Entertainment dolphin robots should turn towards people who want to interact with them, while swimming autonomously. It is assumed that the basic ways of communication are based on sound such as voice and claps.

It is required for a dolphin robot to swim naturally in a given area avoiding collision against obstacles while displaying its features of interaction when it detects viewers' interests. A dolphin robot uses three microcontrollers to reduce calculation loads for the required functions of water pump operations for swimming and collision avoidance, analog sensor data acquisition including ADXL, potentiometers and infrared distance sensors, decoding GPS information, and communications.

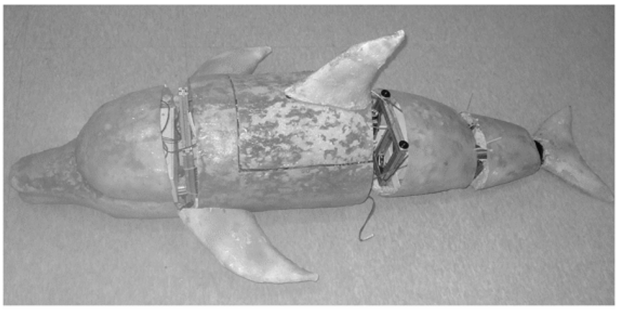
The traditional methods based on using cameras and image processing techniques indoors and using GPS receivers for outdoor applications are common for robot navigation problems[7, 8, 9]. However, due to the advent of ubiquitous sensor network technologies, navigation of service robots is possible through the application of USN instead of using cameras and image processing techniques. In this work, a general framework to get location information of a service robot[10, 11] based on ubiquitous sensor networks with infrared sensors without relying on conventional methods using cameras or sonar sensors, is described. GPS provides simple position data while USN motes provide accurate geographical information for the robots. A combination of distance sensors of laser range finders for medium and long ranges, and infrared sensors for short ranges is an efficient tool for the detection of obstacles. Vision systems provide excellent information about surroundings, but it takes much load to calculate the information for simple applications. The proposed method using USN motes with accompanying sensors for navigation is one of the optimal tools for various applications of service robots.

Functional modules of a dolphin robot are explained in Section 2. The overall system for improved movements and interaction features are described in Section 3. The conclusion is given in Section 4.

2. Modules of a dolphin robot

Several building blocks such as body and chassis structures, many types of sensors and actuators, governing microcontroller boards and related interfacing circuits, and swimming and interaction features are described as basic modules to construct a dolphin robot (Fig. 1). They should be in harmony in capacities as well as in sizes to be a successful model of a real dolphin.

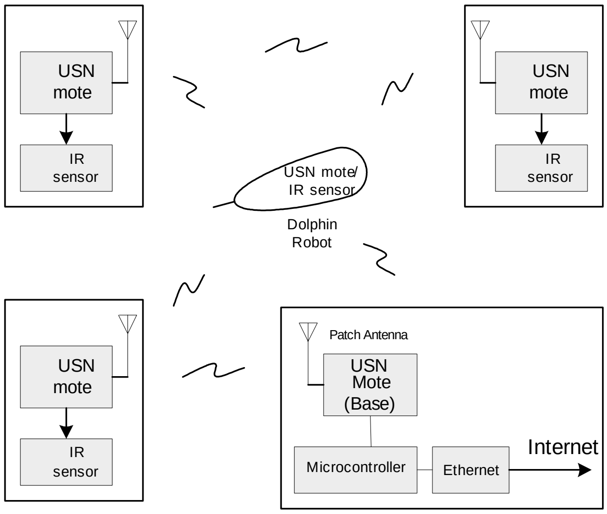
Generally, an autonomous mobile robot uses GPS system, camera and various distance sensors for the localization, recognition of surroundings and obstacle avoidance outdoors. Therefore, many kinds of localization methods have been developed so that required robot performance can be achieved based on the acquired positional data. The traditional methods based on using cameras and image processing techniques are common for robot navigation problems. However, there are practical restrictions to using images in ubiquitous sensor networks



(그림 1) 엔터테인먼트 돌고래 로봇
(Fig. 1) Entertainment dolphin robot

〈표 1〉 돌고래 로봇의 규격
〈Table 1〉 Specification of a dolphin robot

Item	Specification
Length	160Cm
Width (except pectoral fin)	28Cm
Height (except dorsal fin)	35Cm
Weight	30Kg
Minimum turning radius	2.5m
Main actuator (4 water pumps)	14 litre/min



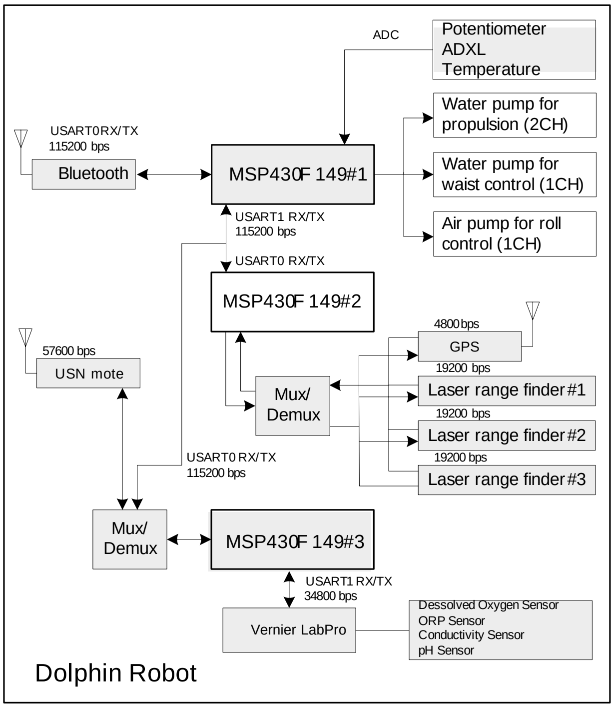
(그림 2) USN 모트의 배치
(Fig. 2) Deployment of USN motes

due to low traffic rates, large amount of information, low capacity of microprocessors and power consumption. Therefore, a new method is adopted that does not need cameras to get position data. The adopted method utilizes the functions of ubiquitous sensor networks that are assumed to be deployed as in (Fig. 2).

When a dolphin robot needs more accurate location information, it requests the execution of infrared sensors on USN motes through USN RF communication. IR sensors on the robot are in operation continuously to detect obstacles in a short range. Then a mote on the robot receives pairs of infrared data and its serial ID. The maximum infrared signal can be considered to be the one that is detected by the mote which resides at the closest distance from the robot.

3. Integration of routines for dolphin robots

The main objective of entertainment dolphin robot is to show the reaction for the viewers



(그림 3) 돌고래 로봇의 블럭도
(Fig. 3) Block diagram for dolphin robot system

A pair of microphones as the ears of a dolphin robot, in order to improve the entertainment dolphin robot's ability to interact with people, is used to estimate the peak sound directions from surrounding viewers.

A dolphin robot uses three microcontrollers, MSP430f140 by TI, to reduce the load of processing data. The main microcontroller reads data from several sensors: 1) reading three IR sensors, potentiometer, ADXLs and one temperature sensor through ADC ports, 2) reading directional sensor to obtain directional information, 3) control of water pumps by producing independent PWM signals for propulsion, direction changes, and roll control, and 4) communicating with a server using bidirectional Bluetooth modules to send commands or to get various data.

The main microcontroller handles all actions of a dolphin robot such as:

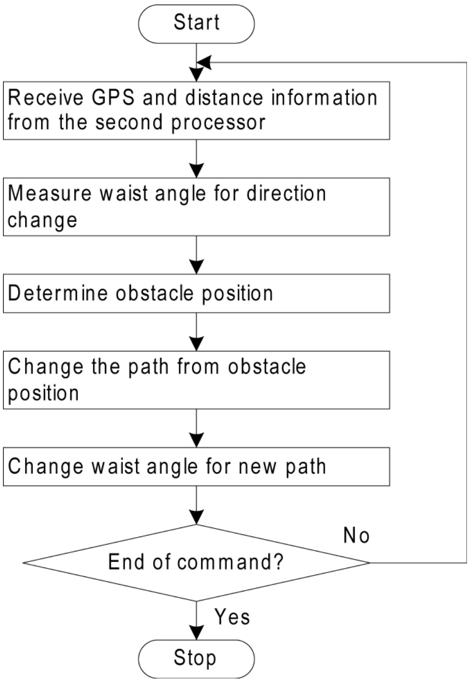
- reading three IR sensors for small range distance
- reading flex angles of its lower body by a potentiometer
- reading roll angles of its body by ADXLs
- reading directional angles by an e-compass
- control of water pumps for propulsion
- control of water pumps for reverse movement
- control of water pumps for direction changes
- control of water pumps for roll control

- ◦ manipulation of interaction: water blow and mouth opening
- ◦ path control in view of position and obstacle data from the second microcontroller
- ◦ collision avoidance when obstacles are found
- ◦ communication with a server

The main routine of the first microcontroller is shown in (Fig. 4) as a flowchart and in (Fig. 5) as a main routine.

The second microcontroller operates three laser rangefinders for medium and long range distance detection. This microcontroller is also connected to a GPS receiver for general position data. The third microcontroller is connected to a USN mote which is installed for communication between pre-installed motes at known locations for exact localization. It is interfaced to a LabPro board which is reserved for water monitoring tasks. The main routine of the second microcontroller is shown in (Fig. 6) as a flowchart and in (Fig. 7) as a main routine.

The dolphin robot makes direction changes by flexing its lower body using water pumps and bellows pipes. The

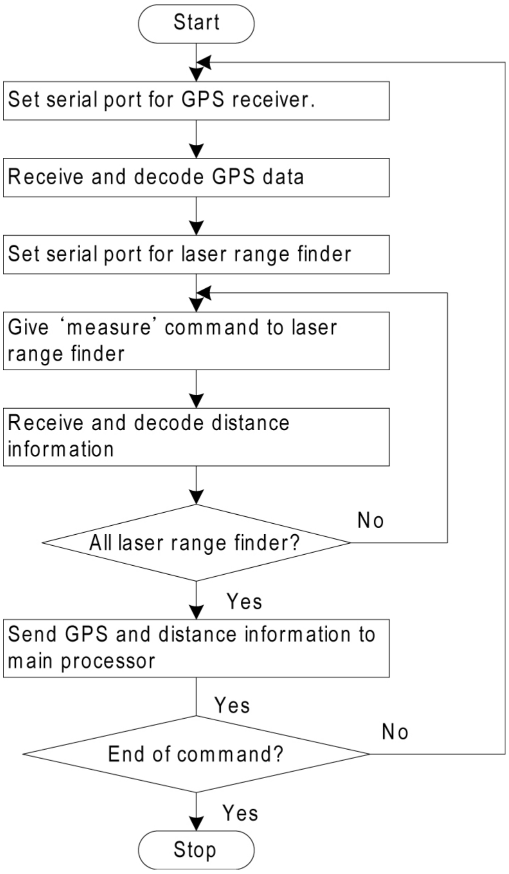


(그림 4) 주 마이크로프로세서의 흐름도
(Fig. 4) Flowchart for main microcontroller

```
Main routine of main microcontroller.
   Make main clock(25Hz) for operation.
   Run this function every 40msec.

   Input W(waist angle) and r(roll angle);
   Input GPS/distance information(0.55msec,1Hz);
   Run path finding routine ;
   If Obstacle is near, then
      Run Change new path.
   Endif
   Run waist angle control routine;
   Run roll angle control routine;
```

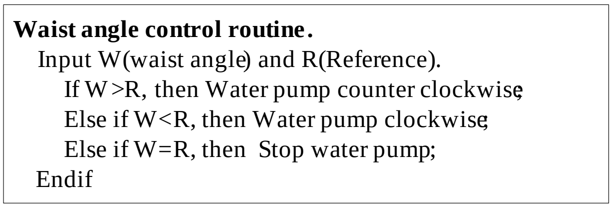
(그림 5) 주 마이크로컨트롤러의 메인 루틴
(Fig. 5) Main routine of the main microcontroller



(그림 6) 두 번째 마이크로컨트롤러의 흐름도
(Fig. 6) Flowchart for second microcontroller

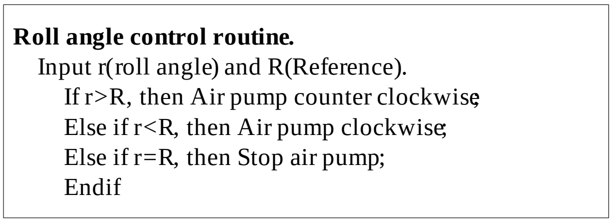
```
Main routine of the second microcontroller.
   Input GPS information GPS receiver.
   Decode GPS information.
   While N<=2
      Send 'g' to #N for measurement;
      Input distance data;
      Decode distance data;
      N++;
   Endwhile
   N=0;
   Send GPS and distance data to main microcontroller.
```

(그림 7) 두 번째 마이크로컨트롤러의 메인 루틴
(Fig. 7) Main routine of the second microcontroller



```
Waist angle control routine.
  Input W(waist angle) and R(Reference).
    If W>R, then Water pump counter clockwise;
    Else if W<R, then Water pump clockwise;
    Else if W=R, then  Stop water pump;
  Endif
```

(그림 8) 허리 각도 제어 루틴
(Fig. 8) Waist angle control routine



```
Roll angle control routine.
  Input r(roll angle) and R(Reference).
    If r>R, then Air pump counter clockwise;
    Else if r<R, then Air pump clockwise;
    Else if r=R, then Stop air pump;
    Endif
```

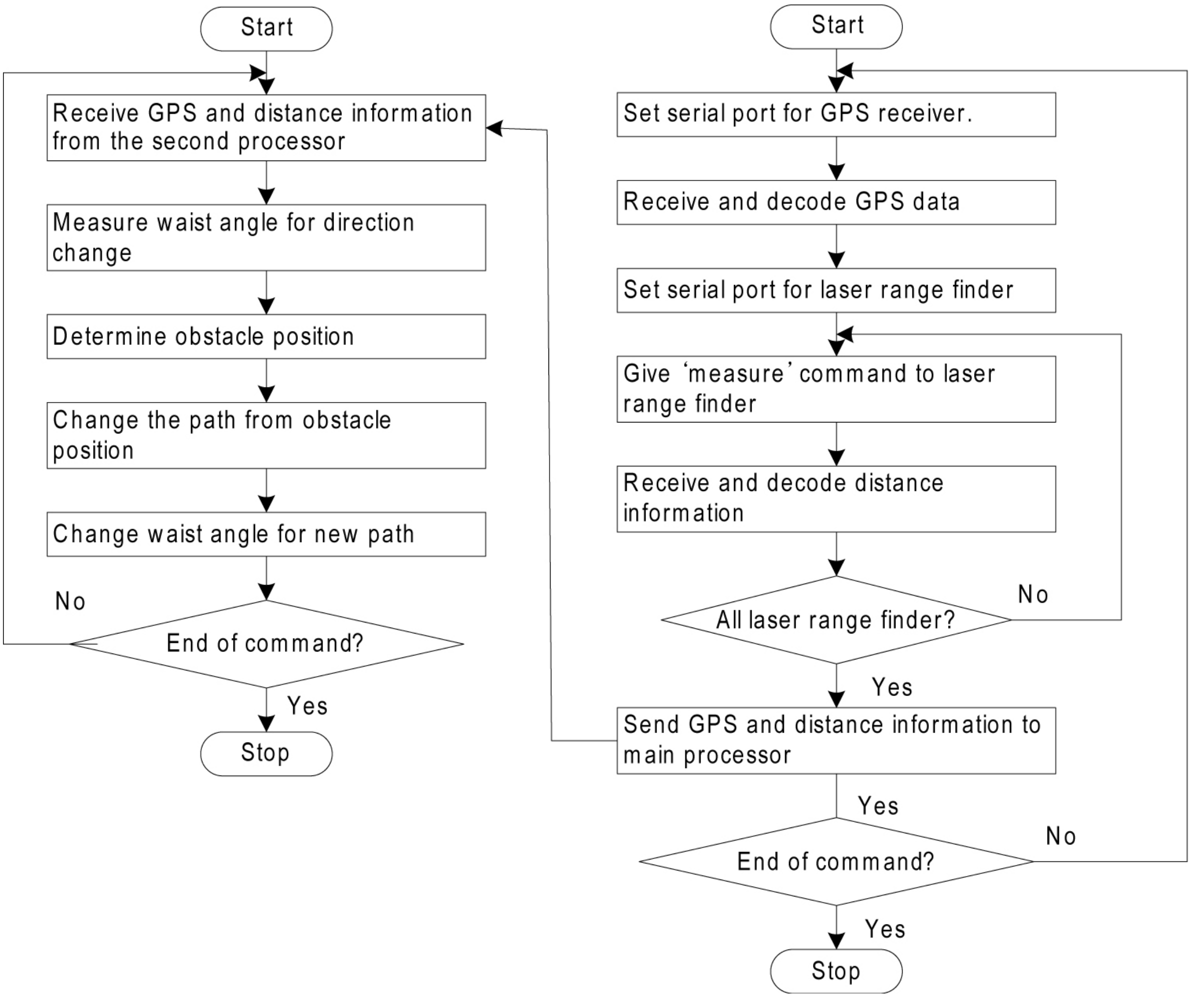
(그림 9) 롤 각도 제어 루틴
(Fig. 9) Roll angle control routine

degree of body flex is measured by a potentiometer. The routine is expressed in (Fig. 8). The roll angle of the robot's body can appear due to out of weight balance when the lower body is flexed. The roll angle can be corrected by producing buoyant force using air bags and an air pump inside of its body. The routine is described in (Fig. 9).

The overall routine of the microcontrollers is shown in (Fig. 10).

The dolphin robot swims trajectories autonomously which are specified by multiple points of interest. Between the two pre-specified points, the robot finds its route using GPS data based on its current position and direction. The routine of following a specified trajectory is expressed in (Fig. 11).

When obstacles are found on its trajectory, it makes a proper detour to avoid collision. When obstacles are not detected any more, then the robot tries to find a new path to return to the previous trajectory. The routine of



(그림 10) 돌고래 로봇의 흐름도
(Fig. 10) Flowchart for dolphin robot system

```
Path finding routine .
  Input start, end and current position SP, EP,CP.
    nSP=SP-SP;
    nEP=EP-SP;
    th=atan(nEP[1]/nEP[0]);
    nEP[0]=EP[0]*cos(th)-EP[1]*sin(th);
    nEP[1]=EP[0]*sin(th)+EP[1]*cos(th);

    pnCP=nCP[1];
    nCP=CP-SP;
    nCP[0]=nCP[0]*cos(th)-nCP[1]*sin(th);
    nCP[1]=nCP[0]*sin(th)+nCP[1]*cos(th);

    dx=nCP[0];
    dy=nCP[1]-pnCP;
    dir=atan(dy/dx)/pi*180;
    If  dx>1.0, then
      If dir>=-5, then dirW=-10;
      Else if dir>=-15 && dir<-5, then  dirW=dir+5;
      Else if dir<-15, then  dirW=0;
      Endif
    Else if  dx>=1.0 && dx<3.0, then
      If dir >=5, then dirW=-10;
      Else if dir >=-5 && dir<5, then  dirW=-(dir+5);
      Else if dir>=-15 && dir<-5, then dirW=0;
      Else if dir<-15, then dirW=(dir+15);
      Endif
    Else if dx>=-1 && dx<1, then
      If dir >=15, then dirW=-10;
      Else if dir >=5 && dir<15, then dirW=-(dir-5);
      Else if dir >=-5 && dir<5, then dirW=0;
      Else if dir >=-15 && dir<-5, then  dirW=-(dir+5);
      Else if dir <-15, then  dirW=+10;
      Endif
    Else if dx>=-3 && dx<-1, then
      If dir >=15, then  dirW=-(dir-15);
      Else if dir >=5 && dir<15, then  dirW=0;
      Else if dir >=-5 && dir<5, then  dirW=(dir+5);
      Else if dir <-5, then  dirW=+10;
      Endif
    Else if dx<-3, then
      If dir >=15, then  dirW=0;
      Else if dir >=5 && dir<15, then
            dirW=(dir-5);
      Else if dir <5, then dirW=10;
      Endif
    Endif
```

(그림 11) 경로 설정 루틴
(Fig. 11) Path finding routine

finding a new path to return is described in (Fig. 12).

```
Change new path routine .
  Input left, forward and right obstacle distance l, f and r;
  If f >m && l>m && r<m, then
     SP[0]=SP[0]-m;
     EP[1]=CP[1]+m;
  Else if f>m && l<m && r>m, then
     SP[0]=SP[0]+m;
     EP[1]=CP[1]+m;
  Else if f>m && l<m && r<m, then
     SP[0]=SP[0]+(r-m)/2;
     EP[1]=CP[1]+m;
  Else if f<m && l>m && r>m, then
     If l>r, then
        SP[0]=SP[0]-r;
        EP[1]=CP[1]+m;
     Else if l<r, then
        SP[0]=SP[0]+l;
        EP[1]=CP[1]+m;
     Else
        SP[0]=EP[0]-r;
        EP[1]=CP[1]+m;
     Endif
  Else if f<m && l>m && r<m, then
     SP[0]=SP[0]-r;
     EP[1]=CP[1]+m;
  Else if f<m && l<m && r>m, then
     SP[0]=SP[0]+l;
     EP[1]=CP[1]+m;
  Else if f<m && l<m && r<m, then
     Swim Backward;
  Else if f>m && l>m && r>m, then
     Swim Forward;
  Endif

  If (EP[1]-CP[1])<m/2), then
     Return Previous Path.
  Endif
```

(그림 12) 새로운 경로 변화 루틴
(Fig. 12) Change new path routine

The current position of the robot can be monitored ubiquitously using USN motes. A peak infrared signal is detected by a BS520 sensor on a USN mote. This sensor is connected to one ADC channel of Atmega processor of a mote. The measured infrared data and the ID serial data of the sensor mote are broadcast to the base mote which is connected to a server. Thus it is possible to monitor the robot's position and to change the pre-determined trajectory.

4. Conclusions

An autonomous entertainment dolphin robot system based on ubiquitous sensor networks(USN) is proposed with emphasis on user interaction. Navigation of the underwater robot in a given area is based on GPS data and the acquired position information from deployed USN motes. Body structures, sensors and actuators, governing microcontroller boards, and swimming and interaction features are described for a typical entertainment dolphin robot. Dolphin robots should turn towards people who demand to interact with them, while swimming autonomously. The functions that are relevant to human-robot interaction as well as robot movement such as path control, obstacle detection and avoidance are managed by microcontrollers on the robot for autonomy. Distance errors are calibrated periodically by the known position data of the deployed USN motes.

5. Acknowledgment

This work was supported by the Second BK21, CNU and the NURI-CEIA, CNU.

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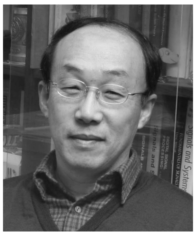

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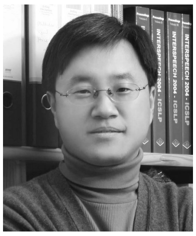

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