Development of a Pet Robot Chasing a Moving Person in Outdoor Environment

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In a park or street, we can see many people jogging or walking with their dogs that are chasing their masters. In this study, a pet robot that imitates dog's behavior is developed. The task of robot is to chase a person who is recognized as the master. The physical structure and the sensor system are designed for the task and environment. A three-wheel type locomotion system is designed as the robot's physical structure which can follow a person who is jogging in outdoor environment like a park. A sensor system, which can detect relative position of the master to the robot in highly dynamic and hazardous worlds, is developed. This sensor system consists of a signal transmitter which is held by the master and ultrasonic sensor array which are mounted on the robot. The transmitter emits RF (radio frequency) and ultrasonic signals simultaneously. The ultrasonic sensor array detects the signals and calculates direction and distance between the robot and the transmitter. The developed RF-ultrasonic sensor is evaluated through experiments. A purely reactive behavior-based control architecture is used for the robot. The behavior control performance of the robot is assessed in outdoor and indoor tests.

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1. Introduction

Contents In this paper a pet robot "CARTRI" is introduced. CARTRI robot is able to chase a person who is walking or jogging in outdoor environments such as a park. Recently, many kinds of pet robots and entertainment robots have been developed[1,2]. However, most of them are restricted to indoor environments and their working range is as small as room size. Comparing with other robots, the task of CARTRI robot demands very dynamic motion in somewhat hazardous outdoor environment. The key issue in development of such a robot is the need for an appropriate sensor system which is effective in detecting a particular person's movement.

There are some related research efforts to develop target chasing sensor system using vision sensors and ultrasonic sensors. But they are restricted to indoor operation or relatively low speed and can not assure reliable performance in the hazardous outdoor environment[3,4,5]. Most vision sensor systems are expensive, vulnerable to the change of lighting, and the sampling frequency is too slow to do the task of the CARTRI robot. The ultrasonic sensor system works well in outdoor and indoor environment, but the reflection type ultrasonic sensor systems for usual mobile robots can not distinguish the master from other obstacles. CARTRI robot needs a sensor system which can detect the position of the master reliably in outdoor and indoor environments with enough sampling frequency to catch up the fast movement of the master.

In this study an RF-ultrasonic sensor system suitable for the task of CARTRI has been developed. It is composed of sensors mounted on the robot head and a signal transmitter gripped by a person who is recognized as the master. The physical structure of the robot is constructed so that the robot could traverse outdoor terrain and move fast enough for the proposed behavior. By combining the physical structure with the sensor system CARTRI robot is created. The performance characteristics of the developed RF-ultrasonic sensor system is evaluated through experimental test. The performance of target chasing behavior of CARTRI is evaluated by experiments in outdoor and indoor environments.

2. Physical Structure of the Robot

The proposed robot must be able to detect and chase a target in outdoor environment. Considering fast walking the maximum speed of a human may be at least 6 km/h. The physical structure of CARTRI is designed to satisfy such requirements demanded for its proposed behavior.

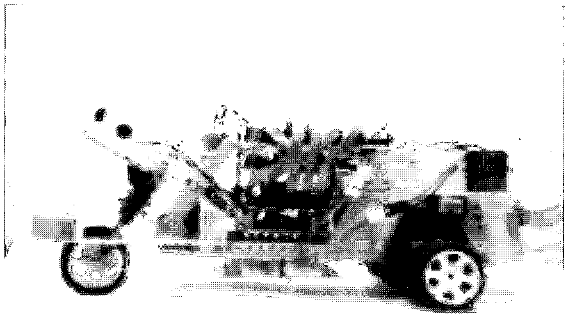

Fig. 1 Appearance of CARTRI

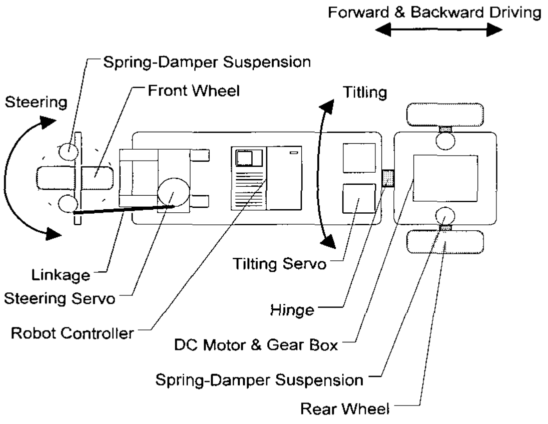

Fig. 2 Physical structure of the robot

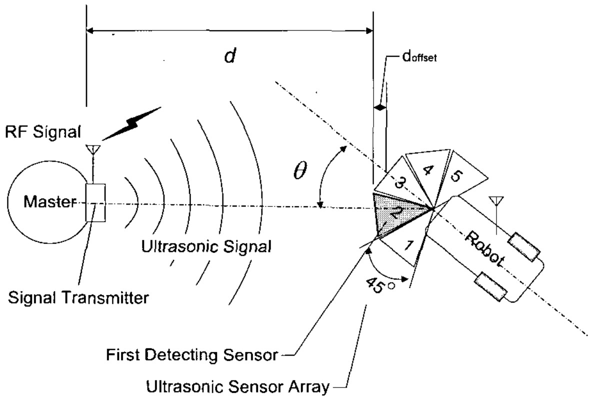

Fig. 3 Structure of the sensor system

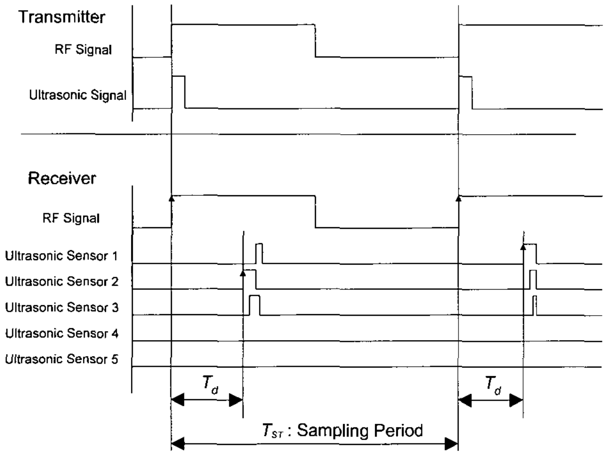

Fig. 4 Timing of RF and ultrasonic signals

Fig. 1 shows the appearance of CARTRI. Fig. 2 shows the physical structure of the robot. It is three-wheel type locomotion system which has 3 DOF: steering, driving and tilting. Steering part uses a servo motor (HS-705MG, HITEC RCD, Inc.) and a potentiometer is attached on the steering axis to detect steering angle. Tilting part uses two servo motors, HS-605MG(HITEC RCD, Inc.). DC motor (RS-540, MABUCHI MOTOR, co.) and an incremental rotary encoder are used to drive and detect driving speed. The specifications of the physical structure of the robot are listed in Table 1.

Table 1 Specifications of CARTRI

Maximum speed	10 km/h
Acceleration time from 0 to 4 km/h	0.5 sec
Deceleration time from 4 to 0 km/h	0.5 sec
Weight	3.4 kg
Length	57 cm
Width	18 cm
Height	21 cm
Steering range	±45°
Tilting range	±30°
Minimum radius of turning	40 cm

The maximum speed of the robot is 10 km/h and minimum turning radius is 0.4 m. Acceleration time from 0 to 4 km/h and deceleration time from 4 to 0 km/h is 0.5 seconds. Considering the maximum walking speed of human these specifications are supposed to be sufficient to achieve the aim of the robot. The locomotion system is designed with shock absorbing devices and can traverse outdoor terrain such as a park.

3. RF-ultrasonic Sensor System

3.1 Concept of the sensor system

For outdoor target chasing behavior of the proposed robot, an appropriate sensor system must be designed. The sensor system is designed to satisfy several requirements as the followings.

- Non-contact distance measuring
- Capability to recognize the master
- Broad area detection
- Reliability in outdoor application
- Relatively small size and simple structure
- Low-cost
- Need not high resolution

Considering these requirements, ultrasonic sensor is the most possible solution. However usual applications of ultrasonic sensor for mobile robots are the reflection type. The reflection type, sensor transmits ultrasonic signal and receives the signal reflecting from an object to recognize the object[6,7]. However, this type of ultrasonic sensor can not recognize the master reliably. Thus, the opposed type of ultrasonic sensor is chosen. The sensor system is composed of ultrasonic transmitters attached the target and receivers mounted on the robot. By using this type, the robot can detect the master reliably because the target itself transmits ultrasonic signal. When using this opposed type, the receiver and the transmitter must be synchronized using a signal because the receiver must know the time when the transmitter sends ultrasonic signal. The time data is the key parameter to calculate the distance between the transmitter and the receiver.

In this research, by using RF wireless signal for synchronization, an RF-ultrasonic sensor system which can meet all requirements is developed. Fig. 3 shows the concept of the sensor system. The ultrasonic transmitter and receiver are the MA40B8S and MA40B8R (MURATA MANUFACTURING Co.). The RF transmitter and receiver module are TX2-433-160-5V and RX2-433-160-5v (RADIO METRIX Ltd.). The transmitter emits RF signal for synchronization and ultrasonic signal. The five-ultrasonic sensor array is mounted on the robot's steering wheel. In the five sensors, the sensor which receives the signal first indicates the direction of the transmitter. In Fig. 3, the transmitter is located at the direction of sensor 2 of the five-sensor array, therefore sensor 2 receives the ultrasonic signal first. Fig. 4 shows the timing chart of the signals which describes overall signal processing on the time domain. T_{ST} is the sampling period of the sensor system. Considering the dis-

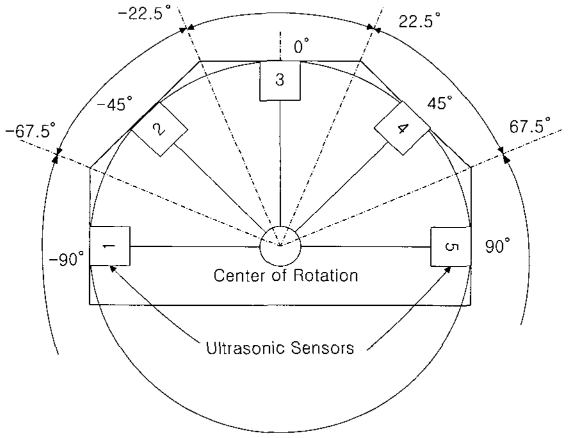

Fig. 5 Design of five-sensor array

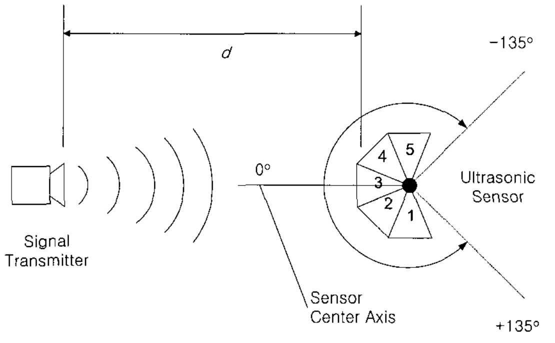

Fig. 6 Sensor performance test method

sipation rate of ultrasonic signal it is set as 40 ms in this system. At rising edge of the RF synchronization signal the transmitter emits ultrasonic signal. By checking the rising edge of the RF signal the sensor system knows the time when the transmitter sends ultrasonic signal. When using the opposed type of ultrasonic sensor, the distance data *d* is calculated by

$$d = v_s T_d \qquad (v_s = 340\ m/s) \qquad (1)$$

where the period T_d, shown in Fig. 4, is the time lag between the transmission and the first receipt of the signal and v_s is the speed of sound in the air of the normal temperature.

Fig. 5 shows the design of the sensor housing. Because of the circular shape of the housing, the sensor nearest to the direction of the master is closest to the transmitter and receives the ultrasonic signal first. The graph of Fig. 4 shows two sampling periods. In the first period, the sensor 2 receives the signal first. The neighboring sensors detect the signal a little later. Sensor 4 and 5 do not detect the signal because their directions are different to the transmitter. In the second period, sensor 1 receives the signal first. The sensor number which catches the signal first determines the direction data according to Fig. 5. When the sensor 2 receives the signal first, the master is located between the direction of -67.5° and -22.5°. When the sensor 3 receives first, the master is located between -22.5° and 22.5°. As the five-sensor array is mounted on the steering wheel, the direction data are expressed by the addition of the steering angle and the nominal angle of the sensor which receives the signal first. In the case of Fig. 3, sensor 2 detects the signal first and steering angle is 0°, then the robot recognizes that the master is located at -45° by the addition of the nominal angle of sensor 2 and steering angle at that moment.

3.2 Performance test of the sensor system

The performance of the developed RF-ultrasonic sensor system is evaluated by experiments. The performance test of the sensor system is carried out to show how well it detects the position of the target which is the signal transmitter. Fig. 6 shows the experiment method of performance test. The signal transmitter is fixed at a distance *d* from the sensor system. The sensor housing is mounted on a stepping motor with 0.9° step intervals and the velocity of step/100ms. At each step angle, the direction and the distance data are acquired. The motor rotates from -135° to 135°. After the stepping motor turns 100 rotations, the data are processed to find the detection probability of each sensor at each angle of the transmitter. The detection probability shows the rate at which the sensor detects the transmitter within distance error of ±0.1m. Fig. 7 shows the result of the performance test when *d* is 1.0m. The direction axis of Fig. 7 means the angle where the transmitter is located. The sensor 2 detects the transmitter at 100% when it is located between -60° and -25°. The result shows that the sensor system works well as the intention of the design shown in Fig. 5.

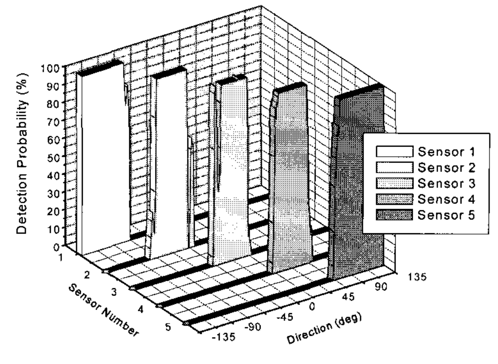

Fig. 7 Sensor performance when *d* = 1.0m

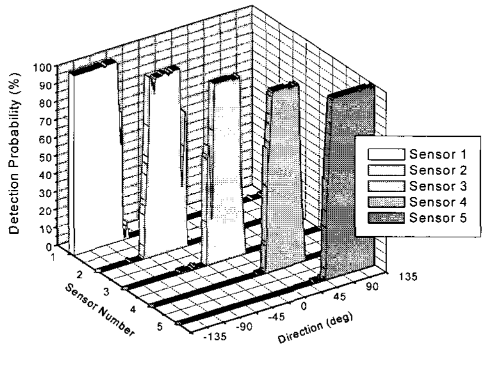

Fig. 8 Sensor performance when *d* = 3.0m

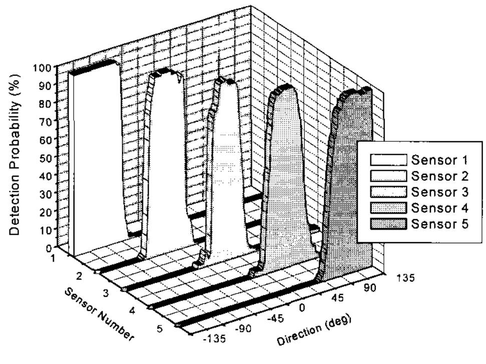

Fig. 9 Sensor performance when *d* = 6.0m

Fig. 8 shows the result of the test when *d* is 3.0m. Fig. 9 shows that

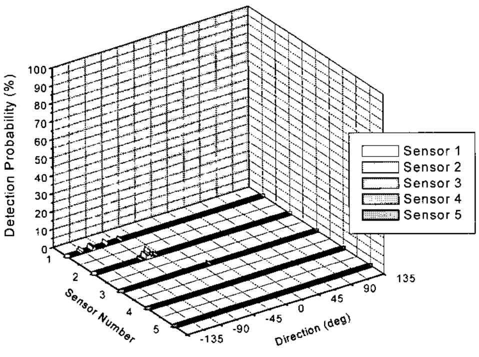

Fig. 10 Sensor performance when $d = 7.0\text{m}$

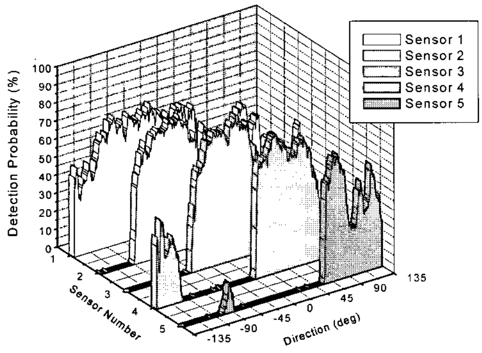

Fig. 11 Sensor performance when RF noise exists

of 6.0m and Fig. 10 shows that of 7.0m. The results show very similar graphs until d is 3.0m and it means that each sensor detects the transmitter in its direction range at almost 100%. Until d is 6.0m, the sensor system works well, although the detection rate at the boundary area between two neighbour sensors becomes somewhat lower. When d is 7.0m, the sensor system hardly detects the transmitter as shown in Fig. 10. The experimental results show that the developed sensor system is able to detect the position of the transmitter within 6.0m.

The RF-ultrasonic sensor system is naturally vulnerable to RF noise because RF signal plays the essential role of synchronization. Fig. 11 shows the result of the test which is affected by RF noise made by other devices when d is 1.0m. Comparing with Fig. 7, Fig. 11 shows that the performance degenerates with respect to both direction and distance detection. Thus, if there are some other RF devices operating nearby, the sensor system may not work well.

4. Control Architecture

4.1 Purely reactive control[8,9,10]

CARTRI chases a person moving in outdoor environment, which imitates a dog following its master. For such behavior, the robot should move in highly dynamic and hazardous worlds, where the path of the robot is unpredictable. Therefore, a purely reactive behavior-based method is used as the control architecture of the robot.

Purely reactive robotic system is derived from a pragmatic view that a behavior, simply put, is a reaction to a stimulus. A behavior in these systems typically consists of a simple sensorimotor pair, with the sensory activity providing the necessary information to satisfy the applicability of a particular low-level motor reflex response. Purely reactive systems react directly to the world as it is sensed without intervention of a complex reasoning that predicts the outcome of the actions of the robot on the basis of representational knowledge about the world. This is of particular value in highly dynamic and hazardous worlds, where unpredictability and potential hostility are inherent.

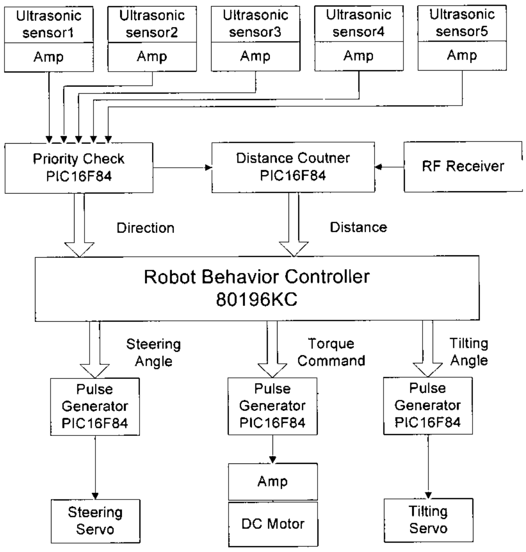

Fig. 12 Structure of the robot controller

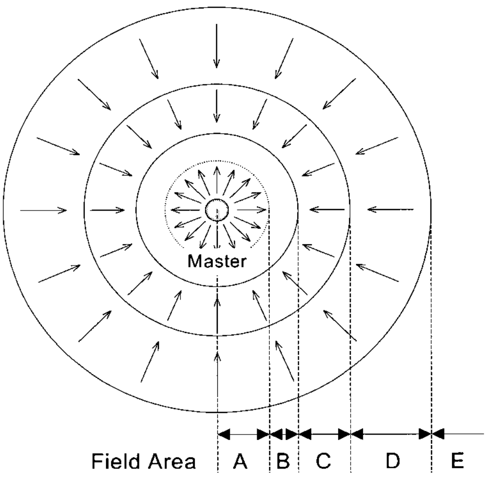

Fig. 13 Behavior pattern at each field area

4.2 Control architecture of the robot

Fig. 12 shows the structure of the robot controller. The perception consists of direction and distance information from the sensor system. The actuators used in the chasing behavior are steering servo motor and driving DC motor. The movement of the master becomes the stimulus to which the robot reacts. Fig. 13 shows the reaction behavior pattern of the robot. Direction of the arrow of Fig. 13 means direction of the robot's movement and length of the arrow means driving strength. The field is divided into five areas according to distance between the master and the robot. In area A, the robot moves back from the master to avoid collision to the master. Area B means the safety zone and the robot stops in this area. In area C, the robot moves toward the master. In area D, the robot moves toward the master with its full strength. Area E means that the robot misses the master, thus it does not move until it detects the signal of the master again.

The control architecture of purely reactive robot system is very simple and instinctive, but, it requires a well-designed sensor system which provide sufficient information for action. The developed RF-ultrasonic sensor system and physical structure fully satisfy this condition. The distance information of sensor system is directly coupled to driving actuator as a sensorimotor pair and the direction information is coupled to steering actuator. Fig. 14 shows the control architecture of CARTRI.

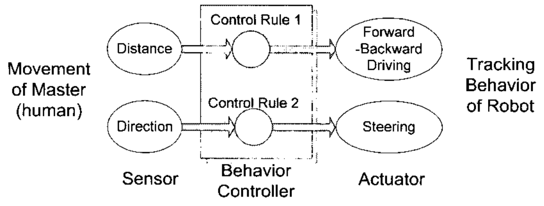

Fig. 14 Robot architecture

Table 2 Control rule 1 for strength

Area	A	B	C	D	E
Distance (m)	0 ~ 0.6	0.6 ~ 1	1 ~ 2.5	2.5 ~	N
Strength (%)	60	0	80	100	0

Table 3 Control rule 2 for orientation

Sensor	No.1	No.2	No.3	No.4	No.5
Angle	90°	45°	0°	-45°	-90°
45°	45°	45°	45°	22.5°	0°
22.5°	45°	45°	22.5°	0°	-22.5°
0°	45°	22.5°	0°	-22.5°	-45°
-22.5°	22.5°	0°	-22.5°	-45°	-45°
-45°	0°	-22.5°	-45°	-45°	-45°

Distance data is coupled to driving action by the control rule 1, and direction data is coupled to steering action by the control rule 2. Table 2 shows the control rule 1 that determines the current input of driving motor. The notation N of the area E means that the sensor system does not detect the master. The value of driving strength in each area is chosen to make the behavior described in Fig. 13. Table 3 shows the control rule 2 that determines angle of steering servo motor. The rule 2 is designed so that the robot would be heading for the master always. The row part of Table 3 means sensor number which detects the master and the nominal angle of the sensor. The column part of Table 3 means current steering angle of the robot. In order to simplify the control rule, the steering angle is restricted to five value, -45°(maximum left), -22.5°(middle left), 0°(center), 22.5°(middle right) and 45°(maximum right). Because the five-sensor array is mounted on the steering wheel the steering angle command for the steering servo motor is determined by nominal angle of the sensor which detects the master and current steering angle. According to the control rule of Table 3, when sensor 1, whose nominal angle is 90°, detects the master and the steering angle at that moment is -22.5°, the steering command becomes 22.5°. When sensor 3 detects the master and the steering angle at that moment is -22.5°, the steering command becomes -22.5°.

5. Experiments

The target chasing behavior of the robot is verified through experiments in outdoor and indoor environment. Fig. 15 shows the scene of an indoor experiment. The master is walking along the line which is drawn on the ground and the robot is following master. Fig. 16 shows an outdoor experiment. The robot is following the master walking in a park. Fig. 17 shows the estimated robot's position relative to master's position when the robot follows the master walking along straight line on average speed of 3 km/h, in indoor environment. The origin of the polar coordinates means the master and the triangular marks means the robot. The forward direction of the master movement is set as 0° in the graph. When the robot is following the master, it is behind and heading for him or her. Assuming the robot is always heading for the master, the steering angle of the robot could be the angle of robot's position on the polar coordinates. Using the distance data of the sensor system and the steering angle of the robot, the estimated robot position is plotted

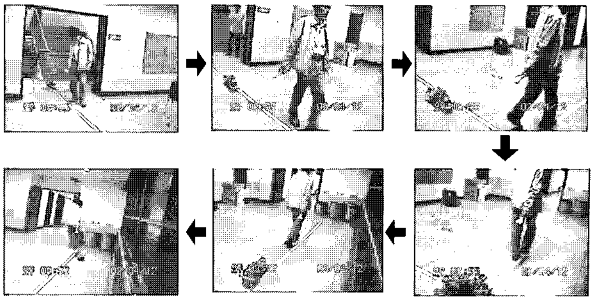

Fig. 15 Indoor chasing experiment

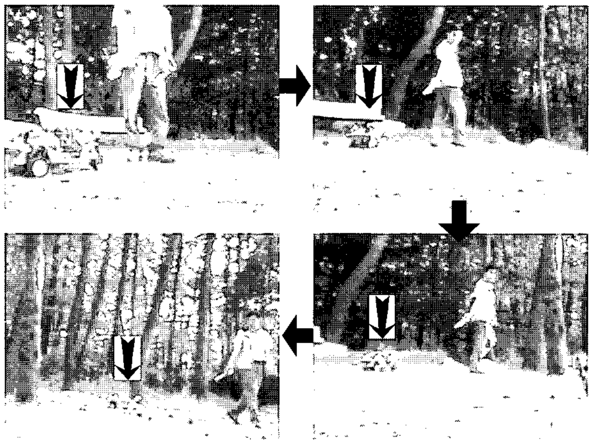

Fig. 16 Outdoor chasing experiment

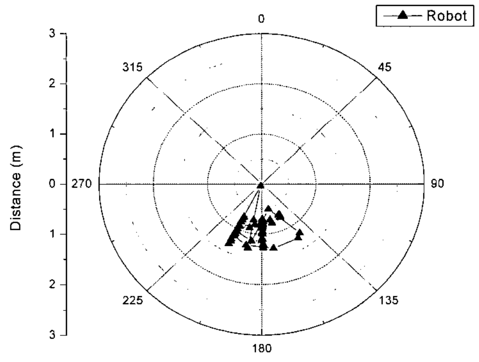

Fig. 17 Indoor chasing behavior at 3.5 km/h

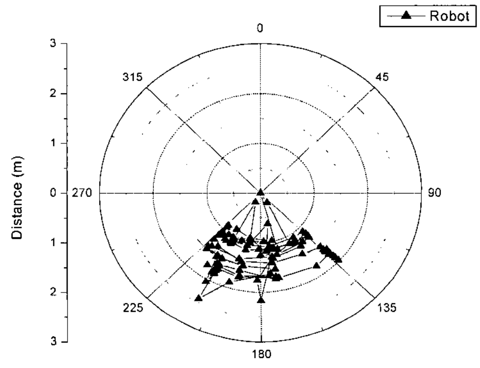

Fig. 18 Outdoor chasing behavior at 4 km/h

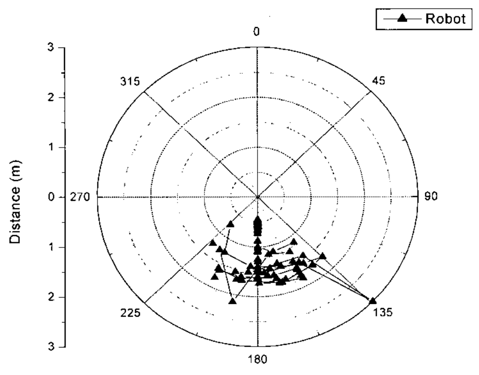

Fig. 19 Indoor chasing behavior at 6.5 km/h

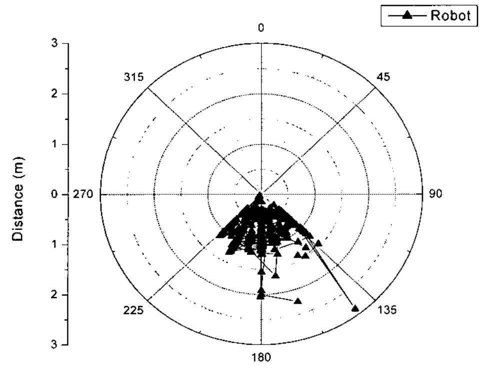

Fig. 20 Indoor zigzag behavior

around 180° axis of polar coordinates. This figure may show the characteristics of the chasing behavior. Fig. 17 shows that the robot is chasing its target steadily around distance of 1 m.

Fig. 18 shows the outdoor behavior when the master walks along straight line on average speed of 4 km/h. The outdoor chasing behavior is more rough than the indoor chasing of Fig. 17. Because outdoor ground is covered with soil, tiny stones, leaves, etc., the robot slips and is disturbed by small obstacles sometimes. Thus the steering angle changes more roughly and the range of distance variation is wider than that of indoor operation.

Fig. 19 shows the chasing behavior when the master walks along the line shown in Fig. 17 on average speed of 6.5 km/h. When the movement is fast, the average distance is longer than slow walking. Fig. 20 shows the chasing behavior when the master arbitrarily zigzags in indoor environment. The robot remains around the safety zone and follows the master well.

When the master moves very fast, the chase would fail because he is out of the detection range of the sensor system before the robot catches him. If walking speed is higher than 6 km/h, there is high probability that the chasing behavior fails in both outdoor and indoor environment. In outdoor environment, the condition of the ground affects the performance of the chasing behavior.

6. Conclusion

In this study, a pet robot, CARTRI, which could chase a person moving in outdoor and indoor environment was developed. For implementation of such robot, an RF-ultrasonic sensor system that could detect the position of the target was developed.

The performance tests proved that the developed RF-ultrasonic sensor system could detect its target reliably within the distance of 6 m. The performance of the robot was evaluated through outdoor and indoor experiments in which the robot chased the master who was walking at various speed and paths. CARTRI could chase the master well when the average speed was lower than 6 km/h in both outdoor and indoor experiments.

Future work is to provide the robot with more intelligence and advanced sensor system in order to deal with various situations like losing its master and avoiding collision with an obstacle.

ACKNOWLEDGEMENT

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