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Research on the Real Time Obstacle Avoidance Control Technology of Biologically Inspired Hexapod Robot

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***Abstract* - In order to meet the demand of the biologically inspired hexapod robot's task and its working environment, this paper proposes the distribution of the compound sensing system based on multiple infrared sensors and ultrasonic sensors, which enlarges the robot's sensing range and eliminates the interference. The authors use the fuzzy control obstacle avoidance strategy, which overcomes the disadvantage that the unstructured environment is difficult to model and improves the system's robustness. The hardware test experiments results show that the designed sensing and control system can meet the real time demand. Using the Mobotsim software, the authors finished the simulation experiment. The experiment results show that this obstacle avoidance control method has perfect real-time performance, robustness and flexibility, not only to the immovable obstacles but also to the movable obstacles, which establishes the foundation to realize the biologically inspired hexapod robot's intelligent control.**

Index Terms - biologically inspired hexapod robot, sensing and control system, fuzzy logic control, obstacle avoidance.

I. INTRODUCTION

Insects, in general, are agile creatures capable of navigating uneven and difficult terrain with ease. They perform strong adaptability to the nature. Therefore, engineering problems can be solved using biologically inspiration in varying degrees. Biologically inspired legged robots have the ability to move over uneven and discontinuous terrain with more agility than wheeled or tracked vehicles. Many of the applications, such as surveillance, search and rescue and off-world exploration, have been suggested for biologically inspired legged robots. Enlightened by that, many researchers concentrate on the study of biologically inspired legged robots.

Within the legged robot community, only robots with at least three degrees-of-freedom per leg are capable of moving in three dimensions. Bipeds, quadrupeds, hexapods and octopods are all potentially able to perform the required movements. However, bipeds and quadrupeds are less stable. Six-legged and eight-legged robots are naturally stable, even while in motion; but additional two legs of octopods are considered redundant.

Biologically inspired legged robots usually work under the complex unstructured environment, the qualities of robot's sensing and control system such as reliability, real-time performance and robustness should be improved. Furthermore, the unstructured environment can not be modeled easily; therefore, traditional robot obstacle avoidance technology based on environment models will not be used on the biologically inspired legged robots.

This paper mainly discusses the real time obstacle avoidance control technology of the biologically inspired hexapod robot. The rest of the paper is organized as follows: In section II, we start by introducing the biologically inspired hexapod robot. The design and developing of biologically inspired hexapod robot's sensing and control system is presented in section Ⅲ.Section Ⅳ focuses on the biologically inspired hexapod robot's obstacle avoidance control strategy. Experiment results and analysis are shown in section Ⅴ.Finally section Ⅵ proposes the conclusions and future work.

II. BIOLOGICALLY INSPIRED HEXAPOD ROBOT

Based on the observation and measurement for the walking insects in nature, considering of the factors such as locomotion demand, carrying ability and integration, we designed a new type of the biologically inspired hexapod robot, which integrates bionic technology, mechanism design technology, intelligent control technology, sensing technology and signal processing technology. The biologically inspired hexapod robot can be seen from Fig.2.The robot's legs are distributed symmetrically and each leg has three rotational joints, which can realize swing, pitching and flexing respectively. There is one Maxon BLDCM(Brushless DC Motor) in each joint. The foot tip can move freely in the reachable area through corresponding motors' running. Therefore the structure ensures that biologically inspired hexapod robot has strong flexibility and adaptability. Furthermore, this robot is equipped with sensors and GPS/INS devices, through which obstacle avoidance and orientation can be realized under the unstructured environment.

Ⅲ. BIOLOGICALLY INSPIRED HEXAPOD ROBOT'S SENSING AND CONTROL SYSTEM

The ultrasonic sensor has the advantages such as low price and strong anti-interference performance; therefore it is widely used in robot measurement, orientation and environment modeling. However, its angle resolution is low and there exists bind area. While the infrared sensor has the complementary characters, whose angle resolution is high and sensing area can cover the ultrasonic sensor's bind area. In addition, some objects such as the slight fabric which can not detected ultrasonic sensors can easily be detected by infrared sensors while some objects such as the black plastic which don't reflect infrared can reflect ultrasonic well. Based on what we discussed above, we choose the compound sensing system based on multiple infrared sensors and ultrasonic sensors for the biologically inspired hexapod robot to sense the surroundings. Through analysis and comparison, we use PEPPERL Company's UB300 ultrasonic sensors and OBT500 infrared sensors, which have the advantages of high precision, low power consumption and small volume.

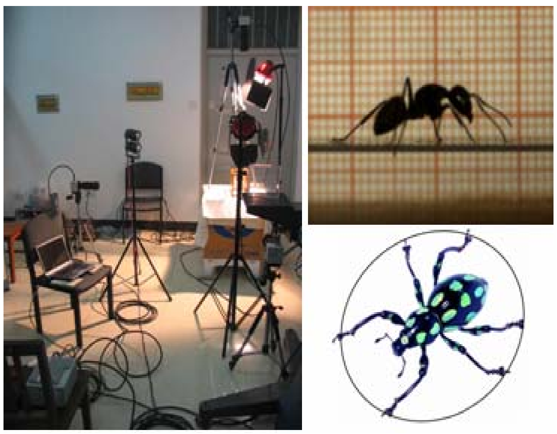


Fig. 1 Hexapods observation experiment

Fig. 2 Biologically inspired hexapod robot

The distribution of sensors will directly influence the robot's sensing performance. A good arrangement can enlarge the robot's detecting area and decrease the blind area. According to the performances of chosen sensors and the biologically inspired hexapod robot's structure characteristic, through experiment and analysis, we work out the compound sensing system distribution based on multiple infrared sensors and ultrasonic sensors, shown from Fig.3. Five Ultrasonic sensors are equably and symmetrically fixed on the biologically inspired hexapod robot's head, whose radius is 35cm.One infrared sensor is fixed on the two neighboring ultrasonic sensors' midpoint. This distribution can decrease the blind area to the minimum and eliminate interference of the sensors effectively.

The TMS320VC5509A fixed-point digital signal processor (DSP) is based on the TMS320C55x DSP generation CPU processor core. The C55x™ DSP architecture achieves high performance and low power through increased parallelism and total focuses on reduction in power dissipation. Therefore, we use TMS320VC5509A DSP as the biologically inspired hexapod's signal processing core, whose Instruction Cycle Time is 5 ns while power consumption is 1.2V.

When the biologically inspired hexapod robot starts to walk, the compound sensing system based on multiple infrared sensors and ultrasonic sensors begins to work synchronously. A Data Acquisition Card is used to gather the distance information acquired by sensing system and conduct A\D Conversion. After A\D Conversion, the digital data is sent to the assistant CPU TMS320VC5509A DSP for disposal. The corresponding obstacle avoiding strategy is formed there too. Last, the obstacle avoidance strategy is transmitted to the main CPU ARM946E-S through CAN bus.Fig.4 shows the flow.

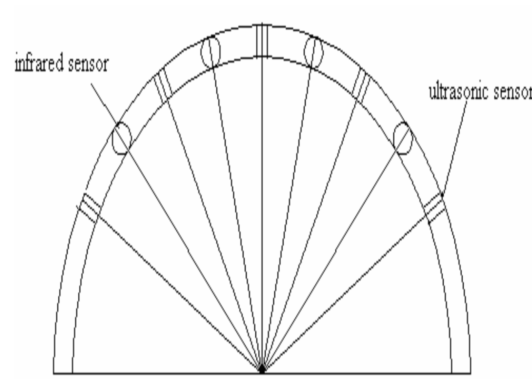


Fig. 3 Arrangement of multiple infrared sensors and ultrasonic sensors

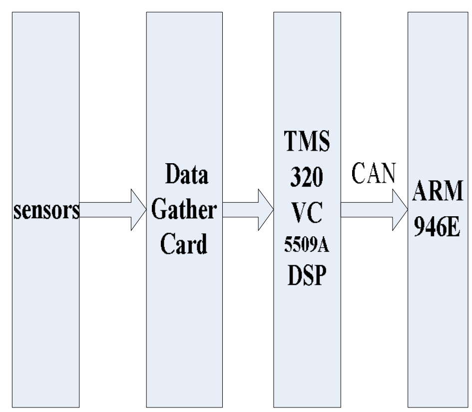


Fig. 4 Hardware of biologically inspired hexapod robot sensing and control system

Ⅳ. Obstacle Avoidance Control Strategy of Biologically Inspired Hexapod Robot

The biologically inspired hexapod robot usually works in the rough terrain, there are some uncertain parameters in the environment model. Traditional obstacle avoiding control strategies need precise environment model, therefore they cannot be used as biologically inspired hexapod robot's obstacle avoidance control strategies under the unstructured environment. The fuzzy logic control strategy based on the human expertise is an intelligent control method, which doesn't need to build up the precise object model. It has the advantages such as strong robustness and flexibility, furthermore the fuzzy controller is easy to design and realize.

For the fuzzy logic control strategy, the inputs and the outputs should be considered. We divide these sensors into five groups. Take the front ultrasonic sensor as one group solely. For the rest, we divide the neighboring ultrasonic sensor and the infrared sensor into one group. The distance information sensed by the five group sensors is used as the input, therefore we have five inputs. The hexapod walking bio-robot's walking direction is defined as output. The robot's fuzzy controller design includes Fuzzification, Rule Evaluation, Aggregation and Defuzzification.

A. Fuzzy Language of Inputs and Outputs

Suppose Si（i=1,2,3,4,5）is the input obstacle's distance information, according to the sensors' performance, we can get the input variable's Membership Function, as can be seen from Fig.5. In which, the distance variable's fuzzy language is: Near and Far. And the input fuzzy variable's range is(0，1.5m）.

Suppose θ is the hexapod walking bio-robot's turning angle, whose range is〔-60°,60°〕.

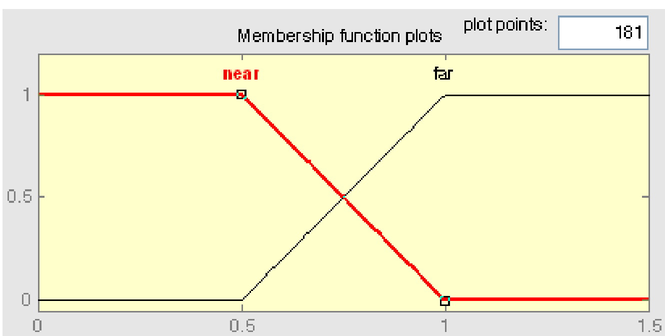


Fig. 5 The input variable's membership function

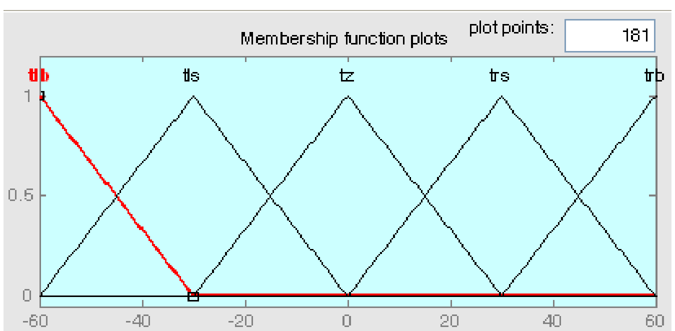


Fig. 6 The output variable's membership function

The negative stands for turning left while the positive means turning right. θ's fuzzy language is:

tlb (turn left with a large angle), tls(turn left with a small angle), tz(go forward),trs(turn right with a small angle) and trb(turn right with a big angle), whose Membership Function can be seen from Fig.6.

B. Rule Evaluation

The whole fuzzy control system has five inputs and one output. We use Mamdami model as the fuzzy controller, the fuzzy control rules can be established as following:

Rj: IF S1 is A1 AND S2 is A2 AND S3 is A3 AND S4 is A4 AND S5 is A5 THEN Θ is A6

The biologically inspired hexapod robot fuzzy control rules are established based on the following principles:

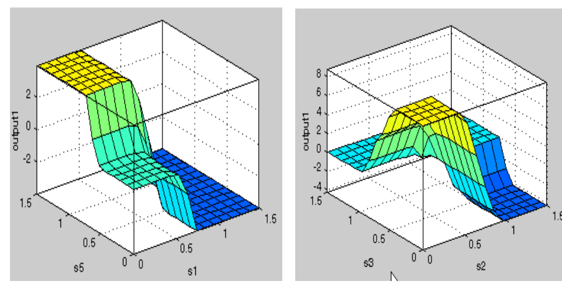
(1)If two or more than two obstacles appear in the same area, we only consider the nearest one.

(2) The hexapod walking bio-robot should turn to area where there are no obstacles.

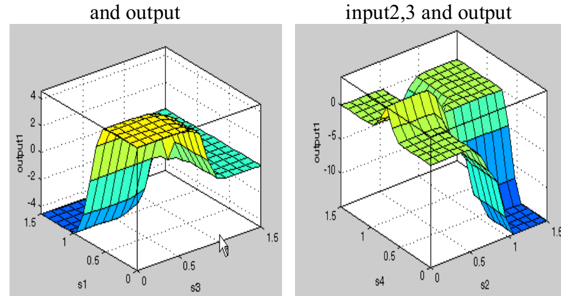
(3) Under the precondition that the obstacles should be avoided, the robot's turning angle should be the smallest.

(4) If the obstacles are sensed existing all the directions and the distance is near, biologically inspired hexapod robot should stop.

According to the principles talked above, we can establish 32 fuzzy control rules. We put them into the data library for inquiring and transferring during obstacle avoidance control process. The fuzzy control rules show the mapping relationship between the input distance information and the output, which is the reaction control in essential. Therefore it can be used in the dynamic changing unstructured environment as well.



(a) the relationship between input1,5 and output (b) the relationship between input2,3 and output



(c) the relationship between input1,3 and output (d) the relationship between input2,4and output

Fig. 7 The relationship between inputs and outputs after fuzzy reasoning

C. Aggregation and Defuzzification

Through comparison and experiment, this paper uses MN-MAX Aggregation method and Barycenter Defuzzification method. With MATLAB simulation software, we can get the relationship between inputs and outputs after fuzzy reasoning, as can be seen from Fig.7. From the figure we can see that the curved surfaces are smooth and consecutive without abrupt change, which shows the control strategy has good robust performance.

V. EXPERIMENT RESULTS AND ANALYSIS

A. Hardware Performance Test Experiment

Fig.8 shows the hardware of biologically inspired hexapod robot's sensing and control system. Hardware performance test experiment results show that the signal can be gathered and processed in 191.7ms. Compared to the biologically inspired hexapod robot's speed (0.2m/s), it can meet the real time demand.

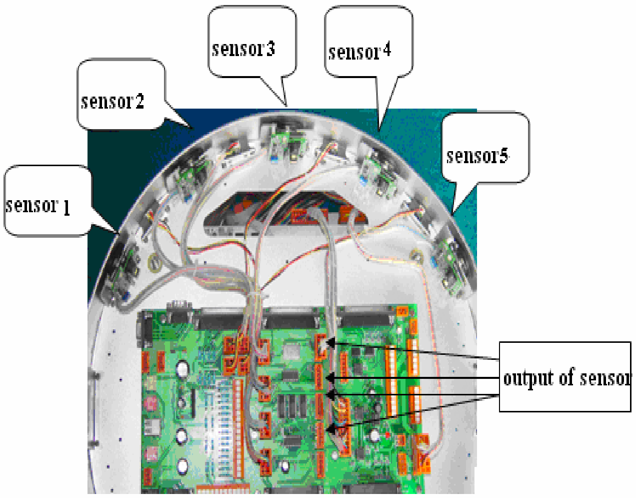


Fig. 8 The hardware of biologically inspired hexapod robot's sensing and control system

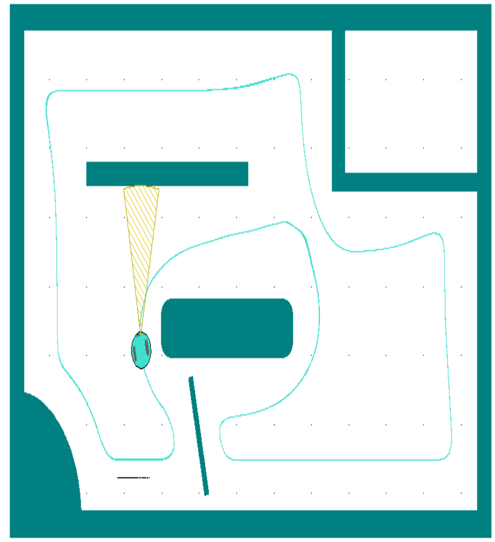
B. *Immovable Obstacles Avoidance Simulation Experiments*

The authors conducted the simulation experiment of biologically inspired hexapod robot's obstacle avoidance control system with Mobotsim software. The results can been seen from Fig.9(a)shows the biologically inspired hexapod robot's walking trace without fuzzy control obstacle avoidance strategy while (b)shows the robot's walking trace with fuzzy control obstacle avoidance strategy. As can been seen from these two pictures, the robot can adapt the environment well and complete the obstacle avoidance task successfully, which indicates the biologically inspired hexapod robot 's sensing system is validity and rationality. From the comparison of the two pictures, we can see that fuzzy control obstacle avoidance strategy optimizes the robot's walking trace, improving the hexapod walking bio-robot's real time performance for obstacle avoidance, which will do favor to saving the robot's energy consumption.

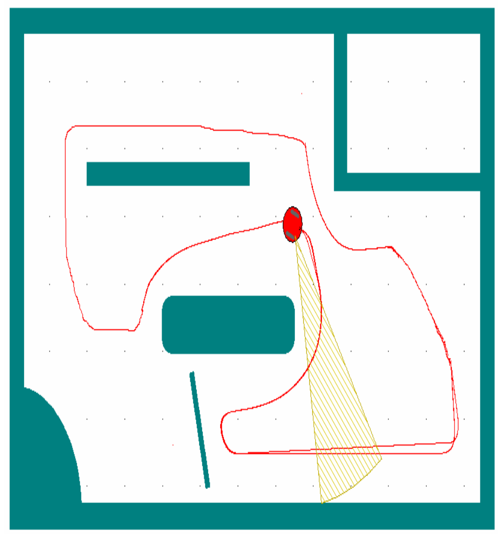
C. *Movable Obstacles Avoidance Simulation Experiments*

Fig.10 shows the result of movable obstacles avoidance simulation experiment. The ellipse object moves at the speed of 0.5m/s, while the robot moves at the speed of 0.2m/s. As can be seen from the robot's walking trace, it can avoid movable obstacles.

Changing the robot's beginning position and obstacle's location and shape; we can also get the ideal experiment results.



(a) The robot's walking trace without Fuzzy control obstacle avoidance strategy

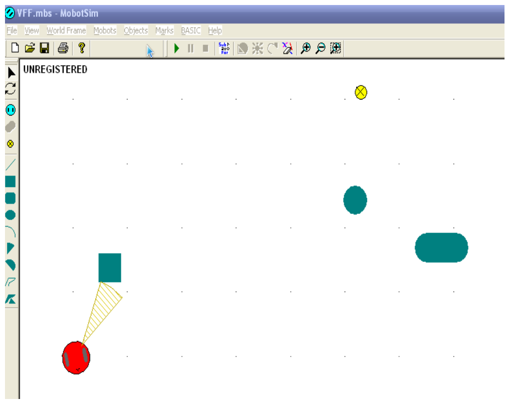


(b) The robot's walking trace with Fuzzy control obstacle avoidance strategy

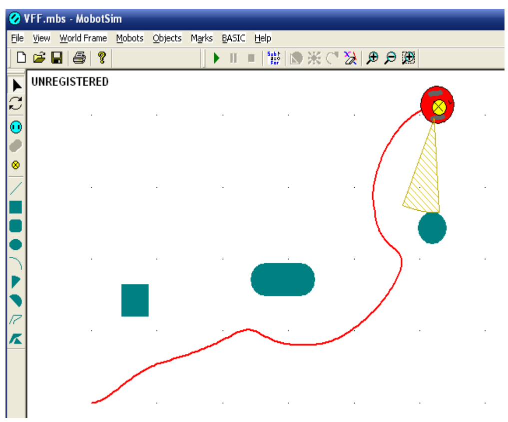
Fig. 9 Immovable obstacles avoidance simulation experiments

VI. CONCLUSIONS

In order to meet the demand of the biologically inspired hexapod robot's task and its working environment, this paper proposes the distribution of the compound sensing system based on multiple infrared sensors and ultrasonic sensors, which enlarges the robot's sensing range and eliminates the interference. The authors use the fuzzy control obstacle avoidance strategy, which overcomes the disadvantage that the unstructured environment is difficult to model and improves the system's robustness. The hardware test experiments results show that the designed sensing and control system can meet the real time demand. Using the Mobotsim software, the authors finished the simulation experiment. The experiment results show that this obstacle avoidance control method has perfect real-time performance, robustness and flexibility, not only to the immovable obstacles but also to the movable obstacles. What we have done establishes the foundation to realize the biologically inspired hexapod robot's intelligent control.



(a) The beginning of the simulation experiment



(b) The end of the simulation experiment

Fig. 10 Movable obstacles avoidance simulation experiment

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