Intelligent Robot Obstacle Avoidance System Based on Fuzzy Control

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***Abstract*—Autonomous obstacle avoidance technology is the best way to embody the feature of robot strong intelligence in intelligent robot navigation system. In order to solve the problem of autonomous obstacle avoidance of mobile robot, an intelligent model is used in this paper. Adopting multi-sensor data fusion technology and obstacle avoidance algorithm based on fuzzy control, a design of intelligent mobile robot obstacle avoidance system based on S3C2410X is described. Its perceptual system is composed of nine ultrasonic sensors to detect the surrounding environment from different angles, enhancing the reliability of the system on the based of redundant data between sensors, and expanding the performance of individual sensors with its complementary data. The S3C2410X processor receives information from perceptual system to calculate the exact location of obstructions to plan a better obstacle avoidance path by rational fuzzy control reasoning and defuzzification method. The paper focused on the analysis of the difference between the simulation results and the actual effects. The analysis shows that: the robot can avoid obstacles with a better security path to solve the problems of mobile robot intelligent obstacle avoidance. Through the comparison results, we can also find that the design of mobile avoidance obstacle system has a good navigation effect s because of its advanced characteristics of adaptability, stability and robustness.**

Keywords- fuzzy control; intelligent obstacle avoidance; ultrasonic sensors; data fusion technology

I. INTRODUCTION

Active mobile robot is one of the most important branches of robot research. With the development of sensor technologies, autonomous mobile robot has become the focus of research and exploitation. Autonomous avoidance operation would be desirable under special circumstances, for example, in indoor environment where there are complex chaotic obstacles or extremely hazardous activities. Furthermore, a robotic task might be complex and the environment might be unstructured to the extent that some degree of intelligence would be required for satisfactory performance of some tasks. In order to guarantee the safe rapid effective implementation among man, machinery and environment, a real-time obstacle avoidance method is especially important. Autonomous mobile robot obstacle avoidance algorithm[1] can be described as below: first, initializing starting point and goal point; then the robot updates the map real-timely with the prophet environment information and sensors; and a better motion path from the starting point to terminate point is obtained by the robot, making use of its own avoidance obstacle algorithm which can enable the robot to bypass safely and collision-freely all obstacles with the shortest path. If the environment is unknown, the robot must plan and modify path real-timely. Many typical algorithms are available for planning robot navigation path, for example, artificial potential field method[2], behavior control method[3], genetic algorithm[4,5], random tree[6], ants colony algorithm[7] and so on. Although the algorithms mentioned above are widely used, there are several severe and well-documented problems for mobile robot navigation. These limitations include large search space, complexity of algorithm, low efficiency, as a result the complexity of the path planning algorithm will greatly increase and even impossible to solve, particularly if they occur in the case of the number of barriers increasing and terrain obstacles trending to be more complex. These limitations led researchers to make improvements to the mobile robot navigation.

In this paper, the design of an intelligent four-wheel obstacle avoidance robot is presented. The S3C2410X with a fast processor is applied taking into account the complexity of algorithm. Robot can real-timely detect working environment by multi group ultrasonic sensor, integrate the data of multiple group ultrasonic sensor with the help of technology of data fusion, establish the external environment map, plan the real-time path driven by the fuzzy logic inference algorithm, and through these steps, the machine can avoid barriers safely with a better path in unknown environments.

II. ARCHITECTURE OF MOBILE ROBOT SYSTEM

A. *Ultrasonic Sensor and Data Fusion Technology*

Ultrasonic sensor detects the location of obstacle by means of time difference, its work principle is described as follows: first, the ultrasonic transmitter of sensor launches ultrasonic wave in a direction; then the wave spreads in the air. Simultaneously, the sensor begins timing until the ultrasonic wave is blocked by obstacles and received by the receiver. In this way, it can calculate the distance of obstacles from the launcher according to the velocity of ultrasonic wave and the time interval recorded by the sensor timer.

One technique for obtaining the consistent explanation or description of the observed objects is the blending of data from sensors with redundant or complementary spatial and temporal characteristics, with the aim of generating synthetic ruler through the reasonable allocation of sensor and observation information, as the human brain integrates general information resources. In this way, it can enhance the reliability of the system on the based of redundant data between sensors, expand the performance of individual sensors with its complementary data. With the help of data fusion technology, it can also expand the spatial and temporal coverage, improve reliability of the system, increase the credibility of the confirmation of targets or events, and reduce

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the ambiguity of information, which is impossible for any single sensor.

Because of the mobile robot's unstructured and uncertain work environment, a lot of sensors are required for the purpose of detecting obstacles. The system often adopted an information blackboard-based integration structure. By this way, it make the central unit as an exchange center of all units, which can share the calculation burden and help relieve bottleneck problem arising from the concentration calculation, thereby, the robot obstacle avoidance and autonomous navigation become a reality.

B. The Overall Design of Mobile Robot

In our study we have a four-wheel mobile robot that is composed of two driving wheels, two driven wheels, nine ultrasonic sensors, a control panel and a motor drive board. The structural diagram of robotic overall module is shown in Figure 1. Among them, the driving wheels play the role of robot walking, while ultrasonic sensor serves as a machine to detect and perceive the environment information around the robot; the control panel mainly functions as a controller which can inference optimal path based on fuzzy control algorithm, and send commands to the motor drive board through RS232 serial communication interface to guide the robot to move or turn around. It can also recognize comprehensive signals conveyed from ultrasonic sensor signal processing circuit.

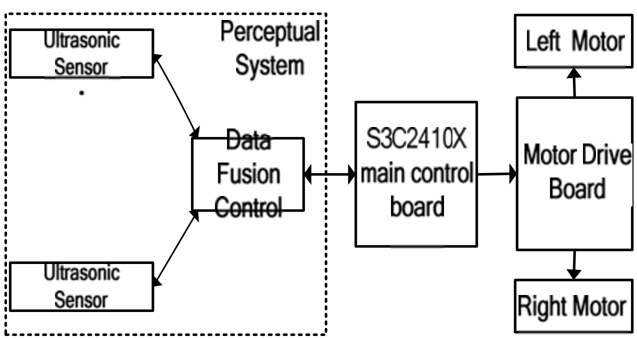

Figure 1. Robotic overall module structure

C. Mobile Robot Perception System

Since ultrasonic sensor is characterized with poor direction and limited angle ranging, one channel ultrasonic ranging system can not completely meet the requirements of high-precision ranging and obstacle avoidance. In order to meet the requirements of high precision and accuracy, we add some sensors to the hardware architecture of the mobile robot, and introduce the methods of compensation for the limitations of the single sensor angle point to make the direction and distance of main obstacle in front of the robot more accurate. Robot perception system model is shown in Figure 2, each robot has nine ultrasonic sensors divided into three array sensors for measuring the distances around it and locating the target i.e., the distance from the obstacle in front of it, left obstacle distance, right obstacle distance respectively, and then choose the minimum value among each distance between the robot and obstacle. At the same time, attention should be paid to the crosstalk between each of the ultrasonic sensors. A position sensor is also used to detect the location of the target, and the direction angle will be positive when the target point is located on the right side of the machine[8].

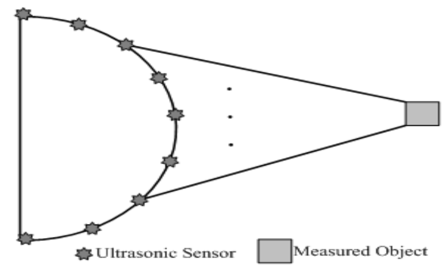

Figure 2. Robotic perception system model

III. Fuzzy Controller Design

In some tasks the environment are "qualitative and fuzzy" in nature, and cannot be expressed in precise quantitative terms. For example, there is a difference between the way a human hand grasps a light bulb and the way it grasps a rubber ball. But transformation of this process accurately into a control algorithm for a robot is quite difficult and may involve a set of protocols which cannot be expressed as a precise algorithm. In particular, fuzzy control, where control rules may be expressed as a set of fuzzy linguistic statements, has been employed for this purpose.

The fuzzy logic operation mainly includes fuzzification, knowledge base, fuzzy reasoning and defuzzification. The fuzzification converts the accurate input variables into input grades namely fuzzy variables. The knowledge base is used to store relevant data and fuzzy control rules. The inference and aggregation namely fuzzy reasoning generate a resultant output with respect to fuzzy rules and finally the defuzzification converts fuzzy variables to accurate output variables. The composition diagram of fuzzy-controller is shown in Figure 3.

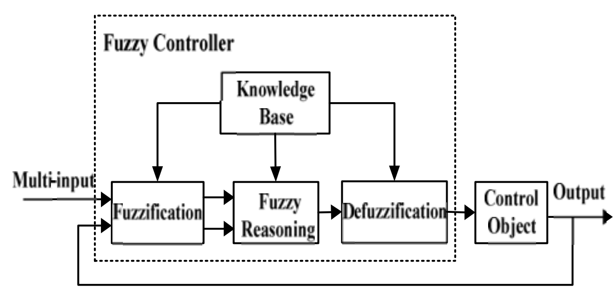

Figure 3. Composition diagram of fuzzy-controller

A. Determination of Input Variables and Output Variables

The fuzzy obstacle avoidance strategy adopted here is to make a compromise between the target reaching behavior (with the target attracting the robot) and the obstacle avoidance behavior (with the obstacles repelling the robot). This basic fuzzy logic controller is applied to coordinate various behaviors of the robot reaction in unknown environment [9].

The nine ultrasonic sensors on the robot can be grouped as left-front sensors, right-front sensors and front sensors. These three groups of array ultrasonic sensors measure the distance ranging from zero to 180 degrees in front of the robot, accordingly the orientation is divided into three directions, namely obstacle positions which are right-front, left-front and front. The inputs to the fuzzy reasoning are the obstacle orientation angle relative to the robot heading (θ) and the distances measured from obstacle to the orientation of left-front (dl), right-front (dr) and front (df) side of the robot. The output is the robot rotation angle (Φ).

B. *Fuzzification*

In this research the domain of distances dl, df and dr is constructed adopting linearization method after many tests. Linguistic variables such as ‘‘FAR’’, ‘‘MIDDLE’’ and ‘‘NEAR’’ are taken for three-membership function (in which “FAR” signify far; “NEAR” signify near and “MIDDLE” signify middle). Three types of membership functions of quantitated distances including dl, dr and df are considered combined with the experience of operator. Figure 4 (a) shows the membership function of dr, dl and df. Similarly, the domain of robot target orientation angle θ is constructed with {N, Z, P} (in which N signify negative, Z in token of zero and P signify positive) and the membership function of robot orientation angle θ is shown in Figure 4 (b). The domain of robot turning Φ is constructed with {LB, LM, LS, Z, RS, RM, RB}(LB signify “left big”, LM signify “left middle”, LS indicates “left small”, Z in token of “zero”, RS signify “right small”, RM signify “right middle” and RB signify “right big”) and the membership function of robot turning angle Φ is shown in Figure 4 (c) .

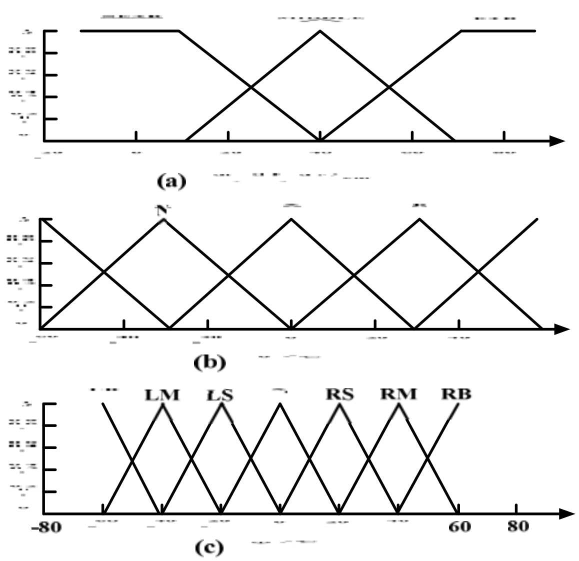

Figure 4. The membership functions of variables

C. *Development of Fuzzy Rules*

Robot navigation is actually governed by rules in the fuzzy controller which represents the human driving heuristics qualitatively. For any N-rules system, it is important that what kind of information needs to be supplied to the fuzzy logic controller and what kind of decisions it needs to provide.

In our study when the target is exactly at the left (right) side of the barrier, the robot must turn to left (right) side, and when the obstacles is next to the front of the robot, the machine must turn to the default right side. Because there are three inputs to the fuzzy controller and each has three categories, therefore there are $3^3\times 3 = 81$ if-then rules in total according to Fuzzy Set Theory [10, 11]. Space of paper is limited so that we can only give the reasons for a fuzzy control rules in the following.

For example, if the distance of obstacle at left front is “NEAR”, the distance of obstacle at exact front is “FAR”, the distance at right front is “FAR” and the target angle of orientation is “P”, accordingly, we can conclude that the robot will turn toward right side slightly. Therefore the rule “if (dl is NEAR, and df is FAR, and dr is FAR, and θ is P) then Φ is RS” will be obtained. Similarly, if the distance of obstacle at left front is “FAR”, the distance of obstacle at exact front is “NEAR”, the distance at right front is “FAR” and the target angle of orientation is “N”, we can conclude that the robot will turn toward left side greatly. Therefore the rule “if (dl is FAR, and df is NEAR, and dr is FAR, and θ is N) then Φ is LB” will be obtained equally.

D. *Defuzzification*

Fuzzy reasoning is based on the implication relationships and fuzzy logic reasoning rules. There are three major operations: logical and operation "and", synthetic operation "O", and implication operation "→". In our study, first, we use the max-min synthetic methods to carry out fuzzy reasoning; then calculate the defuzzified variables by weighted average method according to the established rules of fuzzy control table; finally, convert the defuzzified outputs for turning angle to actual control output. As a result, the robot will turn and shift automatically [11].

IV. TEST AND RESULTS ANALYSIS

We used the computer to simulate the indoor environment for robot obstacle avoidance test so as to show the performance of the proposed algorithm. At the same time, some actual indoor tests of obstacle avoidance of multi-sensor robot were did. In the actual investigation, the robot was equipped with three arrays of nine ultrasonic sensors. Besides, some factors must be taken into account when we did test tasks. First, we can not simply take the robot as a particle when the autonomous obstacle avoidance task of mobile robot was implemented. It is necessary to take into account its actual size. Second, the acceleration and speed can not keep too fast because there are some peak restrictions for them. Third, the turning curvature value must be greater than a certain threshold for there is a minimum turning radius; in addition, some other factors such as slope instability must also be considered.

Figure 5 shows the map of simulation experiment route of the robot intelligent avoidance obstacle. In the figure, the beginning location of the robot and the location of the aim were given for each navigation task. A lot of black blocks were used for obstacles graphic representation. The programming language was VC++ added with special functions for robot motion and self localization. The actual tracking trajectory line is depicted in Figure 6.

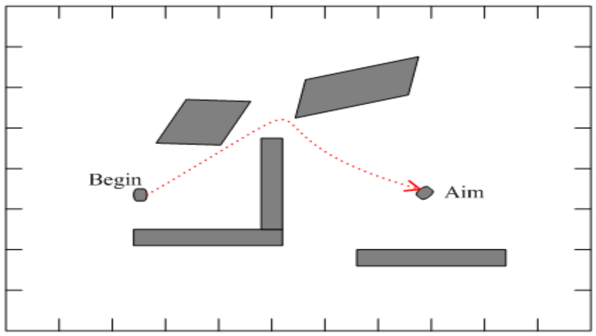

Figure 5. simulation route map of intelligent avoidance obstacle

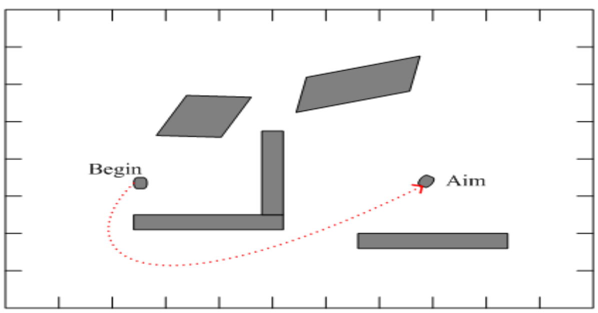

Figure 6. actual tracking trajectory line

We can observe from Figure 5 and Figure 6 that the robot simulation result is not the same as the actual trajectory with identical terrain and starting point. The main reason is that the robot is only simplified as a particle in the simulation test without considering the actual conditions such as body size, friction force of the bed and so on. However, in the practical process, the robot will be affected by lots of unforeseen outside conditions such as friction force, body size and shape, et cetera. As a result, the actual tracking trajectory has wandered from the simulation path. Generally speaking, Figure 5-6 demonstrates the better performance of the proposed robot avoidance obstacle algorithm. Through the comparison results, we can find that the design of mobile avoidance obstacle system has a good effects because of its advanced characteristics of adaptability, stability and robustness.

V. CONCLUSION

A fuzzy logic control system is developed for intelligent avoidance obstacle of mobile robot. The inputs to the fuzzy controller are: the obstacle positions relative to the robot heading and the target orientation which is defined as the angle between the robot heading direction and the robot-to-target direction. Using multiple ultrasonic sensors to compensate for the direction defects of a single sensor, adopting methods of multi-sensor data fusion, the robot can acquire information of environment accurately, thus the effectiveness of avoidance obstacle of mobile robot is desirable. Simulation results and actual test outcome have demonstrated that the proposed fuzzy control system is safe for the robot obstacle avoidance, and further, the robot is able to walk with optimal path. At the same time this system can easily be expand as an intelligent navigation subsystem of active mobile robot in special circumstance.

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