Interactive Robot Usher Architecture Organization

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Abstract : - This paper presents the design of a safe, friendly, and living autonomous Interactive Robotic Usher (IRU). IRU is able to run independently to achieve specific commands, intelligently interact with humans and environments, move safely and avoid obstacles in her way. In this paper, both the hardware and software architecture of the intelligent autonomous mobile robot are described. And some primary operations such as path tracking, obstacle avoidance, guest following, interactive with humans etc. are discussed. Our project contains a collection of new ideas, especially, the artificial intelligence concepts are widely used in path tracking, control, decision-making and information processing etc. Most of the system organization has been put into use and successfully proved to be feasible by our experiments on IRU in National University of Singapore.

Key words: Mobile robot, architecture, path-tracking, decision-making, interactive, AI.

1 Introduction

Recent years have witnessed an increasing interested in studying on mobile robot. In [1], a car-like mobile robot is presented and the kinematic and dynamic model of the mobile robot was discussed in detail. In [2], a tricycle mobile robot was introduced and path tracking strategy was developed. A non-holonomic mobile platform was provided with visual controller in [3].

Our project emphasizes on developing a safe, friendly and living autonomous Interactive Robotic Usher (IRU). The proposed objective of IRU is to research and design a multi-sensor-relying integrated decision-making and control system. Especially, the uniqueness of our work is the development of essential technology including intelligent control, path tracking, guest following, recognition and multi-sensor fusion. IRU is expected to have the capability guest reception by integrating visual and audio information for interaction, in indoor office environments with a speed of approximately 90 cm/s. IRU is different from other present mobile robots which were well developed in the past several years. IRU can follow people with a polite distance, move around autonomously, avoid collision and steer clear of obstacles on her way. It can recognize the command gesture, recognize face, and lead guests to a destination room by finding a suitable way. Also, IRU can communicate with guests, she can understand simple sentences, ask routine questions and answer simple questions. All of these capabilities are distinctive.

The architecture is very critical for the mobile robot to fulfill its objectives. In Section 2, the configuration of IRU is described, followed by the most important function organization, hardware structure and software organization of the mobile robot system. Then, the specific system operation including self-localization, path tracking, guest following, interact with human and obstacle avoidance are presented for the mobile robot system in Section 3, in this section artificial intelligent are well used to handle the problem during operation. Finally, a brief conclusion is given as a summary in the last section.

2 System Architecture Description

In this project, the architecture of IRU will be developed so that it can receive guest in a safe, friendly way. The integrated system architecture is shown in Fig.1.

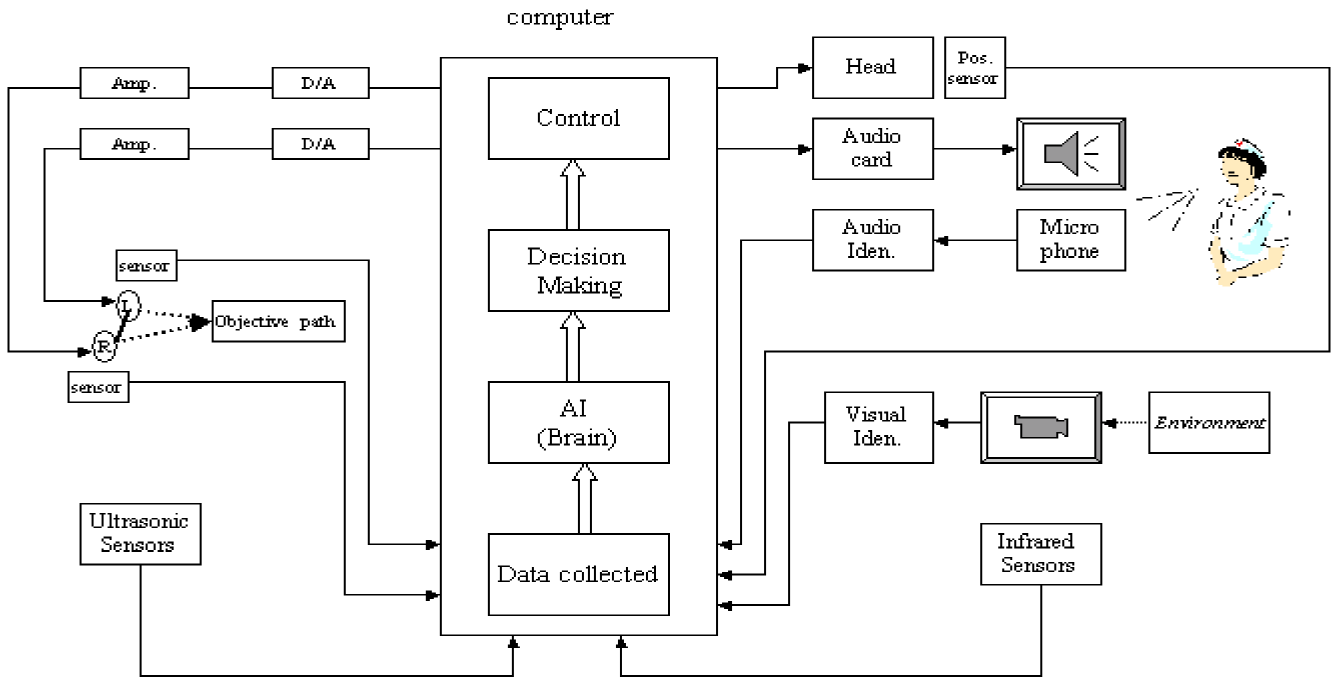

Fig.1 Integrated System Architecture

2.1 The Configuration Of IRU

The body of IRU is a structure formed by 4 aluminum profiles and 2 plates of polygon shape. The plates are the bases to mount the ultrasonic sensors and reinforce the body structure. Cameras and long-range ultrasonic sensors will be mounted on top of the head.

The drive base of mobile robot consists of two independent driving wheels and two non-driven castor wheels. The kinematic motion of the wheel is considered as pure rolling and non-slipping. The two electrical motors of the two driven wheels are controlled in a way that the left wheel velocity of the robot v_l and the right wheel velocity of the robot v_r can be considered as the control variable of the system, which implies that the forward velocity v and the angular ω of the robot can be controlled. Then, by controlling the two independent velocities of the robot wheels, three configuration variables, namely two Cartesian coordinates characterizing the position of the mobile robot, and its orientation.

2.2 Hardware Structure

Hardware Architecture of IRU(the Interactive Robotic Usher) consists of the following parts:

(1)Sensors

- Ultrasonic sensor arrays: there are six long-range ultrasonic sensors for obstacle avoidance and object detecting.
- Infrared sensor arrays: 32 infrared sensors for emergency obstacle avoidance and anti-collosion.
- Microphone: 4 microphones collect voice from four different directions.
- Head ultrasonic sensor: to estimate distance of object in sight and therefore aid navigation.
- Cameras: a high sensitive digital camera, collect clear picture for visual information.
- Optical rotation speed transmitters: each sensor transmits the rotation speed of the corresponding driven motor for wheel and head motion, it encodes the rotation signal and send it to computer.

(2)Head movement and motion controller card

This motion control card is a DSP based controller card connected directly with computer, it receives computer control command, after D/A and amplifying, and output the direction voltage to the head attitude control motors and robot movement control motors.

(3)Audio card and speaker

The audio card is connected with computer, which is used as voice generator to communicate with guests.

(4)PC

PC is the nerve center of IRU, it receives all information from every sensors including camera. Then, process all the information, such as voice identification, and image processing etc. And then, according to the processed information collected, decision is made so that it can respond to the environment including human interactive environment. Consequently the command signals are issued to operate every corresponding module, e.g. turn head and step up or down.

2.3 Software Architecture

The software of IRU is the critical part for its good performance. The software was developed in Language C, C++ and Visual C++, and operated on PC computer. The general software operation system is shown in Fig.2. IRU's software architecture consists of many function modules, which work as different function modules. Generally speaking, All of these modules can be classified as three level groups, that is, low level modules, medium level modules, and high level modules.

The low-level modules work directly with the hardware devices, including sensors and servos. They compose of sensor data-reading modules and command executive modules. These data reading modules consist of image input modules from camera, voice from microphone, sensed data from ultrasonic sensor, infrared sensor, wheel speed sensor, head attitude sensor. These modules are mainly responsible for raw data collection and transmit them to the medium module for information processing. The command executive module is responsible for executing operation. After decision making and path planning from the high-level software module, command executive modules are informed to operate servos such as audio card, wheel operation etc. so that they can finish the corresponding command, through DSP control board and amplifier.

The medium-level modules sit between the low level and high level modules. In this level, the crude data from low level modules will be refined so that they can be used by the high level artificial intelligence decision-making and path planning. For example, the information from camera is processed by Neural Network pattern recognition in this level. And the processed data such as whether there is an object or not in sight, distance away from the robot and the direction of objects, will be used for the high level decision-making and path-planning. Another instance, for the wheel speed sensor information, according to position estimation introduced later in this paper, the position is calculated in this level and the corresponding data is stored for the high level module to issue next operation command.

The high level modules perform global mission planning and issue control command. In this level, the integrated data from the medium level are considered for decision-making. The decision process is a very complicated one. The priority of every sensed data is set

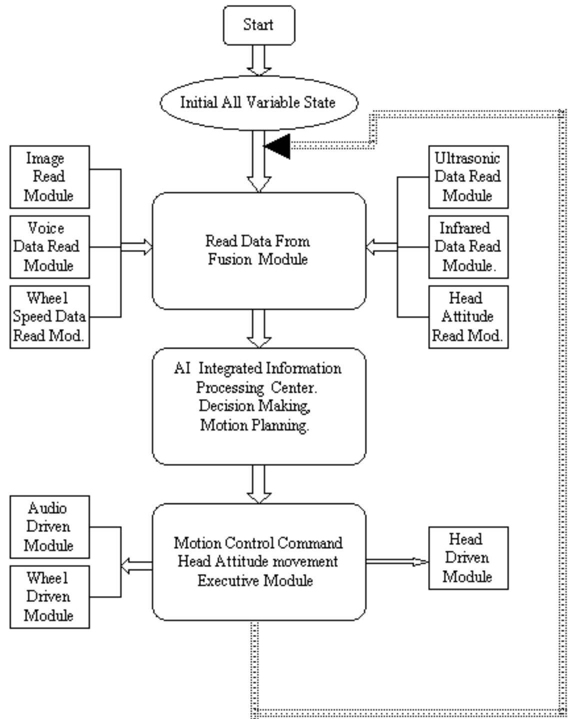

Fig.2 Software Structure of the System

so that IRU can make correct decision. For example, IRU is on her way to one objective room, when meeting obstacle, she has to plan a new path to get to her destination, at this time, voice command require her to go back, then, she should go back according to the priority of data. In this level, artificial intelligent technique is well used and its superiority shows.

3 System Operation

3.1 Self-localization

Self-localization is a very complicated integration system by visual, self-position estimation and other sensors. The land markers and beacons are needed for her to recognize the position of herself by recognizing the object and process in the AI center. Self-localization at any place depends on the self-position estimation.

Because the model of the vehicle used in our project is based on a differential-drive. The dynamic model of the vehicle motion is described by the following equations.

$$\dot{x}(t) = v(t)\cos\theta(t) \quad (1)$$
$$\dot{y}(t) = v(t)\sin\theta(t) \quad (2)$$
$$\dot{\theta}(t) = \omega(t) \quad (3)$$

Reference to Fig.3

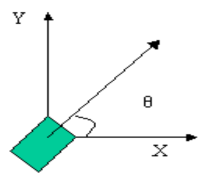

Figure. 3 Position and Orientation Calculation Coordinates

where:

$v(t) = (v_r(t) + v_l(t))/2$

$\omega(t) = (v_l(t) - v_r(t))/L$

L is the distance between the left-driven wheel and the right-driven wheel. Supposing the sampling space is h, on our control computer, h takes value 0.001s, the real time discrete-time position and orientation is calculated as follows:

$$d\theta = \omega h \quad (4)$$
$$\theta = \theta + d\theta \quad (5)$$
$$dx = v\cos\theta \quad (6)$$
$$x = x + dx \quad (7)$$
$$dy = v\sin\theta \quad (8)$$
$$y = y + dy \quad (9)$$

3.2 Path tracking

3.2.1 PID control for Straight Path Tracking With Compensation and NN Calibration

For the straight-line path tracking, suppose that IRU is at the start point of the objective path, for simplicity. Because of the maximum speed of the driven wheel of IRU is about *0.9m/s* and the required calculated speed by PID may be very large, a fuzzy rule is applied to overcome the saturation of wheel speed, when the required speed is greater than the maximum speed, then, IRU moves at the maximum speed

In our project operation experiment, the mobile robot may not strictly go straightly along the straight line because of the difference between the velocities of the two driven wheels. To overcome this problem, we add a compensatory item $k_c\Delta\theta$ to v_r command and subtract the item from v_l command to keep robot aligning with the desired straight line. Here, the $\Delta\theta$ is the difference between the desired angle and the actual angle. Then, if any angle error happens, the robot can automatically return to the desired line and therefore keep stay on the desired straight line. Dozens of experiments was done on IRU and proved its good performance.

Another problem met in our project experiment is that she may stay at a position more or less away from the desired destination. In order to offset the error of the system, we introduce the Multi-layer Neural Networks error calibration method to address the position error. A large number of experiments were done for calibrating the operation error, couples of the error and the desired distance can be obtained. By introducing the Multi-layers Neural Network, with one input layer, one output layer together with one or more hidden layers as shown in Fig. 4. We consider the desired distance as the input of the neural network and the actual deviation from the desired as the output of the neural network. Take the sigmoid function $f(x) = 1/(1+e^{-x})$ as the activation function and Back-propagation (BP) algorithm to train the Neural Network. By training the neural network offline using the typical experiment data couples, adjusting the weight and the threshold of the neural networks, the structure of the Neural Network can be built up before it is put into use. Then, to control the system, the sum of the estimated error and the desired distance (x_d+y_{nn}) is considered as the "desired distance". By this way, the control accuracy can be improved to a large extent.

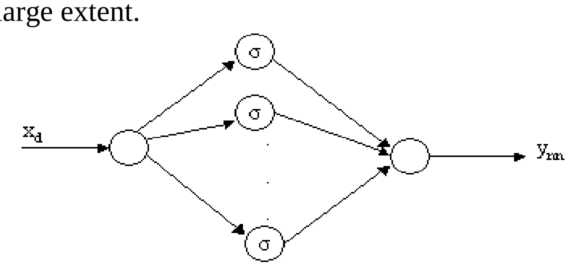

Figure.4 Neural Network Error Calibration

3.2.2 Fuzzy Path Tracking for An Arbitrary Path

Path tracking usually involve a pure delay in the control loop, due mainly to the mobile robot position estimation, particularly, when other system processing is in progress in the meanwhile. Path tracking algorithms are based on the selection of objective point on the desired path, which is critical. The objective point on the desired path is selected according to the speed of robot, the deviation error from position, orientation, and curvature. The faster the speed is, the further the objective point is ahead; the greater the error is, the further ahead. For our robot, the speed is considered as a constant. Then, comparing the current position with the objective point, we can get the three difference variable, $d, \Delta\theta, \Delta\rho$, which determines the value of the output control variable. As shown in Fig. 5, where, *d* is the distance from the objective point to line of the velocity of the current velocity.

$$\Delta\theta = \theta - \theta_d$$

$$\Delta\rho = \rho - \rho_d$$

Since the input of the system is only related with the above three variables, then the input *u* can be expressed as:

$$u(v_l, v_r) = f(d, \Delta\theta, \Delta\rho)$$

Therefore, fuzzy controller to generate the control signal *u* can be designed from the position error and the heading error, curvature error. This controller appears easy to understand and can be implemented intuitively.

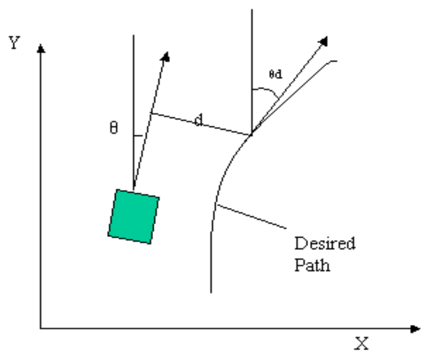

Figure. 5 Fuzzy Control Path Tracking

3.2.3 Path Tracking by Aid of Vision

Good control algorithm, accurate position and turn angle estimation is critical for us to control the robot to go as we planned. However, in the real work environment, it sometimes may not be able to satisfy the requirements of our design. To handle this problem, visual detection were introduced so that they can work as the calibration of path tracking. IRU can detect the markers and beacons by her "eyes" and therefore know where she is in the building, since the marker and beacon indicate a unique position there. This makes sure that the mobile robot arrives in the objective position without large errors. And calibrate the position estimation error to avoid the accumulation of estimation error. Consequently, the controller can issue corresponding direction to align with the desired path or go on moving to her destination.

3.3 Guest Following with Polite Distance

One of the distinct characters of IRU is that she can follow guest from here to there, keeping a certain distance away from the guest. In our project, we consider the polite distance is one meter away. When, it is farther than one meter, IRU can move near the guest until one meter from the guest. To realize this, the camera together with ultrasonic sensors can provide two real-time discrete data, one is the distance *s* from guest to IRU, which should be a positive scalar, the other is the orientation angle θ relative to the forward direction of IRU. Here the angle θ should take value from $(-\pi, +\pi)$. We work out point-to-point tracking strategy to handle this problem. Once the guest is within one meter away, i.e, (s-1)<1, no moving needed. If the guest is localized at a direction θ angle from the forward direction beyond one meter away, IRU is able to adjust his forward direction to align with the guest direction and move near the guest. Supposing that the sample space is *h*, and the v_{max} is the maximum speed the wheel can move at. The software realization can be expressed as figure.6.

3.4 Interactive with Humans

There are several microphones mounted around the head. The microphone can collect the voice data from the corresponding direction, after digitalization the information was sent to AI information processing center. On one hand, the AI system can judge which direction the guest is around her by identifying the intensity of sound collected from every microphones, together with the information from other sensors such

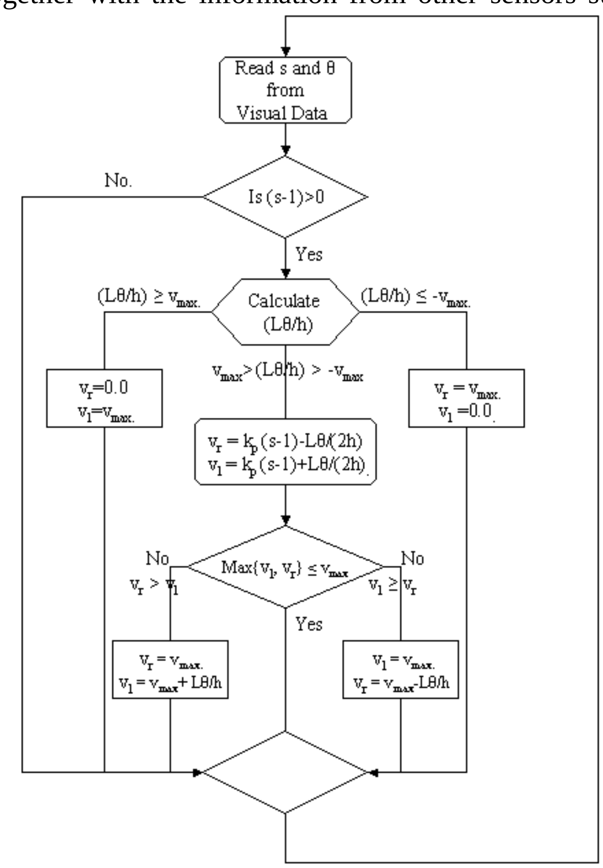

Figure 6. Guest Following

as visual camera and ultrasonic sensors, and therefore, head control command was concluded so that the head can turn to the guest, otherwise, the guest will feel that he/she is talking with an arrogant guy. On the other hand, IRU can understand the routine voice, based on which the intelligent system can response in a polite voice by speaker, and in the meanwhile, IRU make an appropriate decision, reference to the data collected from other related sensors.

There is a digital camera on IRU's head, which is the “eye”. The “eye” is in charge of gathering information from the environment and collecting information who is communicating with her. And then, using the AI technique pattern recognition, the image will be processed in the image-processing center. Some of the environment information will be helpful to self-localization, decision-making and path planning etc. In addition, an ultrasonic sensor is mounted on the head to help the “eye”. With the assistant of head control, the “eye” can keep tracking the face of the guest, so that the guest feel that IRU is paying attention to his/her voice.

Once decision made to start for a destination room, IRU can move in front of the guest and lead the guest to the objective room, keeping a polite certain distance from the guest by the aid of object sensors. Thus, IRU could interact with the guest by aiding of “eye”, “ear”, “mouth”. Consequently, the guest must be pleasant to talk with this living, friendly guy.

3.5 Obstacle Avoidance

Camera, six long range ultrasonic sensors and 32 infrared sensors can assure IRU walk in a safe, smooth, obstacle-avoiding, and anti-collision way. Ultrasonic sensors and infrared sensors are mounted around the body of IRU and on her head. A laser or ultrasonic beam is emitted in a certain direction in space, the beam is reflected from objects. A matching sensor detects the reflected beam and the distance is calculated according to the time difference between emitting and receiving the beam. By continuous scanning the environment, the obstacles can be found instantaneously. As soon as obstacles are found on her way, the information will be sent to the “Brain”, and new path will be scheduled on the current status. the obstacle-avoidance process can be seen as Fig.7.

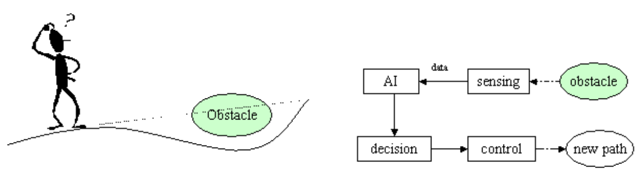

Figure 7. Obastacle Avoidance

4. Conclusion

Both the hardware and software architecture of IRU, a safe, friendly and living Interactive Robot Usher, are presented in detail in this paper and the operation of the system is described. The general system organization of the mobile robot architecture has been proved to work pretty well by our experiments on IRU in our project, although, the ability to understand and pattern recognition, voice identification and decision-making is limited because our database is limited to some extent. Our research will be useful to apply to wheel chairs or mobile manipulators. This project is the initial for our long-term research of a range of intelligent service robots that can assist people in their daily living activities.

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