The Design of an Indoor Guide Robot Based on Embedded Control System

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ABSTRACT

A Guide Robot based on embedded electronic System is designed in this paper. An embedded control system is proposed to integrate modules of indoor self-localization sensors, differential driving mechanism and multimedia interaction to build the robot. The core indoor self-localization function is achieved by fusing dead-reckoning and visual measurement involving inertial measurement unit (IMU), a pair of hall encoders and a camera. On this basis, introducing audio files are embedded into the module of multimedia interaction, which are related with the location coordinates. Then the robot can leads the visitor to approach the visitor sites by location coordinates and plays the multimedia files for introducing. A prototype of the Guide Robot is developed to prove the rationality of the design with guiding and introducing service instance.

Categories and Subject Descriptors

D.4.7 [**Operation Systems**]: Organization and Design – *Real-time systems and embedded systems*.

General Terms

Design.

Keywords

Guide Robot, Embedded Control System, Indoor self-localization, Visual measurement.

1. INTRODUCTION

Based on the development of embedded control system [1-2], vision measurement[3-5] and vision SLAM [6-7], the cost to manufacture a service robot is much lower than before, making the robot more attractive to the consumers and entrepreneurs. A new researching wave concerning service robots is rising, where much more attention is paid to consuming demand and manufacturing cost. As a result, researchers are working hard in designing proper technical routes and building robots within cost level of common consumer electronics commodities, not only focusing on algorithms. For example, the yard grass mowing robot uses magnetic field stimulated by the DC wire loop to sense boundaries and go back to the charging pile[8]. And the sweeping robot in [9] applies infrared light signal for docking. The window cleaning robot recommended in [10] is by means a pair of magnet consisting of an inner unit and an outer unit to adhere on the window glasses, while performing self-localization and navigation with gravity meter and encoders. Both of them are based on low cost embedded control system.

In this paper, a guide robot based on low cost embedded control system is designed, which guides indoor visitors and introduces the demanded destinations in indoor scenes such as a work center or exhibition rooms. The rest paper is organized as follows. In section 2, the embedded control system of guide robot is described. Then, the approach of indoor self-localization based on multi-sensor fusion is introduced. The section 4 describes the process of human-robot interaction in brief. And the robot prototype is demonstrated with its service instance in section 5. The last section concludes this paper.

2. EMBEDDED CONTROL SYSTEM

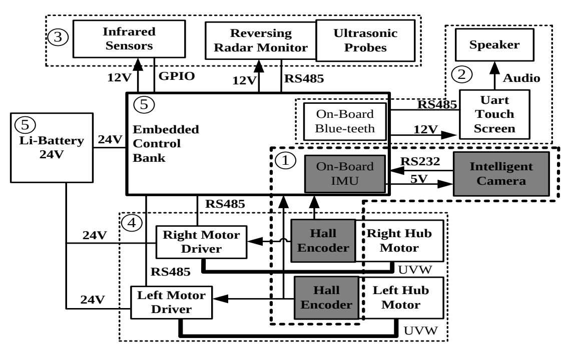

Figure 1. Framework of the Embedded Control System.

Figure 1 shows the framework of the embedded control system designed for the indoor guide robot, which consists of five parts: the self-localization sensing sensors, the multimedia interaction module, the obstacle avoidance sensors, the differential driving mechanism for movement, and the embedded control bank.

- Self-localization sensing sensors: these sensors includes an on-board inertial measurement unit (IMU) to measure heading course of the robot, a pair of hall encoders of motors whose electronic states are cloned for distance estimation, and a camera to capture landmark features and fix error of dead-reckoning for accurate self-localization. It is needed to point out that, the camera owns an independent CPU to extract the image feature, as helps the embedded control bank puts all computing power into real-time information integration & reliable decision making.
- Multimedia interaction module: it consists of a Uart touchscreen, a speaker and an onboard Blue-teeth block. The Uart touchscreen is loaded with coded screen UI buttons and media files concerning the destination sites of guiding. Via a serial port, the embedded control bank reads the IDs of touched UI buttons and command the screen played related Medias file. And the on Blue-teeth block enables the mobile phone of users to connect the embedded control bank, which would replace the Uart touchscreen to reduce the price of the robot for consumers.
- Obstacle avoidance sensors: these sensors contain infrared (obstacle avoidance) sensors and ultrasonic probes, and they overcome defects of each other. For example, the infrared sensors can detect sound-absorbing obstacle that ultrasonic probes cannot sensing, and the ultrasonic probes can discover transparent glass which cannot trigger the infrared sensors.
- Differential driving mechanism: it consist of two Hub motors with matched hall encoders and motor drivers. Benefiting from the hub motors, the robot could be built without complex transmission mechanism. It should be pointed out that the electronic states of the hall encoders are checked and decoded by the embedded control bank at the same time. And the consuming time between the two parts to transmit odometer distance increment is eliminated, which makes the self-localization timelier.
- The embedded control bank is designed based on a Core MCU configured with CPU of STM32F429, Storage of 4G Flash, 256 Byte EEPROM, and 32M SDRAM. The On-board IMU and Blue-teeth employ mechanical electronic chip of MPU9250 and HC06 respectively, and MCU exchange data with them via IIC or TTL buses. SP3232 and SP485 chips convert TTL Uart of the MCU into RS232/485 serial ports. TLP521 optocoupler chips are used to finish signal coupling between infrared sensors and GPIO of MCU. And the embedded control bank converts voltage for every parts via DC-DC chips of TPS5450 from Li-battery on 24 Volt and 20 AH capacity.

3. INDOOR SELF-LOCALIZATION

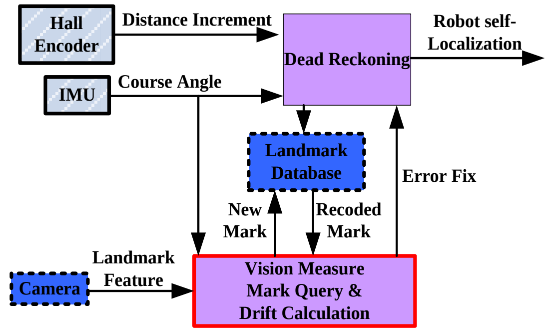

Figure 2. Fusion Model of Sensors for Self-localization.

The approach of indoor robot self-localization is based on multi-sensors fusion of on-board IMU, Hall encoders and camera. Figure 2 illustrates the fusion model of multi-sensors. The MCU of embedded control bank decodes the hall encoder to get the distance increment and reader course angle of the robot from IMU for dead-reckoning (reckonnning the location coordinates of the robot without vision measurement). Meanwhile, if a landmark feature is captured by the camera, the vision measurement will be performed involving pixel coordinates, course angle of the robot and dead-reckoning results to estimate landmark position coordinates. And the measured result is used to check whether the captured landmark has been recorded in the database. If it has been recorded, the recorded location of the landmark will be used to calculate the drift error of dead-reckoning. Otherwise, the landmark database should record the new landmark with its estimated position coordinates.

3.1 Dead-reckoning

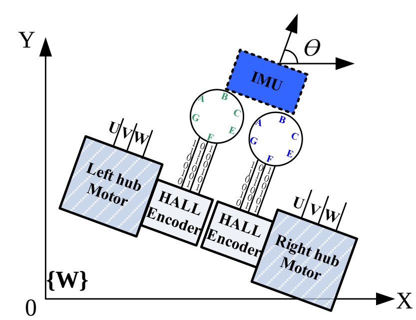

Figure 3. Dead-Reckoning via encoders and on-board IMU.

Figure 3 is illustrated to explain process of dead-reckoning. Each hub motor is equipped with a hall encoder, which outputs three electronic IO signal. These signal lines could form 2^3=8 states in theory, but only 6 states are outputted in practice. Once the embedded control bank check out that the state is switched, it means the hub motor moving forward or backward with a resolution distance Δd. And the Δd equals to the value of wheel circumference divided by the total states switching number of the encoder during a complete circle. And the dead-reckoning coordinates $({}^{d}x_t, {}^{d}x_y)$ keeps refreshing with formula (1)

$$\begin{aligned} {}^{d}x_{\mathrm{t}} &= {}^{d}x_{\mathrm{t1}} + \Delta d \sum_{\mathrm{i(t1)}}^{\mathrm{i(t)}} \left[({}^{L}\lambda_i + {}^{R}\lambda_i) \cos {}^{d}\theta / 2 \right] \\ {}^{d}y_{\mathrm{t}} &= {}^{d}y_{\mathrm{t1}} + \Delta d \sum_{\mathrm{i(t1)}}^{\mathrm{i(t)}} \left[({}^{L}\lambda_i + {}^{R}\lambda_i) \sin {}^{d}\theta / 2 \right] \end{aligned} \quad (1)$$

where $({}^{d}x_{t1}, {}^{d}y_{t1})$ represents the last dead-reckoning location coordinates of the robot. ${}^{L}\lambda_i$ and ${}^{R}\lambda_i$ represent the switching states of hall encoders of left and right hub motors, with a value from of 1, -1, 0 that mean switching forward, backward or no switching. ${}^{d}\theta$ is the course angle provided by IMU.

3.2 Vision Measurement

When the camera captures a landmark, it sends the pixel coordinates (u_L, v_L) of its center to the embedded control bank. And the plane coordinates ${}^{R}P_L$ $({}^{R}x_L, {}^{R}y_L)$ of the landmark in the robot coordinate system $\{R\}$ is calculated by a mapping matrix which could be deduced based on the camera hole model and calibrated internal/external parameters[3]. But the calibration of camera is commonly very tedious, considering the camera distortion. Then the second order Taylor model is introduced to calculate ${}^{R}P_L$ in this paper as shown in formula (2). And the second order Taylor model could be calculated via least squares method with six given pairs of pixel coordinates and the related plane coordinates in $\{R\}$.

$$\begin{pmatrix} {}^{R}x_L & {}^{R}y_L \end{pmatrix} = \begin{pmatrix} u_L & v_L & u_L^2 & v_L^2 & u_L v_L & 1 \end{pmatrix} \begin{bmatrix} k_{xu} & k_{yu} \\ k_{xv} & k_{yv} \\ k_{xuu} & k_{yuu} \\ k_{xvv} & k_{yvv} \\ k_{uv} & k_{yuv} \\ k_{x0} & k_{y0} \end{bmatrix} \quad (2)$$

$$\begin{pmatrix} {}^{d}x_{\mathrm{L}} \\ {}^{d}y_{\mathrm{L}} \end{pmatrix} = \begin{pmatrix} {}^{d}x_{\mathrm{t}} \\ {}^{d}x_{\mathrm{t}} \end{pmatrix} + \begin{bmatrix} \cos {}^{d}\theta & -\sin {}^{d}\theta \\ \sin {}^{d}\theta & \cos {}^{d}\theta \end{bmatrix} \begin{pmatrix} {}^{R}x_L \\ {}^{R}y_L \end{pmatrix} \quad (3)$$

Then the dead-reckoning coordinates $({}^{d}x_L, {}^{d}y_L)$ of landmark could be calculated with formula (3), which is used to query its recorded coordinates value ${}^{W}P_L({}^{W}x_L, {}^{W}y_L)$ based on landmark database in world coordinate system $\{W\}$. And the drift vector from dead-reckoning location value to self-localization by multi-sensor fusion value could be calculated. Then the coordinates $({}^{W}x_t, {}^{W}y_t)$ of the robot in {W} could be achieved with formula (4):

$$\begin{pmatrix} {}^{W}x_t \\ {}^{W}y_t \end{pmatrix} = \begin{pmatrix} {}^{d}x_{\mathrm{t}} \\ {}^{d}x_{\mathrm{t}} \end{pmatrix} + \begin{pmatrix} {}^{W}x_L \\ {}^{W}x_L \end{pmatrix} - \begin{pmatrix} {}^{d}x_L \\ {}^{d}x_L \end{pmatrix} \quad (4)$$

4. HUMAN-ROBOT INTERACTION

On the basis of indoor self-localization, the man-robot interaction function of the guide robot can be realized by means of touchscreen and the speaker. And there are two types of man-robot interaction function. The first type is during the stage of engineering deployment and happens between the field engineer and the robot. At the beginning, the screen UI buttons used to call out guiding & introducing missions are downloaded into the Uart touchscreen of the robot with the related media files such as pictures, audio or video files. Then the field engineer pushes the robot walk around the working field. When it closes to the destination facility or item, the field engineer touches the corresponding screen UI button. The Uart touchscreen send the ID of touched button and related media files to the embedded control bank. Then the embedded control bank combined the ID with the location coordinates. And the history location coordinates of the robot during this stage are recorded to form path map for navigation planning. The second type of man-robot interaction is between visitor and robot when the robot works. The visitor touches UI buttons to demand robot for guiding and introducing services. Then the robot finds the coordinates of the called introducing destination and the navigation paths for guilding. After arrival, the embedded control bank asks the Uart touchscreen to play related files and introduce the destination facilities or items.

5. THE ROBOT PROTOTYPE

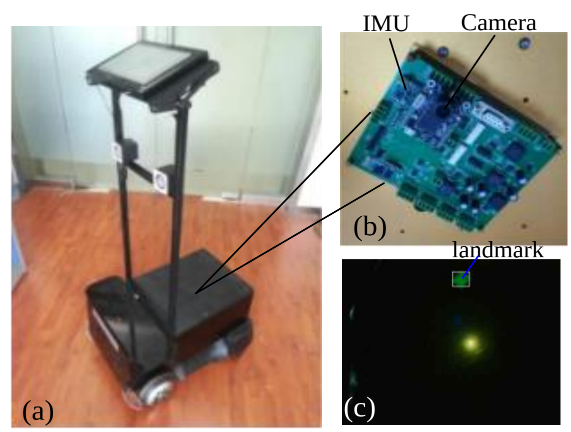

Figure 4. The robot prototype and its embedded control bank.

(a) Robot prototype, (b) Embedded control bank, (c) Landmark captured by the camera

According to the above design, a robot prototype and its embedded control bank are developed as shown in Figure 4(a) and Figure 4(b). The Uart touchscreen and speaker are mounted on the top of the robot. And the last parts of the robot constitute an intelligent mobile platform at the bottom, driven by a pair of brush-less DC Hub Motors. The mechanical structure of the platform is optimized into a downward opening cavity, where the embedded control bank is amounted in the internal center with its camera facing to the floor. Benefiting from the cavity structure, external natural or indoor lights are shielded, and the camera could capture and extract pixel features of the landmarks much faster and stably with an inner LED. Figure 4(c) shows image captured by the camera, where the landmark is marked with a white rectangle and the other round light spot in picture center is the reflection of the lighted LED on floor. On these hardware bases, the robot realizes self-localization function with approach proposed in the section 3. And the screen UI buttons are designed into a screen interface as shown in Figure 5, every button of which is related to an indoor position coordinates, an introducing picture and an audio file. Figure 6 shows a perform service instance of the robot to prove rationality of the design in this paper. When the visitor touched UI button "Service Robot Lab" in the center of the screen, the robot found the navigation line according to the taught history locations. Then the robot guided the visitor to the destination and showed the introducing picture in Figure 6 and played the related introducing audio file via the Uart touchscreen with its speaker.

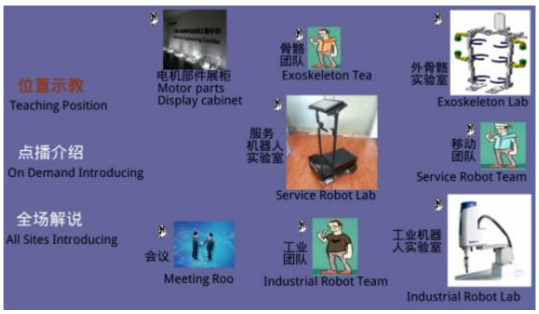

Figure 5. Screen interface of the prototype.

Figure 6. An introducing picture of the robot.

6. CONCLUSION

This paper designs an indoor guiding robot based on embedded control system to guide visitor and introduce facilities or items in indoor scenes such as a work center or exhibition rooms. Firstly, this paper designs an embedded electronic system framework to build low cost guide robots, involving self-localization sensors, multimedia interaction module, obstacle avoidance sensor, and differential driving mechanism for motion and embedded control bank. Secondly, a multi-sensor fusing approach to integrate the data of hall encoder, IMU and camera is given and completes the core function of indoor self-localization. At last, an indoor guiding & introducing service instance is performed with the developed robot prototype.

7. ACKNOWLEDGMENTS

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