Development of an Intelligent Patrol Robot System

Qiankun Sheng, Fei Xie, Weihan Bo and Yong Yue
Department of Computer Science and Software Engineering
Xi’an Jiaotong-Liverpool University
Suzhou, China
{qiankun.sheng11, fei.xie12, weihan.bo11}@student.xjtlu.edu.cn, {yong.yue}@xjtlu.edu.cn

Abstract — This research investigates the design and implementation of a patrol robot system with intelligent navigation. The patrol robot focuses on environmental modelling, path planning and real-time screen monitoring via multi-sensors. Challenges for the research are how to build a sensor network, how to design an algorithm for patrol path planning and how to build a video surveillance system in an effective way.

Keywords — patrol robot; intelligent navigation; multi-sensor network; video motion detection system

INTRODUCTION

Nowadays, driverless technology is able to perceive the road condition, automatically completing route planning and managing to arrive at the scheduled destination, which works mainly via vehicle sensor systems [1]. Patrol robots derived from this technology are considered to have broad application prospects, for example, in community patrol, environmental monitoring in dangerous areas and information consultation services in busy areas [2].

The main goals demonstrated in this research are as follows. Firstly, patrol robot is able to move automatically according to information collected by a multi-sensor system, and the patrol robot detects specific information of obstacles which is then applied to path planning, after which the patrol robot is able to plan the routes effectively. In addition, the camera on the patrol robot is designed to collect real-time information of surrounding the routes. The next step is to deal with the streaming media collected, mainly targeting on moving objects in the surroundings and taking photos of these objects into records.

SYSTEM FUNCTIONALITY

This research utilises several contemporary technologies including: multi-sensors to collect data and information in the surrounding environment; path planning to create effective routes and avoid collision; video motion detection to capture moving obstructions. These units communicate and co-ordinate with a control centre to enable the patrol robot to detect and avoid obstructions effectively while moving along the routes generated. The system architecture is shown in Fig. 1.

HARDWARE

Raspberry Pi 2B is chosen for the control centre. The Raspberry pi foundation provides Debian Linux ARM distribution as the operate system [3]. It also provides a lower level output by a number of GPIO pins which act as input or output pins to support hardware communications.

![System function architecture](image)

Figure 1. System function architecture

Numerous types of sensors can be used for the multi-sensor unit, such as human infrared sensor, light sensor, humidity sensor, temperature sensor and ultrasonic sensor. Human infrared sensor has advantage of low power consumption, high sensitivity and low price. Light sensor plays an active role to monitor light intensity in the surroundings to turn on the LEDs and allow the camera to collect clearly real-time video images in the surroundings. The humidity and temperature sensors acquire information of humidity and temperature in the surrounding environment. If the humidity and temperature data is abnormal, the robot will send out alert information. Ultrasonic sensor works by emitting ultrasonic waves and then calculating the interval time between emitting and receiving reflected ultrasonic waves, providing an effective method of distance measurement, which has a very low power consumption and is easy to use [4]. When ultrasonic projects on obstructions and reflects, a response signal is output by the ultrasonic module, and it measures the distance between the ultrasonic module and the object by calculating the time interval between the trigger signal and the response signal. The calculation is \( S = \frac{340 \times T}{2} \), where \( S \) is the distance and \( T \) is the duration of the Echo pin high level state (Fig. 2) [6].

The camera supports two types of video format, which are YUY2, 16/bits per pixel; MJPG, 24/bits per pixel, and 30 fps. The camera does not require any driver while being used with the Raspberry Pi via a USB connection. The camera is used cooperatively with OpenCV to detect motivating targets in the surrounding environment.

SOFTWARE

Because GNU/Linux is a well-known open source operation system which has been published under GPL [7], all
the software codes are run by Raspberry as the operation system in Dedain Linux.

In artificial potential field optimization, attractive field function and repulsive field function are applied to calculate attractive force and repulsive force accordingly. Then with the results, it would be able to figure out the resultant force. The attractive field function is shown as:

$$u_{atr}(q) = \frac{1}{2}\epsilon^2\rho^2(q, q_{goal})$$

where $\epsilon$ denotes the scaling factor of the attractive force; $\rho(q, q_{obs})$ indicates the distance between the current and target locations. The attractive field derivative of the distance is the attractive force and the formula is shown as:

$$F_{atr}(q) = -\nabla u_{atr}(q) = \xi(q_{goal} - q)$$

The repulsive field function is shown as:

$$u_{rep}(q) = \begin{cases} 
\frac{1}{2}\eta^2\left(\frac{1}{\rho(q, q_{obs})} - \frac{1}{\rho_0}\right)^2, & \text{if } \rho(q, q_{obs}) \leq \rho_0 \\
0, & \text{if } \rho(q, q_{obs}) > \rho_0 
\end{cases}$$

where $\eta$ denotes the scaling factor of the repulsive force; $\rho(q, q_{obs})$ is the distance between the current location and the obstruction; $\rho_0$ expresses the effecting radius of every obstruction. The repulsive field derivative of the distance is the repulsive force. The calculation formula is shown as:

$$F_{rep}(q) = -\nabla u_{rep}(q) = \begin{cases} 
\eta\left(\frac{1}{\rho(q, q_{obs})} - \frac{1}{\rho_0}\right)^2\nabla \rho(q, q_{obs}), & \text{if } \rho(q, q_{obs}) \leq \rho_0 \\
0, & \text{if } \rho(q, q_{obs}) > \rho_0 
\end{cases}$$

The resultant field is the superposition of the attractive field and repulsive field. The formulas are shown as:

$$U(q) = U_{atr}(q) + U_{rep}(q)$$

$$F(q) = -\nabla U(q)$$

**Video motion detection**

Video stream collected by the camera is processed by the video motion detection unit. Then every two adjacent images in the image collection are processed for differential detection [9], aiming to find the result of the background subtraction of the two images [10], which is shown as:

$$\theta_{dif}(x, y) = \theta_t(x, y) - (x, y)$$

In order to make the movement visible, the differential of three adjacent images requires comparison, which are Image_(t-1), Image_t, Image_(t+1). The differential between Image_(t-1) and Image_t, and the differential between Image_t and Image_(t+1) are measured. The results are written as $\Delta$ Image_(t-1) and $\Delta$ Image_(t+1) respectively. The operation formulas are shown as:

$$\Delta Image_{(t-1)} = Image_t - Image_{(t-1)}$$

$$\Delta Image_{(t+1)} = Image_{(t+1)} - Image_t$$

Finally, the intersection of $\Delta$ Image_(t-1) and $\Delta$ Image_(t+1) is achieved, which is the motion target detected [11].

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**Multi-sensor unit**

The multi-sensor unit collects information in the surrounding environment, to enable the comprehension of the environment by the control centre [8]. The information collected is incorporated into the JavaScript Object Natation (JSON) data format. The information collected is preliminarily delivered to Arduino in order to process it into human language. Then the data is sent to the control centre via serial communications for processing in the JSON format.

**Path planning**

Robot path planning is categorised into two types: Global path planning based on all environmental information, also called static or offline planning; Partial path planning based on sensors, also known as dynamic or online path planning. In this research, partial path planning based on sensors is applied.

There is prospective research in real time obstacle-avoidance and smooth trajectory control. Although there are improvement resolutions for the local minimum problem, no satisfied solutions have been found. In addition, some factors limit the broad application of path planning techniques based on artificial potential field optimisation. The difficulty in the application is the design of gravitation field and repulsive field, and the local minimum problem.
\[ \Delta \text{Image} = \Delta \text{Image}_{(t-1,t)} \land \Delta \text{Image}_{(t,t+1)} \]

The above formula enables the quick removal of useless background, so as to detect motion targets efficiently.

EXPERIMENTAL RESULTS

The intelligent patrol robot system is shown in Fig. 4 below.

![Figure 4. The hardware of intelligent patrol robot system](image1)

Java programing simulation is performed to demonstrate the potential field path planning. Fig. 5 shows the path planning results when the patrol robot faces a wide range of obstacles. The testing result of motion detection is shown in Fig. 6.

![Figure 5. Path planning algorithm testing](image2)

Figure 6. Video motion detection algorithm testing

CONCLUSION AND FURTHER WORK

In this research, an unattended intelligent patrol robot system has been designed and implemented. Good performance has been achieved in exploring the environment, path planning and video motion detection.

REFERENCES


