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An Autonomous Positioning and Navigation System for Spherical Mobile Robot

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Abstract

In this paper, we provide an autonomous positioning and navigation system for spherical robot. Firstly, the working principle and advantages of the spherical robot in our laboratory are described particularly. Secondly, the autonomous positioning and navigation system is presented. In this system, the GPS (global positioning system) navigation and visual navigation are used coordinately to realize their own advantages to improve the accuracy and reliability. Thirdly, in the visual navigation system, the algorithm of wavelet analysis used for the image identification to reduce image data processing amount is given, which can improve identification accuracy and efficiency. Finally, the experimental result in the spherical robot shows feasibility of the autonomous positioning and navigation system.

Keywords: spherical mobile robot; positioning and navigation system; GPS navigation; visual navigation; wavelet analysis

1. Introduction

Navigation is a major task for autonomous mobile robots. The common methods to realize navigation are: visual navigation, map model navigation, bionic navigation and global positioning system navigation. Visual navigation [1] is used in many kinds of robots, such as medical robots, space robots. It is required for local, very precise navigation, and this navigation rarely is applied for the long distances. And in the visual navigation, the image identification is the main and hot topic for a long time. The automobile guidance and localization for traveling long distances based on GPS has developed maturely [2]. Although many kinds of spherical robots are proposed by many scholars, there are few designs about the positioning and navigation for the spherical mobile robot, which can make the robot execute the tasks

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independently in many fields, such as environment monitoring and working in the severe conditions. So a design of positioning and navigation system based on a combination of GPS and visual navigation for spherical robot is presented in this paper.

As a novel mobile robot, spherical robot has been studied by many scholars in recent years [3-4]. A spherical robot is a kind of mobile robot which has a shape of ball and consists of driven mechanism and control system inside the spherical shells. Most of these robots rely on the relocation of internal weight distribution or mass point for propulsion. Spherical robot has the character of flexible movement, and can protect the mechanism and electronic devices in the spherical shells, so it is suitable to be used in many harsh environments, such as in the rain or snow weather and bumpy surface.

Professor Sun, Hanxu in Beijing University of Posts and Telecommunications started to research spherical mobile robot in 2000 and later developed a variety of spherical mobile robot prototypes. More details of the development of spherical robots can be found in [5-7]. Some of the spherical robots made in our laboratory are shown in Fig 1. These robots are designed as tools and toys, and in practice, many of them have achieved a lot of functions. BYQ-8, as a novel kind of spherical robot, was developed in 2009, and it has obvious advantages in many aspects. In order to realize autonomous movement and navigation, a GPS positioning and visual navigation system is installed in the BYQ-8 spherical mobile robot prototype.

Fig. 1. Some of spherical mobile robot prototypes made in BUPT

The rest of the paper is organized as follows: in the following section the working principle and unique advantages are described in detail. In Section 3 process of the autonomous positioning and navigation system using GPS and visual navigation is introduced with the diagram and interpretation. In the visual navigation system, wavelet analysis used on the image identification to reduce image data processing amount is introduced detailedly in Section 4. Finally experimental result on the system is given in Section 5 to attest the feasibility of the design. The paper ends with some conclusions in Section 6.

2. Working Principle of Spherical Mobile Robot

Many researchers developed different kinds of spherical robots considering relocation of internal weight distribution of the ball for propulsion. While the spherical robot in Fig 2, named BYQ-8, is driven through the left and right hemispherical shells differentially to realize movement. It is still like a ball and just makes the two shells have a gap, but the way of the motion is different from relocation of mass point.

This spherical mobile robot contains two parts: two hemispherical shells (with driven system) and the inner actuator. The two parts connect together with the flanges. Two hemispherical shells, as the moving parts, can drive the robot to make motions. When the two shells have the same speed of rotation, the robot walks a straight line. When the two shells have the different speeds, the robot turns a corner to the side of slow shell. The inner actuator, as the platform of the robot, carries the power supply, the automation positioning and navigation system devices and etc.

Fig. 2. Model and prototype of the spherical robot(BYQ-8)

This spherical robot's unique design leads many advantages prior to other spherical robots:

Movement: Based on the structure, the robot has a flexible movement. It can turn on the spot and move with a high speed. The robot has the ability of climbing and over obstacles, so it is suitable to variety of different terrains and environments.

Control: The control of the spherical robot's movement is based on the differential driven system. And the main controller connects the sensors inside to monitor the robot moving automatically.

Stability: This robot has a stable platform to carry the sensors and payloads. The hemispherical shells can protect the inner mechanical parts and sensors effectively.

3. Autonomous Positioning and Navigation System

The design of autonomous positioning and navigation system is based on GPS, visual processor, gyroscope, and main controller. The GPS system is used for the robot to position and navigate in a long distance, and the robot compare the robot's GPS data and the target's GPS data to get the relative position between both, which guides the direction of motion for the robot later. The visual processor is adopted in the close distance, and when the robot is away from the target in some distance (outside of the GPS's accuracy), the visual processor is launched and searches the target. From gyroscope, the robot gets the pose information. It is used to decide the motion of the spherical robot. The main controller is the core of the autonomous positioning and navigation system.

The process of the system includes 2 parts: the GPS navigation and the visual navigation.The GPS navigation: The main controller is given the GPS data of the destination by the user, and the robot gets its own GPS data from GPS system and its pose information from the gyroscope. Then the main controller combines the robot's own data with the GPS data of the destination to get the destination's position relative to the spherical robot, which decides the direction of the spherical robot movement. Combined the relative position data and the pose information, the spherical robot calculates the angle to change the direction in the main controller. The main controller sends the signal to the motor driven systems to changes the direction of motion. When the robot's direction points to the destination, the spherical robot makes a linear motion to move closer to the destination. In order for the robot to reach destination, the above process is a continuous loop until the robot is certain meters (outside of the GPS's accuracy) away from the target.

The visual navigation: When the robot's GPS data are close to the destination's GPS, the robot starts its visual navigation system and stops its GPS navigation system. It rotates with zero radius and uses the camera to get the images to find the destination by image matching. The image identification is processed in the visual processor. When finding the destination, the robot stops rotating and runs to destination with a linear motion.

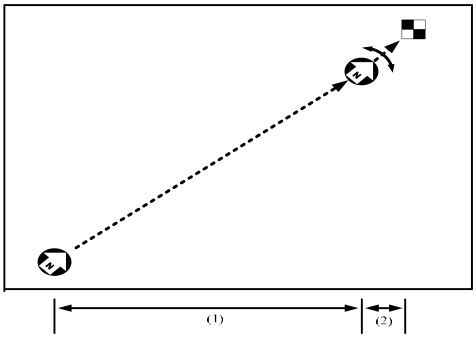

Fig.3. the process of the autonomous positioning and navigation system ((1): the GPS navigation; (2): the visual navigation)

4. Wavelet Analysis used on Visual Processing

In this system, there are too many data including GPS data and image data need to be processed. For the part of GPS, The data obtained from the GPS system fluctuate more than expected, which have an adverse impact on the positioning of the robot itself. So the GPS data received are dealt with the Kalman filter algorithm in the main controller to improve the accuracy of data [8]. For the visual processing, a boundary of image data should be solved to identify the destination, so the visual data need to be handled fast to accelerate the process.

The wavelet theory and its application have been developed fast in the last years, especially in the field of visual processing. It is a mathematical tool that cut up data into different frequency components, and then study each component with a resolution matched to its scale. It has obvious advantages over Fourier transform in analyzing the signal that contains discontinuities.

A mother wavelet can be defined by

$$\psi_{a,b}(x) = \frac{1}{\sqrt{a}}\psi(\frac{x-b}{a})$$

where a, b are the factors of the function. And this function satisfies the condition below,

$$c_{\psi} = \int_{-\infty}^{\infty} \frac{|\psi(\omega)|^2}{|\omega|} d\omega < \infty$$

where $\psi(0) = \psi(\infty) = 0$, $\int_{-\infty}^{\infty} \psi(x)dx = 0$.

When taking a and b as the discrete integers, for example, $a = 2^j, b = 2^j k$, then

$$\psi_{j,k}(t) = 2^{-j/2}\psi(2^{-j}t - k), j,k \in Z$$

In 1910, Mathematician Haar, A. in [9] proposed a first mother function

$$\psi(\omega) = \begin{cases} 1, & if\, 0 \le t \le 1/2; \\ -1, & if\, 1/2 \le t \le 1; \\ 0, & elsewhere; \end{cases}$$

where $\psi(\omega)$ is an orthonormal wavelet for $L^2(\Re)$. This is called the Harr wavelet. It is a basis for $L^2(\Re)$.

Multi-resolution analysis (MRA) comes from computer vision theory, for example, when watching the objects, people always follow the far to near objects from low resolution to high resolution. The profile of the object is got firstly, and then an increasing number of clear details about the object image are solved, such method is called Multi-resolution analysis.

After researching the details and approximation of the signal, Mallat in [10] found a mother wavelet could be used in the different resolutions. So he provided the MRA theory, and gave the specific mathematical description.

$$\phi_{jmn}(x,y) = 2^{i}\phi(2^{-j}x - m, 2^{-j}y - n) \ ,(m,n) \in Z^2, j \in [1,\infty)$$

So MRA in $L^2(\Re)$ is defined by

$$\begin{cases} S_j f(n,m) = (f(x,y)\phi_j(x,y))(2^{-j}n, 2^{-j}m) \\ W_j^1 f(n,m) = (f(x,y)\phi_j^1(-x,-y))(2^{-j}n, 2^{-j}m) \\ W_j^2 f(n,m) = (f(x,y)\phi_j^2(-x,-y))(2^{-j}n, 2^{-j}m) \\ W_j^3 f(n,m) = (f(x,y)\phi_j^3(-x,-y))(2^{-j}n, 2^{-j}m) \end{cases}$$

The MRA wavelet, as the fast wavelet transform algorithm, is popular in the field of computer science and signal process. So we decide to adopt the algorithm in the visual system. Target detection process includes image acquisition, image preprocessing, image segmentation, target identification. The last three parts above can be handled by wavelet analysis. In my design, the wavelet analysis algorithm is mainly applied in the target identification.

5. Experiment of System

In this system, we use ARM processor AT91SAM7X256 as the main controller. And we choose a puck-size 3DM-GX1 Inertial Measuring Unit (IMU) as a gyroscope, a PCB-EX11DP CCD camera with visual processor, and a GPS system named NEWSTAR220E to make up this system.

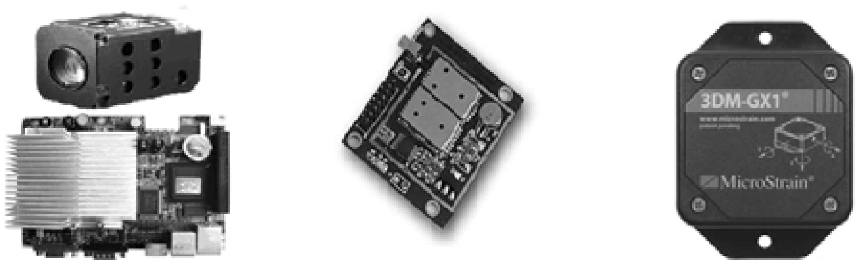

Fig.4. The autonomous positioning and navigation system (left to right: camera with visual processor; GPS system; a gyroscope)

The experiment for the system is carried out in a broad ground. The distance between the robot and the target is about 200m. The target location information and destination images are respectively input into the main controller and image processor. Due to the fluctuate of the spherical robot's own GPS data still exist and the GPS data are not accurate enough, so the spherical robot cannot reach the destination precisely. It can reach the specified location within about 12m. Then the spherical robot starts the visual navigation system, rotates and searches the mark of destination by image matching. After finding the mark, the robot stops rotating and makes a linear motion to near the destination. In the end, the robot reaches the destination and finishes the task.

Of course, in this paper, we consider the ideal environments, such as the broad ground without any obstacles. In the next step, we prepare some sensors for the robot to detect the surrounding and make reactions in time.

6. Conclusion

In summary, an autonomous positioning and navigation system for spherical robot is presented. As the spherical robots have been studied for many years, we design an autonomous positioning and navigation system for the spherical robots developed in our laboratory. The autonomous positioning and navigation system includes two parts: GPS navigation and visual navigation. The combination of the two parts can achieve this function well. In the system, the image identification based on wavelet analysis can make the whole movement more reliable and efficient. Finally, the experimental result on the spherical robot indicates the effectiveness of the design of the autonomous positioning and navigation system.

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