Design of Intelligent Safety Protection Robot Based on Global Position System and Machine Vision

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Abstract. In this paper, an intelligent safety protection robot based on the integration of Global Position System(GPS) and machine vision is designed. The robot takes STM32F407 as the control core and is equipped with a variety of environmental monitoring sensors to realize real-time monitoring of the surrounding environment and alarm for potential safety hazards. In order to realize the stable and accurate autonomous navigation of robot, a system combining GPS technology with visual simultaneous localization and mapping (V-SLAM) technology is designed. GPS module collects longitude and latitude information, driving speed and heading Angle to complete the absolute positioning of the robot. Machine vision device collects image information, and the relative positioning of the robot is completed through digital image processing technology. The two positioning information was fused and output new positions and postures through Unscented Kalman Filter (UKF). Through the experimental verification of the combined navigation and positioning effect, the GPS and machine vision integrated navigation device has high precision, and the maximum error is controlled within 0.1 meters.

1.Introduction
The traditional security system relies on the way of "human defense + physical defense". The "human defense” system has the disadvantages of serious aging of staff, easy negligence and delay in finding problems. The "physical defense" system can only be installed in a fixed position, it has the disadvantages of high cost and maintenance trouble. With the development of economy and society, people's safety awareness is gradually improved, the requirements for the security system are also more and more high. The intelligent safety protection robot with the advantages of flexible inspection, simple maintenance, low cost and high safety factor is the trend of the future security system and has a huge market prospect. The intelligent safety protection robot integrated with GPS and machine vision is designed based on the above objectives.

2.Hardware system design of intelligent safety protection robot
The safety protection robot system takes STM32F407 as the control core, which controls its straight going, steering, starting and stopping. The drive chip -L298N is used to drive the DC motor to make the robot move. The GPS module is used to collect the longitude and latitude of the robot's location, the heading angle and the traveling speed. Machine vision navigation device uses vision sensor to collect the image information of the environment, and then uses modern image processing technology.
to obtain the navigation baseline and feature points. The HY-SRF05 ultrasonic sensor to achieve the robot to avoid obstacles; the temperature and humidity sensor is used to monitor the ambient temperature; the smoke sensor is used to monitor harmful gases; the independent 360 webcam can realize face recognition and real-time video monitoring; Wi-Fi module is used to communicate with remote administrator and report alarm information in time. Figure 1 is the block diagram of the hardware system of the intelligent security protection robot.

Figure 1. Block diagram of hardware system of intelligent security protection robot.

3. GPS and V-SLAM integrated navigation system
An accurate and reliable autonomous navigation system is the core technology for robots to realize intelligence. The common positioning and navigation systems include vision navigation system, inertial navigation system, satellite navigation system and magnetic navigation system. GPS is an absolute positioning and navigation system, which is widely used and has mature technology. It can measure the position and path of the robot in real time. But GPS signal is easily affected by the weather, buildings and obstacles and lost signal. V-SLAM technology equipped with camera sensors, can establish the environment model and estimate the robot's motion without prior knowledge. V-SLAM technology has obvious advantages in cost, intelligence and energy consumption, but the vision sensor is easy to be affected by light and weather, and its calculation is complex and real-time is poor. This paper proposes a scheme based on the integration of GPS technology and V-SLAM. Figure 2 shows the principle block diagram of GPS and V-SLAM integrated navigation system.
4. Principles of visual simultaneous localization and mapping

Visual simultaneous localization and mapping (V-SLAM) system usually includes several modules: image acquisition, visual odometer, back-end optimization, mapping and loop detection. Figure 3 is the block diagram of V-SLAM principle.

- Vision sensor is used to collect image information. V-SLAM system has monocular, binocular, and RGB-D V-SLAM according to different vision sensors.
- Visual odometry (VO) estimates camera motion based on the information of adjacent images. According to whether feature points need to be extracted or not, the implementation of VO can be divided into feature point method and direct method.
- The back-end optimization is based on the camera pose information and loop detection information measured by the receiving visual odometer. It deals with the noise problem in SLAM process, and establishes the trajectory and map consistent with the global situation.
- Loop detection is used to detect whether the camera passes through the same place. It provides more effective information for back-end optimization and limits the accumulation of camera trajectory error.
- Mapping is based on the practical application of SLAM to establish the corresponding map.

5. Unscented Kalman filter algorithm

Unscented Kalman filter (UKF) can be regarded as the combination of UT transform and standard Kalman Filter (EK). EK algorithm is a widely used information fusion method. Its main function is to predict the state of linear system and modify the prediction. However, EK is not effective for nonlinear systems. UT transform technology enables the standard EK algorithm to effectively fuse the information of the nonlinear system and filter out the interference and noise in the system. It studies the past of the target, and makes the optimal estimation of its present and future states.
5.1. UT transformation is the key of UKF in dealing with nonlinear systems. The specific steps of UT transformation are as follows:

- Let \( x \) be the \( n \)-dimensional state vector, its mean value is \( \bar{x} \) and its variance is \( P_x \). According to the formula, \( 2n + 1 \) sigma points \( x_s \) are constructed and their weights \( \omega_i \) are calculated.

\[
\begin{align*}
x_s &= \bar{x} + \left( \sqrt{(n + \lambda) P_x} \right), \quad s = 1, 2, 3 \ldots n \\
x_s &= \bar{x} - \left( \sqrt{(n + \lambda) P_x} \right), \quad s = n + 1, n + 2, n + 3 \ldots 2n \\
\omega^s_0 &= \lambda / (n + \lambda) \\
\omega^s_0 &= \lambda / (n + \lambda) + (1 - \alpha^2 + \beta) \\
\omega^s_{i} &= \omega^0 = 1 / 2(n + \lambda), \quad i = 1, 2, 3 \ldots 2n
\end{align*}
\]

- After the nonlinear function \( y_s = f(x_s) \) transformation, the mean and variance of \( Y \) are predicted according to the formula.

\[
\begin{align*}
\bar{y} &\approx \sum_{i=0}^{2n} \omega^s_{i} y_s \\
P_y &\approx \sum_{i=0}^{2n} \omega^s_{i} \left[ y^i - \bar{y} \right] \left[ y^i - \bar{y} \right]^T
\end{align*}
\]

5.2. UKF mainly includes prediction and update. Its complete steps are as follows:

- According to the construction method of sigma point, the \( i \)-th sigma point \( x^{(i)}_{k-1} \) at \( k-1 \) time is determined, its mean value is \( x_{k-1} \) and its variance is \( P_{k-1} \).

- According to the obtained sigma points at \( k-1 \) time \( x^{(i)}_{k-1} \) and the prediction model, the predicted value of sigma points at \( k \) time \( x^{(i)}_{k} \) is calculated. Its predicted mean value is \( x^' \), and its covariance is \( P^' \).

\[
\begin{align*}
x^{(i)}_{k} &= A_{k-1} x^{(i-1)}_{k-1}, \quad i = 1, 2, 3 \ldots 2n \\
x^' &= \sum_{i=0}^{2n} \omega^s_{i} x^{(i)}_{k} \\
P^' &= \sum_{i=0}^{2n} \omega^s_{i} (x^{(i)}_{k} - x^') (x^{(i)}_{k} - x^')^T + Q_{k-1}
\end{align*}
\]

- The sigma points are updated according to the predicted mean and variance.

- The predicted values are calculated by the observation function matrix and the observation mapping function.

\[
\begin{align*}
\hat{z}^i_{k} &= H_k x^i_{k}, \quad i = 1, 2, 3 \ldots n \\
\hat{z}^i_{k} &= \sum_{i=0}^{2n} \omega^s_{i} \hat{z}^i_{k} \\
P_z &= \sum_{i=0}^{2n} \omega^s_{i} (z^{(i)}_{k} - \hat{z}^i_{k}) (z^{(i)}_{k} - \hat{z}^i_{k})^T + R
\end{align*}
\]
\[ P_{x,x} = \sum_{j=0}^{2n} a_j^c (x_k^{(i)} - \hat{x}_k) (z_k^{(i)} - \hat{z}_k)^T \] (14)

- GPS module and machine vision navigation module get the observation value and use it to update the optimal value of K time. \( K_k \) is the gain matrix of UKF. The updating formula is as follows:

\[ x_k = \hat{x}_k + K_k(z_k - \hat{z}_k) \] (15)
\[ K_k = P_{x,x}^{-1} \] (16)
\[ P_k = \hat{P}_k - K_k P_x^{-1} K_k^T \] (17)

6. Experiment and result of integrated navigation

In order to verify the positioning effect of the safety protection robot, the experiment is carried out in the campus of Wuhan Technology and Business University. The GPS module is mounted on top of the robot. The machine vision navigation device is installed at the front end of the robot, the height from the ground is 0.95 meters, and the angle between the robot and the horizontal plane is 45 degrees. The robot runs at a speed of 0.6 m/s, and the direction is east-west. After 8 groups of data are collected and analyzed, the fusion positioning effect of GPS and machine vision is better than pure vision positioning, and its maximum error is controlled within 0.1M. Figure 4 shows the positioning error curve of the combination of GPS and machine vision.

![Positioning error curve of GPS and machine vision](image)

7. Conclusions

The integrated navigation technology of GPS and machine vision proposed in this paper is conducive to the accurate navigation of robot in complex environment such as weak GPS signal and poor lighting conditions. The maximum error is less than 0.1M. Intelligent safety protection robot is developing in the direction of autonomy, integration and function diversification. It is the inevitable trend of the future security system development.

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