Research on All Terrain Tracking Platform Based on Inertial Navigation

Gan Yong¹, Zhang Qiufeng²*, Pan Siliang³, Meng Xu⁴, Zhu Weiqiang⁵

College of Electrical and Mechanical Engineering, Guilin University of Electronic Science and Technology, Guilin 541004, China

*Corresponding author’s e-mail: 925253380@qq.com

Abstract. In order to solve the dangerous situation that search and rescue personnel are not suitable for direct internal search and rescue in harsh closed environment without GPS signals, an all-terrain trajectory tracking platform based on inertial navigation is designed and studied. An autonomous navigation system is composed of low cost, low power consumption, small size MEMS inertial elements, which do not depend on external information and radiate energy. Kalman filter is used to fuse the data of accelerometer, gyroscope and magnetometer and output stable and reliable azimuth angle. By combining the Hexapod joint structure with the roller track structure, the multi-environment and all-terrain machine traveling is realized. The experimental results show that the three-dimensional and two-dimensional space trajectories can be clearly drawn in outdoor complex environment. In indoor environment, the platform achieves positioning error within 5 meters, deviation is not more than 10 cm, and draws a map that conforms to the platform trajectory. The development of the platform provides a powerful help for exploration work.

1. Introduction

Dangerous accidents often occur unexpectedly. Search and rescue in the case of unfamiliar terrain and unknown terrain risk factors often waste a lot of time. The existing rescue platforms have various problems, such as the crawler rescue platform. It meets the needs of military reconnaissance, dismantling dangerous objects, etc., and develops on the basis of traditional wheeled robots. It has a fast moving speed, but it can’t travel in the face of a rugged environment. It is relatively large in size and inconvenient to enter narrow. Space, and most of the rescue platform design research is based on GPS positioning for trajectory simulation. Although the wired communication method is relatively stable, the terrain of the dangerous area is complicated and the space is small. The transmission mode using wired communication affects the progress of the rescue platform. Moreover, in the real environment, GPS satellite navigation has certain restrictions[1]. For example, in buildings, tunnels, caves and other closed environments, the attenuation is very serious. In most cases, accurate positioning information cannot be provided. Therefore, the use of inertial navigation system to build an expedition platform is proposed, and the inertial navigation system is currently used for indoor positioning. For example, Zhou Wei[2] proposed an indoor positioning system based on micro-electromechanical inertial measurement unit, which is applied in the field of outdoor exploration. less. In order to solve these problems, we develop an all-terrain trajectory tracking platform based on inertial navigation.
2. Design of the system and structure of the platform

Inertial navigation system (INS) is an important positioning method in the field of navigation at present\cite{3}. It has many advantages such as high autonomy, full-parameter navigation (providing 9-dimensional navigation parameters such as carrier position, speed, course, etc.) and high precision of short-term navigation\cite{4}. Aiming at this advantage, an all-terrain trajectory tracking platform based on inertial navigation is developed as shown in Figure 1(a) and (b), which includes a set of high-precision, less disturbed inertial navigation system for plotting the platform's motion path and a set of all-terrain motion structure suitable for various complex terrain. Its features are as follows: the system is mounted on the omni-terrain mobile robot, tracking and recording the path of the robot in search and rescue, providing simple maps of dangerous environment and environmental conditions for staff, and making anticipated preparations for further search and rescue work.

![Figure 1(a)](image1)

![Figure 1(b)](image2)

Figure 1. All Terrain Tracking Platform Based on Inertial Navigation

Inertial navigation system is composed of trajectory tracking module and automatic return module. The function of tracking module is to use complementary algorithm to give different weights to acceleration and gyroscope, and combine them together to correct and oblique. The Kalman filter receives the angular value, angular velocity value and time increment of an axis, and estimates the angular value of noise elimination. According to the current angle value and the last estimated angle value, and the interval time between the two estimated rounds, the angular velocity of noise elimination is deduced. The function of the automatic tracking return module is to store the data of the platform's trajectory. When the signal interruption occurs and the external staff can't control it, the platform begins to read the trajectory data and realize the platform's automatic trajectory return along the original path.

3. Design of Platform Control System

3.1 Hardware Design

Aiming at the complex and diverse application occasions of all terrain trajectory tracking platform, the tracking platform adopts bionics design, combines the Hexapod joint structure with the roller track structure, supports remote control switching, and develops a traveling mechanism suitable for various complex terrain. The hardware connection block diagram is shown in Figure 2 (c). The trajectory tracking function is realized by using STM series of Italian Semiconductor Company as the main control chip, matching with InvenSense's 6-axis motion module MPU6050 and Honeywell's three-axis geomagnetic sensor HMC5883L. Figure 2(d) shows the hardware connection block diagram drawing control chart for inertial navigation trajectory, which is composed of a serial port receiving data host computer programmed by Matlab and a remote controller for trajectory display of TFT-LCD 4.3 inch touch display screen. It has the functions of three-dimensional and two-dimensional trajectory acquisition and rendering and environmental data acquisition and receiving.
Figure 3 is the circuit diagram of INS. It consists of MPU6050, HMC5983 and BMP280. MCU can read the digital data of sensor through IIC communication protocol. After fusion algorithm, the information of device attitude angle and speed can be obtained. MPU6050 supplies power through simple RC filter, and communicates with the main controller through IIC communication protocol. One foot, 10 feet, 11 feet grounding, 20 feet grounding, 21 feet grounding and adding filter capacitor, 6 feet, 7 feet are connected with BMP280 by IIC slave communication, 5 feet and 8 feet of BMP280 are connected by decoupling capacitor to remove power noise, which provides stable external conditions for BMP280 work. HMC5983 also uses IIC communication protocol to communicate with the main control, one foot to connect the clock line and 16 foot to connect the data line. Two feet are connected to the positive pole of the power supply and decoupling capacitors are added. Five feet are drawn out and 15 feet are convenient for the main controller to control.

3.2 Research on the Navigation algorithm of system

Inertial navigation is essentially a dead reckoning system\(^5\), which is shown in Figure 4 as a sketch of dead reckoning algorithm. The platform adopts passive inertial navigation, collects the original data of inertial elements of remote control platform in inertial reference system, and calculates the information of velocity, attitude angle and yaw angle in navigation coordinate system by data fusion and attitude calculation. The inertial coordinate system diagram is shown in figure 5. According to the working principle of inertial navigation system, the mathematical models of each attitude angle and position are established\(^6\). The following is a differential equation of inertia. The displacement of the target object is obtained by quadratic integration of linear acceleration\(^7\). The motion of the platform starts from the position of a known point. According to the direction angle and velocity measured continuously, the position of the lower point of the platform is calculated, and the trajectory of the moving body is plotted according to the coordinate information of the continuous calculation. Specifically: the component of the accelerometer is compressed, and the "inertia force" of the object is measured by the sensor, and the inertial force of the object is measured by the:
The acceleration value is calculated. According to the Coriolis force principle of the gyroscope, the angular velocity of the rotating object is output, according to:

$$\dot{\theta} = \int \omega(t) dt$$

Calculating the rotation angle of the platform, collecting the rotation angle at a certain time interval, obtaining the plane acceleration direction, and combining with the magnetometer, compensating the correction direction in real time. The attitude angle is obtained by solving quaternion rotation matrix:

$$
\begin{pmatrix}
\cos \frac{\psi_0}{2} \cos \frac{\theta_0}{2} \cos \frac{\gamma_0}{2} + \sin \frac{\psi_0}{2} \sin \frac{\theta_0}{2} \\
\rho_1(0) \\
\rho_2(0) \\
\rho_3(0) \\
\rho_4(0)
\end{pmatrix} =
\begin{pmatrix}
\cos \frac{\psi_0}{2} \cos \frac{\theta_0}{2} \sin \frac{\gamma_0}{2} - \sin \frac{\psi_0}{2} \sin \frac{\theta_0}{2} \\
\cos \frac{\psi_0}{2} \sin \frac{\theta_0}{2} \cos \frac{\gamma_0}{2} - \sin \frac{\psi_0}{2} \cos \frac{\theta_0}{2} \\
\sin \frac{\psi_0}{2} \cos \frac{\theta_0}{2} \cos \frac{\gamma_0}{2} - \sin \frac{\psi_0}{2} \sin \frac{\theta_0}{2} \\
\sin \frac{\psi_0}{2} \sin \frac{\theta_0}{2} \sin \frac{\gamma_0}{2} + \cos \frac{\psi_0}{2} \cos \frac{\theta_0}{2}
\end{pmatrix}
$$

(3)

and the tilt angle of the platform is obtained. Then the acceleration formula:

$$\ddot{a} = a_x \hat{x} + a_y \hat{y} + a_z \hat{z}$$

(4)

is used to get the magnitude and direction of the acceleration at each moment. According to the principle of integral operation, in the time domain from time $t_0$ to time $t_1$, the initial position, initial velocity and acceleration are known. The velocity at the next moment is calculated by integral formula:

$$\dot{v}(t) = \int \ddot{a}(t) dt + \ddot{v}_0$$

(5)

then $V_x$, $V_y$, $V_z$ is obtained by trigonometric transformation according to the attitude angle of the platform. Using the displacement integral formula

$$\ddot{s}(t) = \int \dot{v}(t) dt + \ddot{s}_0$$

(6)

the position of the next moment can be obtained by integrating again. Through remote data transmission to the control end, the platform's motion trajectory is drawn in $(x, y, z)$ coordinate system. As shown in Figure 6, the upper computer trajectory tracking map, the three-dimensional view on the left recorded the path of the platform on the flat ground and complex terrain, and the two-dimensional view on the right showed the path synchronously.

$V_0$ is the instantaneous velocity of the object at time $t_0$ and $S_0$ is the displacement of the object in time domain from time 0 to time $t_0$. 

$$a = F/M$$

(1)
4. Test and analysis of indoor and outdoor motion of platform

The indoor positioning experiment 1 was carried out in the fifth floor corridor of 2 #, and the test environment was the trajectory tracking host computer software. The tracking platform starts at the fixed initial point A and travels three straight lines to point B. Including 2 90 degree turns, and finally automatically return to the original position, cycle four times. As shown in figure (e). The indoor positioning test 2 was carried out in the fifth floor corridor of 2 #, and the test environment was the software of trajectory tracking host computer. As shown in figure (f), the tracking platform starts at the fixed initial point A, travels the fixed rectangular path, and returns to the initial position A.

As can be seen from the graph (e), the tracking platform from point A to point B is in good agreement with the four test curves and can all return to the initial position. However, the tracking platform produces position deviation when turning, so the curve drawing can not be completely coincident. As can be seen from the graph (f), the tracking platform moves a rectangular track from point A back to the initial point A, and the rectangular path drawn is in accordance with the actual trajectory, but there is a position deviation when it returns to the initial position A. The test shows that the running track and the real path are within 5 m, the deviation is less than 10 cm, and the design requirements of the project are basically completed.

5. Conclusion

The experimental results show that the platform can clearly and accurately plot the three-dimensional and two-dimensional space trajectory of the platform movement in outdoor complex environment. The platform can achieve positioning error within 5 m, deviation is not more than 10 cm, and draw a map
that conforms to the platform motion trajectory in indoor environment. The research and development of the platform can enable the later explorers to obtain precious high-precision three-dimensional space and two-dimensional plane map, which facilitates the exploration operation and saves precious time.

Acknowledgments
Thank my tutor for his guidance in this project, and my classmates for their help and encouragement in the experiment. This work is financially supported by National Nature Fund (51665008) Research on Nondestructive Measurement and reconstruction of mechanical parts based on grid slice volume measurement. It’s also supported by Innovation Project of GUET Education(2018YJCX10), Undergraduate Innovation and entrepreneurship training program project (201810595013) (201810595193).

References
[1] Wang Di. Inertial Navigation Technology Based on Kalman Filter [D]. 2018
[2] Zhou Jing, Chen Miaohong, Wu Haojie. Research on plane trajectory estimation based on inertial navigation [J]. Computer Science, 2017 (S1): 592-596.
[3] Vector Road Aided Inertial Navigation Algorithms [J]. Journal of Surveying and Mapping, 2017 (08): 100-112.
[4] Song Lei. Research on multi-stage geomagnetic aided inertial navigation algorithm based on entropy and ICCP [J]. Journal of North China University of Science and Technology, 2014, 11 (10): 70-74.
[5] Lei Hongjie, Zhang Yachong. Overview of Airborne Inertial Navigation Technology [J]. Aviation Precision Manufacturing Technology, 2016, 52 (1): 7-12.
[6] Tao Yunfei, Yang Jianjian, Li Jiacai, et al. Research on the Position and Attitude Measurement System of Roadheader Based on Inertial Navigation Technology [J]. Coal Technology, 2017 (1).
[7] Wang Jiajun, Yang Lu, Zhang Yuanjun. Inertial navigation and positioning system based on MPU-6050 motion sensor [J]. Science and technology and engineering, 2017 (18): 258-262.