Chinese Journal of Polar Science, Vol. 21, No. 1, 91 - 99, June 2010

Experimental Application of Intelligent Robot Technology in Antarctic Scientific Expedition

Li Bingrui(李丙瑞)[1], Qin Weijia(秦为稼)[1], Guo Jingxue(郭井学)[1], Zhao Yiwen(赵忆文)[2], and Liang Jianhong(梁建宏)[3]

1 Polar Research Institute of China, 451 Jinqiao Road, Shanghai 200136, China

2 Shenyang Institute of Automation Chinese Academy of Sciences, 114 Nanta Street, Dongling District, Shenyang 110016, China

3 Beihang University, 37 Xue Yuan Road, Haidian District, Beijing 100191, China

Received February 10, 2010

Abstract Intelligent robot technology has great potential for application in polar scientific expedition. During the 24th Chinese Antarctic Expedition in the summer of 2007/08, our ice-snow surface mobile and low-flying robots were successfully employed for the first time in the Antarctic. This paper firstly gives a brief introduction to the intelligent robot technology developed abroad and used in the Antarctic, then focuses on the ice-snow surface mobile and low-flying robots developed by China as well as their field trials in the Antarctic. Moreover, the authors have considered the potential demand for the intelligent robot technology in China's Antarctic scientific expedition, in the hope of providing some reference for the future development of robot technologies.

Key words Antarctic scientific expedition, ice-snow surface mobile robot, low-flying robot, scientific load.

1 Introduction

There are enormous natural and scientific resources in the polar region. On one hand, the variations of the environmental elements of the polar region covered with ice and snow, as the largest cold source of the Earth, play a critical role in the global climate change[1]; On the other hand, the development and utilization of polar resources is of unparalleled strategic significance in the political and economic aspects[2,3]. At present, major countries in the world have all substantially increased their input into the polar expedition and research, and are pressing forward in the fields of resource utilization, scientific research, etc.

However, the harsh polar environments are the main choke point for further polar scientific development, which include the frequent small spatial and temporal scale weather systems as well as tide cracks in sea-ice, ice sheet crevasse, and low temperature, etc. So far, there have been no mature technical means of ground scientific observation in high-risk polar areas. With the expansion of the polar scientific expedition, it has become an urgent need to introduce hi-tech equipment into future polar observations. Intelligent robots, as a hi-tech equipment, can incorporate scientific loads, partly acts as a substitute for scientists, and effects some functions as roaming about, observation, sampling and analysis, etc., which is of great importance to polar scientific expedition in large-scale and further development.

The special polar environment calls for creative exploration and research regarding robot technology in the fields of material, components, motion mechanism, navigation/positioning, power supply, control and decision-making, etc. Under the funding of China's 863 Hi-Tech Research and Development Plan, the Polar Research Institute of China, in conjunction with the Shenyang Institute of Automation, Chinese Academy of Sciences, and the Beihang University, developed the ice-snow surface mobile and low-flying robot systems, which performed in the field of the Antarctic during the 24th Chinese National Antarctic Research Expedition (2007/08). It was the first application of the intelligent robot technology developed by China in the Antarctic. In the field experiment, apart from the test and verification of the robot technology, a number of scientific load application tests tasked with scientific observation of sea ice and ice sheet were carried out, which have achieved some expected results. The tests also found some inadequacies in the design of the robot system in terms of adaption to the environment. According to those, the researchers have improved the robot systems and hope to make further experiments in the Antarctic during the later Chinese National Antarctic Research Expeditions, so as to realize the substantial use of the intelligent robot technology developed by china.

2 Application of foreign Robot technologies in the Antarctic

The adverse environment of Antarctica restricts the development of human scientific research activities, so it has become a research direction over which countries leading in technology to use robot as "proxy" to lower the risk and cost of polar scientific expedition, raise the operational efficiency and scope[4,5]. In 1992, the US Carnegie Mellon University (CMU) developed the Dante-I four-foot walking robot, and carried out experimental research in Mount Erebus, the Antarctic, for the purpose of making a robotized survey of the cliff sides of the volcano crater. This survey did not succeed due to the failure of the communication system, but it opened up a new approach to the polar expedition by using robots[6]. In 1997, CMU began to apply the Nomad mobile robot which it had developed to the classification of Antarctic rocks and searches for meteorites. The experiment was conducted in the Patriot Hills, Antarctica[7]; In 2000, Nomad successfully walked by itself on the Antarctic ice and snow surface for 10.3 km by making use of laser navigation, covered an area of 2500 m^2 along the planned route and found five meteorites, thus successfully proving that using robots to carry out independent scientific surveys is an effective and practicable plan for mankind to extend its scope of expedition into inaccessible places[8]. In 2002, Italy retrofitted a caterpillar snow car into an unmanned car and developed the Robot Antarctico di Superficie (RAS), which can move independently between campsites following the fixed route[9].

The polar scientific expedition robots which are now being developed include: a) Cool Robot, using solar power, low center of gravity and wheel moving mechanism; 4 direct-drive brushless motors; a closed, thermal-control chamber containing electronic apparatus and cell; maximum speed 0.80 m/s, weight less than 75 kg, payload capability larger than 15 kg. This robot has now undergone field tests and it is planned to be tested in the Antarctic[10]. b) Prism (Polar Radar for Ice Sheet Measurements). This robot is retrofitted from the amphibious, six-wheel, all-terrain vehicle Max ATV Buffalo, using the internal combustion power, caterpillar moving mechanism, carrying a load of 300 kg and towing 150 kg; installed with the SICK laser system, using the RTK GPS positioning system. Its task is to tow the mobile antenna of the distributed radar and accomplish the corresponding scientific research, but its range of operation is limited. It has undergone field test in the Greenland[11].

Britain, Germany, the United States, and Australia have used a number of small-sized, unmanned aircraft platforms to carry out scientific research in recent years, mainly for environmental monitoring, cyclone tracking, atmospheric data observation, satellite remote-sensing test and verification, etc[12]. At present, there appears in the world a new upsurge in applying the small-sized unmanned aircraft in polar environment[13,14].

In 1992, Australia founded the Aerosonde team to develop an economical, small-sized, long navigation time unmanned aircraft for environment monitoring, and accomplished the first trans-Atlantic experiment in 1999, which received broad attention. The US NASA used this unmanned aircraft to carry out low-temperature condition experiment in Alaska, and made preparations for its application in the polar region[15]. Now, Aerosonde has been successfully employed in the scientific research observation of the Arctic region. Researchers in the University of Colorado are planning to apply it in the Antarctic to carry out observation on the turbulent flux at air-sea interface of polynya in the Terra Nova Bay Station of Italy.

Moreover, the British Antarctic Survey in collaboration with the Technical University of Braunschweig (TUBS), Germany developed an unmanned aerial vehicles (UAVs) for the polar environment and carried out field flight tests in the Antarctic in 2007, thus accomplishing the practical application of unmanned aircraft in the Antarctic for the first time. With a wingspan of 2 m and a weight of 6 kg, this aircraft uses lithium cells for power supply and catapult take-off and skis landing techniques. Except that its take-off and landing are controlled by the operator, its flight is carried out autonomously according to the preset program. Between October and December, 2007, this aircraft made 20 test flights in the British Hadley Station, each flight lasted 40 minutes, and with a flight range of about 45 km. The instruments it carried were mainly used to observe heat exchange parameters at the air/ice interface[16].

3 Intelligent Robots developed by China and their first application in the Antarctic

The polar scientific expedition, whether in terms of logistical support or scientific observation, has urgent demand for the intelligent robot technology. Supported by the China 863 Project, Polar Research Institute of China, jointly with Shenyang Institute of Automation, Chinese Academy of Sciences and Beihang University, has developed the ice-snow surface mobile and low-flying robot systems.

The ice-snow surface mobile robot is designed mainly for ice sheet crevasse detection, and the scientific observation of glacier movement and ice surface meteorological parameters. Regarding the robot body, Shenyang Institute of Automation, Chinese Academy of Sciences, carried out researches with respect to mechanical design and processing, cryogenic test of materials, design and integration of the control-sensor system, autonomous environmental modeling algorithm, robot system integration debugging, development of the interface of scientific load equipment and integrated testing, etc. In October, 2007 the test prototype of the ice-snow surface mobile robot was completed. Apart from adapting to the adverse environment of the polar region, this robot needs to carry scientific load including automatic weather station and high-accuracy satellite-based difference GPS so as to effect the function of scientific observation of glacier movement and ice-sheet surface meteorological parameters.

The low-flying robot is designed mainly for the cruising route ice condition survey, scientific observation of physical characteristics of sea ice and sea ice/water skin temperature. Regarding the robot body, Beihang University carried out research and development with respect to the cryogenic testing of components, autonomous navigation and flight control, power supply and low-temperature test, whole-system flight platform, ground control station, communication system, etc. In addition, the developers undertook re-development of the interface between the scientific load equipment and the recorder, and accomplished the debugging of the whole system and the test of autonomous trial flight. In September, 2007, the test prototype of the aircraft was completed. Apart from the special demands in design for resisting wind and snow as well as low temperature, the robot needs to carry such scientific loads as aerial camera, infrared radiometer to conduct the integrated observation test for the sea ice in the Prydz Bay.

4 Experiments and application of Robots in the Antarctic

The field staff of the ice-snow surface mobile and low- flying robot systems took part in the 07/08 24th Chinese Antarctic Scientific Expedition. Between December, 2007 and January, 2008, with the support of Chinese Zhongshan Station, the filed staff carried out a series of the robot system tests and scientific observation experiments in Russian Progress Station.

4.1 Field test of ice-snow surface mobile robot

The ice-snow surface robot mobile platforms include two categories: the caterpillar and the wheel types. The caterpillar robot was developed in the light of the target requirements of the 863 Project and was the main object of test. The wheel-type robot was mainly for emergency use or carrying out some auxiliary tests. The tests undertaken by the field staff included:

(1) Test of the mobility and traversing capacity of the robot (Fig. 1)

The test results show that its movement on the level ground is normal; but its gradeability is somewhat deficient. The robot cannot climb up a slope with a gradient larger than 20 degrees; its capability of getting over obstacles is somewhat poor; on hard snow surface, it can overcome irregular terrain with undulation below 15 cm, but on the soft snow surface its capability of getting over obstacles declines.

Fig. 1 The travel test of snow-ice mobile robot.

(2) Test of adaptability to the polar climate conditions

Tests made on the communication, power supply system and controller of the robot showed that the hardware systems of the robot operated normally under the condition of Antarctic summer climate environment.

(3) Environmental modeling test

The test uses the two-dimensional line scanning laser rangefinder mounted on the wheeled robot (Fig. 2) to collect data from the typical Antarctic snow surface environment. The typical snow surface topography (Fig. 3) includes: trench, ridge, snow ripple, slope etc. After processing the field data by using the raster elevation map and the Gaussion mixed model, the field topography and geomorphology are successfully modeled (Fig. 4). Compared with the field picture, this modeling result basically fulfils the requirements.

Fig. 2 Environment modeling test.

Fig. 3 The typical Antarctic environment.

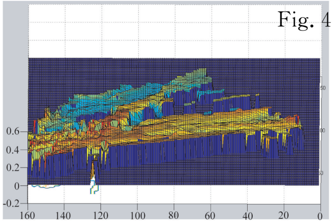

Fig. 4 The results of environment modeling test.

(4) Simulated experiment of glacier movement observation

As the robot could not navigate over several tens of kilometers, it was unable to carry out the planned observational experiment for the Dark Glacier and so a simulated test for it was substituted. The test was set up as follows: put up a pole at the simulated glacier observation point, integrated with the wheeled robot, two-dimensional line scanning laser radar, satellite-based difference GPS and inertial measuring units to form the measuring system of absolute positions, and order the robot at different time to obtain the precise geographical positions of the pole (Fig. 5). Accordingly, the researchers can obtain the movement information of the observed glacier.

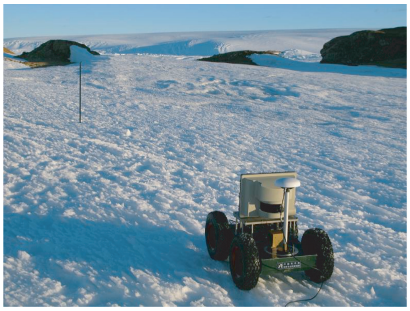

Fig. 5 The simulated experiment of glacier movement observation.

Through the above tests and in combination with the investigation of the Antarctic ice-snow surface environment, the field staff concluded that: (Ⅰ) The caterpillar moving mechanism is suitable for the complicated ground such as in the Antarctic continental margin hills and the sea ice zone, etc. While in the inland of ice sheet, it is necessary to optimize the design and improve the efficiency, or wheeled moving mechanism may be considered; (Ⅱ) The robot needs to increase power and energy reserve, and reduce the weight so as to ensure the long-distance transit capacity on the ice-snow surface; (Ⅲ) Integration design of the scientific load into the robot body meets the test requirements, so if the robot is improved and the long-distance transit capacity is satisfied, it is possible to conduct the scientific observation for ice sheet crack, glacier movement and ice surface meteorological parameters.

4.2 *Field test of the low-flying robot*

The following tests on the low-flying robot were conducted in the Antarctic:

(1) Autonomous navigation and flight control test

A number of tests indicated that the flight control parameters self-adaptive algorithm based on system identification can improve the accuracy of flight-path (realizing the meter-level navigation); and the autonomous flight in the context of 100～150 m low level hads a good stability.

(2) Test on the adaptability of the aircraft platform

The successful flight in the adverse Antarctic environment for 11 days running showed that the optimally designed aircraft platform has a good adaptability to the Antarctic summer environment in terms of its reliability and usability; and low-temperature guarantee technology worked also normal.

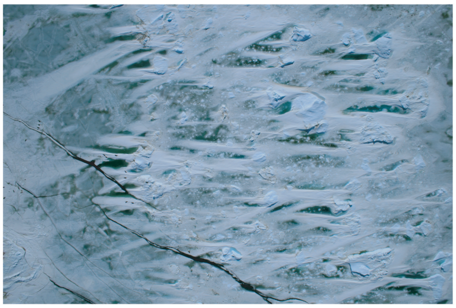

Fig. 6 The sea ice observed by low-flying robot.

(3) The scientific observation experiments

Carrying aerial and video cameras, the robot conducted an aerial photography in the sea area around Zhongshan Station and obtained a lot of physical characteristics information on sea ice/ice leads (Fig. 6); the infrared radiometer on board made a large-scale observation of the sea ice/water skin temperature in the sea area near the Zhongshan Station and some scientific data were obtained. It can be seen from Fig. 7 that in the sea ice/water covered area, as the underlying surface is uniform in nature, the variable-magnitude of skin temperature is small and the mean value is close to −0.5 ℃, whereas in the coastal area, as the underlying surface is complicated with snow cover or exposed sandstone bedrock, the variable-amplitude of skin temperature is large. Based on these, it is possible to separate the sea surface observational data from the whole to provide key support for the research on air-ice (sea) interaction.

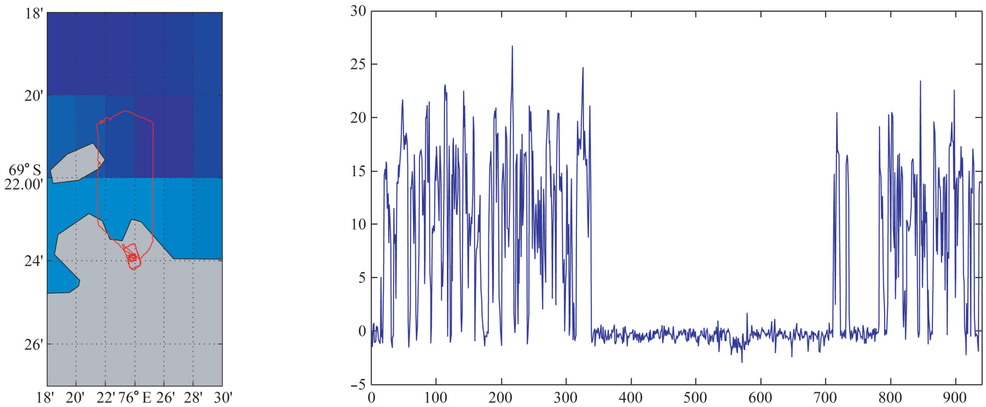

Fig. 7 The track and observed skin temperature of low-flying robot.

It is concluded from the above-mentioned tests and the analysis of test results that: (Ⅰ) The low-flying robot system has good adaptability to the Antarctic summer climate environment and has stable performance; (Ⅱ) the autonomous flight in the context of 100～150 m low level has good reliability, and the effect of high latitude and large magnetic declination on the navigation system is not obvious; and (Ⅲ) the integration of the robot with scientific load is normal and the scientific observation experiments on sea ice have scored a success. In the case of optimizing the wind-resisting property of the aircraft and raising the flight radius, the low-flying robot is expected to be popularized and used in the sea ice observation, etc.

5 Prospects for Application

Using the intelligent robot technology as an effective technical means in the polar expedition can save manpower, material and financial resources, and it is expected to be popularized and used in the future polar scientific research. First of all, in ensuring the safety of polar scientific expedition, the successful use of the low-flying robot can realize the course-line survey of sea ice condition for research vessels and provide accurate ice condition data for R/V "Xuelong" to select the optimum course line; while the successful use of the ice-snow surface mobile robot may accomplish the safety detection for the unloading site and transport route on the sea ice, lower the operational risk and raise the working efficiency. In the field of polar scientific research, by means of the scientific load integrated on the ice-snow surface mobile and low-flying robot, it is possible to conduct scientific observation of the sea ice physical characteristics, sea ice/water surface skin temperature, glacier movement and ice surface meteorological parameters. Besides, the polar region, with its unique extreme conditions, such experiments can provide important technical and experimental support for the robot developed for other special circumstances such as celestial body etc.

Now China has established an inland scientific base-Kunlun Station at Dome A, the summit of the Antarctic ice sheet, and this station has not yet possessed the capacity for personnel wintering. At Kunlun Station it is necessary to develop and use unattended intelligent robots to perform the functions of operational maintenance inside the station and scientific observation in the station area all the year round. Moreover, there exist many risk areas in ground expedition of the Antarctic ice sheet, so it is also worth expecting to develop an ice-snow surface mobile robot, which can accomplish the long-time (over one year), large-scale (within a radius of a hundred miles) scientific observation by overcoming the harsh climate conditions in the Antarctic winter, making full use of solar/wind energy and carrying scientific load such as automatic weather station, ice detecting radar, GPS, etc.

Acknowledgements This study was supported by the National High Technology Development Project of China under grant 2006AA04Z206 and the National International Cooperation Program of China under grant 2008DFR70100.

References

[1] Chen LQ(2002): Study on the role of the Arctic and Antarctic regions in global change. Earth Science Frontiers, 9(2): 245 – 253.

[2] Chen DH(2004): Accelerate and advance the scientific investigation in the South Pole, change from the scientific research and develop to resources and scientific research simultaneously. Ocean Development and Management, 21(3): 37 – 40.

[3] Zhang L(2008): Antarctic treaty system and maritime rights and interests protection of China. O-

cean Development and Management, 25(2): 69 – 74.

[4] Apostolopoulos D, Wagner MD, Shamah B *et al*. (2000): Technology and Field Demonstration of Robotic Search for Antarctic Meteorites. International Journal of Robotics Research, 19(11): 1015 – 1032.

[5] Harmon HP, Stansbury RS, Akers EL *et al*. (2004): Sensing and actuation for a polar mobile robot. International Conference on Computing, Communications and Control Technologies (CCCT), Austin, Texas, Vol. IV, 371 – 376.

[6] Stansbury RS, Akers EL, Harmon HP *et al*. (2004): Survivability, Mobility, and Functionality of a Rover for Radars in Polar Regions. International Journal of Control Automation and Systems, 2 (3): 343 – 353.

[7] Moorehead S, Simmons R, Apostolopoulos D *et al*. (1999): Autonomous Navigation Field Results of a Planetary Analog Robot in Antarctica. Artificial Intelligence, Robotics and Automation in Space, Proceedings of the Fifth International Symposium, the Netherlands, 237.

[8] Wagner MD, Apostolopoulos D, Shillcutt K *et al*. (2001): The Science Autonomy System of the Nomad robot. IEEE International Conference on Robotics and Automation, 2:1742 – 1749.

[9] Bonanno G,? Fantoni R, Fichera A *et al*. (2003): The Sensing Subsystem of RAS, Atti del Meeting Nazionale sulle Nuove Tecnologie, Frascati, Italy.

[10] Lever JH, Ray LE(2008): Revised solar-power budget for Cool Robot polar science campaigns. Cold Regions Science and Technology, 52(2): 177 – 190.

[11] Akers EL, Harmon HP, Stansbury RS *et al*. (2004): Design, fabrication, and evaluation of a mobile robot for polar environments. IEEE International Geoscience and Remote Sensing Symposium. 1:112.

[12] Visconti G(2008): Airborne measurement and climatic change science: aircraft, balloons and UAV,s. , Mem. S. A. It. 79:849 – 852.

[13] Inoue J, Curry JA(2004):Application of Aerosondes to high-resolution observations of seasurface temperature over Barrow Canyon. Geophys. Res. Lett., 31, L14312, doi: 10. 1029/2004GL020336.

[14] Runge H, Rack W, Ruiz-Leon A *et al*. (2007): A solar powered half-uav for Arctic research. The 1st CEAS European Air and Space Conference, Sept., Berlin, Germany.

[15] Holland GJ, Webster PJ, Curry JA *et al*. (2002): The Aerosonde robotic aircraft: a new paradigm for environmental observations. Bull. Amer. Meteor. Soc., 82:889 – 902.

[16] British Antarctic Survey(2008): Unmanned Aerial Vehicles Mark Robotic First For British Antarctic Survey. Science Daily. March 20.