学　位　論　文　内　容　の　要　旨

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学　位　論　文　題　名

Development of a Robot Combine Harvester based on GNSS

（GNSS を用いたロボットコンバインの開発に関する研究）

I　Introduction

Robots were invented to replace human beings in doing the repeated or dangerous work in military, industry and agriculture. It is also an effective solution for the shortage and high cost of the labor force in various disciplines. The shortage of agricultural labor force has become a serious problem in the developed countries. Agricultural robot vehicles were proposed as the solutions. So far, many agricultural robot vehicles have been developed, including a robot tractor, a robot transplanting machine and so on. These robots use various algorithms for navigation, among which a popular positioning is to use a GNSS (Global Navigation Satellite System). Besides, an IMU (Inertial Measurement Unit) is usually used as a complement to the GNSS to ensure higher level of control accuracy. Based on this idea, aims of this study are to develop a robot combine harvester and investigate its performance.

II　Materials and methods

This research was conducted on a Yanmar AG1100 combine harvester. Before developing into a robot, it was modified from an ordinary combine harvester to a machine that can be fully controlled through a CAN bus interface. Also, the combine harvester’s status can be sent to the computer by the same CAN bus. In addition, the robot relies on an RTK-GPS for its position data. Its posture data are obtained from the IMU embedded in the RTK-GPS receiver. To ensure the safety of the robot, a 2D laser scanner was installed. This laser scanner can detect an obstacle by measuring distance. It can also detect human beings if installed in a proper angle.

III　Navigation algorithm of the robot combine harvester

The robot combine harvester is a navigation-map-based robot. A navigation map was designed to be made up of a series of points, called navigation points. In a navigation point, there are coordinates and a code that designates the task that the robot should perform at the point. The accuracy of the robot combine harvester is affected by its accuracy of steering. In this study, the robot was designed to calculate its steering by measuring its distance to the navigation map and the difference between its yaw angle and direction of the navigation map. Besides, since there is a difference between the GPS antenna position and the combine harvester’s cutter position, a compensation method was designed to make corrections to the navigation map.

IV　Improvement of the navigation accuracy based on the combine harvester’s kinematic model

In order to improve the level of navigation accuracy of a robot vehicle, usually repeated field trials are necessary. In this study, to effectively tune a robot controller without a number of trials in the field, a kinematic model was developed and used in the simulation to improve the level of the robot combine harvester's navigation accuracy. The optimization of the control parameters included two steps. In the first step, the vehicle was optimized so that it could approach a target path in the shortest time. In the second step, when the vehicle was close enough to the target path, the control parameters were optimized and it successfully followed the target path without severe oscillations. By using this method, the efficiency of tuning control parameters of a robot vehicle can be improved to a great extent. After the optimizations on a computer, field experiments were conducted to verify the optimized control parameters. Results of the experiments showed that with the initial lateral error set to 0.15 m, 0.3 m and 0.7 m, RMS values of the lateral error were 0.022 m, 0.025m and 0.025 m at the speed of 1.2 m/s, respectively. This indicated that the optimization results were satisfactory to the requirements of almost all farms in Japan.

V The robot combine harvester's path planning for field work

There are usually several path plans that can be applied to harvest a field. In this study, two types of path planning methods for the robot combine harvesters were proposed, developed and tested. One of the path planning methods was named human-like path plan, in which the robot combine harvester imitates what farmers do in the field and harvests from the perimeters of a field to the center. Another path planning method was named high-efficiency path plan, which can only be performed by a robot with a GNSS receiver. By using this path plan, the robot vehicle did not need to decrease its speed when it turned from one path to another. Thus, it saved a great amount of time for the turning of the vehicle. This method can improve the harvesting efficiency greatly in small fields like the ones in Honshu, Japan. Field experiments showed that the robot combine harvester could perform the two path plans in the experimental field of Hokkaido University, Japan.

VI Field verifications of the robot combine harvester

Field verifications were conducted in different areas in Japan so as to test the robot combine harvester's feasibility. In the field experiments for wheat, the high-efficiency path plan was applied. There were totally eighteen paths in the navigation map and results showed that the RMS values of the lateral error and heading error of the test were 0.066 m and 1.24 deg, respectively. In a test on a paddy rice field, the human-like path plan was applied. There were eight paths in total and the RMS values of the lateral error and heading error were 0.053 m and 1.31 deg. Finally, in the test on a soybean field, the RMS values of lateral error and heading error were 0.039 m and 1.03 deg.

VII Conclusion

A robot combine harvester based on a GNSS was developed in this study. An IMU was used as a complement to the GNSS. To improve the level of accuracy, a kinematic model was constructed and optimization of control parameters was conducted. To apply the robot to the harvesting of different crops, two types of path planning methods were developed and verified. They are high-efficiency path plan and human-like path plan. Field experiments showed that the robot combine harvester can perform the two path plans and navigate in a high level of accuracy. The field experiments also showed that the robot combine harvester can perform harvesting tasks for wheat, paddy rice and soybean. The RMS values of lateral error and heading error were 0.066 m and 1.24 deg for wheat, 0.053 m and 1.31 deg for paddy rice and 0.039 m and 1.03 deg for soybean, respectively. The data indicated that the robot combine harvester can be applied to practical use in actual field operation.