学　位　論　文　内　容　の　要　旨

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学　位　論　文　題　名

Development of a Multi-robot Tractor System for Farm Work
(マルチロボットトラクタによる協調作業システムの開発)

I　Introduction

Labor shortage damages farmer revenue, yield and durability. Some of the farm work can cause musculoskeletal disorder risks and chronic health issues to workers. Agriculture robots provide a smart platform to realize precision agriculture (PA); and it benefits on reducing the cost of fuel for machines and the usage of fertilizer and pesticide. A multi-robot tractor system was developed in this study. The coordination of a group of robots allows for the execution of complex tasks, the total work time can be reduced, the work efficiency compared with single robot can be increased and the human labor can be saved.

II　Method and materials of robot tractor

Each robot tractor (*RT*) was equipped with a RTK-GPS, an IMU, a control PC, a laser scanner and a remote switch. The RTK-GPS and the IMU are used for navigation. The control PC is used for data processing and communication with tractor's ECU. The remote switch is used to control the engine of the tractor for a human operator, who can stop the tractor under certain situation. The *RT* was modified from a commercial tractor. The automatic control of the *RT*, called navigator, includes navigation map, algorithm of path tracking, algorithm of headland turn and algorithm of skip path turn. According to the field experiment results, the accuracy of the *RT* is 0.05 m, which is high enough to conduct farm work.

III　Method and materials of multi-robot system

Each *RT* in the multi-robot system can work independently, they can also work together to form a spatial pattern to conduct field work. Each *RT* communicates with others through Internet, a server application was developed to receive and transmit the messages. A monitor application was developed to observe all the *RTs*. A client application was developed to do the cooperation and coordination process. The client mainly has three functions: work process control, headland turn process control and safety control. Each *RT* has its own priority, and the client adjusts its velocity according to the closest higher priority *RT* to keep the formation pattern. During headland turn process, to reduce the total headland space, the *RTs* do not need to keep the formation pattern. Two methods are used to describe the efficiency. One is to use the total time of the multi-robot system comparing with the total time of the single robot system, the other one is to use the running time of the multi-robot system comparing with the total time of the multi-robot system. Both methods are relying on the field conditions and work conditions of the task, and different settings lead to different results.

IV Safety system

Both an external safety system and an internal safety system were developed in this study for the multi-robot tractor system. The external safety system used a laser scanner to detect human, vehicles and objects to avoid collision with them. Wavelet transform method was used to do object detection. Experiment using two *RTs* was conducted to test the external safety system. Field test results show that the external safety system is capable of detecting objects and distinguishing *RTs* from all objects. After detected the object, it took 2.2s until the *RT* fully stop. The internal safety system was developed to tolerant errors inside of the multi-robot tractor system. Field test using four *RTs* was taken to examine the performance of the internal safety system. From the field test results, the internal safety system gains the ability to tolerant these disturbances.

V Simulation results of multi-robot system

Three simulations were taken to testify the availability of the system: 3*RTs* system, 5*RTs* system and 7*RTs* system. With the path length increased from 100 m to 1000 m, the efficiency compared with single robot (η_{cs}) of the 3*RTs* system is 295.2 percent, improved by 26.8 percent, the η_{cs} of the 5*RTs* system is 475.5 percent, improved by 109.9 percent, and the η_{cs} of the 7*RTs* system is 645.6 percent, improved by 207.8 percent. It can be predicted that with the path length continue increasing, the η_{cs} of a system will be close to the number of *RTs* of the system.

VI Experiment results of multi-robot system

Three field experiments were taken to testify the multi-robot system: 2*RTs* system, 3*RTs* system and 4*RTs* system. According to the field experiment results, the average accuracy of *RTs* is 0.04 m, which is high enough to do the work. In 2*RTs* system, the minimum space distance between *RTs* is 0.8 m. The minimum space distance between *RTs* of 3*RTs* system is 0.78 m, and the minimum space distance between *RTs* of 4*RTs* system is 0.82 m. Thus we can conclude that the multi-robot system can work safely in real situation. The efficiency of 2*RTs* system is 88.6 percent, the efficiency of 3*RTs* system is 80.0 percent, and the efficiency of 4*RTs* system is 82.1 percent at the path length at 100 m.

VII Conclusion

In this research, an autonomous robot tractor was developed using multiple navigation sensors. Furthermore, a multi-robot tractor system was developed to reduce work time and improve work efficiency. To deal with external disturbances in the agriculture field, safety system using a laser scanner was developed, and to deal with internal disturbances in the agriculture field, fault tolerant method were developed. Three simulations and three field experiments were conducted to testify the effectiveness of the multi-robot tractor system. According to the simulation and experiment results, the developed multi-robot tractor system can dramatically reduce work time and improve work efficiency.