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Development of Path Planning Algorithm for an Autonomous Mower Tractor

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Abstract: Path planning is an essential part for autonomous mower tractor to travel and mow. Objectives of the paper were to analyze operation patterns by a farmer, to extract and optimize waypoints, and to demonstrate generation of formatted planned path for autonomous mower tractors. An 18-kW mid-mower tractor was operated by a skilled farmer on grass fields. To measure tractor travel and operation characteristics, an RTK-GPS antenna with a 2-cm RMS error, an inertia motion sensing unit, a gyro compass, a wheel angle sensor, and a mower on/off sensor were mounted on the mower tractor, and all the data were collected at a 10-Hz rate. And all of sensor data were transferred through a program to show the status immediately on the notebook. From 3 grass field tests, total 53,412 data points (every 0.1s) were obtained, and amount the data 73% was straight steering, 22% was turning steering, and 5% was for others (e.g. artificial error, needless work). Field test data showed some overlap, especially in the turning areas. Based on the human operation patterns, path planning algorithm was suggested for autonomous mower tractor. Finally path generation was demonstrated in a formatted file and graphic display. Results of the study would be useful to implement and test autonomous mower tractor, but further research needs to be done to improve the performance.

Keywords: Agricultural tractor, Grass mower, Path planning, GPS, GIS

1. INTRODUCTION

Because modern farming size is increasing and the number of farmers is decreasing, more efficient agricultural practices are needed. Mechanization of agriculture has been very rapidly progressed over the world. Agricultural mechanization has been achieved in most field operations such as tillage, land preparation, transplanting, agro-chemical application, harvesting and drying. Although most of the field operations were researched for automation, grass mowing has not been automated in Korea. Autonomous operation of mower tractors would provide efficient management of the mowing operation.

Research on autonomous agricultural machinery has been reported (e.g., Ashraf et al., 2002). Noguchi and Terao (1997) developed a method enabling to create a suboptimal path of an agricultural mobile robot. An autonomous tractor using an optical surveying device and a terrestrial magnetism sensor for ploughing was developed (Gerrish et al., 1997; Masuo et al., 2002). Some researchers have developed machine vision-based vehicle guidance system (e.g., Subramanian and Burks, 2005). Although they was effective for vehicle control along detected crop rows, those guidance system need to be modified for grass mowing because mower operation may face with different situation.

Some researchers used differential GPS (DGPS) receivers for obtaining positional information of the machinery (Nagasaka et al., 2002; Yukumoto et al., 1998). Kalman filtering of DGPS could effectively correct and reduce DGPS positional errors (Han et al., 2002), but it might not provide enough precision for operation in paddy fields. Researchers at Chungnam National University (Seo, 2010) used RTK-GPS and obtained good results in automatic control of a tractor for tillage operation in paddy fields. Many of the researchers employed real-time kinematic differential global positioning system (RTK-DGPS) and gyro compass sensors for more precise operations.

In agricultural field operations, it would be desirable to reduce working time and operation cost, and to increase operation accuracy and quality. One way to achieve such a goal is that the field operation follows a shortest path in the field by properly determining operation orders and patterns. An optimal operation path can greatly improve autonomous working efficiency. Some researchers have developed the path planning and turning function for robot tractors (Noguchi and Terao, 1997; Zhang and Qui, 2004). From the standpoint of precision farming, a shortest operation path was considered as an optimal path and associated algorithms were developed. By minimizing the overall operation distance, fuel consumption, operator's fatigue and soil compaction due to sharp turning at headlands would be reduced (Chung et al., 1999). Seo (2010) summarized 3 turning patterns for autonomous tillage tractor operation (C type, X type, and R type). Overall goal of our research was to develop an autonomous mower tractor with a variable fertilizer applicator for grass fields. Objectives of the paper were 1) to investigate operational pattern by a farmer, 2) to develop and path planning algorithm, and 3) to demonstrate path generation.

2. MATERIALS AND METHODS

2.1 Experimental Facility for Human Operation Pattern

A 27-HP mower tractor (J2030H, LS Tractor Co., USA) was instrumented in the study. Fig. 1 shows the external structure, and an RKT-GPS (Outback® A220/A221, Hemisphere GPS Co., USA) with a 2-cm precision was used to locate the position of the mower tractor.

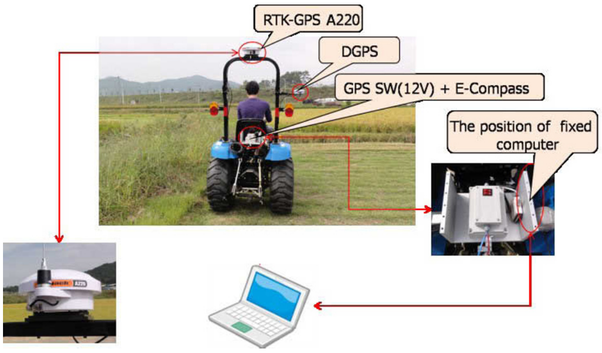

Fig. 1. Diagrams explain sensor installation on the mower tractor in the study.

An IMU (Inertial measurement unit) sensor and a gyro compass were used measure the yaw, roll, and pitch angles. Wheel angle sensors and a mower on/off sensor were also mounted on the mower tractor, and all the data were collected at a 10-Hz rate. The collected data was displayed on a screen and also saved in the memory using a developed program (LabView version 2011, National Instrument, USA). Fig. 2 shows overall data collection scheme.

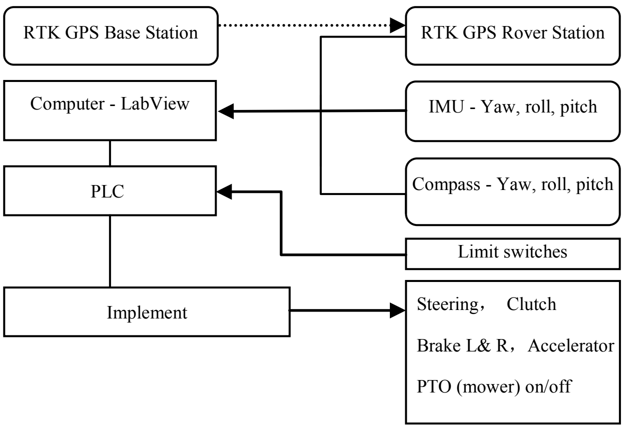

Fig.2. Schematic diagram explaining major implemented components and data collection of the instrumented mower tractor used in the study.

With the instrumented mower tractor, data were collected during the operation by a farmer on rectangular-shaped grass growing fields (Latitude: 35.156N, Longitude: 126.611E) in South Korea. The tractor diver followed typical operational paths: tractor started from entrance to the mowing start point, and travelled with straight and right-angle turning patterns in the work area. In the field tests two operators worked during the whole course, one driver and one collaborator. The collaborator needed to clear the waste grass and make the work areas clear. All of the data were stored in a notebook computer in real-time. Then the data were merged by a software developed using the MATLAB (version R2011a, Math Works, USA) program. Fig. 3 shows trajectory of the field working.

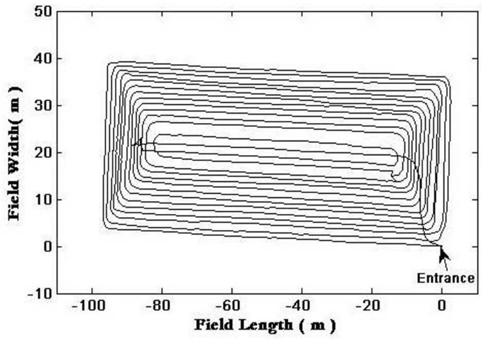

Fig.3. Example of the collected operation paths

2.2 Path Planning Algorithm

Although an autonomous mower tractor may follow farmers' path precisely, the path patterns made by human drivers may contain some unnecessary or inefficient parts that could be minimized for automated operation. Path planning of the study targeted shortest distance and minimum time for the field operation. Fig. 4 shows flowchart of overall path planning.

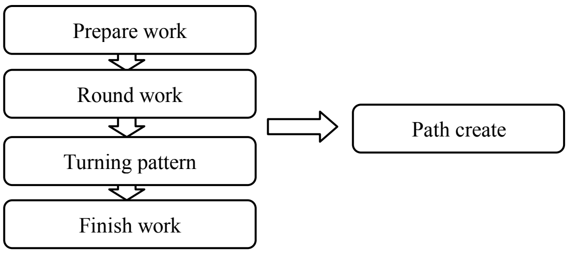

Fig. 4. Flowchart of the overall path planning for the mower tractor.

First, tractor enters into a field through headland area and move to the working start point. Then the tractor make round work pattern. In case that the round work pattern cannot be made due to sharp turning, then the tractor makes turning. Finally the tractor moves to the field exit after the mowing operation.

At the headland, the mower tractor moves forward and backward during a turn so as to minimize the headland space. The width of the headland is about 3.5 m. When the tractor reaches the edge of the field, it first stops mowing and make the turning only when the headland part mowed in the previous paths. Overlap work also appear in this path mode but in the both ends of headland parts can effectively shorten the turning time, so this kind overlap actually could improve efficiency. Fig. 5 shows turning patterns of an autonomous tractor for Korean grass fields autonomous as suggested by Seo (2010).

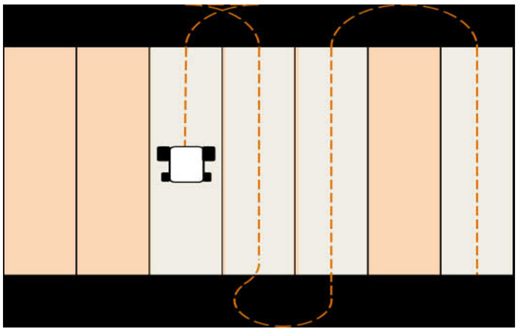

Fig. 5. Example for C type, R type, and X type turnings in the headland areas.

2.3 Demonstration of Path Generation

Autonomous mower tractor uses an RTK-DGPS receiver and a gyro compass for positioning and steering purposes. For path planning and generation, several items should be considered such as tractor size, turning radius, and overlap ratio. Table 1 summarizes field and tractor parameters used for demonstration of path generation.

Table 1. Field and tractor parameters used for demonstration of path generation

Item	Details	
Field data	Length	100 m
	Width	40 m
Autonomous mower tractor parameters	Turning radius	2.7 m
	Distance from GPS to front end	2.5 m
	Mowing width	1.5 m
	Tractor width	1.2 m

3. RESULTS AND DISCUSSION

3.1 Analysis of Human Operation Pattern

The experiment was conducted one week after irrigation of the field. The four corners of the grass field were measured before operation. The size of this grass field was 100 m × 40 m. Table 2 shows summary of human operation statistics.

Table 2. The data of field test

Item		Straight	Turning	Others	Total
Test	Data number	20162	4428	1141	25731
	Time, min	33.6	7.4	1.9	42.9
	Distance, m	2393.2	525.6	135.4	3053.6

Fig. 6 shows the steering and the yaw angles for the first round work path by a human driver. The steering angle ranged from -9.9 to 50 and the yaw angle from -0.14 to 0.52. The figure shows data from the start point to the first turning, and because of the variable terrain conditions, sideslip occurred based on the yaw angle.

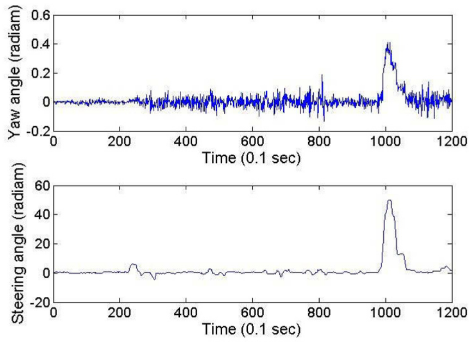

Fig. 6. Steering and yaw angles when the mower tractor was operated by a human driver.

When mowing area had different grass height or had some hard place like rock and ridge soil, the tractor was not able to keep the set traveling speed and sometime even stopped. In this study, the steering control parameters were obtained experimentally. It would be difficult to estimate the location and direction of the vehicle by relying only on calculation of vehicle dynamics, since soil conditions may not be uniform or known. However, as shown in Fig. 6 there was a correlation between steering angle and yaw angle, which led to deviation from the desired path. GPS data had a latency of about 70 ms and the automated system also had a latency that would be a function of mechanical delay, calculation time, and data transfer time.

3.2 Path Planning Algorithm

In this study, the field was divided into two areas, round work and outside work areas, for autonomous mower tractor. At first, tractor worked along the 4 points A, B, C and D to make a standard area. This area may be called outside work area or headland work area. Then, the mower would be operated to finish the round work area.

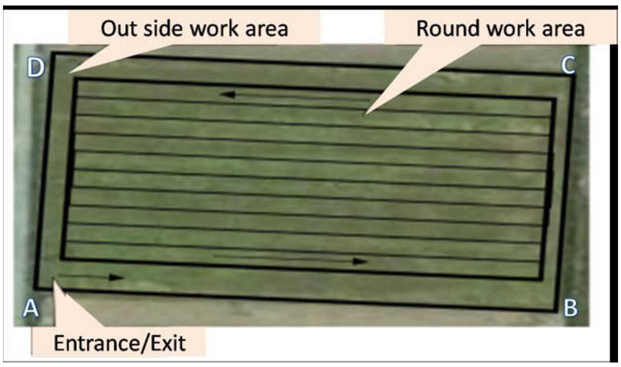

Fig. 7. Separate the field work areas into round and outside work area.

Before starting operation, the computer must create a desired path, along which the mower tractor would travel. In this study, the grass field was assumed to be rectangular. Fig. 8 shows flowchart of the round work operation.

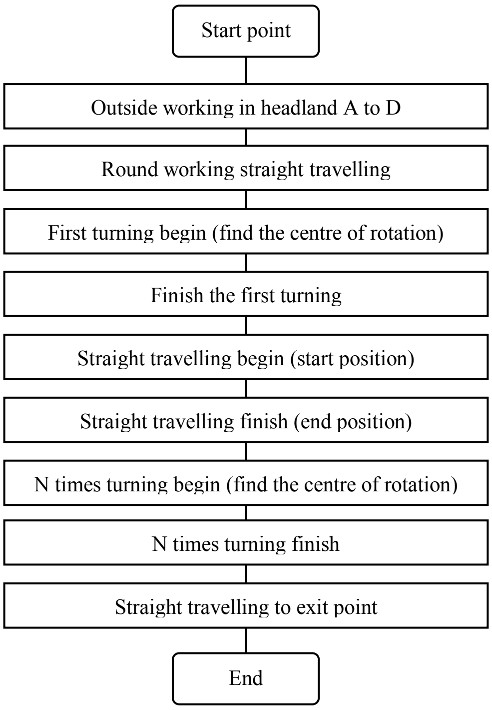

Fig. 8. The flowchart of round work algorithm.

3.3 Demonstration of Path Generation

Fig. 9 is an example of generated path for the autonomous mower tractor. The grass field was assumed to be rectangular. The mowing width of the mower tractor was 1.5 m and the mean velocity was 1.4 m/s. Since a grass field usually has only one entrance, the desired path depends on the width of the field. The field was divided into two parts: outside work area and round work area. Work area contained 13 cycles of round working operation with C type and X type turnings.

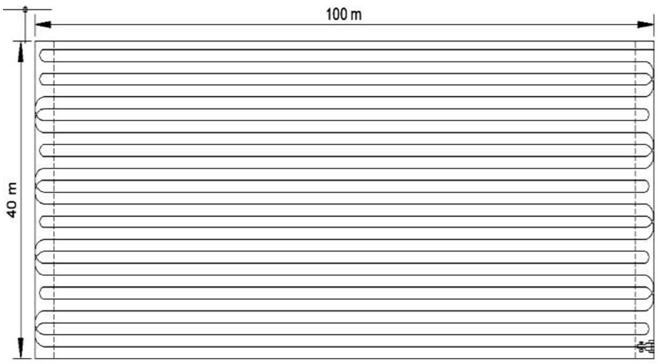

Fig. 9. A comprehensive path planning for 100 m x 40 m rectangular field for autonomous mower tractor.

After optimizing path planning, the working distance decreased by about 13% and saved the working time by nearly 30% as shown in Table 3. But the real automatic autonomous operation test in this path planning would be discussed in the later research.

Table 3. Summary of the generated path

Item		Straight	Turning	Others	Total
Plan	Data(unit)	-	-	-	-
	Time/(min)	28.4	4.5	-	30
	Distance/(m)	2,561	96	-	2,657

4. CONCLUSIONS

This study showed the manned mowing data and improvement for autonomous mower path planning. Ultimate objectives of the research were to analyze operation patterns by farmers, to extract and optimize waypoints, and to generate formatted planned path for autonomous mower tractors.

Next research would include basic statistics such as time, length, and field efficiency using entire data and also sub-data divide by traveling pattern (e.g., straight line, turning curve). And, optimum traveling order, type, and method would be classified and modeled. The study would contribute greatly to increase the grass quality and growth, liberate the labour, and also be integrated with other management practices such as variable rate fertilizer application based on real-time sensing of grass growth status.

5. ACKNOWLEDGMENTS

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