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Path planning for autonomous lawn mower tractor

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Abstract : Path planning is an essential part for traveling and mowing of autonomous lawn mower tractors. Objectives of the paper were to analyze operation patterns by a skilled farmer, to extract and optimize waypoints, and to demonstrate generation of formatted planned path for autonomous lawn mower tractors. A 27-HP mower tractor was operated by a skilled farmer on grass fields. To measure tractor travel and operation characteristics, an RTK-GPS antenna with a 6-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. All the sensor data were transferred through a software program to show the status immediately on the notebook. Planned path was generated using the program parameter settings, mileage and time calculations, and the travel path was plotted using developed software. 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. After optimizing the path planning, a decrease in distance about 13% and saving of the working time about 30% was achieved. Field test data showed some overlap, especially in the turning areas. Results of the study would be useful to implement an autonomous mower tractor, but further research needs to improve the performance.

Key words **:** Precision agriculture, Tractor, Lawn mower, Path planning, GPS

I. Introduction

Efficient agricultural farming practices are needed as modern farm size increases and the number of farmers decreases. Agricultural mechanization has been very rapidly progressed over the world in most field operations such as tillage, land preparation, transplanting, agro-chemical application, and harvesting. Although most of the field operation researches have been concentrated on automation (RDA, 2013), grass mowing has yet automated in Korea. Autonomous operation of mower tractors would provide efficient management of the mowing operation.

In autonomous operation, we need to determine the task to be done, the steps to be completed, and the areas to be performed. The global positioning systems (GPS) typically provide the current location of the machine or implement to the algorithm (Driscoll, 2011). The autonomous navigation of agricultural machinery and the unmanned farm work technology based on GPS position information have been developed (Reid et al., 2000). Some researchers used differential GPS (DGPS) for obtaining positional information of the machinery (Yukumoto et al., 1998; Nagasaka et al., 2002). Kalman filtering of DGPS signal effectively reduced DGPS positional error (Han et al., 2002), but it did not provide enough precision for operation in all fields. Seo (2010) used a real-time kinematic (RTK)-DGPS, 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 and gyro compass sensors for more precise operations.

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Research on autonomous agricultural machinery has been reported (Ashraf et al., 2002). Noguchi and Terao (1997) developed a method to create a suboptimal path for an agricultural mobile robot. Autonomous tractors using an optical surveying device and a terrestrial magnetism sensor for ploughing were developed (Gerrish et al., 1997; Kise et al., 2002; Ahn et al., 2008). Some researchers have developed machine vision-based vehicle guidance systems (e.g., Subramanian and Burks, 2005). Although the guidance system was effective for vehicle control along the crop rows, the system needed to be modified for different lawn mowing operations.

In agricultural field operations, it would be desirable to reduce working time and operation cost, and to increase operation accuracy and quality. Such a goal can be achieved from the field operation that follows the shortest path in the field determining the operation orders and patterns properly. An optimal operation path could improve autonomous working efficiency greatly. Some researchers have developed the path planning and turning function for robot tractors (Noguchi et al., 2001; Zhang and Qui, 2004). From the perspective of precision agriculture, the shortest operation path was considered as an optimal path and associated algorithms were developed. Fuel consumption, operator's fatigue, and soil compaction from the sharp turning at headlands can be reduced by minimizing the overall operation distance (Chung et al., 1999). A dynamic path tracking indicated the root mean squared (RMS) error of the tractor lateral deviation less than 0.03 m, and the maximum lateral deviation was less than 0.1 m while the tractor was traveling on straight or slightly curved paths at speeds up to 3.5 m/s (Zhang and Qui, 2004). Seo (2010) summarized three turning patterns for autonomous tillage operations (C type, X type, and R type). The C type turning was defined by turning radius, R, and turning angle of 90° which features continuous forward motion and avoids reverse movement. X type turning consisted of a combination of straight line and two 90° turns, stopping at the first turning point and moves backward, and turns again to begin a new swath parallel to a master line. The R-type turning was similar to C type but the pattern involves only forward motion. Recently, a new type of field area coverage B-patterns has been introduced (Bakhtiari et al., 2011). B-patterns based ant colony optimization was feasible for the generation of optimal routes for field area coverage and can be followed by any farm machine equipped with auto-steering and navigation systems. In our study C-type or R-type pattern was followed for mowing operation.

Objectives of this study were 1) to investigate an operational pattern by a farmer, 2) to develop a path planning algorithm, and 3) to demonstrate the path generation.

II. Materials and methods

1. Integrated path planning system structure

A 27-HP mower tractor (J2030H, LS Tractor Co., USA) was used in the study (Fig. 1). A RKT-GPS (Outback® A220/A221, Hemisphere GPS Co., USA) at the top of the tractor was used to locate its position.

An inertial measurement unit (IMU) and a gyro compass were used for measuring the yaw, roll, and pitch angles. Wheel angle sensors and a mower on/off

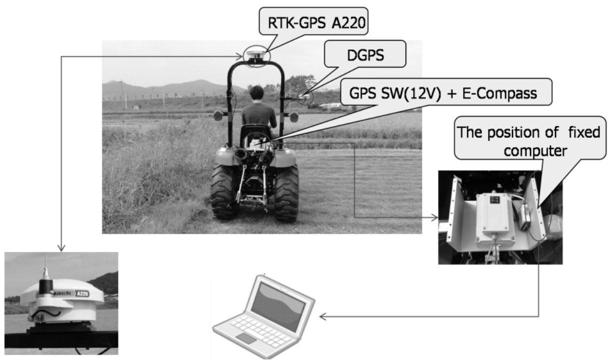


Fig. 1. Diagram explaining sensor installation on the mower tractor.

sensor were also mounted on the mower tractor, and all the data were collected at a 10-Hz rate. A LabVIEW-based (version 2013; National instrument, Austin, Texas, USA) program was used to collect and save the data.

Experimental data were collected during the operation on rectangular-shaped grass growing fields (Latitude: 35.156N, Longitude: 126.611E), South Korea. The tractor diver followed typical operational paths: tractor started from the mowing start point, and travelled with straight and right-angle turning patterns. In the field tests, two operators worked: one driver and one collaborator. The collaborator needed to clear the waste grass and make the work areas clean. All the data were stored in a notebook computer in real time. Then the data were merged by a software developed using the MATLAB (version R2010a; Math Works, USA) program.

2. GPS receivers and antennas

A GPS receiver (R100, Hemisphere GNSS, Scottsdale, AZ, USA) with A220 antenna was selected for this experiment. The receiver tracked GPS and differential correction signals with a 0.6 m DGPS positioning accuracy. The R100 has many differential correction options for various environments. The A220 was designed to maintain tracking of GPS and differential correction signals under unfavorable conditions and able to filter out an additional 30 decibels of radio band frequencies with the superior noise rejection technique. The mounting of GPS antennas was shown in Fig. 2 and data transfer diagram was shown in Fig. 3.

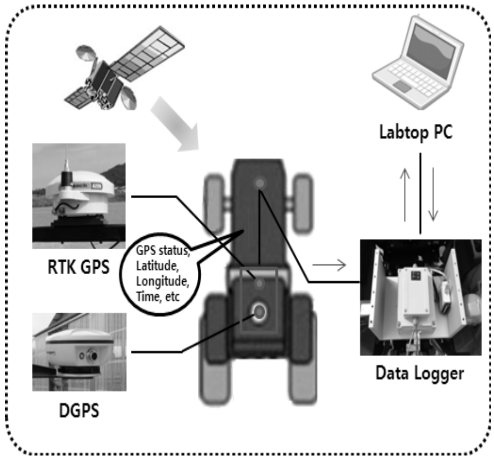


Fig. 2. GPS installation on the autonomous mower tractor.

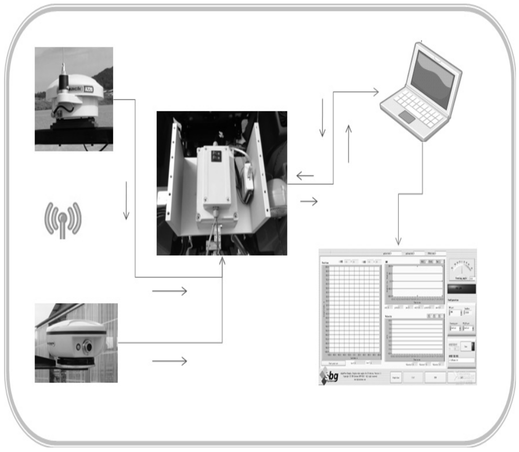


Fig. 3. GPS data transfer diagram in this study.

3. Path planning algorithm

Although an autonomous mower tractor follow farmer's path precisely, the path pattern made by human driver is likely to contain some unnecessary or inefficient parts that could be minimized by automated operation. Path planning in this study was targeted on the shortest distance and minimum time for the field operation. Fig. 4 shows the flowchart of overall path planning. Autonomous mower tractor was also used for the common path operation which was easy for farmer but unable to make fully use of time and take extra farming distances. Thus, the main purpose of this research was to optimize the path planning to the shorter time and distances for autonomous mowing. The work area was prepared in the headland and turning parts for making a full space for round work that could reduce the overlap. The turning pattern should be carefully chosen to minimize operating distance and working time. First, the tractor entered into the field through headland area and moved to the working start point, then the

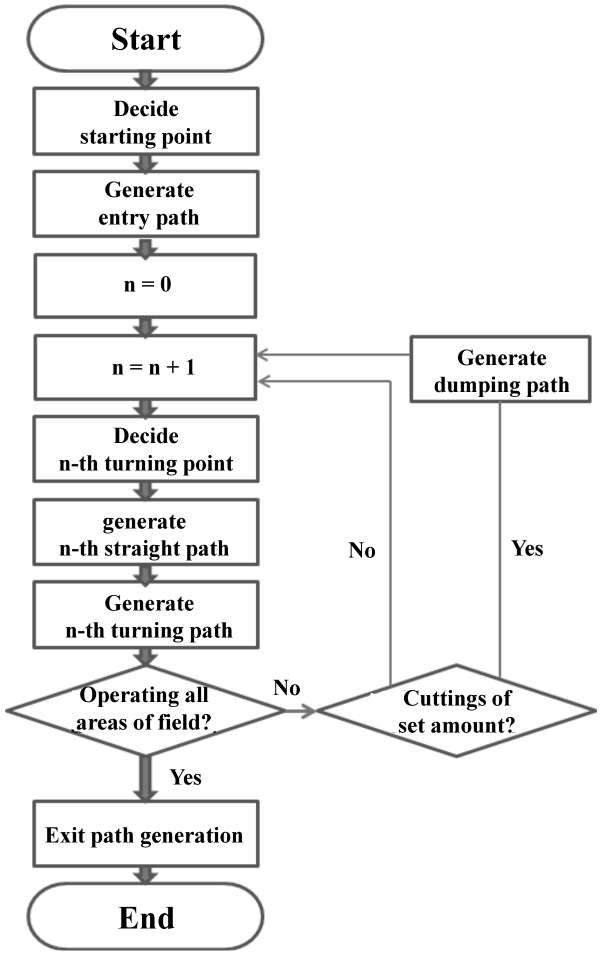


Fig. 4. Flowchart for the mower tractor path work.

tractor moved straight along the path and made round working pattern. The tractor moved out of the field after finishing the mowing operation. At the headland, the mower tractor moved forward and backward during a turn so as to minimize the headland space. The width of the headland was 3.5 m. When the tractor reached the edge of the field, it stopped mowing and made the turning only. Overlap work also appeared in this path, but the turning time could be effectively shortened in the both ends of headland parts.

Before starting the mowing operation information of the radius of the traveling path, the processing of turning operation, determination of the shape of the lawn area, use and field operation of the tractor mower should be available. Operation starting point was determined by considering the working width of spaced apart from the outer part of the lawn and running in a straight line from the lawn. A route was generated from entering the mower starting position and the lawn inlet. The start and end points were determined with the turning radius of the tractor size and the mower's primary rotation around the center point of rotation. The first straight traveling path was generated from the start point to the first rotation point. Then a turning point was created and rotation was done by rotating the end point. The start and end points were determined by taking into account the turning radius, mower tractor size, and the working width of the n^{th} tractor mower rotation center point. A straight path was generated by the path of traveling from n primary end pivot point to the n−1 turning point. A turning path was generated from a starting point n, and then n primary rotation difference straight running was done to the end. A travelling path of the lawn mower was confirmed through the analysis of practice driving of the lawn from the outskirts to the operations in progress inside of the field and the circling was progressed at each of the 90° angle from the C−type or R−type pattern.

During the round work area, driving practices were conducted through the analysis of the path running from the outskirts of the lawn to the turning progress in the field operation for the C−type operation or the mower proceeded to work after a 90° angle from the previous input method of the R−type. The area and shape of the field and the radius of the traveling route information were determined. Start working point was determined by considering the working width and a straight line was run near the entrance of the branch. Or the mower was preceded from the scheme by 90° from the outskirts of the lawn at each of the R−type pattern and the process had been conducted through travel analysis practices in the travel path of the C type turning.

4. Path planning program

Autonomous path was generated using the program parameters, mileage, and time calculations, and was plotted using Matlab. The required input variables to generate autonomous path were: (I) field variable input which creates a path for determining the size or shape of the lawn and packaging operations at the starting point coordinates of the edge of the lawn. (II) mower tractor variable input which determines the mower tractor traveling route interval such as distance, mower turning radius, front and back, left and right length of mower, GPS mounting position, length of the front mower and GPS position, GPS position and the length of the end mower. A straight path was created with the working width of (1.2 m) and its interval (0.2 m). After path generation, travel of mower tractor was turned to the straight path up to 50° and the angle was calculated from approximately 1.5 m to the front, and turning radius of the rear wheel was 2.3 m. Similarly, the outer edge of the wheel travel path was created and the first generation of straight and turning, straight path segment, and turning intervals were created. The work was progressed after going to the designated area for cutting the grass as few came from outside of the area putting some distances in driving courses (path analysis for driving practices resulted 600~750 m). The driving travel path was less for the next generation flat outskirts grass area before preceded for inside job progresses. Considering the turning radius and the working width, a straight line and turning traveling route was progressed for the operation. While traveling on a C-shaped pattern, the same turning path length was generated from the outer area section and a traveling route at the working width of about 10 m was remained. A straight red card was created in the path of the entrance point to the end of the running path and the path of the lawn was generated when the lawn was outside of the inner region.

III. Results and Discussion

1. Manual operation path Analysis

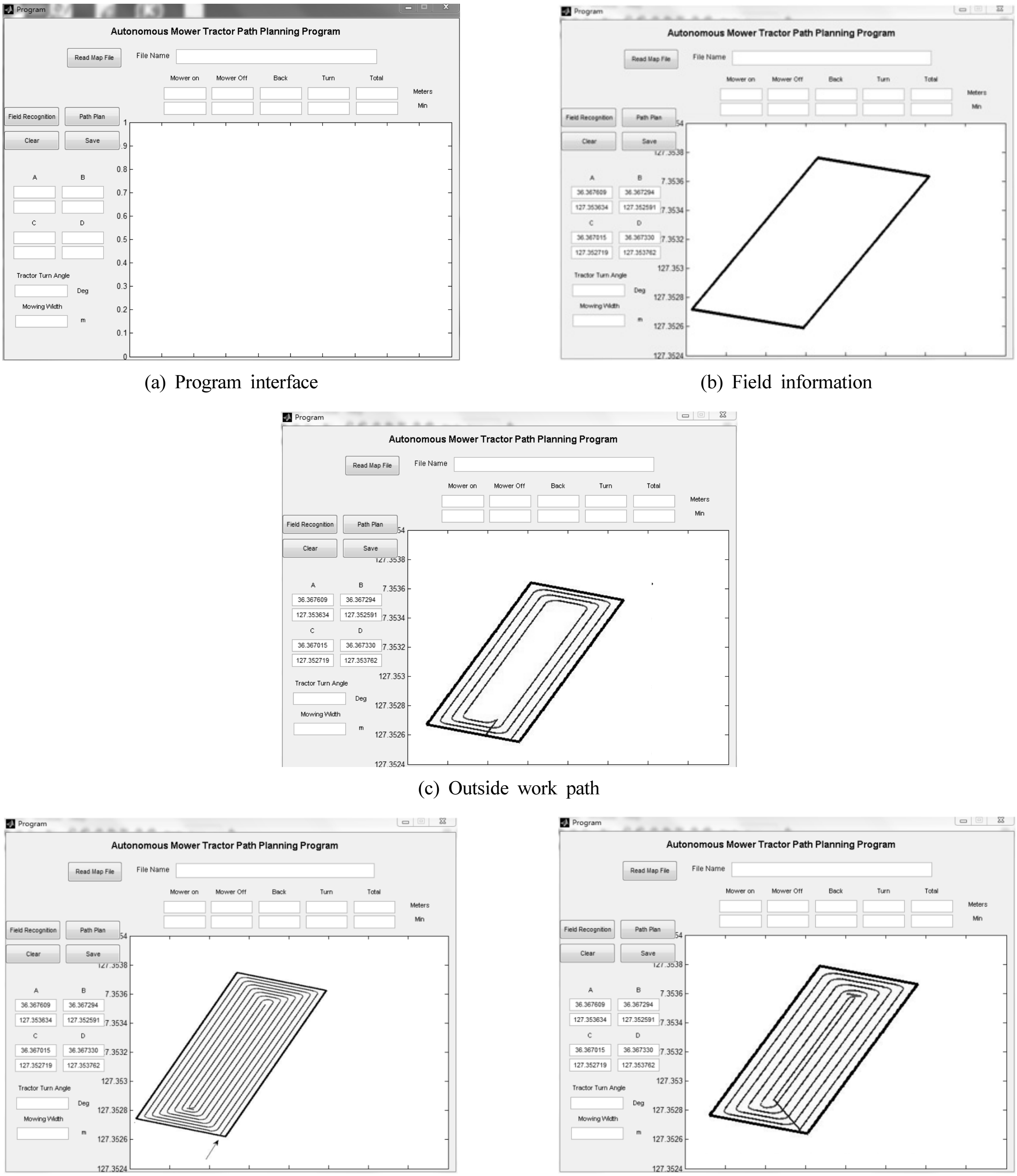
This experiment was conducted in three different field conditions in Hampyeong, Jeollanam-do, South Korea (Latitude: 35.156N, Longitude: 126.611E). According to the field number 1, field number 2, and field number 3, the coverage density of the grass was about 90%, 70%, and 50% reported by a skilled farmer who had an experience of grass growing over 10 years (owner of the farm). The variety of grass was *Z. japonica Steud* (Korean lawn). The experiment was performed in the middle of September and the average temperature was 36ºC. The soil properties at different field conditions are shown in Table 1 and the whole path is show in Fig. 5.

The tractor diver used the common path generation: started from the entrance, worked with straight traveling, and turned right-angle only. The whole field took 14 times cycle operation for completing the test. The whole path and satellite map is shown using the Matlab software (Fig. 6).

The RTK-DGPS receiver and gyro compass were used for positioning and steering purposes. Tractor

Table 1. Soil texture of the experimental fields.

Parameter	Field 1	Field 2	Field 3
Acreage	40 m×100 m	60 m×100 m	20 m×150 m
Soil moisture	31.41	26.94	20.34
Soil EC	0.72	0.69	0.63
Soil temperature	27.08	24.28	31.77



(a) Program interface

(b) Field information

(c) Outside work path

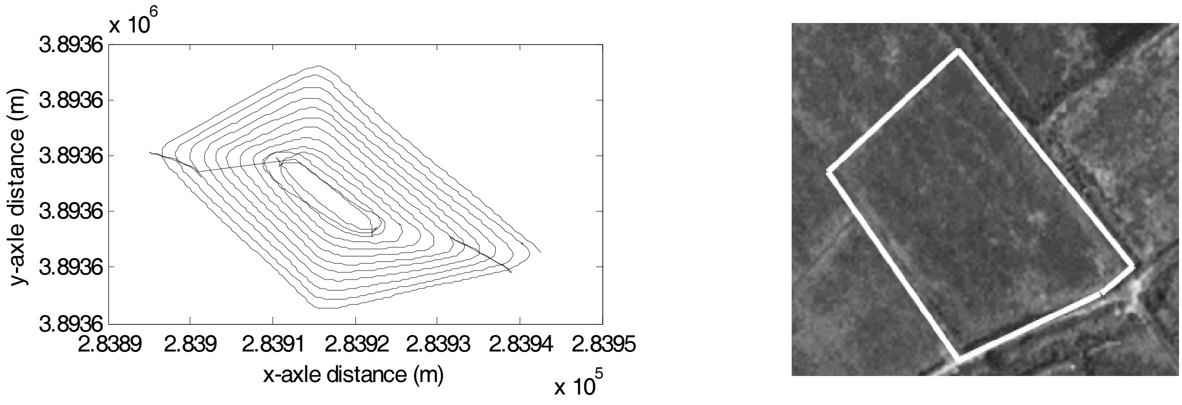
(d) Round work path

(e) End work path

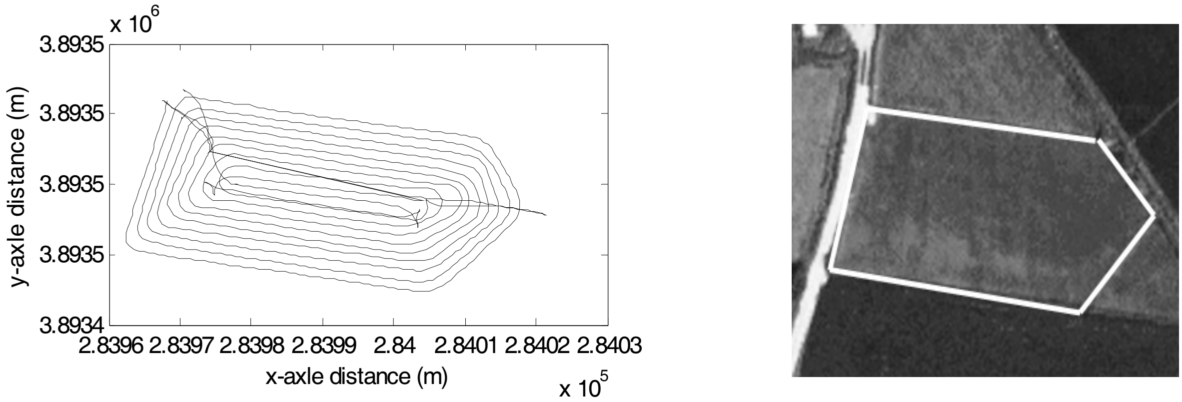
Fig. 5. User interfaces and menu

size, turning radius, and overlap ratio were considered for path planning and generation. The field and tractor parameters used for demonstration of the path generation are summarized in Table 2.

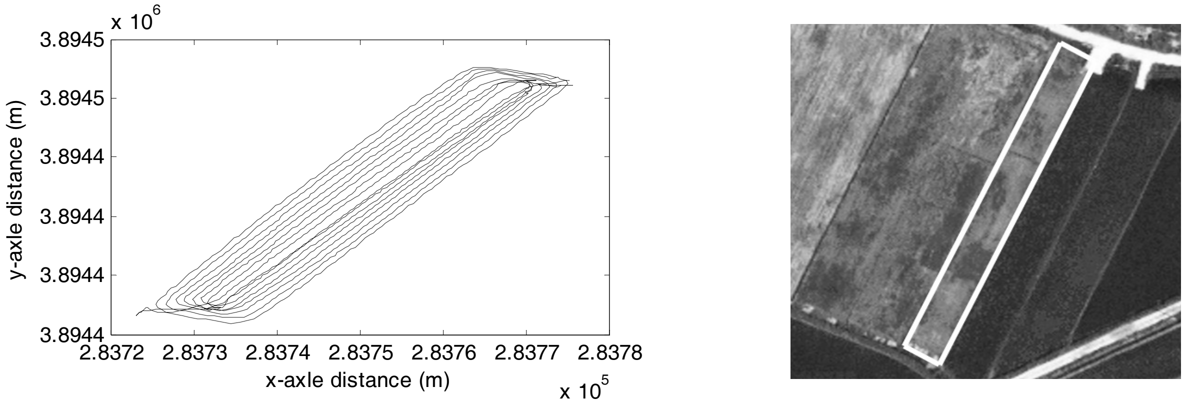
The experiment was conducted one week after irrigation in the field. Results of manual operation and autonomous path planning are shown in Table 2 and Table 3, respectively. In manual operation, overlaps existed in the turning areas. After optimizing path planning, the distance was decreased about 13% and



(a) Field 1



(b) Field 2



(c) Field 3

Fig. 6. Manual operation path and satellite map.

the working time was saved nearly 30%. The autonomous path was produced using the autonomous navigation route guidance program with a total distance of 915.91 m, and 77.0% of which was a straight line running the entire traveled distance of 705.24 m; the turning was 153.71 m. Although the distance of the straight traveling path was occupied about 77.0% of the total distance, it was faster than the other driving and turning; the corresponding value at time was only 57.7%.

IV. Conclusions

In this study, an approach was made for the generation of optimal path for autonomous mower tractor. This experiment was conducted in three

Table 2. Results of the manual operation path analysis in three fields

Field	Data	Total	Straight	Turning	Others		
					Exit	Dumping	Overlap
1	Distance (m)	1008 (100%)	742 (73.6%)	153 (15.2%)	44 (4.4%)	35 (3.5%)	35 (3.5%)
	Time (sec)	2399 (100%)	1753 (73.1%)	342 (14.3%)	77 (3.2%)	141 (5.9%)	86 (3.6%)
	Data	2237 (100%)	1583 (70.8%)	383 (17.1%)	78 (3.5%)	103 (4.6%)	30 (1.3%)
2	Distance (m)	1024 (100%)	808 (78.9%)	108 (10.5%)	16 (1.6%)	21 (2.1%)	71 (6.9%)
	Time (sec)	1393 (100%)	1021 (73.3%)	162 (11.6%)	31 (2.2%)	93 (6.7%)	86 (6.2%)
	Data	2240 (100%)	1620 (72.3%)	273 (12.2%)	63 (2.8%)	108 (4.8%)	176 (7.9%)
3	Distance (m)	1498 (100%)	1231 (82.2%)	116 (7.7%)	87 (5.8%)	39 (2.6%)	26 (1.7%)
	Time (sec)	1838 (100%)	1684 (91.6%)	193 (10.5%)	104 (5.7%)	165 (9.0%)	54 (2.9%)
	Data	2706 (100%)	1996 (73.8%)	317 (11.7%)	150 (5.5%)	161 (5.9%)	82 (3.0%)

Table 3. Results of autonomous path planning

Data	Total	Straight	Turning	Others		
				Exit	Dumping	Overlap
Distance (m)	915.91 (100%)	705.24 (77.0%)	153.71 (16.8%)	38.79 (4.2%)	18.15 (2.0%)	-
Time (sec)	1087.8 (100%)	627.44 (57.7%)	404.52 (37.2%)	41.26 (3.8%)	17.24 (1.6%)	-

different field conditions by a 27-HP mower tractor. The tractor driver followed typical operational paths and one collaborator helped for preparing the work areas. The comparison between the manned operation and autonomous operation showed a decrease in distance of 13% and saving 30% of the working time. This research would be useful to implement and test autonomous mower tractor.

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