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Field Automation Using Robot Tractor

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ABSTRACT

The objective of the study was to develop a field robot in agricultural operation environment. The navigation sensor consisted of an RTK-GPS and an inertial measurement unit (IMU). The sensor fusion algorithm was capable of identifying FOG bias and compensating location error in real-time for providing sufficient navigation information in support of accurate robot guidance in the field. The field tests of a field robot have been conducted in Sapporo, Japan. Tillage, planting, cultivating and splaying on soybean field has been conducted. In addition, the robot itself could transfer between a shed and a field to be operated. The accuracy of the vehicle was better than skilled farmer's operation. The adopted speed of the vehicle was conventional human operation speeds. The r.m.s. lateral error of the guided vehicle was less than 5 cm. Even crop row was slightly curved, the autonomous vehicle could travel without running over the crops.

KEYWORDS. Agricultural mobile robot, GPS, Precision farming, Autonomous vehicle

INTRODUCTION

As the 21st century approaches, it is very important to develop the production technology required to decrease the cost of food production and to ensure a stable food supply. In advanced countries, the lack of labor and aging work force complicate the situation. To solve these problems, vehicle guidance system that can reduce operator's fatigue will play an important role in the next century. In particular, the vehicle guidance systems provide for more efficient work and reduction of production costs (Noguchi, 1997, 2000). However, because the environment in which the guidance system is used is an outdoor space with many disturbances resulting from variable soil and weather conditions, there are many problems in developing a robust vehicle guidance system for crop production. Machine vision that has high possibility for the guidance has been widely investigated to utilize as a sensor of the guidance system (Reid, 1988, Marchant, 1997, Billingsley 1997). However, row detection by the image processing in the outdoor environment, which includes various disturbances such as shadow, weed infestation and various soil colors and types, still has fairly difficult problems. Recently, there has been some research, which explores the possibility for an RTK-GPS for the vehicle guidance system, because of the decreasing costs of RTK-GPS while the positioning accuracy is improving. This paper presents solution of the challenging problems on a developing agricultural robot using a real-time

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kinematics GPS (RTK-GPS) and a fiber optic gyroscope (FOG). This solution includes a robot control algorithm and mission planning. In addition, some field tests were carried out for investigating a performance of the developed robot tractor.

ROBOT TRACTOR PLATFORM

Overview of Platform

The platform of the robot is a conventional 56kW tractor (MD77, Kubota ltd.) which was modified to utilize as the robot. **Figure 1** shows the hardware platform, and **Table 1** shows list of controllable items of the robot from a PC. The attached internal controller is built in the tractor cabin and control actuators for those functions. The internal communication is based on a serial, RS232C, while the communication between the PC and internal controller is conducted through CAN-Bus. The developed navigation system basically composed of "Mission planner" and "Autonomous Operation" as shown in **Figure 2**. The "Mission planner" has two functions for creating both travel paths of the robot tractor, and maneuvers of the robot to properly achieve the field management such as hitch functions, engine speed set, etc. during autonomous operation. On the other hand, the "Autonomous Operation" can be used in guided situation. The "Autonomous Operation" has functions of following the predetermined path and controlling hitch function, power-take-off and engine speed set etc. based on the posture information from the RTK-GPS and the FOG in reference with a navigation map.

Navigation Sensors

As mentioned above, the developed navigation system is based on sensor fusion integration of the RTK-GPS (Trimble MS750) and the Inertial Measurement Unit (IMU; Japan Aviation Electronics Industry, JCS7401A). As shown in **Figure 3**, the RTK-GPS is able to measure a position within the error of 2 cm at update rate of 20Hz. Since the RTK-GPS needed a base station to provide a correction signal to a robot, the base station with radio modem was established on the top of the office building in a farmstead of School of Agriculture,

Hokkaido University, Japan. Basically, the IMU is a three-axes FOG for detecting angles and angular velocities for roll, pitch and yaw directions. As seen in Fig.1, since the GPS antenna was located on the roof of the tractor cabin, there was some position error caused by the robot inclinations. Therefore, the IMU was used for correcting GPS positioning data.

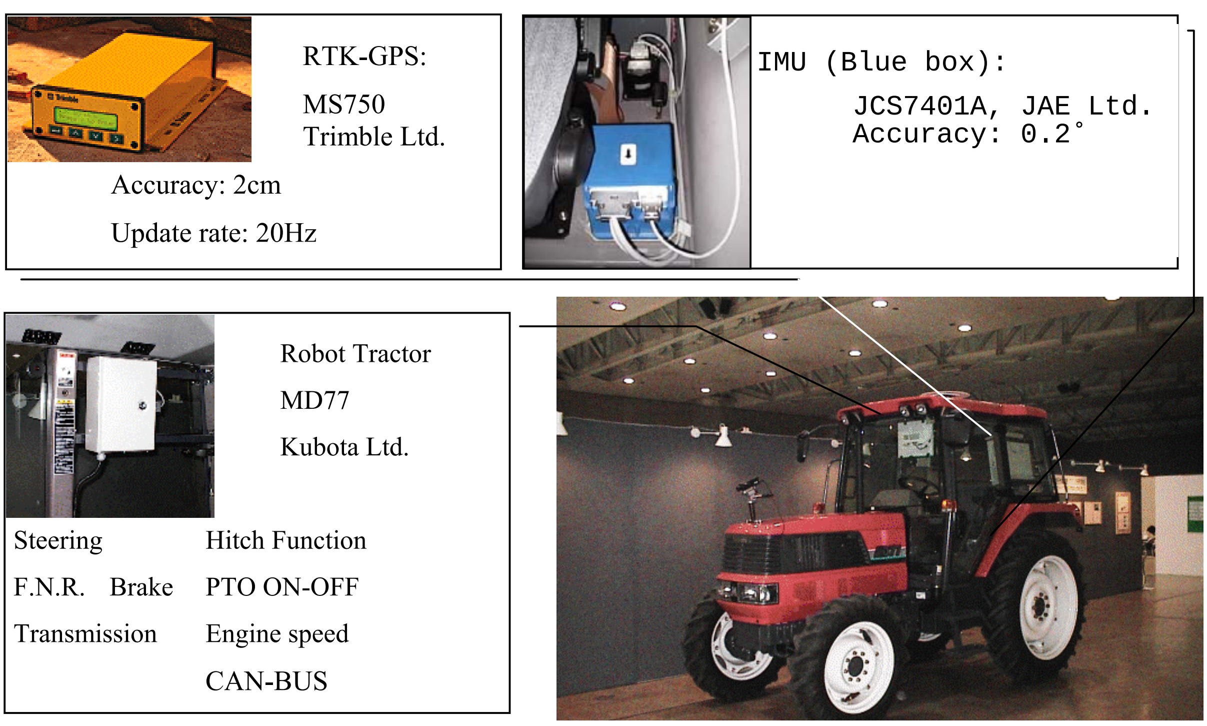


Figure 1. Robot tractor hardware

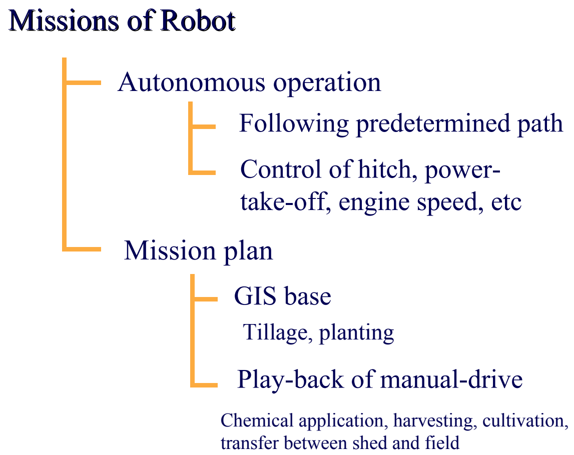


Figure 2. Functioning of a robot tractor.

Table 1. Controllable maneuvers to a robot tractor.

- Steering
- Transmission change
(eights for each two sub-transmissions)
- Switch of forward and backward movements
- Switch of Power-take-off
- Hitch functions
- Engine speed set
(two sets; manual and maximum)
- Engine stop
- Brake

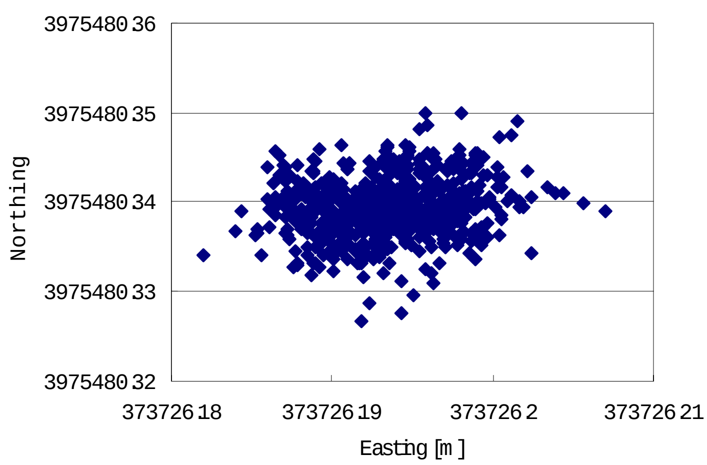


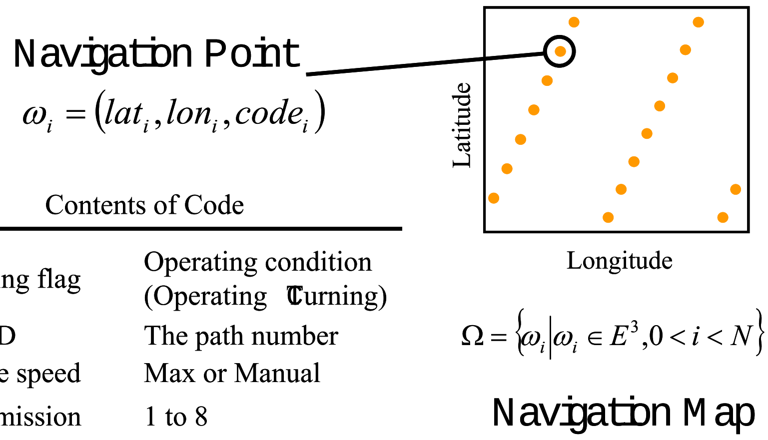
Figure 3. Accuracy of the tested RTK-GPS

Mission Planner

Using our navigation system, a navigation map can be made by both GIS and actually recording travel paths with human driving. Namely, the developed navigation system can repeat completely same operations and travels with human previously driving. The RTK-GPS can gather the position data at the update rate of 20 Hz, the spatial resolution of the navigation map is limited by the GPS update rate and the travel speed. Functions for identification of FOG bias and position correction by roll/pitch inclinations are also plugged into the "Mission planner" to improve positioning accuracy. In addition, a navigation map can be created under a GIS environment. The coordinate system of the navigation map is based on global coordinate; WGS-84. The navigation map is defined as a set of the navigation point of latitude and longitude (**Figure 4**). And the code data that is operation commands to the robot such as hitch function, transmissions change, and engine speed set, is added at the end of each navigation point. The robot can decide the maneuver in each spot by referring the navigation map with current robot's posture.

Autonomous Operation

"Autonomous Operation" functions provide guidance signals in terms of an offset and a heading error and determination of a desired steering angle. These functions include correcting position by vehicle roll/pitch inclinations, identification of FOG bias, and calculating a steering angle for



Contents of Code

Working flag	Operating condition (Operating Turning)
Path ID	The path number
Engine speed	Max or Manual
Transmission	1 to 8
Power-Take-Off	On or Off
Hitch function	Rising or Downing

Figure 4. Construction of navigation map

the robot. “Autonomous Operation” functions also dynamically plan the turning path trajectories at the headland of the field operations.

A navigation map was used to calculate navigation signals from RTK-GPS and FOG (offset and heading error) sensors. As shown in **Figure 5**, the offset, ε, was calculated from the desired path determined from the two closest points, ω_{c1}^* and ω_{c2}^*, relative to the current vehicle position, η retrieved from the map data. The heading error, $\Delta\phi$ is defined as shown in Figure 5. The heading error, $\Delta\phi$ was computed from the relative angle between the desired angle vector, ϕ_d and actual heading vector, ϕ. The desired angle vector was defined by the vector whose tail is the point of orthogonal projection along the map trail and whose head is the point with a look-ahead-distance; L, forward along the trail. The desired steering angle, $\Delta\psi$, was computed assuming a proportional controller for both a heading error and an offset as follows,

$$\Delta\psi(k) = k_\phi \Delta\phi(k) + k_p \varepsilon(k) \qquad (1)$$

Where, control gains k_ϕ and k_p were determined by preliminary experiment.

FIELD TESTS FOR THE ROBOT

Field Test Procedure

Field tests were carried out at the experiment farm of School of Agriculture, Hokkaido University. Field operations including tillage, planting, fertilizer application, chemical application, and cultivation in soybean fields were carried out in the 2000 production season. All field tests included automatic transfer from the storage shed to the field, as well as field operations. The navigation maps for tillage and planting were generated using a GIS and path planning software. Navigation maps for other operations, like cultivation, were completed using the navigation map recorded during planting. The robot speed depended on the specific requirements of the implement and field operation. The lowest speed was 0.5m/s for rotary

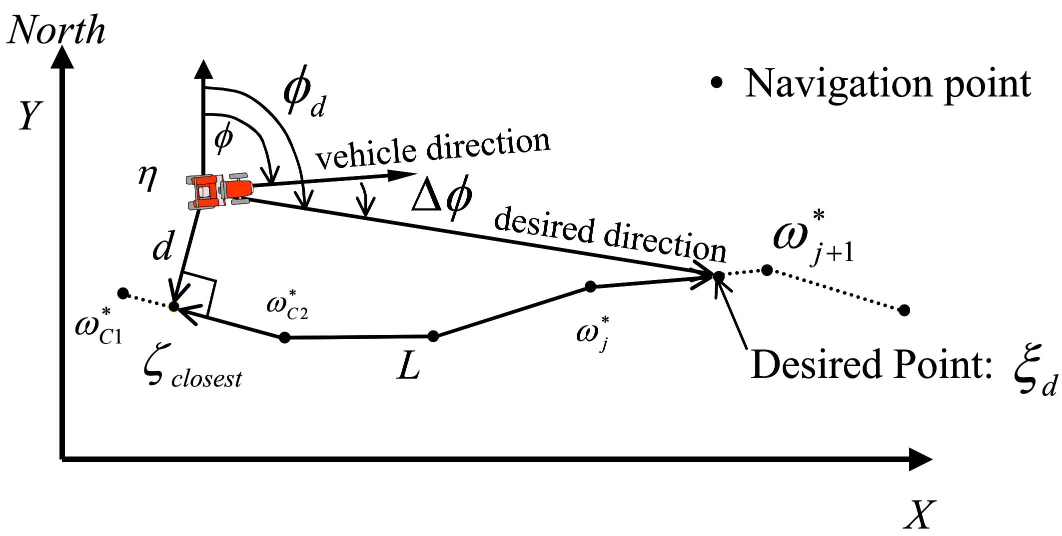


Figure 5. Definition of navigation signals based on map.

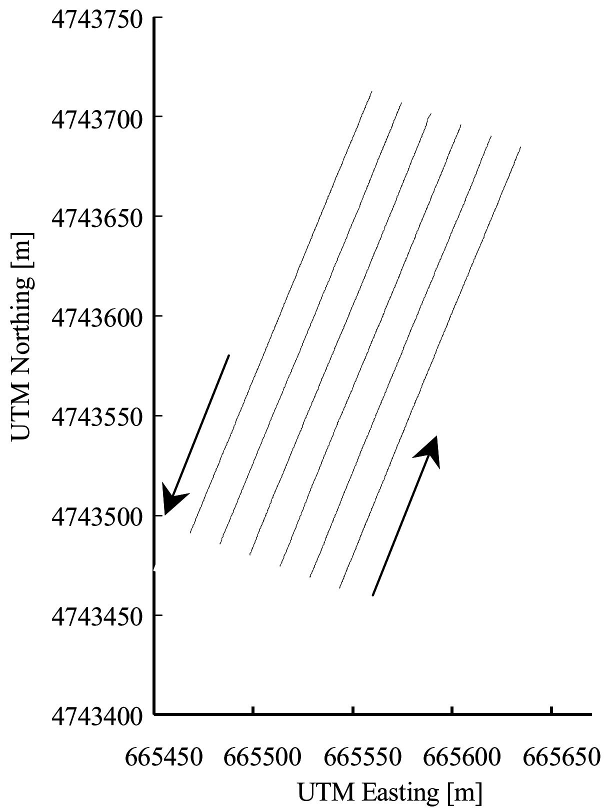


Figure 6. Navigation map for chemical application on sugar beat field..

tillage and cultivation, while a highest one was 2.0 m/s for chemical application by a sprayer. The range of the speed completely covered over all field operations for upland farming in Japan.

<u>Results and discussions</u>

Figure 6 shows a navigation map for a chemical application on sugar beat field, which included six parallel work paths. The field size was 2ha, and the boom width of the sprayer was 18m.

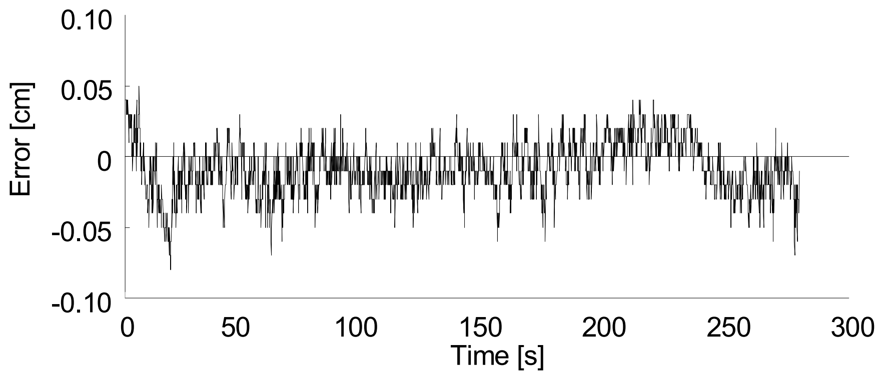


Figure 7. Lateral offset of #1 pathway on sugar beat field..

Because planting on the field was conducted by human operation, the desired pathways for splaying were taken by human driving. The operation velocity was 2.0m/s under the proper speed for the splay. The guidance system could follow the predetermined paths accurately. **Figure 7** shows the lateral offset on the robot splaying. The working distance for splaying was 280 m and the results are illustrated for the #1 path. As seen in the figure, the maximum error was 8 cm, and R.M.S. error was about 2 cm. The 2 cm RMS error is accurate enough for field operations.

CONCLUSIONS

This paper presents a solution to several challenging problems for robot tractors using a fusion of RTK-GPS and FOG sensors. The sensor fusion algorithm was capable of identifying FOG bias and compensating location error in real-time for providing sufficient navigation information for accurate robot guidance in the field. The guidance system could navigate the agricultural robot automatically to follow either straight or curve paths including crop rows at speed up to 2.0 m/s. This robot system resulted in a RMS pathway offset error of less than 2 cm. The experimental results for chemical splaying were presented to represent the robot performance. The navigation map generated by human driving pathway. The map included six straight paths. The overall accuracy of the RMS travel error was 2 cm and the maximum error was 8 cm. These results indicate that the navigation system was capable guiding an agricultural robot accurately and robustly under normal agricultural field operations.

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