AUTOMATIC GUIDANCE SYSTEM FOR COMBINE USING DGPS AND GYRO SENSOR

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ABSTRACT

An automatic guidance system for combine was designed to harvest paddy rice by following a predetermined path. The automatic guidance system consisted of DGPS to locate position of combine, a gyro sensor system to measure heading angle, ultrasonic sensors to detect obstacles, a hydraulic system, microcomputer as a controller, and I/O interface system. Hydraulic cylinders and valves were installed to control movement of the combine. The heading angle and the position of the combine, and ultrasonic measurements from edge were used as the inputs of the controller. The operating position of hydraulic cylinder was determined as output of the controller. The automatic guidance system was evaluated at the 45-m straight path by changing the posture of the combine. The average RMS errors were 14.0 cm without offset and 15.0 cm with 1-m offset. The DGPS provided accurate position information within the limited error to guide the combine in the field. The results showed that the automatic guidance system could guide the combine autonomously in the paddy field when the posture of the combine was changed.

Key Word : Combine, Guidance System, DGPS, Gyro Sensor

INTRODUCTION

Most agricultural field operation were performed using parallel path patterns and repetitive. An operator determines a desired path from visual cues such as stationary object at the edge of the field, previous swaths, or some kind of deliberately placed guidance. The operator observes the current posture of the vehicle and initiates appropriate steering adjustments by turning the steering wheel. The hydraulic and mechanical linkages then cause a change in the steering angle of the front wheels. The posture of a vehicle is the position and the orientation of the vehicle relative to the reference in the field. As agricultural machines become bigger and faster, the operator has become more difficult to control the posture of a vehicle relative to the desired posture.

Automatic guidance systems have been studied to reduce operator fatigue and to operate implements precisely in the agricultural field. Automatic guidance system that will control the posture of the vehicle more precisely than currently achieved by driver will permit the elimination of skips and overlaps and precise machine positioning relative to a previously defined location such as rows or wheel tracks. An essential requirement for automatic guidance system is a means of in-field location and navigation. Various techniques have been studied to determine the position of the vehicle and the desired path within a field. Automatic guidance system requires the in-field position information in term of a global reference system or relative to the fixed points in the field such as the field boundary. In this case, real time positioning is always required and, indeed, forward prediction of position may be necessary to allow for processing delays through the control system (Stafford and Ambler, 1994).

Local positioning systems depend on techniques to determine distances and angles of the vehicles relative to the fixed reference positions. Distance measurement generally depends on measuring the phase change of electromagnetic radiation of given wavelength and using the speed of propagation. A laser system (Shmulevich et.al., 1989), a radio system (Choi et al. 1990), and a microwave system (Searcy et al., 1990) were evaluated in the field. Although, the systems determined the position information within the given ranges, it was claimed that the systems overcome the problems of limited operation distance and signal interference. Ultrasonic sensors and a machine vision system were used to determine the desired path in an orchard (Cho and Ki, 1999). The ultrasonic sensors did not contribute to improve the vehicle guidance, but could be used to avoid obstacles. The weather condition and number of leaves in the field of view affected image quality and thus the effectiveness of the image processing operation. The machine vision alone could not find the desired path exactly as the operator did.

The most widely used system for location and navigation is probably the Global Positioning System (GPS) based on a constellation of satellites. Several studies showed the potential of differential GPS (DGPS) and real time kinematic (RTK) GPS for agricultural vehicle guidance. Ramalingam et al. (2000) developed DGPS based navigation system for agricultural vehicles. Nagasaka et al (2000) developed and tested automatic guidance system based on RTK GPS and fiber optic gyro (FOG). The GPS system will provide precise position information, but the navigation is required to change the position information into vehicle guidance parameter.

Significant research efforts have focused on development of feedback controllers for automatic vehicle guidance. Choi et al. (1990) developed the discrete-time equations to describe the motion of an agricultural tractor. Erbach et al. (1991) stated that under normal field conditions and especially at low speeds, cornering forces are small, rendering sideslip negligible and vehicle dynamics models valid. Stombaugh et al. (1999) developed the dynamic model for guidance control based on DGPS.

The purpose of this study is to implement an automatic guidance system on a combine harvester. Our primary goal is to design and test the feasibility of guidance system of combine to harvest in the small-sized paddy field autonomously.

MATERIALS AND METHODS

Guidance System

An automatic guidance system was designed to determine the position and the heading of a combine in the field, and to steer the combine based upon the difference between the combine position and a predetermined path. The predetermined path was input as a series of x-y coordinates. The automatic guidance system consisted of DGPS to locate position of combine, a gyro sensor system to measure heading angle, ultrasonic sensors to detect obstacles, a hydraulic system, microcomputer as a controller, and I/O interface system (Figure 1).

A combine (Kukje Machinery Co., Korea, Model KC300) was instrumented with the automatic guidance system. The combine had a total mass of 2100 kg and dimensions of 3985 x 1680 x 1995 mm (length x width x height). The width and the length of track were 400 mm and 1045 mm, respectively. The width of header was 1150 mm. The combine steering and header position were controlled by joystick located in front of driver seat. As the joystick was pushed forward or pulled backward, the electric signal was generated and the header moved upward or downward, respectively. As the joystick was pushed sideways, the hydraulic clutch and brake were activated. When the joystick was pushed left, the left track was braked and the combine was skidded. Torque from the engine was applied to only the right track.

Two sets of GPS (RT-STAR, Canadian Marconi Co., Canada), one for base station and the other for roving unit, were used to determine the positions of the combine in the field. The base station broadcast its differential data and the roving unit received them through a data port, directly connected to a radio receiver. The GPS receiver was operated using L1 frequency (1575.42 MHz) for code and carrier tracking. The receiver was capable of 12 measurements per satellite per second and complete navigation solution was computed every second with 10 cm of circular error probable (CEP) in real time kinetic (RTK) mode. The software, STARVIEW (Canadian Marconi Co., Canada), was used to install and operate the GPS. A choke ring antenna was used for base station and a geodetic antenna was for roving unit. The base station was set in the building at the Department of Bio-Mechatronic Engineering, Sungkyunkwan University, Suwon, Korea.

The hydraulic system was installed to control the movements of the combine such as selection of travelling direction (forward/backward), travelling speed (forward/backward), steering (left/ right), position of header (up/down), operation of brake, and operation of feeder and thresher. The hydraulic system consisted of five bi-directional hydraulic cylinders, six solenoid directional control valves, and one relief valve. The controller sent the control signals to the solenoid valves through I/O interface. Hydraulic oils were supplied by the hydraulic pump of the combine and returned to the tank.

The Digital Gyro Stabilized Sensor System (DGS^3, KVH Industry Inc., USA) was used to detect the heading angle of the combine. The DGS^3 consists of gyro compass and gyro inclinometer. This system provided digital outputs of absolute azimuth, pitch, and roll information at a rate of 5 Hz. The RS-422 serial output port of this unit was converted to RS-232 port of a microcomputer. The gyro sensor system was placed at the behind of driver seat as its long axes were parallel to the roll axis of the combine

Ultrasonic sensors (Keyence Co., Japan, Model UD-330) were used to detect obstacles and to measure the distance from edges in the field. The ultrasonic sensor had measurement range of 0.4 ~ 30 m with resolution of 1 cm. Two ultrasonic sensors were attached at the rear corners of the combine and the others were at the front corners to detect obstacles. The front ones transmitted and received signals perpendicular to the sides of the combine.

An industrial microcomputer was used as a controller to control the hydraulic system based upon position and heading information. The controller received analog signals from sensors and sent control signals to high hydraulic system through I/O interface system (National Instrument, SCXI). The I/O interface system consisted of interface module (SCXI-1200), 8 channels analog input module (SCXI-1120), 32 channels digital inputs module (SCXI-1162), 32 channels digital outputs module (SCXI-1163), and DC powered chassis (SCXI-1000DC). The I/O interface system was connected to a parallel port of the microcomputer with sampling rate of 20 kHz.

Control Algorithm

The heading angle and the position of the combine were measured, and the deviations and the difference of the heading angle from the predetermined path were computed. As shown in Figure 2, the deviation (d) can be calculated as equation 1 when the predetermined path can be expressed as $ax + by + c = 0$.

$$d = \frac{|a x_i + b y_i + c|}{\sqrt{a^2 + b^2}} \tag{1}$$

When vehicle travels at low speed, the side forces are extremely small and the sideslip will be negligible (Choi et al., 1990). The kinematic equations were developed to calculate the next location of the combine at given time interval. And the deviation at the next location was calculated as the next deviation.

$$\begin{aligned} y_{i+1} &= y_i + v \cdot t \cdot \cos(\theta + \omega \cdot t) \\ x_{i+1} &= x_i + v \cdot t \cdot \sin(\theta + \omega \cdot t) \end{aligned} \tag{2}$$

where,

x, y : current (i) and next(i+1) positions of the combine (m)
v : travelling velocity of the combine (m/s)
t : operating time of hydraulic cylinder (s)
ω : steering rate of the combine (radian/s)
θ : current heading azimuth of the combine (radian)

A control algorithm was developed based on kinematic movement of the combine. The heading angle and the position of the combine, and ultrasonic measurements from edge were used as the inputs of the controller. The current and next deviations, the difference of the heading angle, and ultrasonic measurements from edge were used to determine the operating position of the hydraulic cylinder. The control algorithm determined the operating position of the hydraulic cylinder by considering sampling rate, horizontal error of the DGPS, and delay time of the hydraulic cylinders.

When the combine reached at the each edge of the field during harvesting, it started made 90° counterclockwise turn. Figure 3 shows the schematic diagram of turning sequence at the edge. When the combine reached the target point of the straight predetermined path, it run forward more than 1.5 m. The operation of feeder and thresher was stopped, and the header was raised. The combine moved backward with right turn until it was parallel to crop line of path. The heading information by gyro sensor was used to determine the position to start straight running. After the header was down and the feeder and thresher were operated, the combine traveled the straight path. The turning algorithm was developed based on this sequence.

Field Experiment

The automatic guidance system of the combine was tested in the plain ground at Sunkyunkwan University in summer and fall of 2000. The information from the ultrasonic sensor was not utilized as the crops were not planted at the experimental field. The angular velocity to steer the combine was set at 4.3 °/s and combine travelling speed at 2.52 km/h. The measurement interval was approximately one second.

The control algorithm was evaluated at the 45-m straight path by changing the posture of the combine at the starting position. The combine started with or without 1-m offset and 30° heading angle from the straight path. A metal rod attached to the header made marks on the soil surface where the combine traveled. The deviations were measured every 0.5 m after each run and the root-mean-squared (RMS) error was calculated to evaluate the performance in following the desired path. Four replications were made for 45-m straight run.

RESULTS AND DISCUSSIONS

Guidance Performance

The automatic guidance system was evaluated at the 45-m straight path by changing the posture of the combine. The combine started on the predetermined path without heading angle (Figure 4) and with 30° heading angle (Figure 5). Figures show the lateral deviation from DGPS and manual measurements. The trends of lateral deviations of both measurements were similar, but DGPS measurements had more errors than manual measurements. It was founded that DGPS had 10 cm of position errors during the tests. The RMS errors were founded the minimum of 11.2 cm and the maximum of 17.9 cm from the four trials. The average RMS error was 14.0 cm and the maximum lateral deviation was 39 cm. The results showed that the DGPS provided accurate position information within the limited error to guide the combine in the field autonomously.

Figure 6 and Figure 7 showed the lateral deviations when the combine started 1 m off from the straight path without and with 30° heading angle. The RMS errors and the maximum lateral deviations were founded after the combine crossed the straight path. The RMS errors were founded the minimum of 11.9 cm and the maximum of 18.3 cm from the four trials. The average RMS error was 15.0 cm and the maximum lateral deviation was 51 cm. It was founded that the DGPS measurement indicated the combine traveled on the predetermined path but the combine actually traveled at the right region from the path. These deviations might come from the DGPS measurement errors and the systematic alignment of the combine. The DGPS position errors were changed at odd times. The results showed that the automatic guidance system could guide the combine autonomously in the paddy field when the posture of the combine was changed.

CONCLUSIONS

An automatic guidance system for combine was designed to harvest paddy rice by following a predetermined path. The automatic guidance system consisted of DGPS to locate position of combine, a gyro sensor system to measure heading angle, ultrasonic sensors to detect obstacles, a hydraulic system, microcomputer as a controller, and I/O interface system. Hydraulic cylinders and valves were installed to control movement of the combine. The heading angle and the position of the combine, and ultrasonic measurements from edge were used as the inputs of the controller. The current and next deviations, the difference of the heading angle, and ultrasonic measurements from edge were used to determine the operating position of the hydraulic cylinder. The operating position of hydraulic cylinder was determined as output of the controller.

The automatic guidance system was evaluated at the 45-m straight path by changing the posture of the combine. The average RMS errors were 14.0 cm without offset and 15.0 cm with 1-m offset. The maximum lateral deviations were 39 cm without offset and 51.0 cm with 1-m offset. The results showed that the automatic guidance system could guide the combine autonomously in the paddy field when the posture of the combine was changed. The DGPS provided accurate position information within the limited error to guide the combine in the field autonomously. The gyro sensor could measure the heading angle of the combine, and the ultrasonic would be used to detect the obstacles and the edges of the field.

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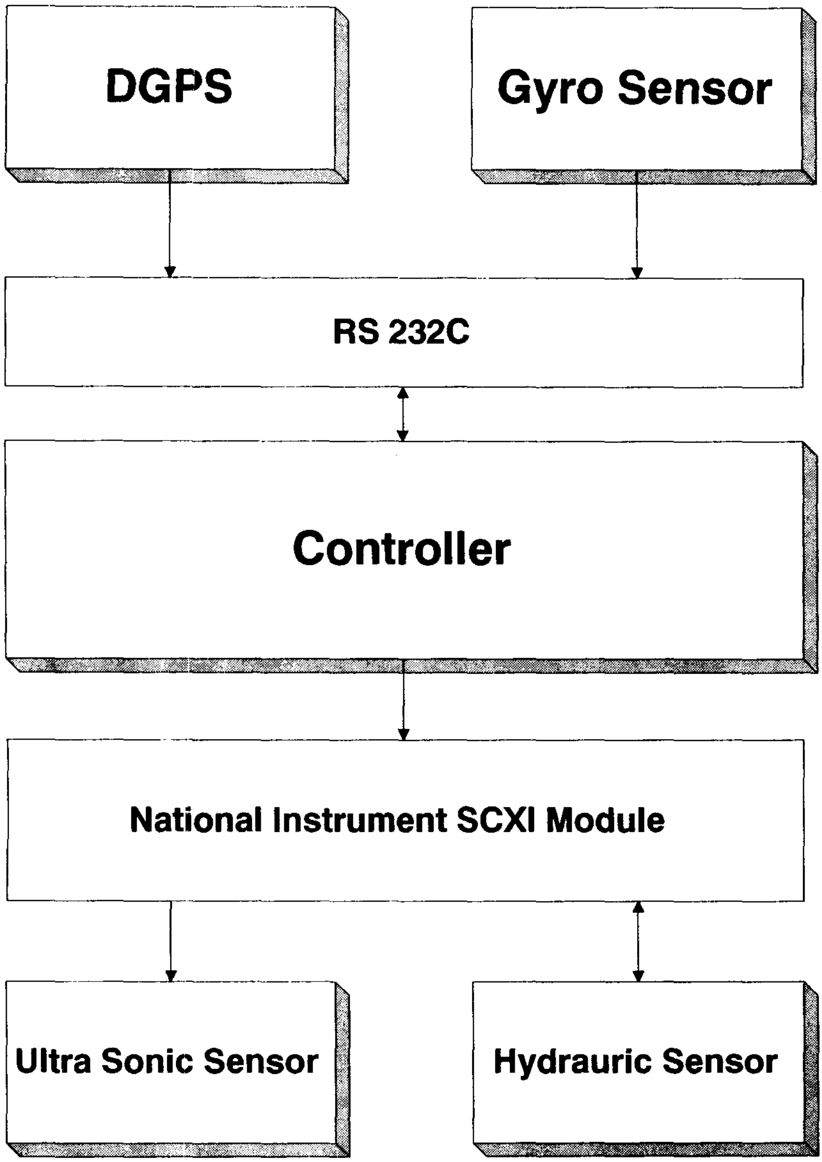

Figure 1. Configuration of the automatic guidance system.

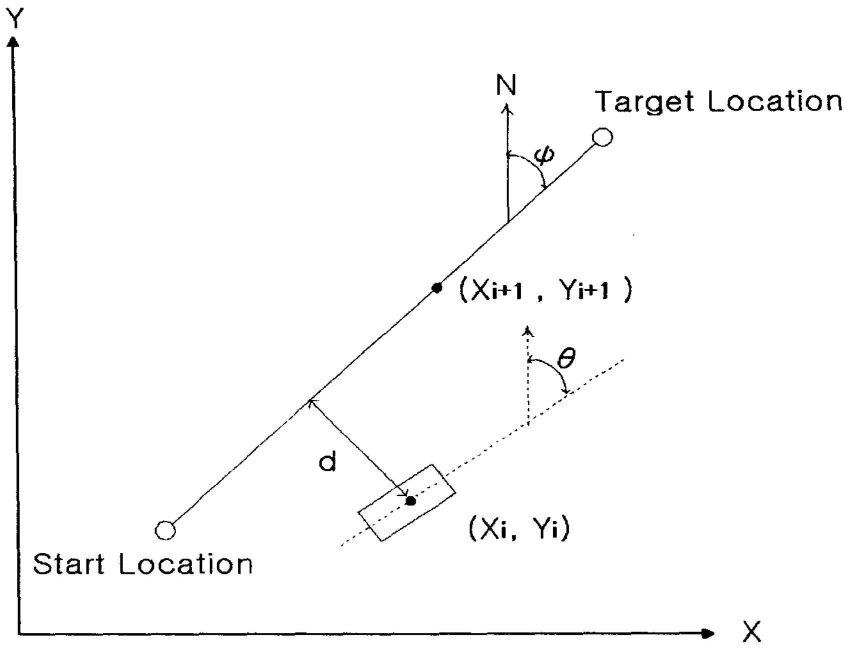

Figure 2. Lateral deviation and heading angle of combine.

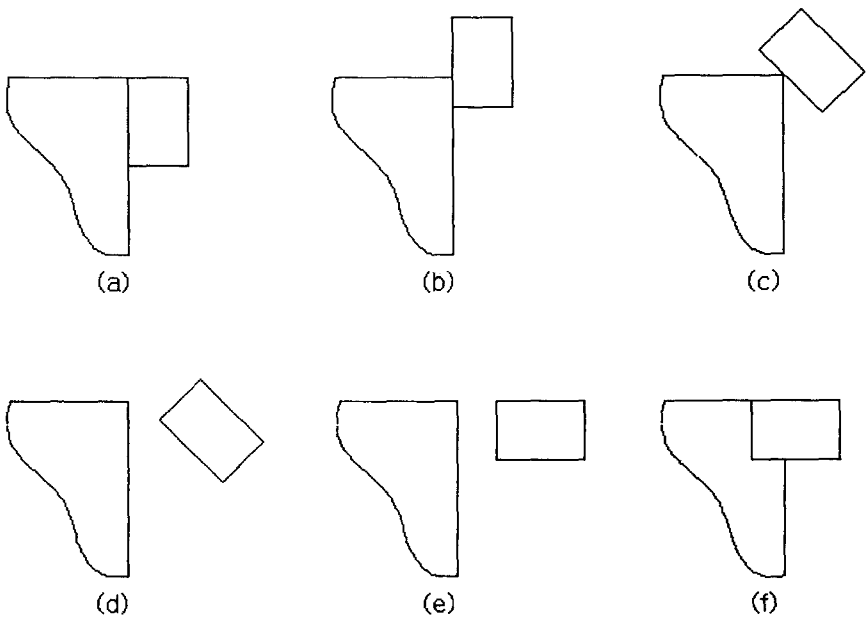

Figure 3. Schematic diagram of turning sequence at the edge.

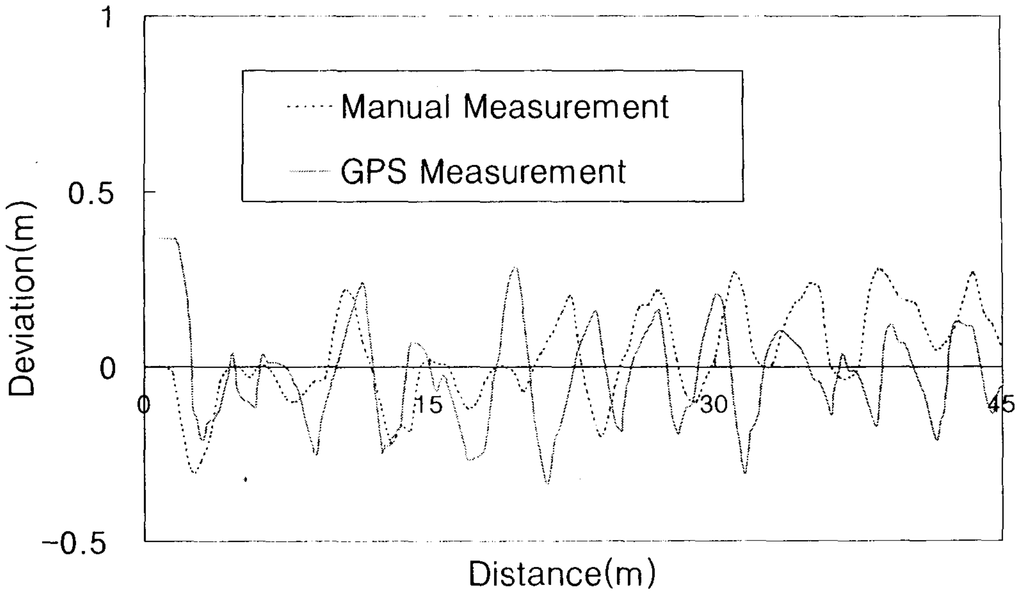

Figure 4. Lateral deviation from straight path.

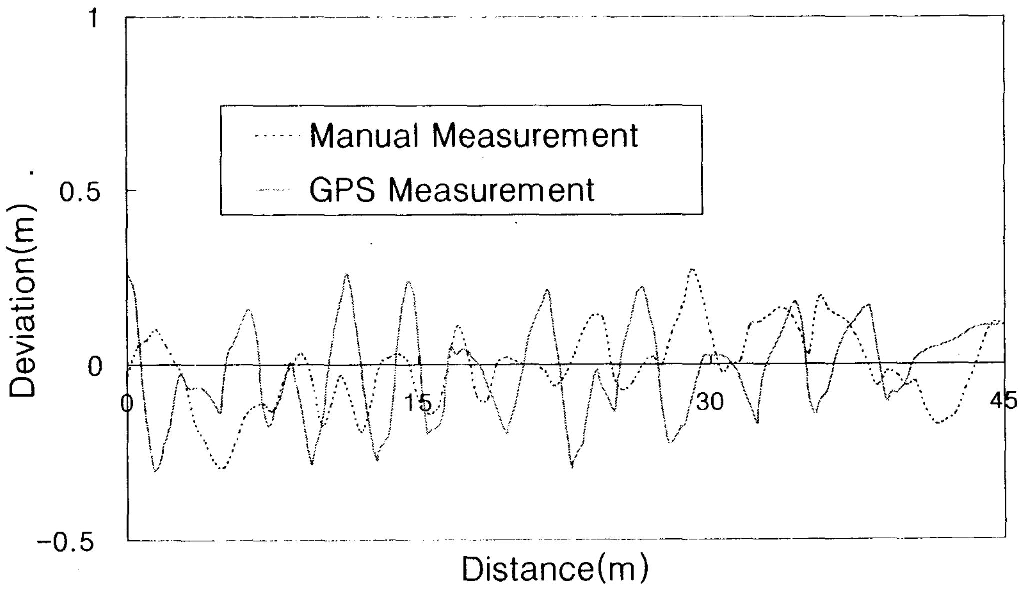

Figure 5. Lateral deviation from straight path with 30° heading angle.

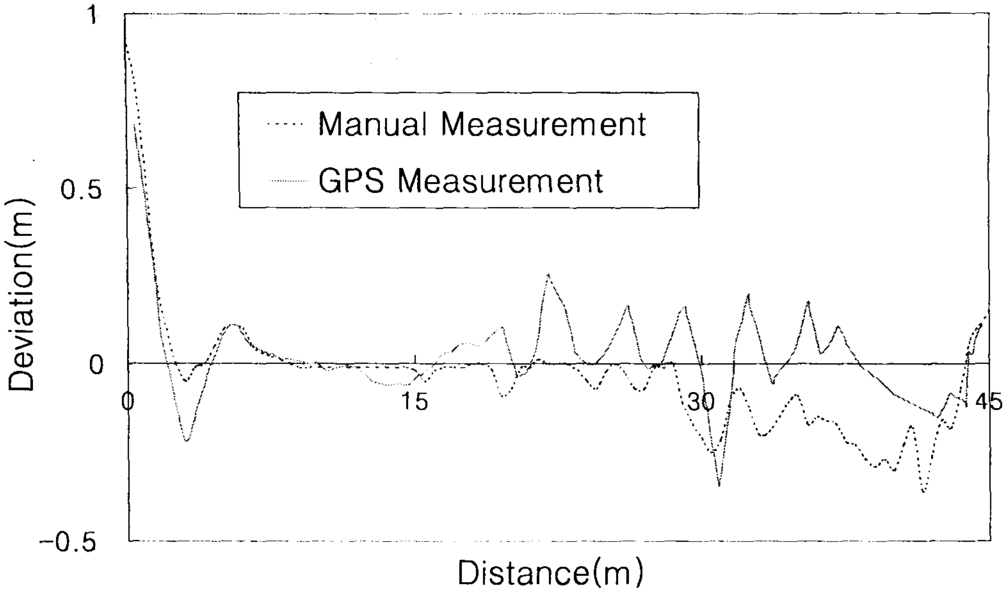

Figure 6. Lateral deviation from straight path with 1-m offset.

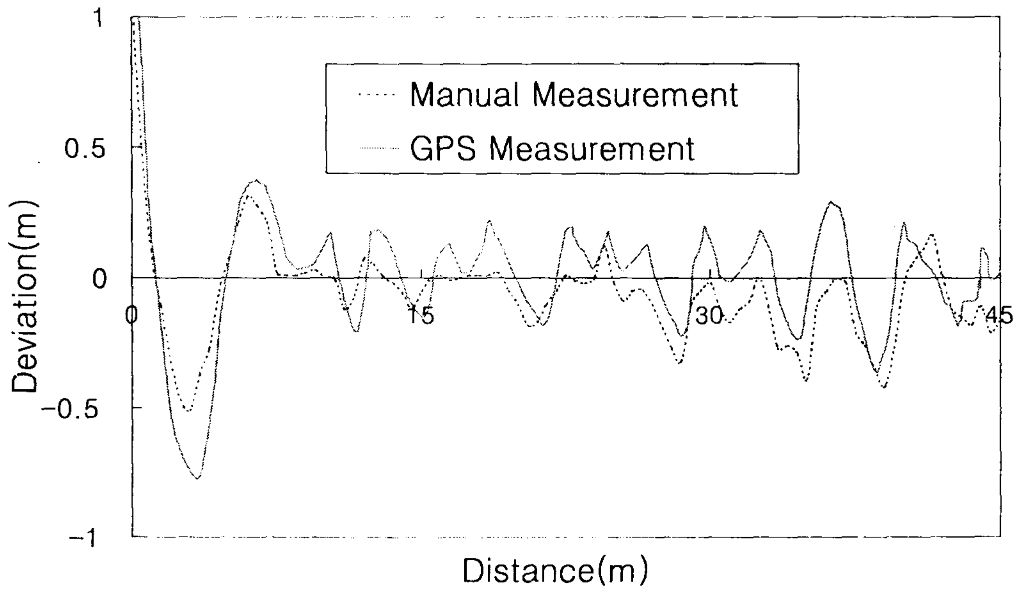

Figure 7. Lateral deviation from straight path with 1-m offset and 30° heading angle.