Development of GPS-based Tracking System to Evaluate the Effectiveness of Tillage using Four-wheel Tractor

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Abstract. The objective of this study was to present the development of GPS-based tracking system to evaluate the effectiveness of tillage using a four-wheel tractor. The system is composed of a location acquisition, using GPS (iGPSport), and data analysis for estimating the tractor trajectories and effectiveness of tillage by measuring the overlap during the tillage. The laboratory stage experiment was conducted to validate the system by measuring the specified size of the field and tractor trajectories. The performance evaluation of the system was done by measuring the displacement error of actual trajectories and the estimated one. The system was also tested for the actual tillage operation using a four-wheel tractor, Daedong Kioti RX7210, in two locations in Yogyakarta: Pajangan, and Moyudan. The tractor tracking system was developed based on GPS for estimating the tractor trajectory path and operation width distance (l) after the operation as tillage effectiveness evaluation by the evaluation of overlap and untillage land systematically using the tracking system. The system performance evaluation in the actual field for tillage operation using the four-wheel tractor in Moyudan and Pajangan shows that the RMSE < 50 cm, and the MAPE < 24% with $R^2 > 0.7$. Overall performance of the tracking system, it could be used to estimate the behavior of tillage operation.

1. Introduction

Tillage is defined as mechanical manipulation of the soil for agricultural preparation of soil by mechanical agitation of various types, such as digging, stirring, and overturning. Soil tillage is a human effort to change the properties possessed by land by human needs for agricultural activities [1]. This activity is important because it can affect the quality of the land, the working time of processing and production of agricultural products. Therefore, this activity requires effective and efficient efforts. The main purpose of tillage is to provide a place to grow for seeds, to loosen the soil in the root area, reverse the soil so that the remnants of the plant sink into the soil and eradicate weeds [1–3].

Efforts to get effective and efficient tillage require a precision farming system. Precision agriculture is information and technology in agricultural management systems to identify, analyze, and manage information on spatial and temporal diversity in the land to obtain optimum, sustainable and environmental benefits [4–6]. Inland processing activities the application of precision agriculture can be done by controlling the work results with the evaluation of the operator after processing the soil. Evaluation of this work can be done with the help of tractor navigation, but the cost of tractor navigation is still relatively expensive. Then an evaluation system is needed for simple implementation. One
alternative is the use of a GPS tracker as an alternative for affordable sensing in precision agriculture implementation [7,8].

The development of GPS tracking used for tractors in tillage has been carried out several studies [9,10]: integrating the use of the Global Navigation Satellite System (GNSS) and sensing system vision sensing sensors with accuracy reaching 2 in (51 mm) at the tractor's forward speed between 2-5 m/s. Whereas [11,12] have developed programming algorithms and GPS navigation systems that have been able to work well to provide precise direction information following the specified coordinate path. The resulting navigation information is used as a guide to the operator so that the tractor moves to follow the predetermined coordinate path. The operator must control the tractor from the edge of the land because it is not equipped with a navigation sensor so that the position of the tractor cannot be detected without being seen directly with a maximum remote-control range of 100 m. GPS tracking control helps to process the soil with high precision and accuracy so that no soil is not treated or overlapping [13].

The objective of this study was to present the development of GPS-based tracking system to evaluate the effectiveness of tillage using a four-wheel tractor. The system design, calibration of accuracy at the laboratory stage, and system performance evaluation in the actual field for tillage operation using four-wheel tractor will be explained.

2. Material and Method

2.1. Tracking System

Figure 1. shows the schematic of the GPS-based tracking system for tillage evaluation. The system composed of GPS device, iGS10 from iGPSport (Wuhan Qiwu Technology Co., Ltd, Wuhan, China) with specification listed in Table 1., Smartphone with Android OS equipped with iGPSport App., and iGPSport (www.i.igpsport.com) cloud as online storage and data visualization. The recorded data (latitude, longitude, and elevation) can be stored locally into a smartphone or synchronize with iGPSport web application for flexible access and data management. The data can be downloaded using *.GPX extension, an XML format designed specifically for saving GPS track, waypoint and route data. It is increasingly used by GPS programs because of its flexibility as an XML schema. For detail procedure of data acquisition using a GPS-based tracking system can be seen in Figure 2. Further analysis can be performed using Spreadsheet Application and R in computer/PC as the data analysis stage.
Table 1. Technical specification of IGS10 iGPSport

| Aspect                | Information     | Aspect            | Information          |
|-----------------------|------------------|-------------------|----------------------|
| Name                  | iGPSport         | Weight (g)        | 57.3                 |
| Model                 | IGS10            | Temperature sensor| Available            |
| Color                 | Black            | Temperature       | -10°C – 50°C         |
| Manufacture           | Hubei, China (Mainland) | Altimeter       | Analog               |
| Dimension (mm)        | 46*71*22         | Transmission      | Bluetooth 4.0BLE     |
| Display (cm)          | 3.0*3.8          |                   |                      |

Figure 2. Flowchart of data acquisition using GPS for tracking system

Figure 3. Estimation of coordinate following the center of reference line $y_L$.

The estimation of distance calculation between two trajectory lines was following the schematic at Fig. 3. At first, a middle line from two reference points ($P_1$ and $P_4$) perpendicular with path trajectory line,
is estimated and denoted as \( y_L \) with equation \( y_L = mx + c \). The next is inline coordinate estimation following the \( y_L \) line from the point path coordinate \( P_2 \). To estimate the perpendicular line from \( y_L \),

\[
m_1 = \frac{y_2-y_1}{x_2-x_1} \tag{2.1}
\]

When \( m_2 = (-1) / m_1 \) if the two line is perpendicularly each other, so \( y_2 = y_L - (m_1 \times x_1) \). Accordingly, cross section-point between \( y_L \) and \( y_2 \) can be denoted as the estimated coordinate for further distance calculation. For calculate the distance between two point, for example \( P_1 \) and \( P_2' \), Haversine Formula was used as follows:

\[
l = 2r \arcsin(\sin(\frac{\lambda_2 - \lambda_1}{2})) \tag{2.2}
\]

\[
l = 2r \arcsin\left(\sqrt{\sin^2(\frac{\varphi_2 - \varphi_1}{2}) + \cos(\varphi_1) \cos(\varphi_2) \sin^2(\frac{\lambda_2 - \lambda_1}{2})}\right) \tag{2.3}
\]

where \( \varphi_1 \) and \( \varphi_2 \) are latitude of point 1 and latitude of point 2 (radians), \( \lambda_1 \) and \( \lambda_2 \) are longitude of point 1 and point 2 (radians), and \( l \) is the estimated distance. The \( r \) represents the earth radius of 6371 km, and 1 degree can be converted to 0.0174532925 radians. Accordingly, the cumulative operation width \( l, 2l, 3l, ..., nl \) will be compared for system evaluation.

2.2. Experimental Setup

Two kinds of calibration were conducted at the laboratory stage to evaluate system performance. The first evaluation was on the distance estimation using the squared distance plot test with an area of 25 x 15 meters. The second one was the pattern evaluation, especially for estimating the distance between two tractor’s trajectory lines with the actual distance 1-meter applying edge pattern for machine operation.

As for performance evaluation in the actual field, tillage operation using four-wheel tractor Kioti RX7210 (Daedong co., South Korea) have been evaluated using the developed tracking system in two places in Yogyakarta: Pajangan - Bantul and Moyudan - Sleman with Latosol and Grumusol soil type respectively. The tillage operation for both locations applied headland casting pattern from edge for primary tillage operation using disc plow (Lambang Jaya, Indonesia) with theoretical working-width 110 cm. The precision of the tracking system will be evaluated by the accuracy of the actual distance and estimated distance by the GPS-based tracking system. To quantify the accuracy, Root Mean Squared Error (RMSE) and Mean Average Percentage Error (MAPE) were used. MAPE is a statistical measure of how accurate a tracking system is, measures as a percentage. The equation for calculating the RMSE and MAPE are listed as follows:

\[
RMSE = \sqrt{\frac{\sum_{i=1}^{n}(\hat{y}_i - y_i)^2}{n}}; \quad MAPE = \frac{1}{n} \sum_{i=1}^{n} \left| \frac{A_t - \hat{E}_t}{A_t} \right| \tag{2.4}
\]

where \( \hat{y}_i \) is the estimated value, and \( y_i \) is the actual or observed value, and \( n \) is the number of observed data, \( A_t \) is the actual value, \( E_t \) is the estimated value. The \( MAPE \) is the most common measure used to forecast error, and works best if there are no extremes to the data.

3. Result and Discussion

Figure 4. shows the result of tracking system calibration at the laboratory stage for squared distance plot and pattern. From the squared distance plot distance can be seen as a straight line and estimated
coordinate based on GPS-tracking. The summary evaluation of the line tracking on squared distance plot with 49 coordinates shows that maximum error was 63.7 cm, minimum error 0.13 cm, and the mean was 15.21 cm. for the corner to corner distance estimation can be seen in Table 2. The RMSE was 0.66 meter and the MAPE was 1.47%.

![Figure 4](image_url)

**Figure 4.** Calibration result for squared distance plot (a) and pattern (b) at the laboratory stage.

| Point | Actual (m) | Estimated (Haversine) (m) | Absolute Error (m) | Percentage Error (%) |
|-------|------------|---------------------------|-------------------|---------------------|
| A – B | 25         | 15.13                     | 0.13              | 0.853               |
| B – C | 15         | 24.93                     | 0.07              | 0.273               |
| C – D | 25         | 14.36                     | 0.64              | 4.283               |
| D – A | 15         | 25.12                     | 0.12              | 0.463               |

The pattern evaluation was used to evaluate the working width, a distance between two trajectory lines according to the point estimated by the GPS. The estimated distance was compared with actual distance using manual measurement as listed in Table 3. The RMS obtained from the 15 trajectory lines was 43.08 cm and the MAPE was 39.55%. Also, to calibrate the tracking system, an equation for transforming the estimated distance to actual distance was obtained by linear regression from cumulative distance from reference point to line 2, 3, …, 15. The linear regression plot can be seen in Fig. 4 with the determination coefficient \( R^2 \) value is 0.9965. The \( R^2 \) value is relatively high, means that the cumulative estimated distance could be used to represent the cumulative actual distance during the pattern evaluation. The obtained linear is \( y = 0.9913x + 41.167 \). Further, the equation will be applied to evaluate the actual observation of tractor trajectory.

| Line | Cumulative Distance (cm) | Absolute Error (cm) |
|------|--------------------------|---------------------|
|      | Estimated               | Actual              |
| 1    | 91.24                   | 100                 | 8.76                |
| 2    | 148.15                  | 200                 | 51.85               |
| 3    | 250.23                  | 300                 | 49.77               |
| 4    | 348.26                  | 400                 | 51.74               |
| 5    | 519.54                  | 500                 | 19.54               |
| 6    | 538.5                   | 600                 | 61.5                |
| 7    | 642.84                  | 700                 | 57.16               |
Figure 5. Linear regression plot for cumulative estimated distance and cumulative actual distance.

Figure 6. Visualization plot in actual tillage using four-wheel tractor using disc plow for two location: (a) Pajangan and (b) Moyudan, the tracking point coordinate displayed as dot and the line distance.

By visual appearance, the quality and effectiveness of tillage operation can be assessed. Tillage operation at Pajangan shows that trajectory line indicated non-straight track that causes an overlapping and un-tillage land. Those phenomena are not expected during tillage operation because it might reduce efficiency and tillage quality. For the second location, Moyudan, by visual appearance, it shows a better trajectory during the straight line. Although the overlapping and un-tillage land still occurs, it relatively lower than in Pajangan.
Figure 7. shows the quantitative evaluation of the tracking system in actual tillage operation in Pajangan and Moyudan. The Estimated and Actual cumulative distance have been plotted to assess the relationship. From 23 estimated distances using tracking system and actual by manual measurement, the determination coefficient ($R^2$) on Pajangan was 0.7072 and Moyudan was 0.8886, means that performance of tracking system for estimating the working width could represent the actual one. The $R^2$ value on Moyudan was relatively higher than Pajangan, in line with the assessment result by visual appearance.

Deeper evaluation using Error and Percentage Error, comparison between estimated and actual for both locations with 23 lines of cumulative distance shows that the RMSE for Pajangan was 33.21 cm and MAPE was 23.19%. For the second location, Moyudan, the RMSE was 16.57 cm and MAPE was 11.25%. Accordingly, the error in Moyudan for both RMSE and MAPE were relatively lower than in Pajangan. The high value of error about 33.21 might cause by the accuracy of the GPS-device when estimating the coordinate precisely. Overall performance of the tracking system, it could be used to estimate the behaviour of tillage operation. The effectiveness of tillage operation could be assessed by the evaluation of overlap and un-tillage land systematically using the tracking system.

4. Current Conclusion
The tractor tracking system was developed based on GPS for estimating the tractor trajectory path and operation width distance ($l$) after the operation as tillage effectiveness evaluation by the evaluation of overlap and un-tillage land systematically using the tracking system. The system performance evaluation in the actual field for tillage operation using the four-wheel tractor in Moyudan and Pajangan shows that the RMSE < 50 cm, and the MAPE < 24% with $R^2 > 0.7$. Overall performance of the tracking system, it could be used to estimate the behaviour of tillage operation.

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References
[1] Suripin 2002 Pelestarian Sumber Daya Tanah dan Air (Yogyakarta: Penerbit Andi)
[2] Derpsch R, Friedrich T, Kassam A and Hongwen L 2010 Current status of adoption of no-till farming in the world and some of its main benefits Int. J. Agric. Biol. Eng.
[3] Ani O A, Uzoejinwa B B, Ezeama A O, Onwualu A P, Ugwu S N and Ohagwu C J 2018 Overview
of soil-machine interaction studies in soil bins Soil Tillage Res.

[4] McBratney A B and Whelan B M 1995 Continuous models of soil variation for continuous soil management Site Specif. Manag. Agric. Syst. Proc. Conf. Minneapolis, 1995

[5] Shibusawa S 2002 Precision Farming Approaches To Small-Farm Agricultural Agro-Chemicals Rep. 2 13–20

[6] Shibusawa S 2003 Precision Farming Japan Model J. Agric. Inf. Res. 12 125–33

[7] Okayasu T, Nugroho A P, Sakai A, Arita D, Yoshinaga T, Taniguchi R I, Horimoto M, Inoue E, Hirai Y and Mitsuoka M 2018 Affordable field environmental monitoring and plant growth measurement system for smart agriculture Proceedings of the International Conference on Sensing Technology, ICST

[8] Okayasu T, Nugroho A P, Arita D, Yoshinaga T, Hashimoto Y and Tachiguchi R 2017 Sensing and Visualization in Agriculture with Affordable Smart Devices Smart Sensors at the IoT Frontier

[9] Easterly D R, Adamchuk V I, Kocher M F and Hoy R M 2010 Using a vision sensor system for performance testing of satellite-based tractor auto-guidance Comput. Electron. Agric.

[10] Watanabe Y, Johnson E N and Calise A J 2006 Vision-based guidance design from sensor trajectory optimization Collection of Technical Papers - AIAA Guidance, Navigation, and Control Conference 2006

[11] Ahmad U, Desrial D, Subrata I D M and Annas S 2010 Pengembangan Algoritma Pengolahan Citra untuk Menghindari Rintangan pada Traktor Tanpa Awak Keteknikan Pertan. 24 81–7

[12] Desrial D, Subrata I, Ahmad U, Annas M and Rahman C 2010 Pengembangan Sistem Kemudi Otonomis Pada Traktor Pertanian Menggunakan Navigasi GPS (Serpong: Balai Besar Mekanisasi Pertanian)

[13] Sutisna S, Subrata I and Setiawan R 2017 Sistem Pengendali Kemudi Traktor Otomatis Empat Roda pada Pengujuan Lintasan Lurus (Tracking Control System of Autonomous Four Wheel Tractor on Straight Agritech 35 106–13