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Spanish Journal of Agricultural Research 23 (1)
January-March, 2025, 20934
ISSN-L 1695-971X, eISSN 2171-9292
https://doi.org/10.5424/sjar/2025231-20934

RESEARCH ARTICLE

A mobile application for recording area and time of farm machine's operation in the field through the global positioning system of smartphone

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Abstract

Aim of study: A mobile application was developed to record machine operations using the Global Positioning System (GPS), including the segregation and area calculation of each plot.

Area of study: Dr. Rajendra Prasad Central Agricultural University, Pusa (Bihar). India

Material and methods: The developed mobile application was designed to record geolocations at user-defined intervals with start-stop controls and user-assigned device IDs. The application was utilized to identify and distinguish field plots traversed by a tractor. Accuracy evaluation involved comparing recorded areas with measured values using a measuring tape across three sizes (small, medium, large) in 25 fields. Segregation efficiency was assessed in five trials involving continuous and interrupted tractor movements, noting the area covered, entry time and exit times for each field over five days.

Main results: The developed mobile application was evaluated extensively in terms of error in area calculation as well as segregation error. It was observed that there was no signification error in recording the time of operation, however, the error percentage in area measurement was about ±10%, in large (2.46%), medium (5.40%) and small (6.91%) fields. The error in field segregation was not observed, however, an error in the point of segregation was already considered in the area calculation.

Research highlights: A mobile application was developed that utilizes the Global Positioning System (GPS) to record the machine's operation. This application can segregate the different fields in which the machine was operated as well as calculate the area of operation. The developed application proved to be highly effective in monitoring farm machinery operations, facilitating custom hiring services billing, and serving various other purposes.

Keywords: area of field, geolocations, geolocation application, Global Positioning System.

Una aplicación móvil para registrar el área y el tiempo de operación de la maquinaria agrícola en el campo mediante el sistema de posicionamiento global del teléfono inteligente

Resumen

Objetivo del estudio: Se desarrolló una aplicación móvil para registrar las operaciones de maquinaria utilizando el Sistema de Posicionamiento Global (GPS), incluyendo la segregación y el cálculo del área de cada parcela.

Área de estudio: Dr. Rajendra Prasad Central Agricultural University,Pusa (Bihar), India.

Material y métodos: La aplicación móvil fue desarrollada para registrar geolocalizaciones en intervalos definidos por el usuario, permitiendo controles de inicio y parada, así como la asignación de identificaciones de dispositivos por parte del usuario. Se diferenciaron las parcelas agrícolas recorridas por un tractor, evaluando la precisión al comparar las áreas registradas con las medidas mediante cinta métrica en tres tamaños (pequeño, mediano y grande) en 25 campos. La eficiencia de segregación se evaluó en cinco ensayos con movimientos continuos e interrumpidos del tractor, registrando el área cubierta, los tiempos de entrada y salida para cada campo durante cinco días.

Principales resultados: La aplicación móvil desarrollada fue evaluada ampliamente en términos de error en el cálculo del área y error de segregación. Se observó que no hubo un error significativo en el registro del tiempo de operación; sin embargo, el porcentaje de error en la medición del área fue de aproximadamente ±10%, siendo del 2,46% en campos grandes, 5,40% en medianos y 6,91% en pequeños. No se observó error en la segregación de los campos, aunque el error en el punto de segregación ya se había considerado en el cálculo del área.

Conclusiones: Se desarrolló una aplicación móvil que utiliza el Sistema de Posicionamiento Global (GPS) para registrar la operación de la maquinaria. Esta aplicación tiene la capacidad de segregar los diferentes campos en los que se operó la maquinaria, así como calcular el área de operación. La aplicación desarrollada demostró ser altamente efectiva para monitorear las operaciones de maquinaria agrícola, facilitando la facturación de servicios de alquiler personalizado y sirviendo para diversos otros propósitos.

Palabras clave: aplicación de geolocalización, área del campo, geolocalizaciones, Sistema de Posicionamiento Global.

Citation: Sharma, A; Pranav, PK; Prasad, R (2025). A mobile application for recording area and time of farm machine's operation in the field through the global positioning system of smartphone. Spanish Journal of Agricultural Research, Volume 23, Issue 1, 20934. https://doi.org/10.5424/sjar/2025231-20934.

Received: 30/11/2023. **Accepted:** 13/09/2024. **Published:** 29/04/2025.

Introduction

It is well proven that farm mechanization is essential for enhancing farmer's income as well as reducing human drudgery. Large and medium farmers are capable of owning tractors and other big machines, and hence, their farms are mechanized. However, small and marginal farmers rely on custom hiring services cultivating more than 80% of the total cultivable area in India. In such scenarios, custom hiring serves as the only viable means to promote mechanization, particularly in India. The practice of providing or availing machine services on a payment basis is called "Custom hiring service". Custom hiring services are provided by state agro-industries corporations, government agencies, cooperative societies, and private machine owners. In recent years, many researchers (Thomson et al., 2014; Kaivosoja & Linkolehto, 2015; Pranav et al., 2016) have explored ways to make custom hiring centers profitable and easily accessible to farmers. Pranav et al. (2016) developed a computer program for cost estimation of agricultural machines as well as break-even analysis for the custom hiring center to prevent losses in custom hiring centers. Jayawant & Joshi (2018) also simulated the operations of custom hiring center (CHC) under different scenarios to estimate its profitability. Daum et al. (2020) developed a mobile application for hiring tractors on demand, similar to taxi booking services through mobile applications. Although these studies were conducted to promote custom hiring services, none of them quantified the amount of work done by the machine for which it was hired. There is no technology-based system to calculate custom hiring charges immediately after completing the work, similar to application-based taxi services. In agricultural services, the hiring charges are calculated based on the area covered in the field as well as time taken. Therefore, this project was undertaken to develop a mobile based application that records the machine's operation using the Global Positioning System (GPS) while also segregating and calculating the area of each plot.

Global Positioning System (GPS) is a technology used to know the location of a tractor or any moving vehicle at a given time. GPS is a U.S. government-owned Radio Navigation Satellite System operated by the U.S. Space Force. It is one of the Global Navigation Satellite System (GNSS) that provides time information and geolocation to GPS receivers anywhere on Earth, where visibility to at least four satellites remains unobstructed. Researchers have successfully utilized GPS for various agricultural applications. Omrani et al. (2013) determined the field efficiency of sugarcane harvester by using GPS data. Stoll et al. (2003) developed an automatic operation planning system for GPS-guided machinery. Maurya et al. (2012) designed a real time, vehicle tracking system by using GPS and Global System for Mobile Communications (GSM). Xiang et al. (2016) developed an ARM11 and GNSS based monitoring system for measuring the information related to working condition of agricultural machinery in real time. Inoue et al. (2009) developed a differential GPS tractor guidance system (DGPS) for monitoring tractor driving to track target lines in the field for sowing, ploughing, spraying, and harvesting. The primary aim of this research was to develop a mobile-based application that utilizes GPS to record the machine's operation. The application was designed to segregate different fields where the machine was operated and calculate the area of operation.

Materials and methods

A mobile application named "Geolocation" was developed to record real-time geolocations at desired time intervals using the inbuilt GPS of the smartphone. The application uses different algorithms to segregate machine operations across different fields and calculate the area of each segregated field.

Development of mobile application

The mobile application developed for this study had distinct front-end and back-end functionalities. The front-end/ user interface (UI) was designed using, React.js (https://react.dev/), a JavaScript library known for building responsive and intuitive user interfaces for web and native applications. The middle layer, responsible for handling Representational State Transfer Application Programming Interface (REST API) calls, was built with Express.js (https://expressjs.com/) a minimal and flexible Node.js mobile and web application framework that facilitates smooth communication between the front-end and back-end. The server-side logic, including all back-end operations, was implemented using Node.js, ensuring efficient processing and data management. The database used was MongoDB (https://www.mongodb.com/), a widely used Not only Structured Query Language (NoSQL) document-oriented database that securely stores the application data and enabled scalable data management. The mobile application itself was developed using React Native, enabling seamless data transfer and compatibility with smartphones. Specifically for Android devices, the application was built using MongoDB, Express, React, Node.js (MERN) stack. The application plotted data using Scalable Vector Graphics (SVG) to provide clear and detailed visualizations. This application was classified as a native application and could be installed through an Android Package Kit (APK) file. The programming language used for the application's development was JavaScript. The app securely stores data in the cloud, ensuring seamless access and data integrity. Additionally, the application was developed on a local platform with role-based access, providing different levels of access and functionalities to users based on their roles. This enhanced security and ensured that only authorized users could access specific features and data.

The methodology employed in developing the application follows the Scrum Agile framework, emphasizing a systematic approach to enhance time and area calculation for agricultural field operations. The application streamlines operations through an intuitive user interface developed in React, ensuring responsiveness and user-friendliness. Middleware integration with Express facilitates seamless API handling, optimizing operational efficiency. MongoDB serves as the backend database for scalable data management and cloud storage, enhancing accessibility and reliability. This approach supports easy deployment via APK files on Android devices, maintaining data integrity in cloud storage. Overall, the development process adheres to Scrum Agile principles, fostering iterative improvements tailored to meet agricultural field requirements.

Recording of Geolocation

The developed application continuously collects geolocations using the smartphone's inbuilt GPS. It allows users to start and stop the recording of geolocation as needed. Further, users can set the recording time interval between 1,000 and 10,000 milliseconds. For better tracking, a user must enter a unique device Id, can be a name, numeric digit or other identifier. The application also displays the coordinates on the main screen in the form of latitude and longitude when the user clicks the "GET CURRENT LOCATION" button. The snapshot of developed user interface of the developed application is shown in Figure 1.

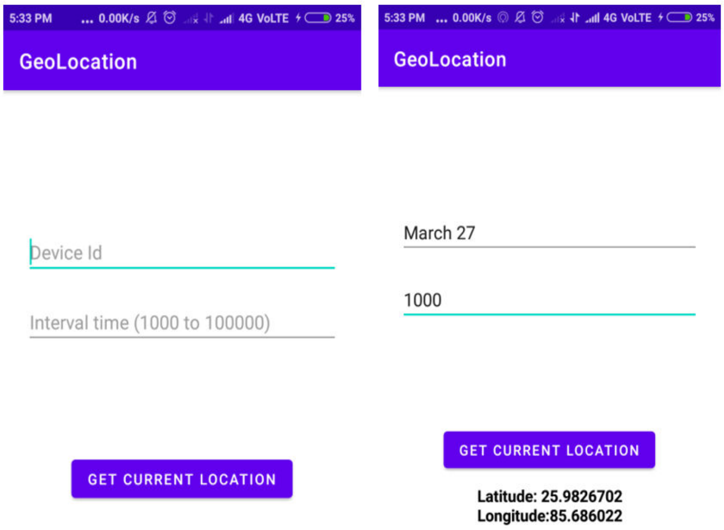

Figure 1. User Interface of the developed GeoLocation Application for field data recording.

Segregation of plots

Segregation of plots refers to the process of identifying and distinguishing the specific plots of land that have been covered or worked on by a tractor during ploughing, cultivation or other activities. As the tractor operates across different plots, the smartphone application logs the traversed areas and differentiates them as individual plots.

Algorithm for plot segregation

1. The process begins by checking whether there are three or more than three points or not because it is required to have at least three points to form a polygon; if no, it does not form any closed loop and if yes, then it starts to identify all closed loops. A closed loop is a path starting from an initial point, traverses some distance and gets return to or near the initial point and, there can be many such loops in the whole track.
   - In the first step, the algorithm identifies all possible closed loops.
   - In the second step, all the points of closed loops are added to the list and filter the duplicity of points, reducing the number of overlapped loops.
2. Further, it identifies the range of boundary points. The range of boundary points refers to the break in continuity shown in Figure 2. For example, there is an input of geolocations from 1 to 600 data points in which, points 1-250 are in loop I (ABCD) and 400-600 in loop II (EFGH) so, from points 251-399 (A-E), represent a discontinuity i.e., these points are in straight path not in any loop. Flow chart for the segregation of plot as per above algorithm is shown in Figure 3.

Computation of plot area

The developed application was capable of calculating the area of segregated plots using an algorithm that identified extreme points and formed a closed loop by joining them. Once the loop was formed, the area was calculated.

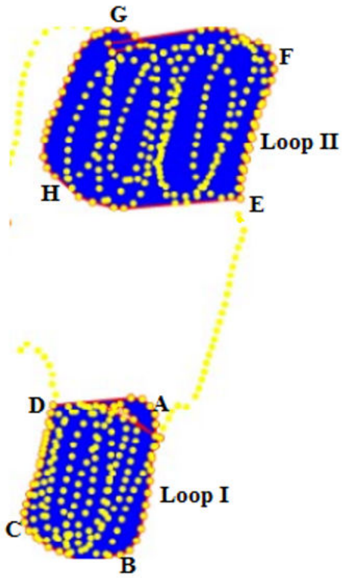

Figure 2. Segregation of field area using developed Geolocation Application.

Algorithm for area computation

The GPS records geolocations in a coordinate system where abscissa (x-coordinate) and ordinate (y-coordinate) represented longitude and latitude, respectively. The basic concept was to create a closed polygon by joining the extreme points. The following steps were taken to calculate the area of field from the recorded geolocations through GPS.

1. A geolocation having the lowest x-coordinate was chosen from the recorded geolocations which was the left most point of the field and named as $L_m(X_L,Y_L)$.
2. Similarly, the top most (T_m), right most (R_m) and bottom most (B_m) geolocations were chosen by searching the highest y-coordinate, highest x-coordinates and lowest y-coordinates, respectively. Coordinates of these points are assumed as $T_m(X_T,Y_T)$, $R_m(X_R,Y_R)$ and $B_m(X_B,Y_B)$. These points are shown in Figure 4 for better clarity of the developed algorithm.
3. Four corners, A, B, C and D were identified having coordinate $A(X_L,Y_T)$, $B(X_R, Y_T)$, $C(X_R, Y_B)$ and $D(X_L, Y_B)$, respectively, and joined them to make a smallest rectangle enclosing all these eight points for traversing the path.
4. After identifying the four edge points and four corners, starting from the edge point L_m in a clockwise direction searching for a point through A to T_m in such a manner that it follows a path of extreme points i.e. point closer to A and Tm, then again searches for a point that is closer to Tm and finally reaches to Tm, that's how the left most point gets connected to top most point.
5. After this, it starts to search for a point from T_m that is closer to B and R_m ignoring other points and reaches to R_m, resulting the top most point gets connected to the right most point. Similarly, right most point and bottom most point gets connected to bottom most and left most point respectively resulting in the formation of a polygon by joining P (x_1, y_1), Q(x_2, y_2), R(x_3, y_3), S(x_4, y_4), T(x_5, y_5), U(x_6, y_6), V(x_7, y_7), W(x_8, y_8), X(x_9, y_9) and so on.
6. The area of the polygon formed by the points P-Q-R-S-T-U-V-W-X-P was calculated using their coordinates. The area was calculated in square unit using Eq. 1

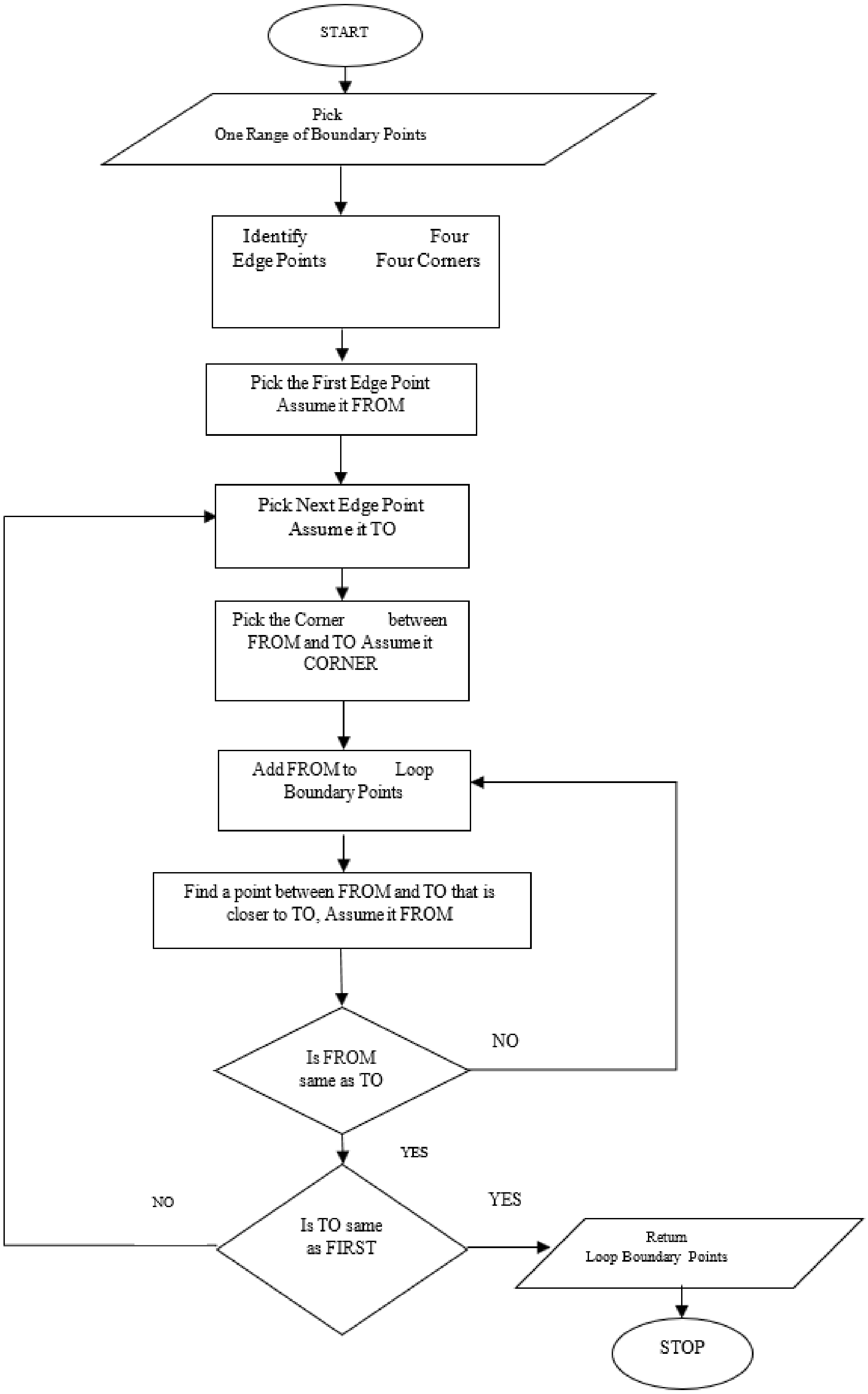

Figure 3. Flowchart depicting the process of plot segregation.

Points	Coordinates
P	x_1, y_1
Q	x_2, y_2
R	x_3, y_3
S	x_{4}, y_4
T	x_5, y_5
U	x_6, y_6
V	x_7, y_7
W	x_8, y_8
X	x_9, y_9

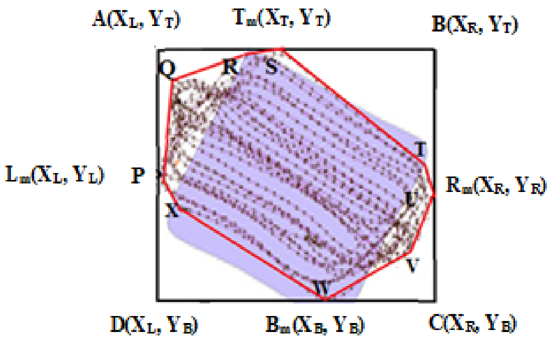

Figure 4. Identification of closed loop in the geolocation mapping process.

Flow chart for the computation of area as per above algorithm is depicted in Figure 5.

$$Area\ of\ Polygon = |[(X*Y) - (Y*X)]/2| = |[\{(x_1*y_2) + (x_2*y_3) + (x_3*y_4) + (x_4*y_5) + (x_5*y_6) + (x_6*y_7) + (x_7*y_8) + (x_8*y_9) + (x_9*y_1)\} - \{(y_1*x_2) + (y_2*x_3) + (y_3*x_4) + (y_4*x_5) + (y_5*x_6) + (y_6*x_7) + (y_7*x_8) + (y_8*x_9) + (y_9*x_1)\}/2]| \quad (1)$$

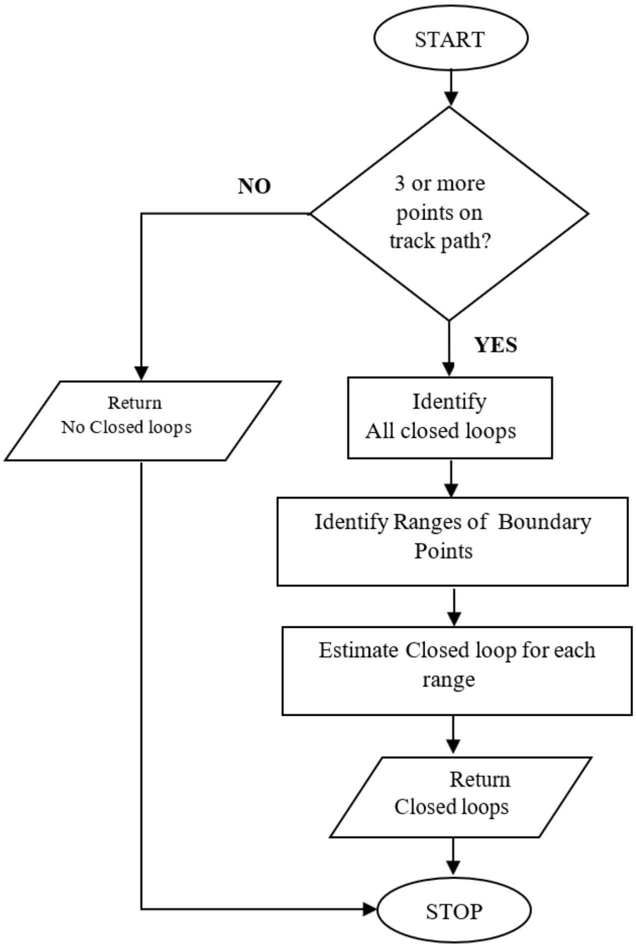

Figure 5. Flow chart depicting the process for area computation.

Evaluation Procedure

The evaluation was carried out in two steps. The first step involved assessing the accuracy of plot area calculation, while the second step focused on evaluating the segregation efficiency.

For accuracy assessment, a tractor equipped with a cultivator was used to till fields while recording the area using the developed application. The evaluation was conducted across 25 fields of different sizes. The areas were also measured manually with the help of measuring tape and calculated by using the formula, $A= (L_1+L_2)/2 *(B_1 + B_2)/2$ where L_1 and L_2 are the lengths of opposite sides of field while B_1 and B_2 are the width of opposite sides of field. The manually calculated areas were then compared with the areas recorded by the developed application. Three different plot sizes (small, medium, and large) were tested with three replications each. Geolocation samples for each plot size are shown in Figure 6.

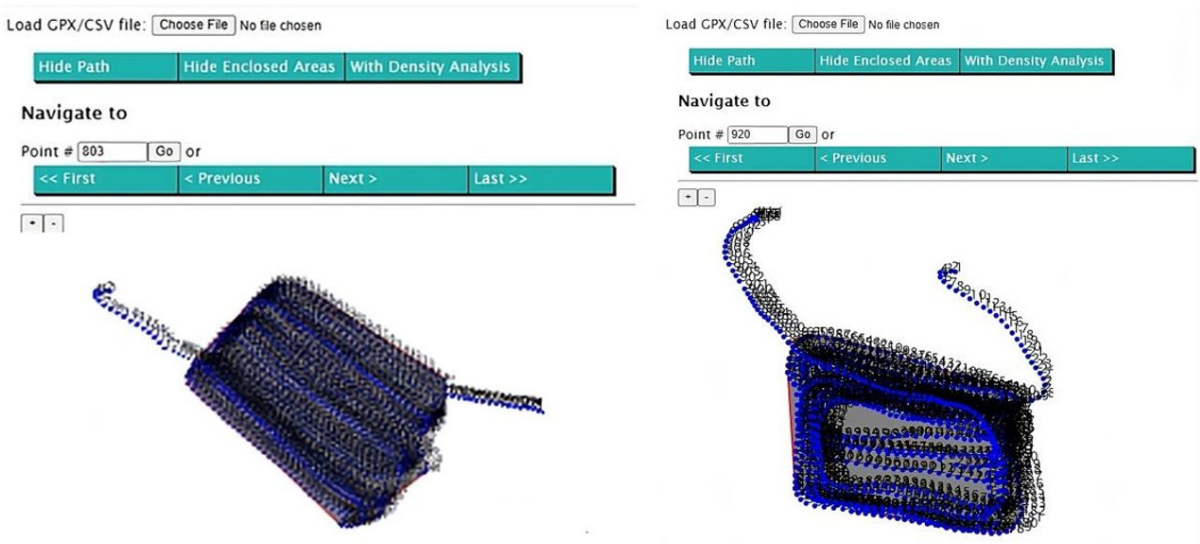

Figure 6. Screenshot of the developed application of recorded geolocation of the fields.

In the second step, the efficiency of plot segregation was evaluated by conducting five different trials in different patterns as follows:

- In the first trial, the tractor started from the origin and covered three different fields continuously without any stoppage (Figure 7).
- In the second trial, the tractor started and covered two fields with three stoppages in between (Figure 8).
- In the third trial, the tractor covered one field, then stopped for fifteen minutes before covering two more fields (Figure 9).
- In the fourth trial, the tractor covered two fields, stopped for half an hour and then covered two more fields (Figure 10).
- In the fifth trial, the tractor covered one field, stopped for 15 minutes, then covered two more fields continuously, took a 20-25-minute stoppage, and finally reached the destination (Figure 11).

The area, entry, and exit times for each field during the five days are presented in the Results and Discussion section.

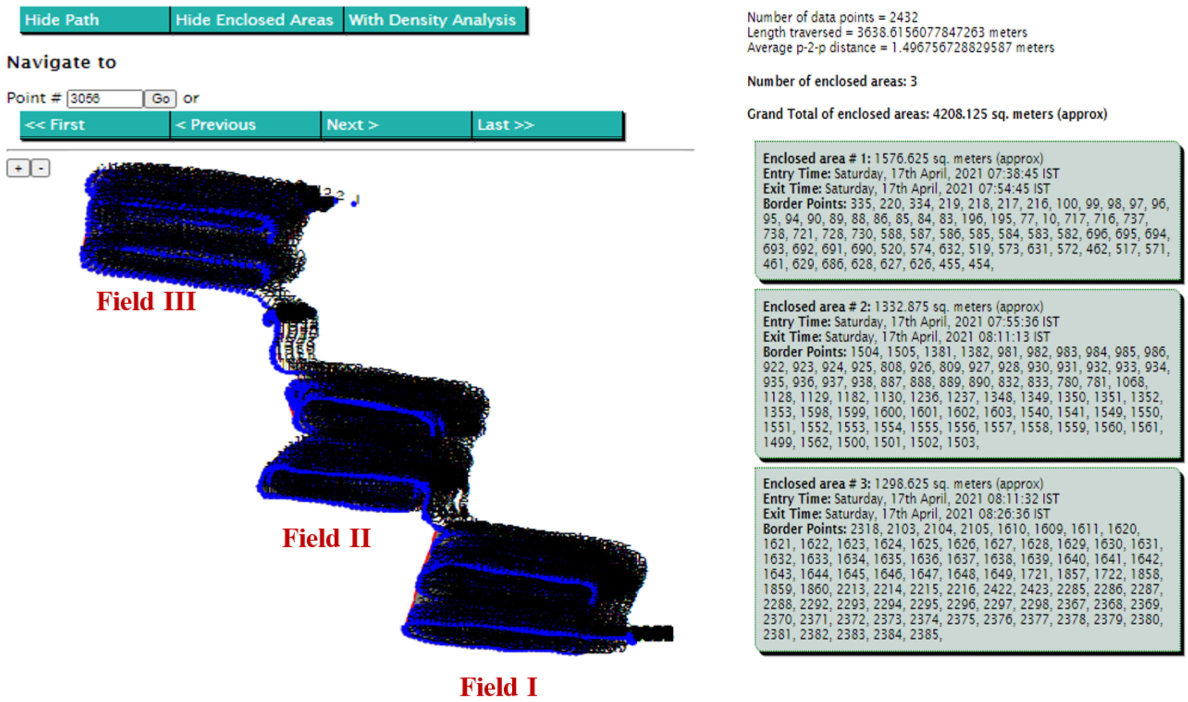

Figure 7. Plot area, entry and exit time obtained from developed application for Day- 1.

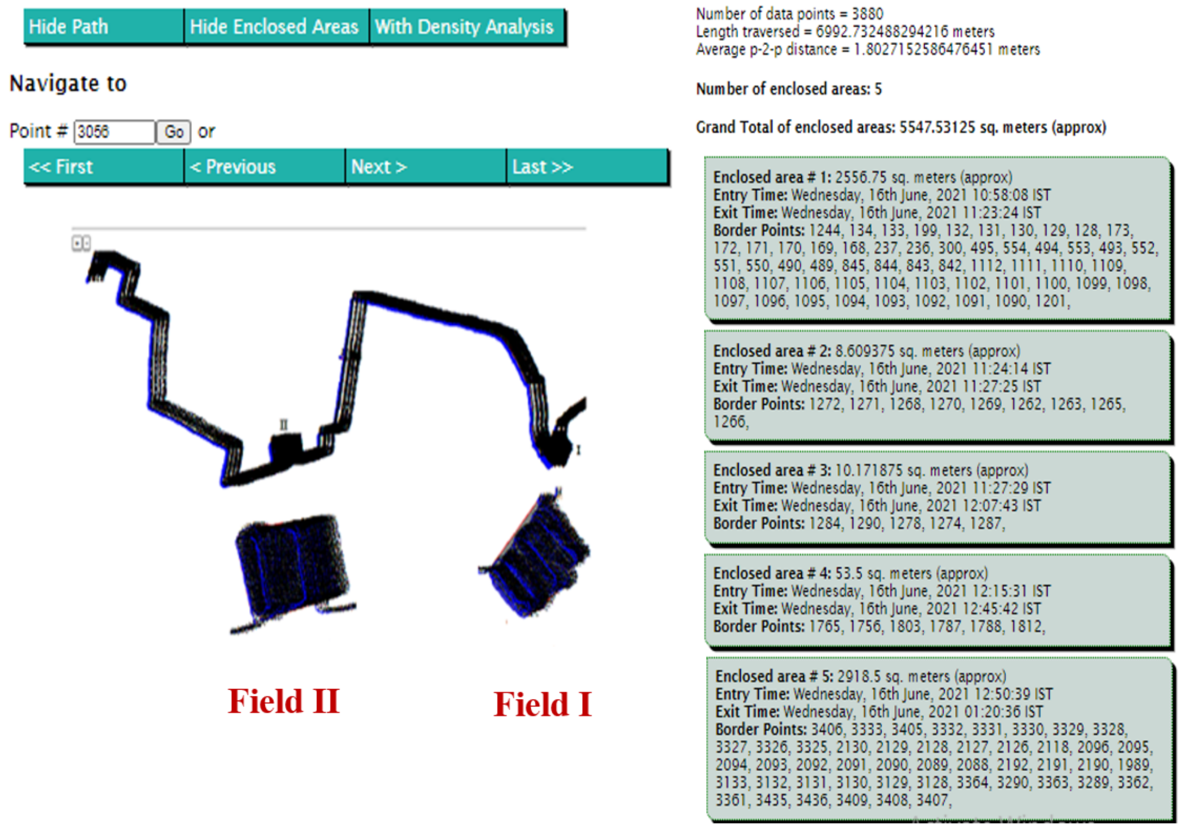

Figure 8. Plot area, entry and exit time obtained from developed application for Day- 2.

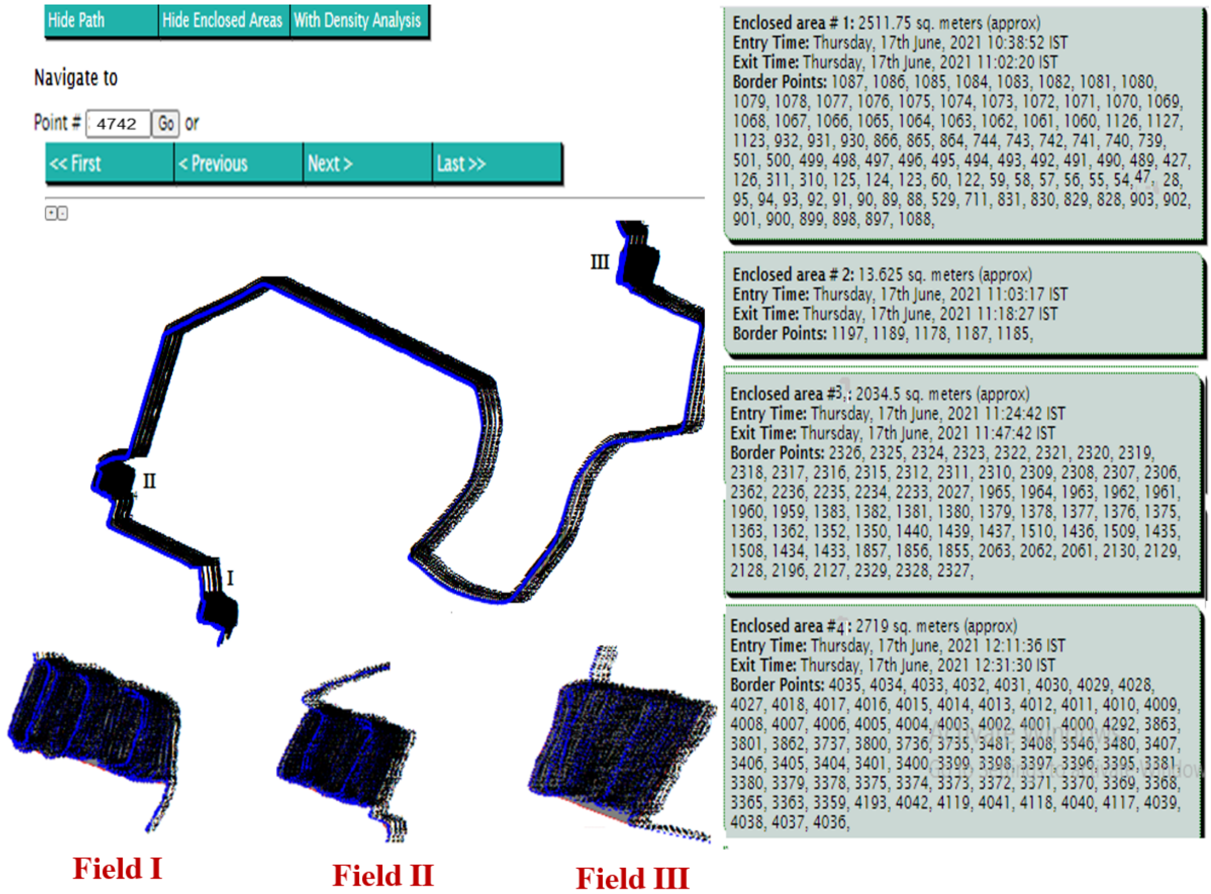

Figure 9. Plotarea, entry and exit time obtained from developed application for Day- 3.

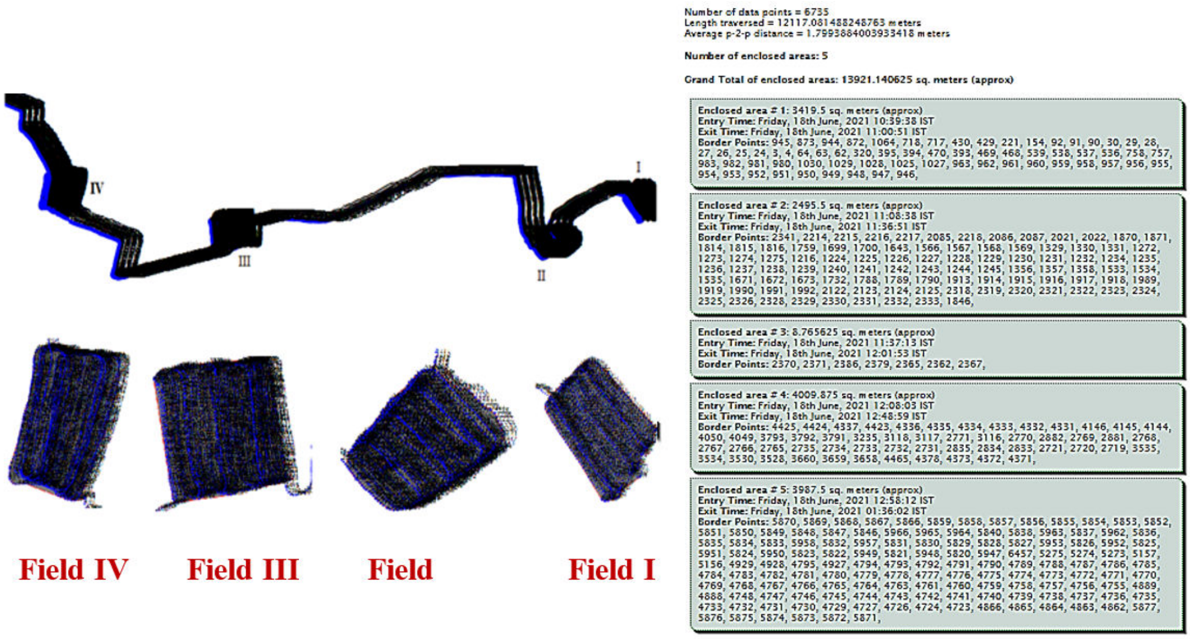

Figure 10. Plot area, entry and exit time obtained from developed application for Day- 4.

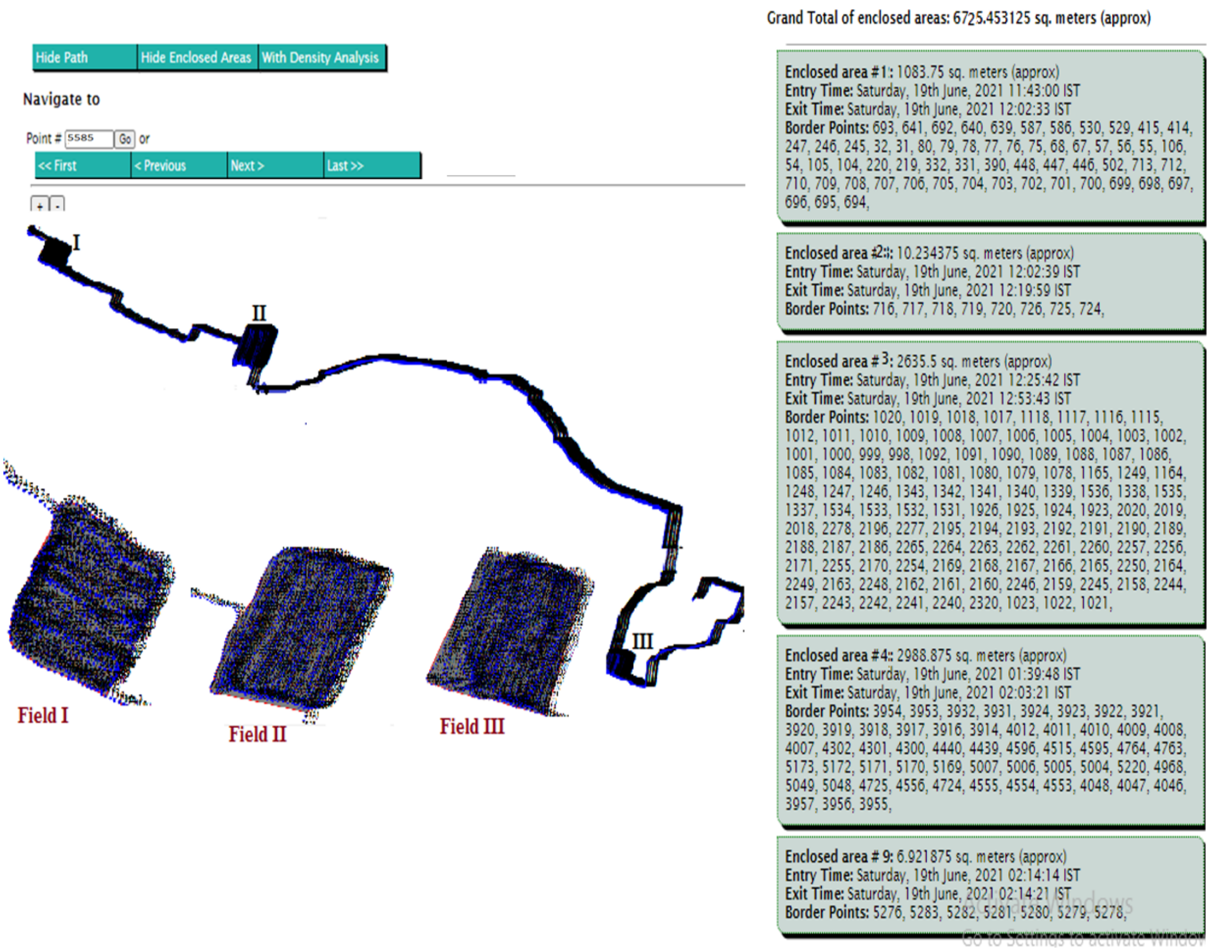

Figure 11. Plot area, entry and exit time obtained from developed application for Day- 5.

Results and Discussion

Validation of time recording

For evaluation, the plot sizes were divided into three categories: small (less than 1,000 m^2), medium (1,000 to 2,500 m^2) and large (more than 2,500 m^2). Tests were conducted to evaluate the accuracy of time recording which is presented in Table 1. The average time recorded for nine small plots, compared to the manually measured time, showed an average error of -1.01 %. The negative sign indicates that the recorded value was higher than the manually measured time. Similarly, for medium and large plots, the error was 0.82 and 0.27 %, respectively which is negligible. Further, it was analyzed that the difference in time between manually noted value and recorded value through developed application was within 10-15 seconds. Though this difference was small, it might have resulted from the selection of starting and ending geolocation points in the developed application, which formed the basis for time calculation. However, statistical analysis showed no significant difference between the manually recorded and application-recorded times, as the p-value was greater than 0.05.

Validation of area recording

Similarly, the area calculated by the developed system was compared with the manually measured area, as presented in Table 2. It is revealed from Table that the maximum percentage error in area calculation, with respect to the manually measured values was found within ± 7%. Further, the average percentage error for the small field was higher (6.99%) followed by medium (5.83%) and large (3.08%) fields. Statistically,

Table 1. Percentage time difference between manually measured time and system-recorded time for different plot sizes.

Category of plot	No. of plot	Manually measured time (minutes)		Time recorded by developed system (minutes)		Percentage time difference (minutes)	
		Average	SD[1]	Average	SD[1]	Average	SD[1]
Small	9	9.3	3.33	9.43	3.52	-1.01	2.53
Medium	9	14.46	6.47	14.31	6.31	0.82	1.49
Large	7	26.42	11.87	26.38	11.89	0.27	2.02

[1]Standard Deviation

Table 2. Percentage area difference between manually measured and system-recorded area for different plot sizes.

Category of plot	No. of plot	Manually measured area (m^2)		Area recorded by developed system (m^2)		Percentage area difference (m^2)	
		Average	SD[1]	Average	SD[1]	Average	SD[1]
Small	9	822.56	115.55	760.71	115.18	6.99	11.32
Medium	9	1,778.99	356	1,668.99	313.13	5.83	4.69
Large	7	2,748.23	1,082.91	2,667.01	1,067.25	3.08	2.64

[1]Standard Deviation

a significant difference was observed in the case of small fields as the p-value was less than 0.05 whereas no significant difference was found for medium and large fields as the p-value was greater than 0.05. The percentage error was calculated using Eq. 2 in all cases. Since the error was dependent on the plot size, a graphical presentation is given in Figure 12 which indicates that as the plot size increased, the absolute percentage error decreased. The possible reason for errors in the area calculation is the propagation of errors while recording geolocations using GPS. In large fields, error was lower compared to smaller fields due to fewer turns. This indicates that a greater number of turns leads to a higher error.

The percentage error is presented in a histogram of the frequency distribution curve (Figure 13) which indicates that the maximum frequency of percentage error falls between 5% and 10%. This positive value indicates that, in most cases, the area obtained through the developed application was less than the manually measured area. This recommends that the developed system can be used with an expected error range of 5-10%. The error can be further reduced by using a more precise GPS.

$$Error \quad (\%) = (Area \quad manually - Area \quad in \quad developed \quad application)/(Area \quad manually) \times 100 \qquad (2)$$

Validation of area segregation

The area of segregated fields recorded by the developed application over five days is tabulated along with the manually measured area in Table 3. The area segregation efficiency was 100% as total of 15 fields were covered on different days and accordingly, the developed system calculated the area for all 15 fields. . Further, the table shows that though maximum error was about 20%, the average error was 9.41 %. Additionally, as the field size increased, the error decreased. Since the data were recorded using the GPS of the smartphone, the possible cause of error can be the satellite position, GPS drift, signal obstruction, calculation inaccuracies, and rounding errors. However, the likelihood of error in area calculation is minimal, as the system employs standard mathematical formulas. The measured error can be further reduced by using a more precise GPS with higher accuracy.

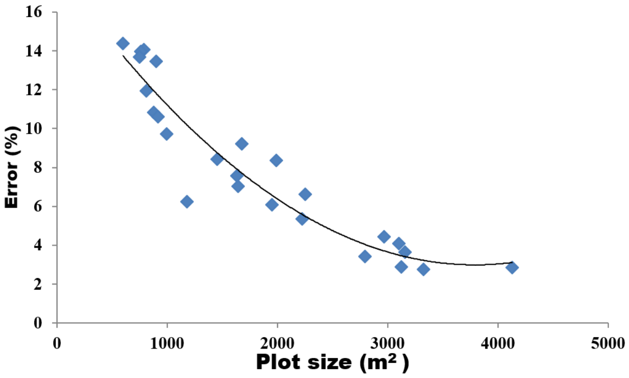

Figure 12. Relationship between plot size and error in area measurement.

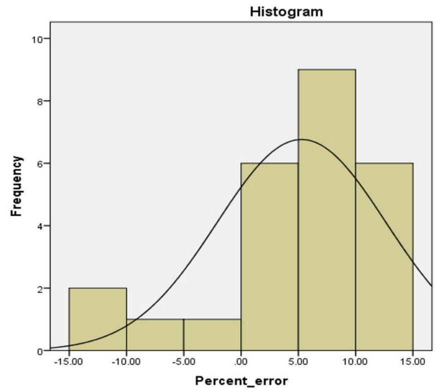

Figure 13. Frequency distribution curve of percentage error.

Table 3. Error percentage between manually measured area and system-recorded area for different fields over multiple days.

No. of Days	Field	Manually (m^2)	Developed Application (m^2)	Error (%)
Day 1	F1[1]	1,890.22	1,576.625	16.59
	F2[2]	1,581.07	1,332.875	15.7
	F3[3]	1,615.62	1,298.625	19.62
Day 2	F1[1]	2,685.75	2,835.4	-5.57
	F2[2]	3,200.5	2,973.59	7.09
Day 3	F1[1]	2,769.37	2,511.75	9.3
	F2[2]	2,294.13	2,035.4	11.28
	F3[3]	2,679.83	2,719	-1.46
Day 4	F1[1]	3,692.6	3,419.5	7.4
	F2[2]	2,788.69	2,495.5	10.51
	F3[3]	4,285.22	4,009.875	6.43
	F4[4]	4,200.62	3,987.5	5.07
Day 5	F1[1]	1,353.37	1,083.75	19.92
	F2[2]	2,978.55	2,635.5	11.52
	F3[3]	3,240.33	2,988.87	7.76
Average				9.41

[1] [2] [3] [4] Denote different fields (Field 1, Field 2, Field 3, Field 4) in the study area.

Conclusion

A mobile application was developed to record the geolocation of machine's movement using the GPS of a smartphone. The developed application was capable of segregating the tractor's operation in different fields and calculating the area of each field. It also recorded the time taken in each field. It was observed that the error in time measurement, compared to the manually noted values, was non-significant. However, in the case of area measurement, the average percentage error was found to be 6.91% for small fields (area less than 1,000 m^2), 5.40% for medium fields (area between 1,000 and 2,500 m^2), and 2.46% for large fields (area more than 2,500 m^2). This indicates that as the plot size increases, the error decreases. Furthermore, no error was found in field segregation, confirming that the developed system is capable of identifying field operations and idle movement. Therefore, the developed application can be considered an effective tool for monitoring farm machines' operation in terms of area coverage and time taken, which will ultimately be useful for charging the custom hiring services.

Acknowledgements: Authors hereby express their profound gratitude, and cordial thanks to the Department of Farm Machinery and Power Engineering, College of Agricultural Engineering, Dr. Rajendra Prasad Central Agricultural University, Pusa, Bihar, India, and RetiUno Technologies Private Ltd. Bangalore, India for the completion of this research.

Statement about use of generative AI: The translation of the title, abstract, and keywords from the original version in English to Spanish has been generated using OpenAI, ChatGPT GPT-4o mini (2024).

Competing interests: The authors have declared that no competing interests exist.

Authors' contributions: Apoorva Sharma: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Supervision, Visualization, Writing - original draft, Writing - review & editing. Prabhanjan Kumar Pranav: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Supervision, Visualization, Writing - original draft, Writing - review & editing. Ritesh Prasad: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Supervision, Visualization, Writing - original draft, Writing - review & editing.

Funding agencies/institutions	Project / Grant
All India Coordinated Research Project on Farm Implements and Machinery (AICRP on FIM).	2,50,000

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