Development of an automatic tracking system to determine field efficiency of agricultural machines

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Abstract. Field efficiency of machines tells how efficient the farm machines are operating in the field. Measuring of the field efficiency used to be a tedious and laborious work which is not worth to collect for further operational optimization. The objective of this study was to develop an automatic system for monitoring the field activities and then evaluation of the field efficiency of farm machines. The system consisted of a microcontroller to collect working data including position, speed heading, and working status of the machine. The system was installed on a farm tractor with plowing disc to test on two fields with the same size, but in different traveling directions, i.e., lengthwise and crosswise. The results showed lengthwise operation yielded a higher field efficiency due to less number of turning at headlands. The proposed system allowed to collect necessary information for detailed efficiency evaluation of farm machines. This technique enables further utilization of the operational information and benefit to use in the optimization of the farm works.

1 Introduction

Field efficiency of agricultural machines is the ratio of actual theoretical field time to the total time spent in the field [1]. It tells how efficient the system is due to operating pattern and field physical conditions. In ideal operation, the machine spends all time (theoretical field time) to operate the major task at its optimum forward speed and perform over its full width of action. However, in actual, the machine also spends time in other unproductive time elements such as turning or stopping for removing the obstructions causing to decrease the field efficiency.

Factors affecting field efficiency are the theoretical capacity of the machine, machine maneuverability, field patterns, field shape, field size, crop yield (in harvesting operation), soil and crop conditions, and other system limitations [1]. Optimizing of the field efficiency must consider these parameters. However, in field works, many parameters are not easy to collect accurately due to their high spatial variation.

Traditionally, field efficiency was determined in manual basis. Time used for all turns and all other activities during the operation were manually recorded. Optimum operating speed was measured during the machine working over the tracks that represent the major field condition. Measurement of field efficiency involves tedious and laborious field works. It is not easy to test under all field and crop conditions to get enough information for precise optimization of the operation.

Advances in computing and information technology allow ease of data collection. GNSS (Global Navigation Satellite System) provides real-time location and traveling speed information. It is possible to collect all operating information while the machine is working without any interruption from the researchers. This allows us to get big data from numerous field conditions that might cover various real situations.

In 2015, Vasu et al. installed a GNSS tracking system to a sugarcane harvester to evaluate the time efficiency in mechanized harvesting operation [2]. Later in 2017, Apidul and Vasu used a similar tracking system installed on three cane harvesters with different horsepower to study the effect of field accessibility to the field efficiency of the harvesting operation [3]. Data could be easily obtained with a lot of operational details. However, it was difficult to install sensors to detect the working status (cutting or no-cutting). Without, the cutting status sensor, the turning time could be obtained with less accurate.

The objective of this study was to develop an automatic system, including a working status sensor for the field efficiency determination. The system was deployed in a plowing operation of a tractor with plowing disc installed. This is a first step to collect complete working information to discover the nature of farm machine operations.

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2 Material and Methods

2.1. Field Efficiency Monitoring System

The system used an Arduino MEGA R3 microcontroller system (Italy) as the central unit to collect and record the machine's spatial and operational information. A GNSS Module (U-blox M8N, Switzerland) was used to acquire positioning, speed, and heading information of the machine's travel at 5 Hz acquisition rate (200 ms interval). Also, a digital compass module (Honeywell HMC5883L, USA) was also used to assist the system to recognize traveling direction (forward/ backward) of the machine.

The system was installed on a tractor with plowing discs. An accelerometer (InvenSense MPU-6050, USA) was used as an inclination sensor attaching to the raising arm between the tractor and the implement. This sensor was used to measure the raising angle for indicating whether the arm was at working depth or not. This indicator represents the working status of the operation. The major components of the agricultural machine monitoring system are shown as a diagram in figure 1. Figure 2 shows locations of each component installed on an agricultural tractor.

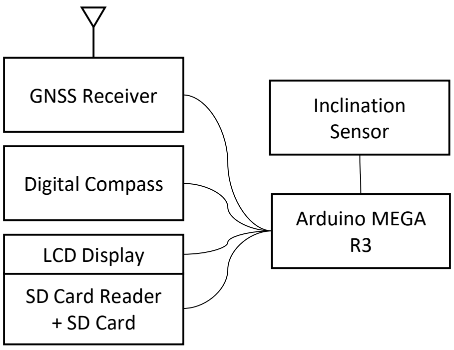

Fig. 1. Major components of the agricultural machine monitoring system.

Fig. 2. The test tractor with the instruments installed.

2.2 Field Test

The system was tested on two plots located in the faculty of Agricultural Technology, KMITL, Bangkok (13°43' 52.1"N 100°47'26.8"E). Both plots had approximately the same size of 0.425 ha (85 m × 50 m). The different operation between 2 plots was the plowing direction, i.e., lengthwise and the crosswise directions of the plots. Theoretically, the first one should result in a better field efficiency due to it has a fewer number of turns.

For each test, the operator performed plowing throughout the field at a depth of approximately 30 cm. Since the headlands were flat, the tractor could make the turns easily outside the field in the fish-tail shape and continue the adjacent rows consecutively.

Total operating time was manually recorded for determining the actual capacity of the operation. Each turning time was also recorded as well. Other related information such as the factory working width of the plowing width (2.2 m) and actual working widths for each pass were also measured and noted.

2.2 Data Analysis

Positioning and moving information from the start to the end of the operation were first plotted using QGIS software to show the trace of the machines in the field. Next, unproductive points were then excluded by following techniques. The backward movement could be detected by comparing the direction of GNSS points and the heading angles from the electronic compass. If they were in opposite directions, the machine was moving backward and must be excluded. The working status recorded by the inclination sensor was used to classify whether it was in productive status or not. An additional step was to check if the machine was not moving by verifying if the speed (from the GNSS) was slower than 0.5 km/h (in stationary, GNSS generated a small speed value due to its positioning calculation).

Mode or the most frequent value of the speed from all productive points was used as the representation of the optimum speed. The reason was that it represented the most desirable operating speed under the corresponding field and crop conditions.

The field efficiency could be calculated from the ratio of actual field capacity and the theoretical field capacity. The actual capacity requires field size and the total operation time to calculate. The theoretical capacity is the multiplication of rated width and the optimum operating speed. (Eqns. 1-3)

$$\eta = \frac{C_{act}}{C_{theo}} \quad (1)$$

$$C_{act} = \frac{A}{t_{tot}} \quad (2)$$

$$C_{theo} = \frac{w_r v_{opt}}{10} \quad (3)$$

where η = field efficiency *[in decimal]*,
C_{act} = actual field capacity *[ha/h]*,
C_{theo} = theoretical field efficiency *[ha/h]*,

A = working area *[ha]*,
t_{tot} = total working time *[h]*,
w_r = rated width of the implement *[m]*, and
v_{opt} = optimum operating speed *[km/h]*.

3 Results and Discussion

Field parameters and working information for both lengthwise and crosswise directions are described and noted in table 1. Tracing points of the operations in both directions recorded from the system are plotted in figure 3. Light green dots show operation in active status (performed plowing), and red dots show inactive status (turning and backing). The working paths shown in the maps are not equally distributed due to the accuracy of the GNSS receiver. However this misalignment is not affect the determination of field efficiency.

Table 1. Field and working parameters including the calculated capacity and efficiency of the operations in both lengthwise and crosswise directions.

Parameters	Lengthwise	Crosswise	
Area	4250		*sq.m.*
	0.425		*ha*
Plot Length	85	50	*m*
Total Time	21.1	23.3	*min*
	0.351	0.389	*h*
Actual Capacity	1.21	1.09	*ha/h*
Rated Width	2.20		*m*
Actual Width	2.08	2.13	*m*
Optimum Speed	6.84	6.92	*km/h*
Theoretical Capacity	1.51	1.52	*ha/h*
Field Efficiency	80.4	71.8	*%*

Theoretical capacities for both plots were similar due to the ignorance of turning operations. It considers working at the optimum speed with the rated implement width (which is the same). The optimum speed of the operation in the crosswise direction (6.92 km/h) was a little bit higher than that of the lengthwise direction (6.76 km/h). Typically, the machine is set to working speed. If the soil conditions are the same and the field allows the adequate length of operation, the speed should not be significantly different. Noted that the plots were already plowed two weeks earlier, the plowing test could be easily performed with a higher optimum speed comparing to the typical operation. Theoretical field capacities were 1.51 and 1.52 ha/h for lengthwise and crosswise operation, respectively.

In actual, the total time for the crosswise operation (23.3 min) was slightly higher than that of the lengthwise operation (21.1 min). This due to more number of turns to operate in the transverse direction. The actual capacity or the working area (same for both plot) and the actual operation time are 1.21 and 1.09 ha/h for the lengthwise and crosswise operations, respectively.

Field efficiency determined from the recorded data were 80.4% and 71.8% for the longitudinal and transverse operations, respectively. There was no doubt that working in lengthwise would yield higher field efficiency. However, it is not necessarily true. There are many factors affecting the efficiency such as soil condition, field shape, machine maneuverability, etc.

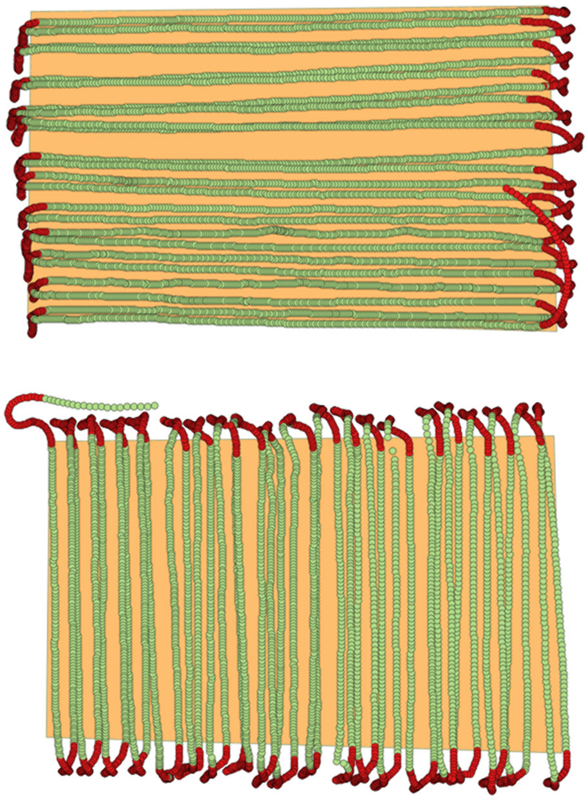

Fig. 3. Tracing points of the operations in lengthwise (upper) and crosswise (lower) directions recorded from the system. Light green dots show operation in active status (performed plowing), and red dots show inactive status (turning and backing).

4 Conclusion

The monitoring system was developed. The center controller recorded the necessary information such as position, speed, heading, and working status of the operations. The tests were performed on two plots with the same size of 0.425 ha. The difference of 2 plots was the working direction, one on lengthwise and another on crosswise directions. Information collected from the system was used to determine the field efficiency. The operation in the longitudinal direction yielded a higher field efficiency due to it contained fewer time losses for turning.

The proposed system shows a possibility of collecting necessary information for detailed efficiency evaluation of farm machines. This technique enables further utilization of the operational information and benefit to use in the optimization of the farm works.

References

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