Analysis of power requirement of a small-sized tracked-tractor during agricultural field operations

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Abstract A low-powered and high-efficiency electric tracked-tractor would be a suitable option for aged and female farmers to accomplish agricultural field operations such as grass mowing, land leveling, and chemical spraying. The purpose of the study was to analyze the power requirement of a small-sized tracked-tractor during agricultural field operations. A lawnmower and a rear sprayer-trailer were attached to the tractor base, and the average power requirement was measured. The forward speed was considered during the field experiment up to 6 km/h for four different operating stages. The torque data were obtained for unloaded and loaded conditions through a wireless data logger, and a GPS receiver was used to measure the working speed of the tractor. A data acquisition module was used to acquire the sensor signals. The average power requirements for the empty platform with the driver, a lawnmower, a sprayer-trailer (150-L payload), and a lawnmower and 150-L payload trailer were 0.93, 1.27, 1.45, and 1.70 kW, respectively. The result showed the lowest power was required for operating only the tractor, and it was about 51.15\% of the motor rated power, where the maximum power consumed approximately 85\% of the total rated power to operate both of the lawnmower and sprayer-trailer. The average power requirements of the tracked tractor varied due to the different payloads and operating stages. The experimental results presented in this study would provide guidelines to improve and commercialize the prototype of the small-scaled tracked-tractor for practical use on the agricultural fields.

1. Introduction
A variety of tractors are used broadly to perform agricultural activities [1]. The working capabilities of those tractors rely on the available required power to handle various farm equipment and trailers. A tractor having with a heavy weight is not comfortable to drive for the aging farmers on uneven terrains, thoroughly challenging to handle without experienced driving skills [2]. However, small and high-powered tractors are being categorized and adopted as the main platform to provide the required power for multipurpose agricultural activities, such as tillage, spraying, mowing, baler operation, loader operation, and transportation [3-5].

Contrariwise, electric-driven tractors are getting popular day by day due to their eco-friendly behaviors with high transmission efficiency and alternative battery power source instead of reliance
on fuel [6-8]. Besides, the need for small-sized and user-friendly tracked-tractors is growing as the world’s elderly population grows, especially in East and South-East Asia (e.g., Republic of Korea, Japan, Singapore, and China) [9]. To ensure the appropriate efficiency for the newly developed and small-sized tracked machinery, fundamental experiments are required during the field applications, and the machine can be modified to reach the goals. In this regard, the tractor configurations have been changed globally, from 2- to 4-wheel drive, and bias-ply to rubber tracks, to increase the production performances in agricultural fields. The working ability and performance of those tractors have been predicted mathematically and assessed during the field operations [10].

Appropriate distribution of power is a crucial factor for various equipment and machinery to assure favorable agricultural field operations with high efficiency and low-cost management. Therefore, the evaluation of the required power and the power transmission systems is essential before fabrication of agricultural machinery [11, 12]. As many of the Asian countries, including Republic of Korea, have already entered an aging society, machine development research is highly focused on according to the situation. In this region, the major machinery and equipment such as sprayer, mower, crusher, and branch pruner for orchard and upland crops are necessary to efficiently carry out the agricultural activities by the female and aged farmers. A small-sized, eco-friendly, and low-power operated multipurpose tractor platform that can attach the required implements, would be a solution by providing the estimated power for operations on the orchard and upland crop fields.

Therefore, an electric motor-driven and small-sized tracked-tractor platform is under development for multipurpose agricultural use. The objective of the study was to analyze the required power to conduct the primary operations for hauling the workable implements in the agricultural field conditions. The assessment of required power focused in this study would help to convey some information to the manufacturer for further modifications of this platform.

2. Material and methods

2.1. Working principle of small-sized tractor and design consideration

A small-sized rubber-tracked tractor used in this study is under development by a company (Sungboo Manufacturing Company Ind., Ltd., Chilgok, Republic of Korea). The major dimensions of the tractor were 948 (L) \times 970 (W) \times 899 (H) mm with a 5,340.70 N estimated weight. The prototype tractor was used as a platform, acting as the main power source to provide the required power to operate agricultural implements.

The test tractor was designed based on the available motor power, where the motor (Model: DCC4M2449A3KROBA, Motion Tech, Chiayi, Taiwan) was able to produce 1.3 kW input power. The motor was received power from the 12V-165 AH battery (Model: Longest 12165, Global Battery Co., Ltd, Bucheon, Republic of Korea). Two batteries distributed the power to control the two DC motors. However, the tractor rated power was 2.6 kW. The motor was stabilized with a speed reducer (Ratio of 10:1). The battery-powered DC motors transferred the output power through the gear shaft and the sprocket obtained the power and delivered it to the rubber-tracked wheel. The tracked belt diameter was 2,200 mm and the width was 180 mm. A total of 38 lug treads was engaged with the rubber belt of the tracked wheel. A sprayer (Weight: 588.39 N) and a lawnmower (Weight: 833.57 N) were used in agricultural operations and attached to the prototype tractor platform for conducting their particular activities. The schematic diagram of the prototype tractor with rubber-tracked wheel is shown in Figure 1.
Figure 1. Schematic diagram of the small-sized tracked tractor: sprocket (1), front wheel (2), joint bar (3), fixing shaft (4), rear wheel (5), support (6), track belt (7), driving direction (8), and main body (9).

2.2. Instrumentation for required power measurement

A wireless data logger (Model: iLOG-Strain-V3, Smart C&S, Co., Ltd, Daejeon, Republic of Korea) was used to collect the torque data during the field operations. The data logger provided a 2.4 GHz band integrated wireless communication, 16-bit A/D converter, and 2MB internal memory for effective field instrumentation, and transmitted a torque signal quickly to the distances less than 200 m. It was installed on the sprocket shaft for measuring the required power for moving the tracked wheel of the small-sized tractor. The torque signal was transmitted wirelessly from the strain gauge to the data acquisition system (DAQ). The sprocket shaft rotational speed was calculated by a sampling rate of 2.4kHz in a single revolution. The required driving power of the prototype tractor was calculated using the equation 1.

\[ P = \frac{T \times W}{9549} \]  

Where, \( P \) is the power (W), \( T \) is the torque (Nm), and \( W \) is the wheel rotational speed (rpm).

A USB-type Global Positioning System (GPS) receiver (Model: BU-353S4, GlobalSat, Inc., New Taipei, Taiwan) was used for navigation, obtaining local GPS measurements to fix the current position coordinates of the tractor. After software installation and initialization, the GPS data were displayed on the notebook screen. A built-in software application was used for real-time data analysis and processing by synchronizing the output signals linking with the measuring devices. The power requirement measurement system assembly was shown in Figure 2.

Figure 2. The components, different loads and power measurement system of the small-sized tractor: rubber-tracked wheel (1), lawn mower (2), rear trailer (3), DAQ-box (4), notebook (5), multi-module receiver (6), wireless data logger (7), power take-off (PTO) joint (8), and GPS receiver (9).
2.3. Estimation of the driving power by field experiment
The power requirement analysis experiment was carried out on an agricultural farm site with sandy clay loam soils, located at the Agricultural Machinery Development Research Center, Kyungpook National University, Daegu, Republic of Korea. The experiment was conducted at the experimental plot with a 50 m long distance (Figure 3a). The performance parameters of the small-sized tractor were evaluated in four different conditions (Figure 3b–3e; 4 stages). After the instrumentation and attachment of the equipment, the tractor platform was tested only, and the data was collected through the system (Fig. 3b; stage 1). Then the sprayer trailer was filled with 150-L water and tested (Figure 3c; stage 2). The next experiment was conducted after removing the sprayer-trailer from the arrangement (Figure 3d; stage 3). Finally, the tractor platform was used to assess the power requirement in driving conditions (figure 3e; stage 4). During the experiment, a maximum travelling speed of 6 km/h was recorded, and 60 s data were used for the power requirement analysis, providing a total of 1,440,000 measurements (2.4 kHz x 60 s). For each experiment, we repeated three times with the same equipment setup and soil conditions. In the experiment with the lawn mower and the sprayer-trailer were attached to the small-sized tractor to haul them around the field for performing their operations. In this condition, the experiment was conducted to evaluate the maximum and minimum traveling speed and power requirements.

![Figure 3. Experimental site (a) and the torque measurement on different conditions in the site: lawn mower and sprayer-trailer attachment (b), lawn mower and sprayer-trailer with 150 L water (c), lawn mower along with the platform (d), only the prototype tractor platform (e).](image)

3. Results and discussion

3.1. Power requirement characteristics analysis by field operations
The power requirement in stage 2 was found to be higher than other three stages. Because of the heavier equipment attachments required more power to complete the task. The minimum power requirement was recorded at 0.2 kW for moving the platform where the maximum power requirement of 2.2 kW was observed during the fully loaded condition. The power fluctuation was noticed frequently during the experiment with and without equipment attachment conditions. The real-time power requirement characteristics of a small-sized tracked tractor which was measured by torque sensor are illustrated in figure 4.
Further, we observed the wheel slip and calculated wheel slip from the two rubber-tracked wheel and the overall slip was found around 1.5%, which was negligible and it had minor effect on power measurements.

3.2. Power requirement during four major field operations

The experiments showed that the prototype tractor was able to operate with a maximum forward speed of 6 km/h due to the design factors and battery capacity of the platform. The average output power of stages 1, 2, 3, and 4 was 1.45, 1.70, 1.27, and 0.93 kW which is referred to as the ratio of 55.77, 65.39, 48.85, and 35.77% of the total motor input power, respectively. The overall power consumption in different speed conditions is shown in Figure 5. With the increase of the speed while carrying load, the torque also increased and different torque generation due to different load conditions caused the variations in power requirements.

![Figure 4](image1.png)

**Figure 4.** Power consumption characteristics during the field operations.

![Figure 5](image2.png)

**Figure 5.** Maximum power requirement measured during the driving conditions in the field test.
3.3. Power consumption comparisons
Figure 6 shows the motor power usage ratio in different stages. As stated in the pie chart, more than 84% power was consumed of the total rated power in stage 2 during the operation. Between the unloaded and loaded situations, the necessary power to drive the tractor platform changed by 33.47%. According to the maximum power consumption, the proposed tractor lost around 19.23% of its maximum power while hauling equipments in the field. During the field test, gear, bearing and shaft losses in the power transmission system might cause this power loss. In addition, the tractor size and wheel shape also need to check for an in-depth study of power losses.

4. Conclusions
In this study, the basic test was conducted to evaluate the power requirements of a developed tractor platform while using it as a primary power source for field operations. The platform was proposed for multipurpose usage, especially for the orchard and upland field conditions. In the present assembly, the machine can run up to 6 km/h, and it used a maximum of 2.2 kW power for hauling the lawnmower and sprayer with 150-L water. As result indicated, stage 2 consumed 84% power of the total rated power which was the most power usage by any stages. For all sorts of operations, an average of 0.2 to 2.2 kW of power is required. The necessary power to drive the tractor platform changed by 33.47% during the unloaded and loaded conditions. Also the power loss was found around 19.23% during the operations. Further study needed to focus on power loss and different field conditions to design the multipurpose agricultural platform for getting better field performances.

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