Design and Development of An Electric Tractor using Simple Remote Control

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Abstract. *This article presents design and development of a simple remote-controlled electric tractor used for plowing the soil. The tractor was designed to have a 1kW powerful soil blender and 4 wheels with dual 250W dc motor drives for sharp turning (0-360 degrees at fixed point) capacity and running speed upto 11 km/hr. A set of 12V 50Ahr battery was used to supply the soil blending motor while two sets of 12V 40Ahr batteries were used to supply the running motors. The tractor prototype was tested by plowing the soil with different blending power rates of 20, 40, 60, 80 and 100% while running at different speeds of 4, 5, 6, 7, 8, 9, 10 and 11 km/hr. The test results showed that the best power rates for soil blender of the tractor prototype were 80%, 60% and 100%, respectively with respect to achieve optimum performance between plowing quality and low power consumption operation. The tractor performed the best plowing quality while retaining good direction control when running at the speed between 7-9 km/hr. The average operation time period for the tractor was between 5-7 hours per one full charging.*

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1. Introduction

Tractors are ones of the most commonly used machines for agricultural activities and farms in Thailand due to the benefits of saving time and labor cost while providing high productivity [1]. Most commercial tractors today are mostly powered by the fossil fuel energy, which would have then the fluctuation in prices, negative impacts for environment and noise pollution [2]. Therefore, electric engines would be an alternative solution. There are several research studies on electric tractors [3]-[7] but most research works only in the theoretical design and literatures [8]-[12]. There are only few works on the autonomous control approach or merely with the remote control technique [13]-[18]. We have studied IoT control and GPS for agriculture [19]-[25].

According to the information from the Ministry of Transport of Thailand [26] from 2012 to 2019, it was found that the number of tractors registered in Thailand was between 334,292 and 560,573 tractors, in other words, 226,281 tractors increased. One tractor operated about 0.32 km^2/ year, which uses about 1,875 liters/km^2 of oil, about 3.77 barrels/year, compared to the current oil price of 10,000-15,000 baht/year (297-446 USD/year). More than 560,000 tractors in Thailand use approximately 2.11 million barrels of oil per year and trend to increase reflected by the increasing rate of the registered tractors every year. It is estimated that if replacing the fuel-powered engine with the electric one, the break-even point will be about 3-5 years with costs that vary according to the price of the equipment [27].

In this research, attention was paid to the conversion of many fuel-powered combustion engines [28]-[31] into a unmanned electric tractor prototype by applying the concept from the designs and driving performance tests similar to [32]-[34]. The simplified radio remote tractor control system employed from [35]-[36] was used. The tractor prototype consisted of two 250W DC motors which were used as the dual motor drives. A 1,000W DC motor was used to rotate the soil blender. The prototype was tested in the open space in the sample region of Khon Kaen province, Thailand. The test data related to electric and mechanical parameters were measured and collected in order to observe its performance and efficiency. The components and design procedures for the proposed tractor were explained in Section 2, the test methods and corresponding results in Section 3, the analyzed results in Section 4 and the summary and discussions of the research work were highlighted in Section 5.

2. Components and Design Procedures

The design procedures for the proposed remote-controlled electric tractors utilized the similar design procedures available in [37]-[39], which composed of the calculating and dimensioning the size of the components such as the motors, control circuit and etc. The required power used to drive the tractor and the design of the equipment, as well as, the components used in the circuits in order to control the tractor's body and its functions with the remote radio control approach were illustrated as follows:

2.1 Determination of power rating of the motor

To determine the power rating of the driving motors for the proposed electric tractor similar to [38], the information related to the total weight, the soil friction coefficient (μ_{rr}) and vehicle resistance coefficient (C_d) have to be known. Table 1-3 show the list of components and their weight, μ_{rr} and C_d, respectively.

Main Components of the tractor	Quantity (units)	Weight (Kg)
Battery 12 V 40 Ah	2	21.2
Battery 12 V 50 Ah	1	12
motor 250 W 12 V	2	6
motor 1,000 W 24 V	1	8
motor control box 1,000 W 24 V	1	1
electric tractor frame	1	20
Total weight		**68.2**

Table 1 List of components and their weight

Type/Condition	μ_{rr}
Paved, Concrete - excellent - fair	 0.014-0.018 0.018-0.020
flagstone	0.023-0.030
gravel	0.020-0.025
Soil - dried - wet	 0.025-0.035 0.050-0.150
sand	0.100-0.300

Table 2 Coefficient of friction at various soil surface conditions (μ_{rr}) [38]

Vehicle Type	C_d
Aerodynamic design	0.15-0.20
Research design	0.22
General car	0.30
Sport car	0.43
Adapted car	0.53
Universal Sport car	0.57-0.63
Motorcycle	0.56-0.63
Convertible car	0.60-0.70
Bus	0.60-0.70
Truck	0.7-1.50

Table 3 Vehicle resistance coefficient (C_d) [38]

In this research, the dry rough soil and research design vehicle was used; therefore, the μ_{rr} and C_d were 0.30 and 0.22, respectively. These values were then used to calculate the forces required for the tractor by using equations (1)-(6) as proposed in [38], which were reproduced here:

Rolling resistance (F_{rr}) is the tire loss that occurs. The main factor is the constant deformation of the wheels when grinding against the road surface; including adhesion and slippage of the tread, the relationship of rolling resistance can be found as follows:

$$F_{rr} = \mu_{rr} mg\cos(\alpha) \quad (1)$$

; where F_{rr} is the rolling resistance (N)
μ_{rr} is the rolling resistance coefficient
m is the total mass of the vehicle (kg)
g is the acceleration of the Earth's gravity equal to 9.81 m/s^2
α is the angle of inclination of the road surface (rad)

By subscribing the known values, give the result as:

$$F_{rr} = 0.30 \text{ x } 68.2 \text{ x } 9.81 \text{ x } \cos(0) = 200.71 \text{ N}$$

Air resistance (F_{ad}) is caused by a phenomenon in two parts: from the shear force of air flowing through the car and air resistance from the shape of the car body that resists air currents from driving the car It can be calculated from the equation as follows:

$$F_{ad} = (1/2)\rho AC_d v^2 \quad (2)$$

where F_{ad} is the air resistance (N)
ρ is the air density (kg/m^3)
A is the cross-sectional area of the car (m^2)
C_d is the drag coefficient
v is the speed of the air (m/s)

Hence,

$$F_{ad} = (1/2) \text{ x } 1.225 \text{ x } 39.6 \text{ x } 0.22 \text{ x } 12 = 5.34 \text{ N}$$

Slope resistance (F_{hc}) is the weight taken along the slope or if the car goes down a steep slope, the sub-force of the weight of the car will be raised in the same direction as the movement of the car and can be expressed as follows:

$$F_{hc} = mg\sin(\alpha) \quad (3)$$

; where F_{hc} is the slope resistance (N)
m is the total mass of the vehicle (kg)
g is the acceleration of the Earth's gravity equal to 9.81 m/s^2
α is the angle of inclination of the road surface (rad)

As a result,

$$F_{hc} = 68.2 \text{ x } 9.81 \text{ x } \sin(0) = 0 \text{ N}$$

Acceleration resistance (F_{acc}) can be divided into two parts: force for linear acceleration and force for angular acceleration for the resistance while driving can be expressed in mathematical equations as follows.

$$F_{acc} = ma \quad (4)$$

; where F_{acc} is the resistance from the acceleration (N)
m is the total weight of the vehicle (kg)
a is the delay (m/s^2)

Thus,

$$F_{acc} = 68.2 \text{ x } 0 = 0 \text{ N}$$

The resultant values from Equations (1)-(4) were summed up to form the total force acting on the tractor in motion (F_{total}) as (5)

$$F_{total} = F_{rr} + F_{ad} + F_{hc} + F_{acc} \quad (5)$$

Which give:

$$F_{total} = 200.71 + 5.34 + 0 + 0 = 206.05 \text{ N}$$

Now the power rating of the motor (P) could be determined as (6), when applying the maximum speed of 1.0 m/s:

$$P = F_{total} \cdot v \quad (6)$$

Using (6) and applying the safety factor of 25%, the motor power rating finally was:

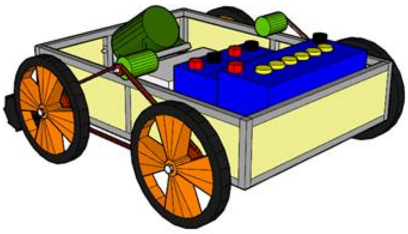
$$P = 206.05 \text{x} 1.0 \text{ x } 1.25 = 257.56 \text{ W}$$

Therefore, the 250 W dc motor was selected and used for the driving system of the tractor.

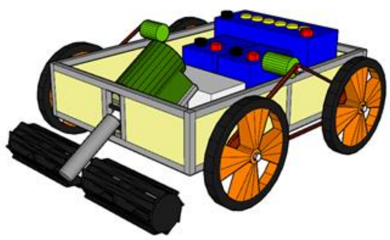
2.2 Structural Design of the Electric Tractor

Development of remote controlled electric tractors it was necessary to systematically design the structure of the tractor for convenience and reduce the driver load weight that affects the motor drive system, reducing motor efficiency by more than 70% [37].

Fig. 1(a)-(b) show the photographs of the designed electric tractor while Fig. 2-3 and Table 4 show the photograph of the actual constructed prototype and components used for it. The tractor had the body frame as a mini 4-wheel car with the width of 66 cm, length of 100 cm and height 30 cm. To reduce driver load weight that affected the motor drive system, the tractor was designed as the symmetrical balancing shape as much as possible. The wheels were adapted from the basic bicycle wheels with the diameter of 32 cm, a rim width of 4.5 cm, made of solid steel, and able to support maximum weight of 100 kg each. These wheels provided capability of loading weight withstanding, less vibration effects, and stable body frame for the components on the tractor's body. There were 2 sets of the 250W dc motors which helped to provide easy sharp turning (0-360 degrees) at the fixed turning point. The 1,000W dc motor was used for soil blending, which was derived from the power of the mower engine used in the soil blender with a power of 1.25hp. The 24V battery was obtained from the voltage at the 1,000W motor used with respect to the motor's specification. The 12V battery was obtained from the voltage specification of the DC motor used to drive it. The soil blender had 32 cm in length, 6 blades, and made from hard-strong solid steel. The optimum speed for the soil blender was 120-180 rpm. There were 2 circuit breakers installed for short-circuit protection for the batteries, power circuit, and control circuit. The remote control system and almost all electric components and devices were put in the protecting box.



(a)



(b)

Fig. 1 Isometric illustration of the designed electric tractor: (a) front side view and (b) back side view

Fig. 2 A photograph of the proposed electric tractor prototype

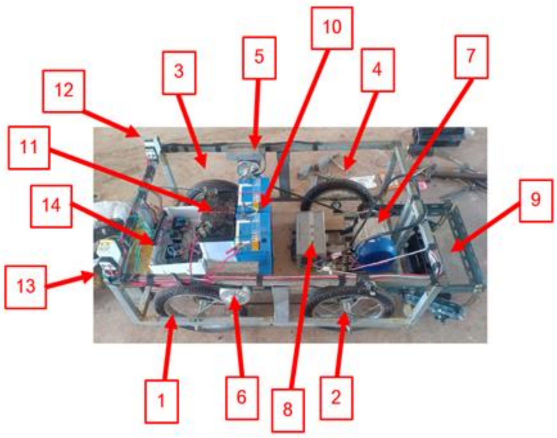


Fig. 3 Components list of equipment installed on electric tractor

Components	Label number
Left Front Wheel	1
Left Rear Wheel	2
Right Front Wheel	3
Right Rear Wheel	4
Right Side DC Motor 250 W 12 V	5
Left Side DC Motor 250 W 12 V	6
Soil blender Motor 1,000 W 24 V	7
Motor control 1,000 W 24 V	8
Soil blender	9
Battery 24 V 40 Ah	10
Battery 12 V 50 Ah	11
DC Breaker (Battery 24 V)	12
DC Breaker (Battery 12 V)	13
System control circuit box	14

Table 4 List of components and their label number according to Fig. 3

Fig. 5 shows a radio remote control Flysky FS-I6X with simple control algorithm, high reliability, no delay time and ability of far distance control (150 m) [40]; having specification as in Table 5.

Fig. 5 A radio remote control Flysky FS-I6X [40]

Item	Specification
Channels	6-10 (Default 6)
Model Type	Fixed-Wing/Glider/HElicopter
RF Range	2.408-2.475GHz
RF power	< 20dBm
RF Channel	135
Bandwidth	500KHz
2.4GHz System	AFHDS 2A / AFDHS
Modulation Type	GFSK
Stick Resolution	4096
Low Voltage Warning	< 4.2V
DSC port	PS/2 Port PPM
Chargeable	No
Antenna Length	26mm(Dual Antenna)
Weight	392 g
Power	6V DC 1.5AA*4
Display	STNTransflective Display, LCD128x64 Lattice，VA 73x 39m，LCD with white backlight
Size	174x89x190mm
On-line Update	Yes
Color	Black
Certificate	CE0678，FCC ID:N4ZFLYSKYI6X

Table 5 Transmitter specification (FS-i6X) [40]

2.3 Design and Components of Electric Tractor Control System Circuits

Design of an electric tractor control system for control the running motor and the soil blending motor has the configuration as shown in Fig. 6 and Fig. 7 while the components in the circuit are listed in Table 6. The circuit was powered by two power sources: a 12V power source for the two 250W dc motors and 24V power source for the 1,000W dc motor.

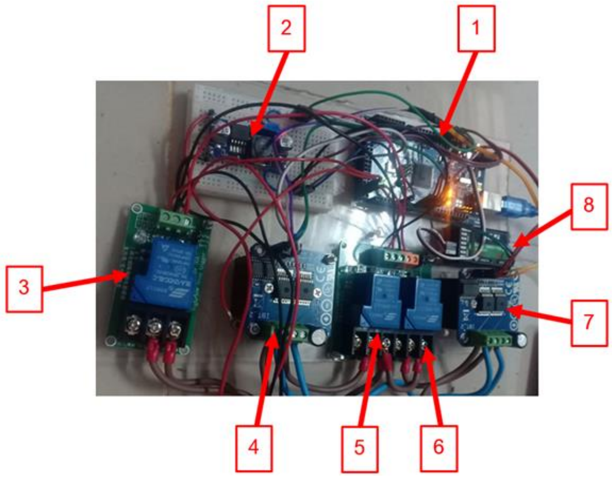


Fig. 6 Electric tractor control circuit

Components	Label number
1) Arduino Mega 2560	1
2) Dc-Dc step down	2
3) Relay 24 V	3
4) Motor drive IBT-2 (BTS7960)	4
5) Relay 12 V	5
6) Relay 12 V	6
7) Motor drive IBT-2 (BTS7960)	7
8) Receiver	8

Table 6 List of components and their label number according to Fig. 6

According to Fig.6 and Fig. 7, the remote control system of the electric tractor operated when the receiver received a command as a radio signal. The receiver would send the command data to the coded Arduino Mega 2560 board, which was used to control digital signals to control a 24 V on-off relay (used to turn on-off a 1,000W motor circuit), a 12 V relays (2 units, turn on-off the electric tractor drive circuit, use two 250 W motors) and control a PWM signal to Motor Diver IBT-2 (2 units) and consequently control the turning left-right motors to drive the electric tractor. The device required a 5V power supply to decrease from 12 V to 5 V to supply voltage to the two Arduino Mega 2560 and IBT-2 motor drivers.

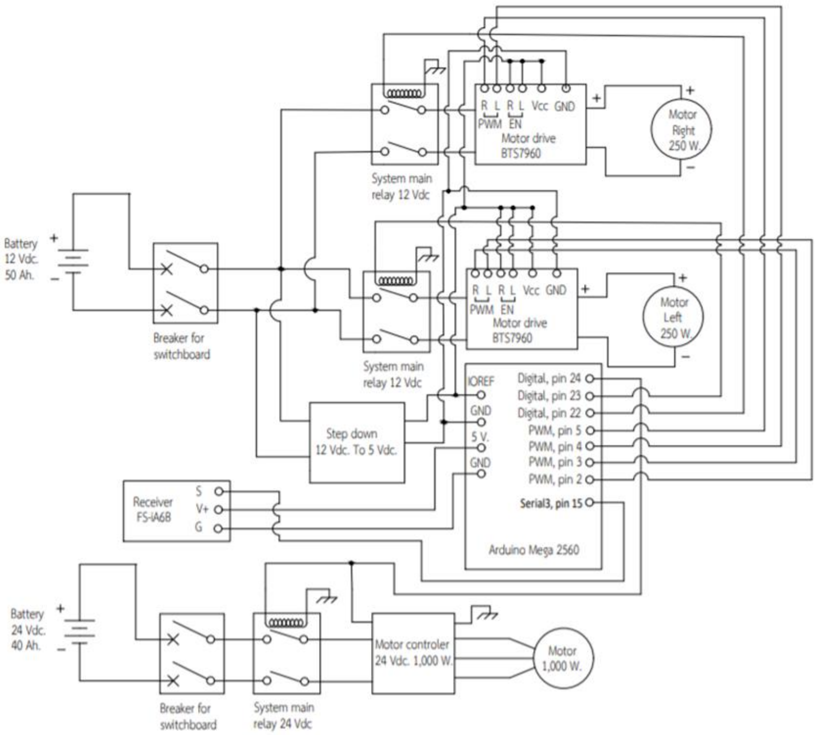


Fig. 7 Schematic diagram for the control system circuit for the proposed electric tractor

3. Testing Methods and Results

Fig. 8 shows the geometrical location and the test position for the prototype, which was conducted under Thai terrain conditions. The test location was at Phabu Sub-district, Phra Yuen District, Khon Kaen Province, Thailand (latitude: 16.249923^{o} and longitude: 102.713881 ^{o}). The test area was approximately 20x40= 0.8 km^2.

Fig. 8 Test area for the tractor prototype

3.1 Test Methods

The tests for the proposed tractor prototype were conducted in the aforementioned location and as shown in Fig. 8. The proposed tractor was tested by moving forward and backward with the distance of 10, 20 and 30 m, respectively. Performance of the tractor was tested under different running speeds from 1-11 km/hr. and soil blending speed of upto 190 rpm.

Fig. 9 Testing condition for the proposed electric tractor

3.2 Speed and Energy Usage Test Results

This section presents the corresponding test results. Table 7-14 show the measured values of electric voltage, current and wheel speed of the tractor when running with the speeds of 4-11 km/hr.

Round	Voltage (V)		Current (A)		wheel speed (rpm)	
	left motor	right motor	left motor	right motor	left wheel	right wheel
1	4.81	4.76	2.60	2.59	65.6	65.4
2	4.80	4.77	2.62	2.74	65.5	65.4
3	4.83	4.77	2.62	2.76	65.9	65.6
4	4.79	4.78	2.69	2.83	65.5	65.5
5	4.79	4.78	2.56	2.79	65.2	65.5

Table 7 Measured voltage, current and wheel speed of the tractor when running with the speed of 4 km/hr.

Round	Voltage (V)		Current (A)		wheel speed (rpm)	
	left motor	right motor	left motor	right motor	left wheel	right wheel
1	5.80	5.76	2.87	2.98	82.9	83.2
2	5.78	5.76	2.91	2.98	83.2	82.9
3	5.79	5.76	2.86	3.01	83.0	83.0
4	5.82	5.77	2.95	3.08	82.9	83.0
5	5.82	5.73	3.00	3.15	83.1	83.4

Table 8 Measured voltage, current and wheel speed of the tractor when running with the speed of 5 km/hr.

Round	Voltage (V)		Current (A)		wheel speed (rpm)	
	left motor	right motor	left motor	right motor	left wheel	right wheel
1	6.92	6.91	3.19	3.18	100.2	102.3
2	6.94	6.88	3.16	3.33	100.1	102.1
3	6.94	6.89	2.98	3.19	100.2	100.2
4	6.95	6.90	2.98	3.23	100.2	100.2
5	6.92	6.90	3.16	3.19	100.1	102.5

Table 9 Measured voltage, current and wheel speed of the tractor when running with the speed of 6 km/hr.

Round	Voltage (V)		Current (A)		wheel speed (rpm)	
	left motor	right motor	left motor	right motor	left wheel	right wheel
1	7.87	7.83	3.10	3.22	116.2	116.8
2	7.87	7.83	3.33	3.33	116.3	116.6
3	7.88	7.83	3.13	3.19	116.1	116.7
4	7.88	7.85	3.12	3.16	116.0	116.9
5	7.89	7.86	3.17	3.20	116.2	116.4

Table 10 Measured voltage, current and wheel speed of the tractor when running with the speed of 7 km/hr.

Round	Voltage (V)		Current (A)		wheel speed (rpm)	
	left motor	right motor	left motor	right motor	left wheel	right wheel
1	9.07	9.02	3.25	3.34	134.8	136.1
2	9.05	8.97	3.24	3.46	134.8	133.6
3	9.06	9.01	3.34	3.31	134.5	134.2
4	9.09	9.01	3.27	3.28	134.5	133.7
5	9.06	8.99	3.32	3.39	134.6	136.1

Table 11 Measured voltage, current and wheel speed of the tractor when running with the speed of 4 km/hr.

Round	Voltage (V)		Current (A)		wheel speed (rpm)	
	left motor	right motor	left motor	right motor	left wheel	right wheel
1	9.80	9.72	3.39	3.55	149.5	150.4
2	9.79	8.73	3.42	3.49	149.5	150.2
3	9.79	9.73	3.50	3.43	149.4	150.3
4	9.76	9.70	3.45	3.41	149.6	150.2
5	9.76	8.71	3.38	3.39	149.5	150.3

Table 12 Measured voltage, current and wheel speed of the tractor when running with the speed of 9 km/hr.

Round	Voltage (V)		Current (A)		wheel speed (rpm)	
	left motor	right motor	left motor	right motor	left wheel	right wheel
1	10.73	10.65	3.58	3.54	164.2	165.8
2	10.69	10.66	3.60	3.65	164.0	165.9
3	10.71	10.67	3.64	3.58	164.2	165.7
4	10.74	10.69	3.61	3.61	164.2	165.7
5	10.71	10.69	3.62	3.63	164.3	165.4

Table 13 Measured voltage, current and wheel speed of the tractor when running with the speed of 10 km/hr.

Round	Voltage (V)		Current (A)		wheel speed (rpm)	
	left motor	right motor	left motor	right motor	left wheel	right wheel
1	11.57	11.57	3.72	3.79	178.9	179.3
2	11.56	11.58	3.70	3.74	179.1	178.8
3	11.57	11.60	3.75	3.77	178.8	178.9
4	11.59	11.58	3.70	3.72	179.3	179.3
5	11.61	11.58	3.79	3.75	178.8	179.1

Table 14 Measured voltage, current and wheel speed of the tractor when running with the speed of 11 km/hr.

3.3 Plowing Quality Test Tesults

To assess the performance of the designed electric tractor regarding quality of soil plowing, the quality of the tilled soil levels were developed by using criteria proposed by the Department of Agricultural Extension, Thailand [41], which were listed as shown in Table 15. The score between 0-5 refer to the quality levels between very poor-excellent.

Score	Quality of the tilled soil
5	excellent
4	very good
3	good
2	moderate
1	poor
0	very poor

Table 15 Criteria for grading [41]

For this test, the tractor prototype was set to operate with different supplying power load levels of the blending unit: 20%, 40%, 60%, 80% and 100% at different driving speed: 4, 5, 6, 7, 8, 9, 10 and 11 km/hr. The corresponding results are shown in Tables 15-22. All the photographs were taken with the same capturing distance of 70 cm from the ground 70 cm. It is noted that the quality of tilled soil was assessed only lumps of different sizes and conditions of tilled soil regardless of the color. It could be concluded that:

- From Table 16-19, the blending power between 60-80% (blending speed of 114-152 rpm) provided the best plowing quality (4.0-4.2) when the tractor ran at the speed of 4-7 km/hr.
- From Table 20-21, the best plowing quality (4.0-4.2) was shifted to the blending power between 80-100%

(blending speed of 152-190 rpm) when the tractor ran at the speed of 8-9 km/hr.

- From Table 22, the tractor reached the highest plowing quality (4.4) when the tractor operated with blending power of 80% (blending speed of 152 rpm) and ran at the speed of 10 km/hr. The plowing quality became reduced to 3.4 when the blending power increase to 100%, in turn, blending at lower power at 60% gained better quality of 3.6. It means that when the tractor ran at high speed 10 km/hr speed, put full power at 100% could not be useful. In fact, the blending power range between 60-80% would provide the better quality.
- From Table 23, when the tractor ran faster (at maximum speed of 11 km/hr.), the quality of plowing became reduced for the whole power range. The best quality of plowing (3.8) was at the blending rate of 80% (152 rpm).

In summary, the tractor achieved the best quality of plowing (4.4) when running at 10 km/hr. with blending power of 80% (blending speed of 152 rpm). The quality of plowing became reduced when the tractor ran at lower or higher than 10 km/hr. while the best blending power range for the whole running speed would be between 60-80%.

4. Analysis of Test Results

The measured values of the electric voltage, current, and speed of the electric dc motors during the off-road condition tests while plowing the soil will be analyzed in this Section.

4.1 Relationship between Measured Voltage and Speed of Tractor's Motors

As aforementioned in the previous Section, the electric tractor prototype consisted of 2 driving dc motors. In order to freely control the direction of the tractor as required, the speed of these two motors therefore had to be linear in relationship when applying the input voltage to the motors' terminals. This experiment measured the apparent voltage at each motor terminal. The voltage had a variable value according to the speed of the motors as designed as shown in Fig.10.

Power of the blender motor (%)	20%	40%	60%	80%	100%
Figure 1					
soil quality	0	3	3	5	3
Figure 2					
soil quality	0	3	2	5	2
Figure 3					
soil quality	0	1	2	4	2
Figure 4					
soil quality	3	1	3	3	1
Figure 5					
soil quality	3	1	3	3	2
average soil quality	1.2	1.8	2.6	4	1.8

Table 16 Plowing quality results when the tractor running at 4 km/hr.

Power of the blender motor (%)	20%	40%	60%	80%	100%
Figure 1					
soil quality	1	3	3	4	4
Figure 2					
soil quality	1	2	3	4	2
Figure 3					
soil quality	1	2	3	3	2
Figure 4					
soil quality	2	2	3	5	2
Figure 5					
soil quality	0	1	3	5	2
average soil quality	1	2	3	4.2	2.4

Table 18 Plowing quality results when the tractor running at 6 km/hr.

Power of the blender motor (%)	20%	40%	60%	80%	100%
Figure 1					
soil quality	1	1	3	4	3
Figure 2					
soil quality	1	1	3	3	2
Figure 3					
soil quality	1	1	3	5	3
Figure 4					
soil quality	0	1	5	4	2
Figure 5					
soil quality	0	3	4	4	2
average soil quality	0.6	1.4	3.6	4	2.4

Table 17 Plowing quality results when the tractor running at 5 km/hr.

Power of the blender motor (%)	20%	40%	60%	80%	100%
Figure 1					
soil quality	1	3	3	5	3
Figure 2					
soil quality	1	3	3	4	3
Figure 3					
soil quality	0	3	4	4	3
Figure 4					
soil quality	0	2	4	4	3
Figure 5					
soil quality	1	2	4	4	3
average soil quality	0.6	2.6	3.6	4.2	3

Table 19 Plowing quality results when the tractor running at 7 km/hr.

Power of the blender motor (%)	20%	40%	60%	80%	100%
Figure 1					
soil quality	1	2	3	4	3
Figure 2					
soil quality	1	2	3	3	3
Figure 3					
soil quality	2	2	3	5	4
Figure 4					
soil quality	2	2	3	5	3
Figure 5					
soil quality	1	3	3	4	4
average soil quality	1.4	2.2	3	4.2	3.4

Table 20 Plowing quality results when the tractor running at 8 km/hr.

Power of the blender motor (%)	20%	40%	60%	80%	100%
Figure 1					
soil quality	1	1	4	5	4
Figure 2					
soil quality	2	2	3	5	4
Figure 3					
soil quality	1	2	4	3	3
Figure 4					
soil quality	1	3	3	3	3
Figure 5					
soil quality	1	3	3	4	4
average soil quality	1.2	1.8	3.4	4	3.6

Table 21 Plowing quality results when the tractor running at 9 km/hr.

Power of the blender motor (%)	20%	40%	60%	80%	100%
Figure 1					
soil quality	1	1	3	4	3
Figure 2					
soil quality	1	2	4	5	4
Figure 3					
soil quality	1	2	4	5	3
Figure 4					
soil quality	2	2	4	5	4
Figure 5					
soil quality	2	2	3	3	3
average soil quality	1.4	1.8	3.6	4.4	3.4

Table 22 Plowing quality results when the tractor running at 10 km/hr.

Power of the blender motor (%)	20%	40%	60%	80%	100%
Figure 5					
soil quality	1	1	3	4	3
Figure 5					
soil quality	2	1	3	4	3
Figure 5					
soil quality	2	2	3	4	3
Figure 5					
soil quality	1	3	3	4	4
Figure 5					
soil quality	1	2	3	3	4
average soil quality	1.4	1.8	3	3.8	3.4

Table 23 Plowing quality results when the tractor running at 11 km/hr.

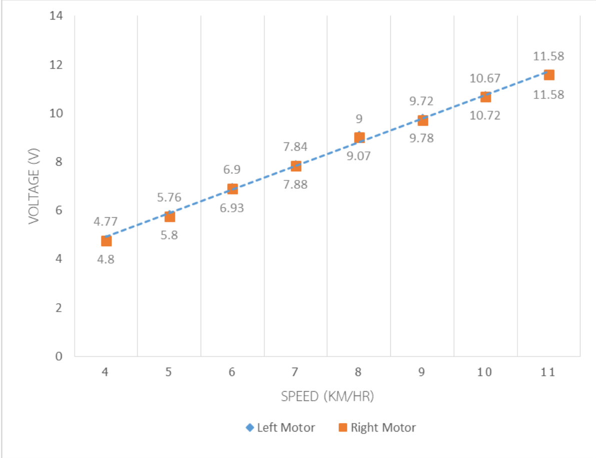


Fig. 10 The relationship between the speed of the left motor and right motor with respect to the apply voltage

4.2 Relationship between Measured Current and Speed of Tractor's Motors

Similar to the applying voltage, the linear relationship between measured current and the speed of the motors of the tractor had to be controlled as well. Fig. 11 confirms the linear relationship between the motor speed and the applying electric current.

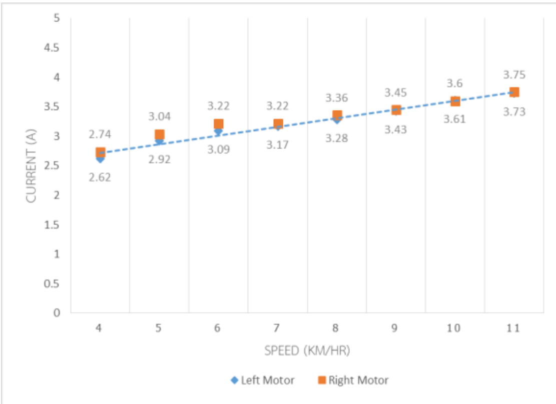


Fig. 11 The relationship between the speed of the left motor and right motor with respect to the apply current.

4.3 Analysis of soil quality

Fig.12 reproduces the results of Table 15-22 in terms of the comparison of soil plowing quality when blending in different power consumption rate between 20, 40, 60, 80 and 100% (or blending speed of 38, 76, 114, 152 and 190 rpm, respectively) with respect to different speeds of tractor's movement at 4, 5, 6, 7, 8, 9, 10 and 11 km/hr. It is clearly seen that the operation with 80% power consumption (or blending speed of 152 rpm) would provide the best soil quality for all the movement speed range. The best soil plowing quality could be when the tractor had speed of 10 km/hr.; where higher speed gave less quality of soil plowing quality.

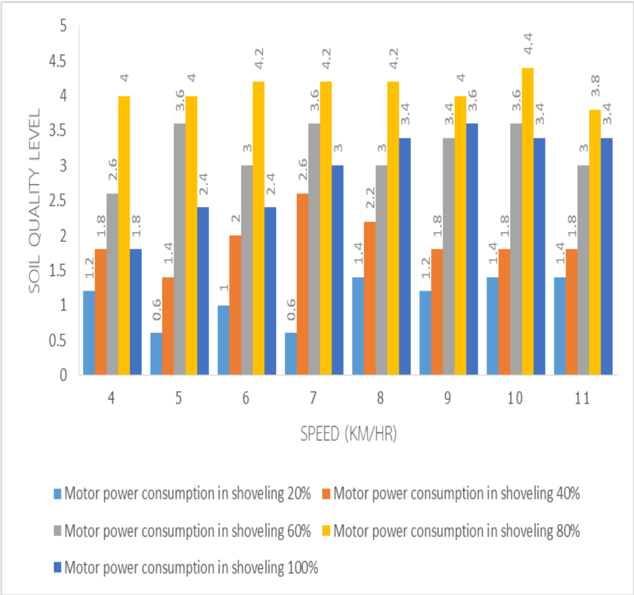


Fig. 12 soil quality at different motor power consumption rates

5. Conclusions and Discussion

This research proposes design and construction of a simple remote-controlled electric tractor. The proposed electric tractor had the length of 100 cm, a width of 66 cm, and a height of 30 cm, which is strong and durable. The tractor had 4 wheels made from solid steel with the diameter and rim of 32 and 4.5 cm that could carry total load weight up to 400 kg. There were 2 sets of dc motors. The first set consisted of 2 motors with power of 250W each that functioned to provide variable moving speed of the tractor between 1-11 km/hr, as well as, providing the sharp turning (0-360 degrees at the fixed turning point). The second set was the 1,000W dc motor connected to the blender set of 32 cm long and 6 blades that functioned to plow and blend the soil with the rotating speed between 0-190 rpm. The 24V battery and 12V battery were used to power the first and second set of the dc motors with fully short circuit protection. The movement speed and blending speed of the motors were control via the radio remote control. The test results show that the suitable speed of the tractor was between 7-9 km/hr due to this speed, it is easy to control the direction of movement. The optimum power consumption for the blending motor were at 80, 60 and 100% (equal to 152, 114 and 190 rpm), respectively. Based on the optimum operation condition above, the electric tractor could operate by 5-7 hours.

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References

[1] K. Kongman, P. Julyusen, K. Watakij, and J. Sompong, "Development of a triaxial force measuring instrument for the three-point coupling of small agricultural tractors," *The 14th TSAE National conference and the 6th TSAE National conference*, *TSAE 2013, TETA-07*, pp.444-450.

[2] J. G. Oliver, K. M. Schure, and J. A. H. W. Peters, "Trends in global CO2 and total greenhouse gas emissions," *PBL Netherlands Environmental Assessment Agency*, 5, 2017.

[3] H. Gao and J. Xue, "Modeling and economic assessment of electric transformation of agricultural tractors fueled with diesel," *Sustainable energy technologies and assessments*, vol.39, 100697, 2020.

[4] J. Caban, J. Vrabel, B. Šarkan, J. Zarajczyk and A. Marczuk, (2018). Analysis of the market of electric tractors in agricultural production," *In MATEC Web of Conferences, EDP Sciences*, vol. 244, p.03005, 2018.

[5] O. Lagnelöv, G. Larsson, D. Nilsson, A. Larsolle and P. A. Hansson, "Performance comparison of charging systems for autonomous electric field tractors using dynamic simulation," *biosystems engineering*, vol.194, pp. 121-137, 2020.

[6] J. Barthel, D. Gorges, M. Bell and P. Munch, "Energy management for hybrid electric tractors combining load point shifting, regeneration and boost," *In 2014 IEEE VPPC*, pp. 1-6, 2014.

[7] C. Jia, W. Qiao and L. Qu, "Modeling and control of hybrid electric vehicles: a case study for agricultural tractors," *In 2018 IEEE (VPPC*, pp. 1-6, 2018.

[8] T. Li, B. Xie, Z. Li and J. Li, "Design and optimization of a dual-input coupling powertrain system: A Case Study for Electric Tractors," *Applied Sciences*, vol. 10, no. 5, pp. 1608, 2020.

[9] M. Liu, L. Xu and Z. Zhou, "Design of a load torque based control strategy for improving electric tractor motor energy conversion efficiency," *Mathematical Problems in Engineering*, 2016.

[10] L. Xu, M. Li and Z. Zhou, "Design of drive system for series hybrid electric tractor," *Transactions of the Chinese Society of Agricultural Engineering*, vol. 30, vol. 9, pp. 11-18, 2014.

[11] Y. Chen, B. Xie, Y. Du and E. Mao, "Powertrain parameter matching and optimal design of dual-motor driven electric tractor," *International Journal of Agricultural and Biological Engineering*, vol. 12, no. 1, pp. 33-41, 2019.

[12] D. Troncon and L. Alberti, "Case of Study of the Electrification of a Tractor: Electric Motor Performance Requirements and Design," *Energies*, vol. 13, no. 9, pp. 2197, 2020.

[13] Y. Chen, B. Xie and E. Mao, "Electric tractor motor drive control based on FPGA" *IFAC-PapersOnLine*, vol. 49, no. 16, pp. 271-276, 2016.

[14] J. Y. He, F. Z. Yang, and X. D. Xu, "Design of Remote Control System for Hillside Crawler Micro-farming Tractor," *Tractor & Farm Transporter*, vol. 2, 2011.

[15] P. Thanpattranon, T. Ahamed and T. Takigawa, "Navigation of autonomous tractor for orchards and plantations using a laser range finder: Automatic control of trailer position with tractor," *Biosystems Engineering*, vol. 147, no. 90-103, 2016.

[16] M. O'Connor, T. Bell, G. Elkaim and B. Parkinson, "Automatic steering of farm vehicles using GPS" *In Proceedings of the Third International Conference on Precision Agriculture. Madison, WI, USA: American Society of Agronomy, Crop Science Society of America, Soil Science Society of America*, pp. 767-777, 1996.

[17] O. R. Oyetunji, W. A. Adesope, P. Ufokima, E. Y. Salawu, A. O. Araoyinbo and F. A. Ishola, "Design and Fabrication of a Pilot Scale Remote Controlled Electric Car Using Additive Manufacturing Approach," *International Journal*, vol. 8, no. 7, 2020.

[18] J. Gabriel, T. Restivo and J. Reis, "Remote Control of a Model Car," *In 1st Experiment@ International Conference–Remote & Virtual Labs-exp.*, vol.11, 2011.

[19] W. S. Kim, W. S. Lee and Y. J. Kim, "A review of the applications of the internet of things (IoT) for agricultural automation," *Journal of Biosystems Engineering*, vol. 45, no. 4, pp. 385-400, 2020.

[20] T. Singh, A. Verma and M. Singh, "Development and implementation of an IOT based instrumentation system for computing performance of a tractor-implement system," *Journal of Terramechanics*, vol. 97, pp. 105-118, 2021.

[21] N. Gupta, S. Gupta, M. Khosravy, N. Dey, N. Joshi, R. G. Crespo and N. Patel, "Economic IoT strategy: the future technology for health monitoring and diagnostic of agriculture vehicles," *Journal of Intelligent Manufacturing*, vol. 32, no. 4, pp. 1117-1128, 2021.

[22] I. Charania and X. Li, "Smart farming: Agriculture's shift from a labor intensive to technology native industry," *Internet of Things*, vol. 9, 100142, 2020.

[23] W. E. Larsen, G. A. Nielsen and D. A. Tyler, "Precision navigation with GPS," *Computers and Electronics in Agriculture*, vol. 11, no. 1, pp. 85-95, 1994.

[24] N. Shalal, T. Low, C. McCarthy and N. Hancock, "A review of autonomous navigation systems in agricultural environments," 2013.

[25] Q. Zhang and H. Qiu, "A dynamic path search algorithm for tractor automatic navigation," *Transactions of the ASAE*, vol. 47, no. 2, pp. 639, 2004.

[26] Ministry of Transport "Cumulative number of registered cars from 2012–2019,"*Office of Transport and Traffic Policy and Planning*.

[27] C. Chaloemthoi, S. Bumrungkeeree, A. Thongkam, J. Anurak, N. Sammaket and S. Bumrungkit, "Study of Fuel Consumption for Disk Harrow," *The 1st Rajamangala University of Technology Suvarnabhumi National*, vol.1, pp. 525-531, 2016.

[28] S. Y. Baek, Y. S. Kim, W. S. Kim, S. M. Baek and Y. J. Kim, "Development and Verification of a Simulation Model for 120 kW Class Electric AWD (All-Wheel-Drive) Tractor during Driving Operation," *Energies*, vol. 13, no. 10, 2422, 2020.

[29] M. G. Matache, M. Cristea, I. Găgeanu, A. Zapciu, E. Tudor, E. Carpus and L. D. Popa, "Small power Electric Tractor performance during ploughing works," *INMATEH – Agricultural Engineering*, vol. 60, no. 1, pp. 123-128, 2020.

[30] Y. Ueka, J. Yamashita, K. Sato and Y. Doi, "Study on the development of the electric tractor: specifications and traveling and tilling performance of a prototype electric tractor," *Engineering in agriculture, environment and food*, vol. 6, no. 4, pp. 160-164, 2013.

[31] A. Polcar, L. Renčín and J. Votava, "Drawbar pull and its effect on the weight distribution of a tractor," *Acta Universitatis Agriculturae et Silviculturae Mendelianae Brunensis*, 2017.

[32] G. Samseemoung, M. Janthong, K. Treeamnuk, W. Upaphai, "Development of an unmanned autonomous tractor using GPS guidance for modern agriculture," *Thai Society of Agricultural Engineering Journal*, vol. 23, no. 1, pp. 39-54, 2017.

[33] T. J-thaun, P. Junyusen, K. Khongman and Y. Sengdang, "Trajectory Planning for Autonomous Tractor using Polynomial Function," *Feat Journal, Farm Engineering And Automation Technology Research Group*, vol. 2, no. 2, pp. 131-138, 2016.

[34] T. Jatuan, C. Ruangchoho, M. Kathapant, K. Vongstan and P. Junyusen, "Development of a steering control system for an autonomous tractor," *Feat Journal, Farm Engineering And Automation Technology Research Group*, vol. 5, no.1, pp. 1-11, 2019.

[35] N. Khumprom, P. Niranon and T. Thongsan, "Remote control electric lawn mower," *Dissertation: Electrical Engineering, Mahasarakham University*, 2018.

[36] K. Pornwarakhachonkul, C. Rachkratok, T. Wongsr and S. Niyomphant, "Radio controlled lawn mower," *Industrial Technology Journal*, vol. 5, no. 2, pp. 51-60, 2020.

[37] G. P. Moreda, M. A. Muñoz-García and P. J. E. C. Barreiro, "High voltage electrification of tractor and agricultural machinery–A review," *Energy Conversion and Management*, vol. 115, pp. 117-131, 2016.

[38] J. Larminie and J. Lowry, "Electric vehicle technology explained," *John Wiley & Sons*, 2012.

[39] M. Singh, "Tractor Design and Testing: Mechanics of tractor chassis and stability analysis," *Research Engineer. Dept. of Farm Machinery and Power Energy, PAU, Ludhiana*, 2014.

[40] Flysky RC, "Flysky FS-l6X Digital Proportional Radio Control System," *Flysky RC model technology Co.,Ltd.*, 2016.

[41] Agricultural Extension, "Soil management information" [Online]. Available: https://www.ldd.go.th/Web_Soil/Page_02.htm (28 January 2021).

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