Short Communication

Conceptual Design of a Self-Propelled Mechanized Pineapple Transplanter

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Abstract: Pineapple cultivation involves several operations, and planting is considered one of the critical operations. The existing machine cannot be applied because it will damage the plastic mulch. This study aims to present a design concept for the development of a pneumatic-powered pineapple transplanter. The major components will be the planting mechanism and the sucker feed mechanism that will be integrated into a semi-autonomous sucker planting mechanism by soil opener, which consists of a puncher and digger to allow the sucker to enter into the grow bed and then compact with soil. The puncher and digger are powered by pneumatic means. The pineapple transplanter was designed with a width of 1074mm and a clearance of 320mm, which could maneuver over the soil bed. From the CAD simulation, it takes 57mm of extending actuator to open the digger 45 degrees. Air compressors provide 8 bars of pressure to punch a hole in the soil with 5 bars of pressure. The design can continue with fabrication and can be used for future research.

1. Introduction

In recent years, the variety many farmers have cultivated MD2 pineapple due to high demand in both local and international markets. According to Bernama, Malaysia Pineapple Industry Board (LPNM) Director-General Mohd Khairuzamri M Salleh (2021) stated that under the 12th Malaysia Plan (12MP), the industry intends to expand Malaysia's pineapple

production area from 16,000ha to 20,000ha, with a focus on MD2 pineapples. These plans are to increase the MD2 pineapple production to fulfil the local and export demands.

Pineapple cultivation involves several operations, and planting is considered one of the critical operations. Planting pineapple sucker also includes a few processes, which are punching the hole with a pole and shoving the sucker into the hole, then compressing the soil to hold the sucker in place if needed. Although several planting machines have been developed, the introduction of plastic mulch (commonly known as silver shine by the local farming community) has reverted the mechanization to purely manual-based. By using plastic mulch, soil properties like soil temperature, moisture content, bulk density, aggregate stability, and nutrient accessibility have been improved (Manickam *et al.*, 2010). Furthermore, plastic mulch has been used massively because high-quality pineapple fruit was produced, and this technique became one of the main factors in producing high-quality MD2 fruit. The existing machines were designed to make furrow and planting suckers continuously (Ahmad *et al.,* 2013). Henceforth, using existing machines damage the plastic mulch. Therefore, a new planting mechanization strategy that can be operated on plastic mulch is needed.

Pneumatics has been used in many machines or implements in agriculture. Some of them were successfully developed and integrated. Utilizing pneumatic systems enables farmers to achieve cost savings, operate with higher precision, and minimize the impact on overall machine weight compared to using other external power sources such as hydraulic (New Holland, 2023). Therefore, in this project, a new technique will be designed to use pneumatic power-actuated in the planting process.

The primary components consist of a planting mechanism and a sucker feed mechanism, operated by a puncher and digger, facilitating the entry of suckers into the grow bed and securely holding them in place with the surrounding soil. The puncher and digger are powered by using pneumatic and control using remote control. This study aims to present a design concept for the development of a pneumatic-powered pineapple transplanter.

2. Materials and Methods

The aim of this study, as described in the objective, is to develop a whole new pneumatic-powered pineapple transplanter that will be designed based on the pineapple's sucker or seedling measurement, grow bed parameter for a mover maneuver over the grow bed, and the strength of the soil bed. A FreeCad computer-aided design (CAD) software designed and automated the pineapple transplanter mechanism.

2.1. Pineapple Suckers Size Measurement and Grow Bed Parameter

Physical parameters of the pineapple suckers, such as weight (g), length (cm), diameter (cm) and canopy (cm) were used to determine the size of the sucker hole. These parameters are very crucial in the design of the sucker hole in the digger and the funnel for the sucker to fall.

Table 1 shows the physical parameters of MD2 pineapple. By taking the average of Grade B MD2 pineapple sucker, the diameter was 4.3 cm, the length was 48.7 cm, the weight was 349.2 g, and the canopy size was 27.0 cm. The distance between suckers to another sucker was around 30.0 cm apart.

Table 1. Statically summary for MD2 pineapple grades. Source by MARDI HQ

Variety	**MD2**		
Grade	**A**	**B**	**C**
Diameter (cm)	5.1(0.6)	4.3(0.6)	3.9(0.6)
Length (cm)	67.8(8.4)	48.7(6.6)	36(6.5)
Weight (g)	664.2 (208.8)	349.2 (88.9)	226.2 (75.1)
Canopy (cm)	37.6(8.7)	27(7.5)	22.1(7.2)

The grow bed for pineapple has many dimensions, but one commonly used dimension was 30.0cm height, 90.0cm width and 50.0m long, according to the Malaysian Pineapple Industry Board [MPIB] (2022). Hence, the clearance of the design of the pineapple planter should allow the planter to maneuver over the grow bed.

2.2. Soil Strength and Pneumatic Parameter

Land preparation is essential because other plants or trees may cause the reduction of pineapple's plant growth and quality. Land preparation includes clearing, ploughing, and tillage, and applied to grow beds. Ploughing was followed by one or two rounds of soil tillage for mineral soil, breaking down the extensive, chunky soil into smaller pieces. Based on a study by Mairghany *et al.* (2019) in Figure 1, with depths of 20cm and 30cm, the penetration resistance was 0.64 MPa, 0.49 MPa, 0.38 MPa, and 0.60 MPa, 0.43 MPa, 0.36 MPa for 1st, second, and third tillage respectively.
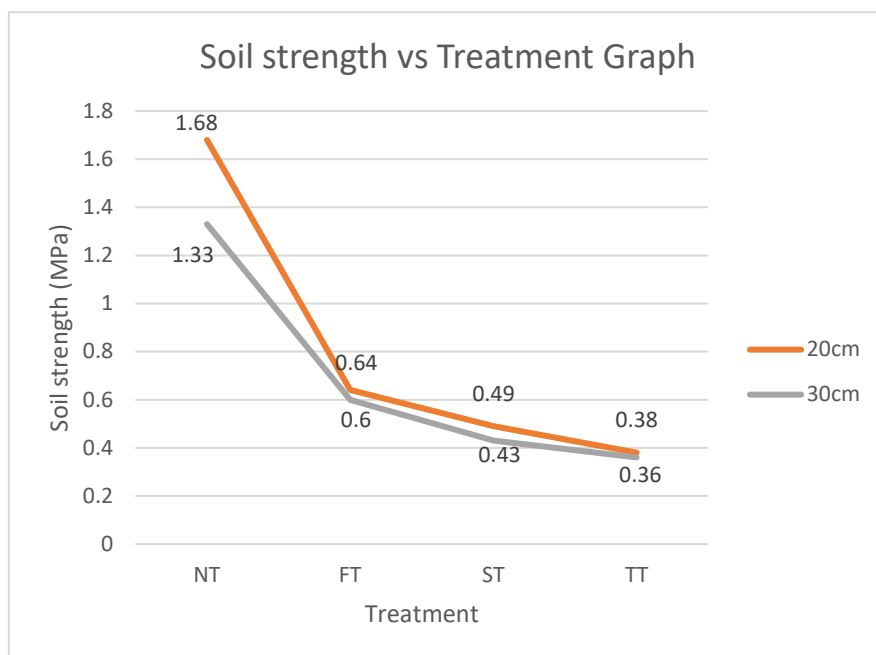
Figure 1. Graph of soil penetration resistance (MPa) in response to tillage operations during the first season. NT – Non-Tillage, FT – First Tillage, ST – Second Tillage, TT – Third Tillage.

Moreover, the pneumatic system selection should surpass the pressure requirements of the soil opener mechanism, given that the soil penetration resistance ranges from 0.64MPa to 0.36 MPa.

2.4. Design of Transplanting Mechanism

The newly proposed design utilizes pneumatic power for penetration, effectively opening the soil. This machine will be attached to a mover capable of maneuvering using motor-driven chains. The idea of the mover was that it could be controlled remotely without any driver. The mover was designed to move over the grow bed while the wheel maneuvered beside the bed. For the planting mechanism, a pneumatic actuator is powered by a digger duckbill shape for soil punching and a set of linkages for opening the soil.

The step of the transplanter process is shown in Figure 1 below. Start with the mover maneuver on the grow bed and stop at the target. Next, the cylinder actuator(C1) is activated to punch the digger into the soil, and another cylinder actuator (C2) is is activated to open up the soil. The pineapple's sucker will fall into the hole, and C1 will retract the digger as well as C2 will close the digger, then repeats the steps.
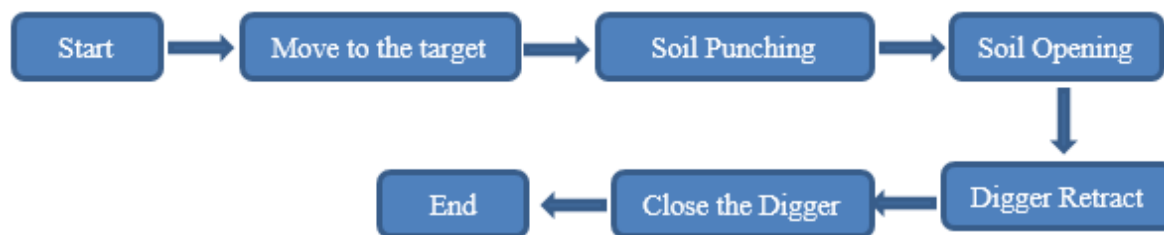
Figure 2. Flowchart of the transplanter process

3. Results and Discussions

3.1. Transplanting Mechanism Design

The pineapple planter design was designed using computer-aided design (CAD) software, FreeCad, to create the 3D model, technical drawing and animated transplanter mechanism, as shown in Figure 3. The transplanter consists of the body frame, funnel, duckbill-shaped digger, two-cylinder actuators for soil punch and soil opener, two motorized back wheels, two swivel front wheels, air compressor, battery, and electronic components for controlling the mover.
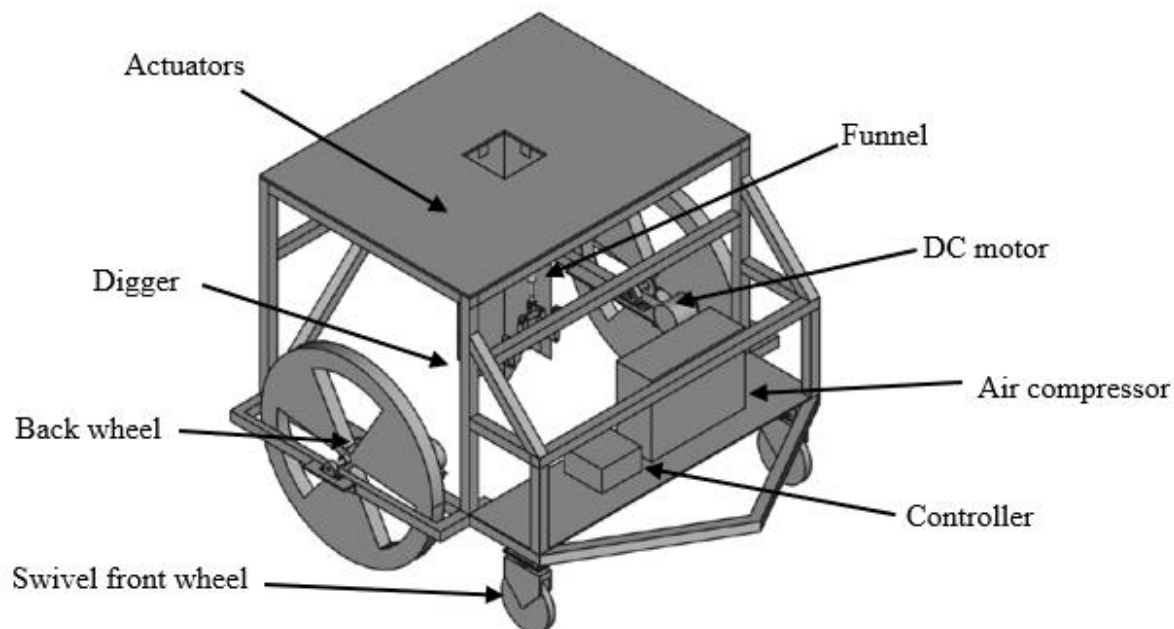

Figure 3. ISO view of the transplanter design.

3.1.1. Mover

The dimension of the mover was designed to maneuver on the grow bed while the wheel was beside the bed. A standard grow bed for MD2 was one meter in width and 300

mm in height. Hence, the clearance of the mover should be enough to maneuver through the grow bed. As shown in Figure 4, the clearance for the grow bed was 1074 mm x 309 mm.
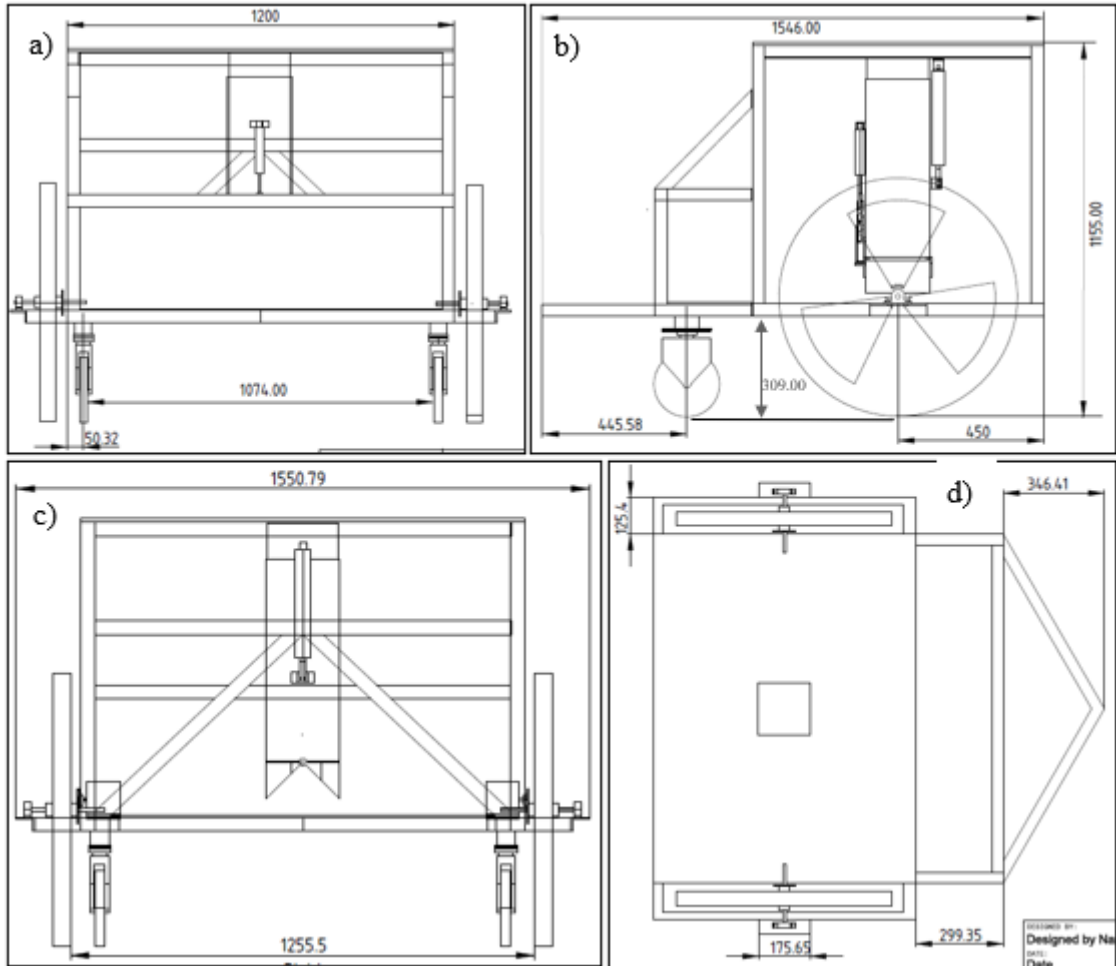

Figure 4. **a)** Front view. **b)** Side view. **c)** Back view. **d)** Top view
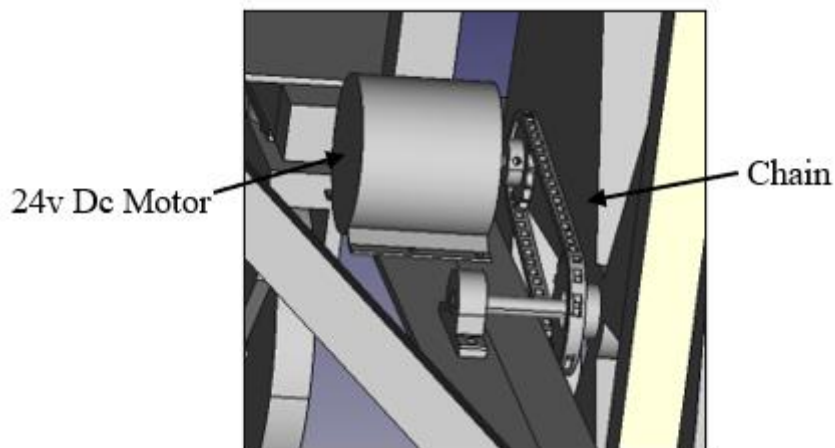

Figure 5. A motor motorized the back wheel through the chain.

The mover was ingeniously designed to be propelled by electrical motors on both sides of the back wheel, with each motor connected to a microcontroller equipped with wireless communication, allowing remote control operation. This design achieves power transfer to the back wheel through chains, as shown in Figure 5. While the back wheels were motorized, the front swivel wheel was proposed so the mover could turn right or left. Furthermore, the mover's maneuvering performance on the outdoor land will be tested once this design is fabricated.

3.1.2. Soil opener mechanism

A soil opener was designed; the sequences are shown in Figure 6.
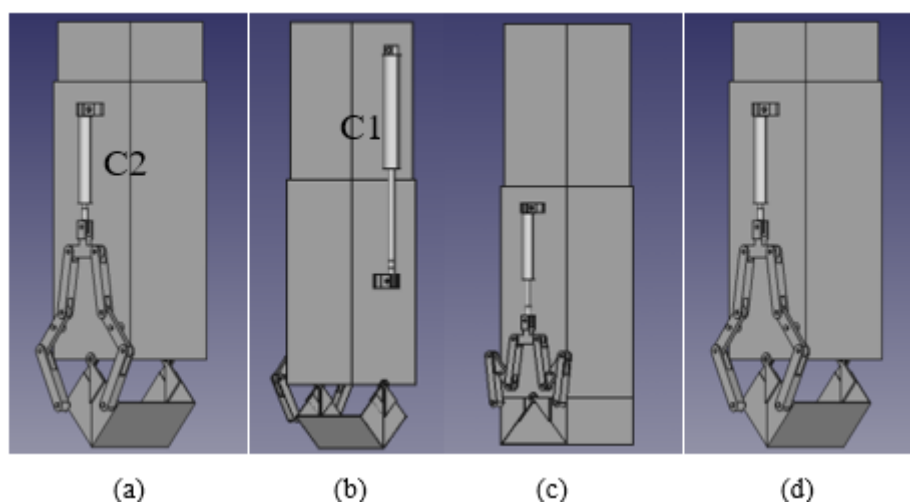

Figure 6. The sequence of the transplanter process. (a) Initially, the C2 retracted, the digger in a close state, and (b) when C1 extended, the digger will punch into the soil. (c) The digger opens the soil. (d) The puncher retracted, and the digger closed back into the initial state.

The soil opener used the Z-shape linkage concept, where the lower boom punches into the soil by C1 while the digger is in a closed state around 15cm depth. The analysis of the opening digger and the length of extension/retraction of the C2 was 57 mm, and the extension/retracting of the C2 will open/close the digger nearly 45 degrees using CAD FreeCad animation. The length of the linkages can be improved for more accessible value.
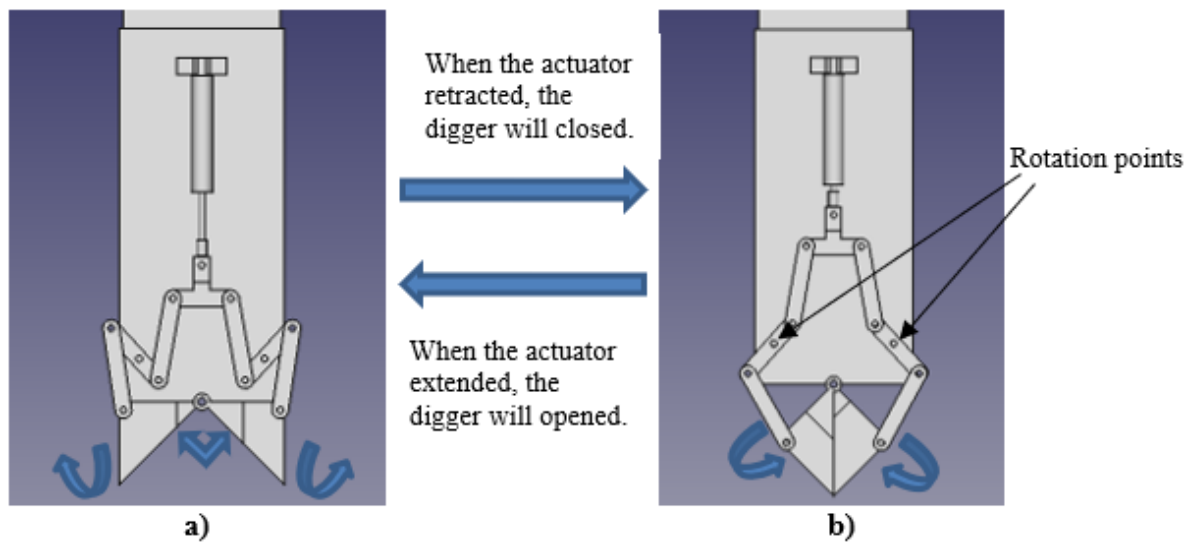
Figure 7. **a)** The digger opens until 45 degrees when C1 extends. **b)** The digger closed when C1 retracted.

3.1.3. Control system

The control system involves a microcontroller, receiver, relay, motor driver, battery, DC motor and other small components. The microcontroller proposed to be the brain for the control system is Arduino Uno because it is usually used as a beginner stage in the program control system. Remote control and receiver are plug-and-play types for more accessible DC motors and actuators control. The motor driver was needed to control the DC motor proportionally to prevent the motor from suddenly moving. The motor driver is connected to Arduino and receives the signal from the remote control. Two 24 V DC motors are connected to the motor driver and powered by a converter (12 V to 24 V) from a 12 V battery. Next, two actuator valves connected to the relay because the solenoid valve required 12 V power and could not directly connect to Arduino. At the same time, Arduino only provided 5 V. Therefore, the relay was used to activate the solenoid valve by receiving the signal from the remote control. The two actuators in Figure 8 indicate a solenoid valve for soil punching and soil digger.
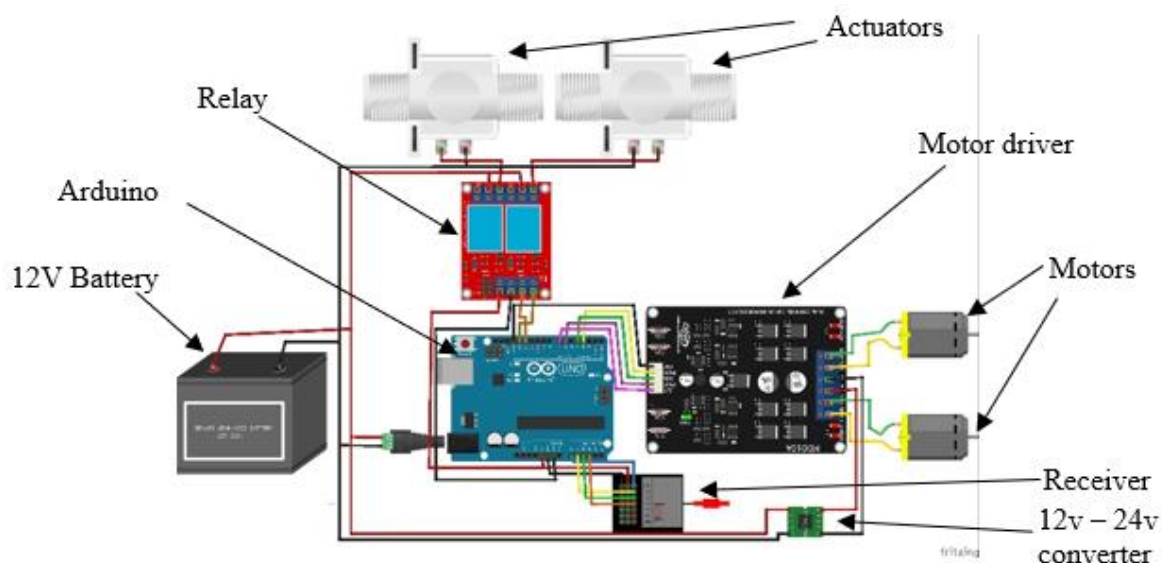
Figure 8. Electric circuit of the control system.

3.1.4. Pump parameter

The air compressor was proposed to operate the cylinder actuators for the soil punching and opening process. As for the air compressor recommendation, the soil strength in the 20–30 cm depth was around 0.40–0.50 MPa, equivalent to 4–5 bar. The air compressor with higher pressure would be enough to operate the soil opener process. Figure 9 shows a recommended air compressor with a tank.

Figure 9. Aerotec Air Compressor.

Aerotec Air Compressor has a dimension of 32 L x 30 W x 34 Hcm and a weight of 6 kg. A very suitable size to mount on the mover and light in weight. The operating pressure was 8 bar, which would be enough to operate the soil opener. However, a physical test is needed to observe whether this air compressor is suitable for this machine. Aerotec Air Compressor has a 6 L tank, 55 L/min flow rate, and 370 W power rate. 6 L of the tank is

enough to operate two actuators, and a 55 L/min flow rate is suitable for operating the actuators. With the parameters given, this air compressor is suitable for this transplanter.

4. Conclusions

In conclusion, the pineapple transplanter was designed to reduce human labour and precise pineapple sucker planting. Hence the requirement to plant a pineapple's sucker was that the mover was able to maneuver over the grow bed with 1074mm x 309mm clearance. The soil opening animation shows that the soil opening process has no problem with the length of linkage designated for the digger, which is fully opened by 57mm of C2 extended. The air compressor proposed was considered suitable to contribute to the pneumatic system in transplanter operation because it can provide 8 bar of pressure, small in size with 32L x 30W x 34H cm and 6kg of weight. Overall, the design can be fabricated and tested in the future.

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