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JSMT

http://publisher.uthm.edu.my/ojs/index.php/jsmt

e-ISSN : 2821-2835

Journal of Sustainable and Manufacturing in Transportation

Omnidirectional Battery Electric Vehicle for Use in Oil Palm Plantation

Ahmad Jais Alimin[1*], M. H. Osman[2]

[1]Centre for Energy & Industrial Environment Studies (CEIES),
Universiti Tun Hussein Onn Malaysia, 86400 Batu Pahat, Johor, MALAYSIA

[2]Centre for Energy & Industrial Environment Studies (CEIES),
Universiti Tun Hussein Onn Malaysia, 86400 Batu Pahat, Johor, MALAYSIA

*Corresponding Author

DOI: https://doi.org/10.30880/jsmt.2023.03.02.002
Received 13 August 2023; Accepted 23 October 2023; Available online 31 December 2023

Abstract: Concerns on the low labour shortage and the need to reduce greenhouse gas (GHG) generation prompted the industrial player to increase mechanisation during operation and adopting low carbon footprint mobile platforms. In this paper, a design and analysis study was conducted and reported on a conceptual battery electric vehicle (BEV) for use in the oil palm plantations. With a maximum operating road speed of 30km/hr and harvesting load of 320kg, the BEV will require a minimum operational power of 44.5kW. In accommodating the soggy ground with the demand to navigate narrow and undulating terrains, the proposed BEV was designed to be equipped with an omnidirectional functionality with continuous track, without the use of conventional wheels. Major components arrangement and design for the omnidirectional mechanism are presented in this paper. This preliminary work will also serve as the foundation towards refining the BEV design, especially on the vehicle functionality and manoeuvrability in the plantation sites. Further recommendations are also outlined that will focus on validating the conceptual design and analysis on the total energy generation and consumption of the BEV.

Keywords: Agriculture BEV, omnidirectional, continuous track, sustainable charging system

1. Introduction

Malaysia is the world's second-largest producer of palm oil, with a significant impact on its economy. The nation's oil palm industry also generates around 90 million tons of biomass, including fresh fruit bunches (FFB), trunks, and fronds. Due to the nature of oil palm harvesting and plantation needs, manual labour is still crucial for completing tasks in the estates. In supporting the daily tasks in the estates, most plantation owners deploy mobile platforms to carry harvested FFB from each oil palm rows to the designated collection points. The choice of powertrain for these mobile platforms is usually using small 4-stroke spark ignition (S.I.) engines or lightweight compression ignition (C.I.) engines. Internal combustion engines (ICE) based system is the preferred choice since the introduction of mechanisation in the oil palm industry. Innovative harvesting and collecting mechanisms also require the usage of reliable and conventional powertrain and mobile platforms. It is well reported that S.I. and C.I. engines are consuming petrol and diesel fuels originated from depleting petroleum-based resources. However, the recent global concerns on issues related to reduction of greenhouse gases (GHG) and urgency to reduce carbon footprints, have encouraged stakeholders in the oil palm plantation industry to begin considering alternative systems that are safe to the environment.

Immediate solution that could achieve lower GHG generation in plantation areas will be the deployment of non-ICE based powertrains such as hybrid system (S.I. combines with or BEV based powertrain) or full BEV systems. BEV that utilises charging from renewable energy sources (RES) would create comprehensive reduction on GHG and carbon

*Corresponding author: ajais@uthm.edu.my

footprint generation, hence contributing towards improving the surrounding air quality. One of the key components for hybrid and BEV system is the battery, which can be recharged using energy generated from RES such as from solar panels. The use of RES is one of the components that contribute to a more sustainable agricultural operation. Aside from environmental benefits, RES may also provide long-term economic benefits, resulting in a favourable perception of the agricultural industry.

The purpose of this research is to propose a dedicated BEV, which will be capable to perform in the plantation terrain and generating the lowest GHG and carbon footprint. This BEV must also be capable to support agricultural tasks normally implemented in oil palm plantation. In this aspect, it is proposed that the BEV to have an omnidirectional capability to enable it to manoeuvre between the oil palm trees effectively. Therefore, it is important to understand the design of the sub-frame that suits the designated BEV and the choice of the BEV major components, such as the electric motor and battery. Correct combination of the BEV components is important to ensure enough power and torque are always available upon demand by the users. To achieve this, it is important to investigate thoroughly the specifications of each BEV components and the required operating conditions on the plantation terrain, notably the must have ground speed range and the expected rolling resistance. Vehicle's mass and weight distribution are additional factors to be considered due to the soft soil condition of the plantation ground.

Current mobile platforms being used for collection and transportation of oil palm, such as pickup trucks and bulky tractors, are inefficient and impractical in certain operating requirements. Conventional pickup chassis lacks mobility thus making it difficult and time consuming to navigate and overcome physical barriers and manoeuvre various undulating terrains on the plantation. The reliance on fossil fuels is also needed to be reduced to suppress GHG and carbon footprint generation. The wet and soggy soil serve as natural element challenges, which requires an innovative mobile solution.

The work described in this paper would attempt to propose a mobile BEV platform concept suitable for use in oil palm plantation. A conceptual omnidirectional mechanism is also disclosed that will become a key functionality for this BEV. Adoption of electric-based powertrain will assist in reducing reliance on fossil-based fuels and improving the air quality in the plantation areas.

2. Agriculture BEV Concept

As depicted in Figure 1 below, an EV powertrain has fewer components than the powertrain of a conventional ICE powered vehicle. Major important components for the conceptual BEV are battery packs, electric motor, transmission system, DC/AC converter and the battery charging system. In an operational summary [1], a battery pack is made up of multiple Li-ion cells that stores energy needed to run the vehicle. Battery packs provide DC output, which is then is converted to AC and supplied to the electric motor. The electric motor converts the given energy to mechanical energy that is delivered to the wheels via a transmission system. Lastly, an on-board charger converts AC received through charge port to DC and controls the amount of current flowing into the battery pack. The travelling requirements and the estimated load the BEV needs to carry is summarised in Table 1. A hectare of land may hold 143 to 145 oil palm plants when they are planted in a triangle pattern with a 9m x 9m x 9m spacing [2] and this will dictate the dimensions for the proposed BEV. For the BEV operating power, the value was calculated based on the theoretical Road Load Power equation [3, 4].

Table 1 – Road/ground and load requirements for the BEV concept

No.	Item	Description
1.	Maximum travelling speed	30 km/hr
2.	Operational weight	320 kg
3.	Frontal area	1.05 m^2
4.	Vehicle drag co-efficient and rolling resistance	0.4

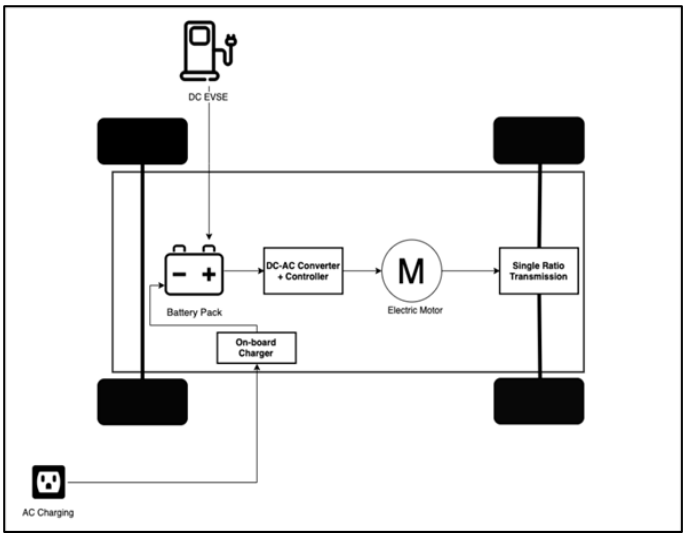

Fig. 1 - Main components of a battery electric vehicle (BEV)

2.1 Battery

A battery with a Li-ion chemistry would be used as the primary power source for this BEV concept. Numerous favourable traits of Li-ion batteries include their high efficiencies, protracted life cycles, high energy densities, and high-power densities. Due to these qualities and their capacity to quickly discharge, they are considered the preferred choice of energy storage for conventional BEV [5]. Furthermore, as the interest on EV is increasing over the recent years, manufacturers prefer battery materials that is favourable for reuse, recycle and repurpose (3R) concept, and Li-ion is one of the preferred battery materials for this purpose. An example of the Li-ion battery pack recommended is Bluesun BSM12200 with nominal voltage of 12.8V and capacity of 200Ah/2560Wh.

2.2 Motor Selection

Based on the calculations of load road power made, the minimum power required is 44.5kW, which will be sufficient to carry the vehicle weight, its operator (one person) and the related oil palm harvesting tools. According to the study [6], brushless AC motors are frequently used for high-performance drives, such as industrial robots and machine tools, due to their benefits of high efficiency, high power density, high torque/inertia ratio, and less maintenance. For this project, a brushless AC motor has been chosen. The proposed electric motor is U-15II KV80 brushless motor from T-MOTOR.

2.3 Transmission Selection

The double differential steering system is hence the one that is most appropriate for this project. This is because of it being the most trustworthy omnidirectional steering system. In most cases, the steering shaft is directly connected to the engine rather than using the transmission output. The steering shaft is split into two output shafts that can revolve either forward, backward, or not at all using a clutch mechanism. Because one side of an idler reverses the direction, they perpetually spin in the opposite way, which enables the BEV to navigate around the oil palm farms' confined spaces and uneven terrain with ease.

2.4 Continuous Track System

Soft, soggy and uneven terrain, such that is discoverable in oil palm plantation, could resist greatly any land-based movement. To mobilise the BEV, a continuous track system is much more practical since it is capable to distribute the vehicle's weight over a vast surface area. Tyres is replaced with continuous tracks because they greatly expand the area of contact. The effect of force is reduced with increasing contact area. Consequently, a continuous track aids a vehicle in dispersing its weight over a vast surface area more equally than wheels can [7], eventually avoiding the BEV to become immobilised by poor ground conditions. Continuous tracks are typically utilised for power efficiency because they have higher performance and an improved traction system than wheels, which is advantageous for power delivery efficiency. Even on slick conditions like mud or loose dirt, traction is strong. Additionally, the continuous band of treads can climb and descend, overcome challenges like fallen branches, and traverse ditches.

3. Omnidirectional Mechanism Development

The purpose of this conceptual BEV is for manoeuvring through narrow and undulating terrains. Hence, the key component of this vehicle is the steering system which was designed with a double differential alongside continuous tracks instead of wheels. For designing the omnidirectional mechanism, SolidWorks 3D modelling software was used where key connections and positioning of main operating gears were created and modelled. The exploded view, front view, top view, side view and isometric view are shown in Figure 2, Figure 3, Figure 4, Figure 5 and Figure 6 respectively. ANSYS simulation were also carried out the designed mechanism and will be reported in the future.

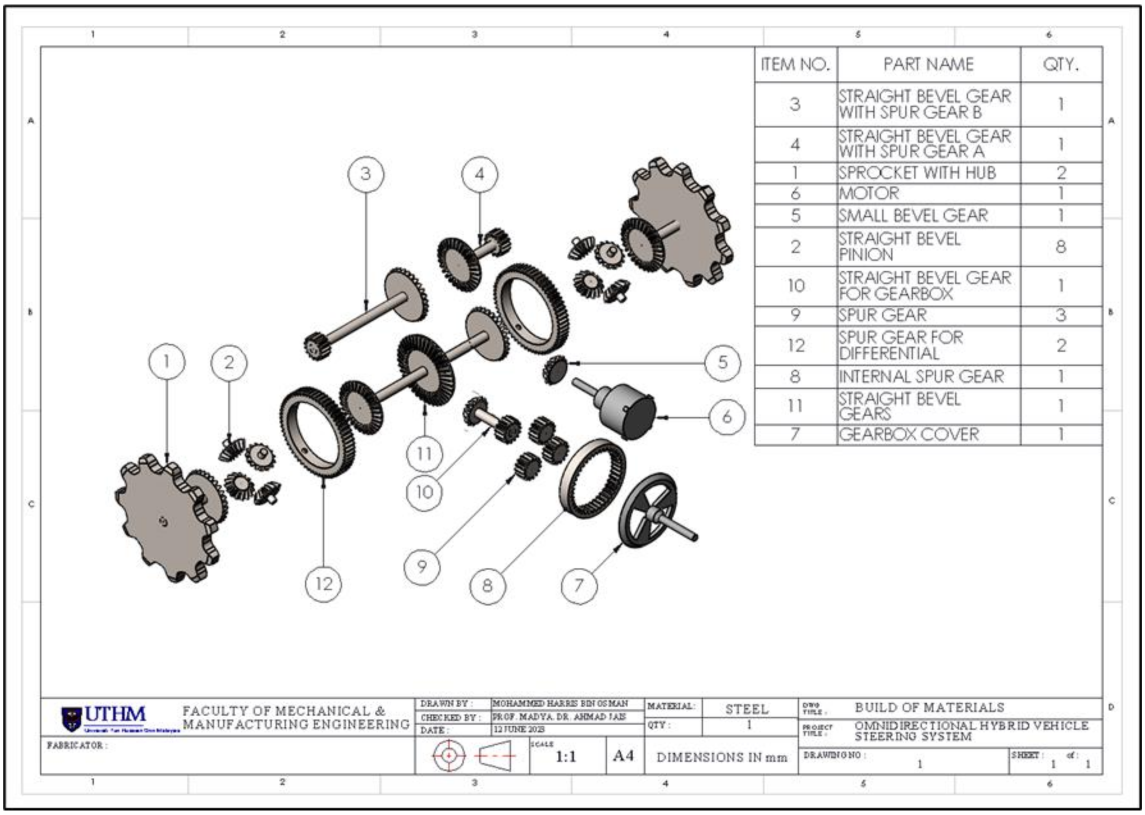

Fig. 2 - Steering system exploded view

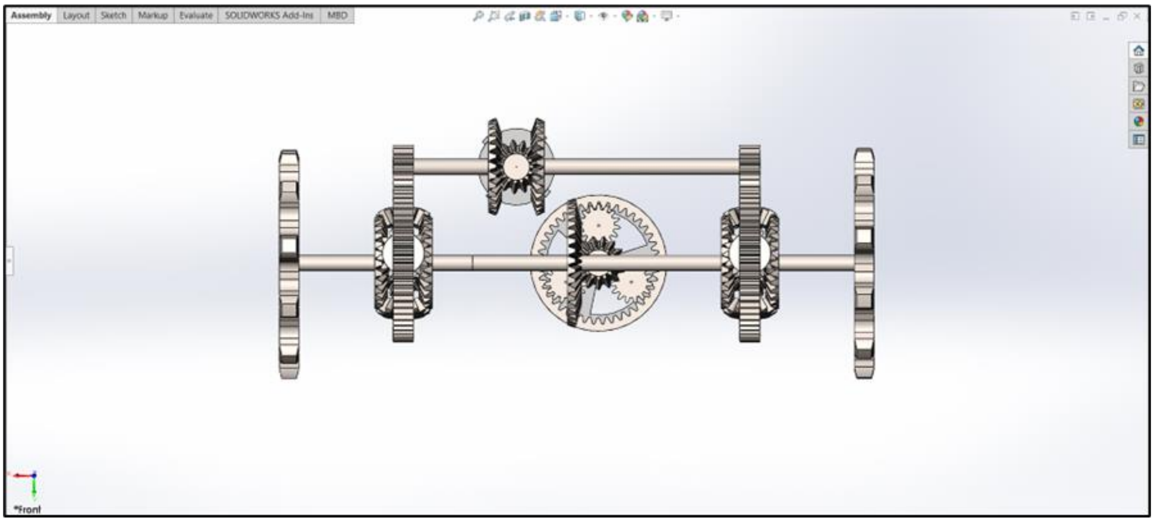

Fig. 3 - Steering system front view

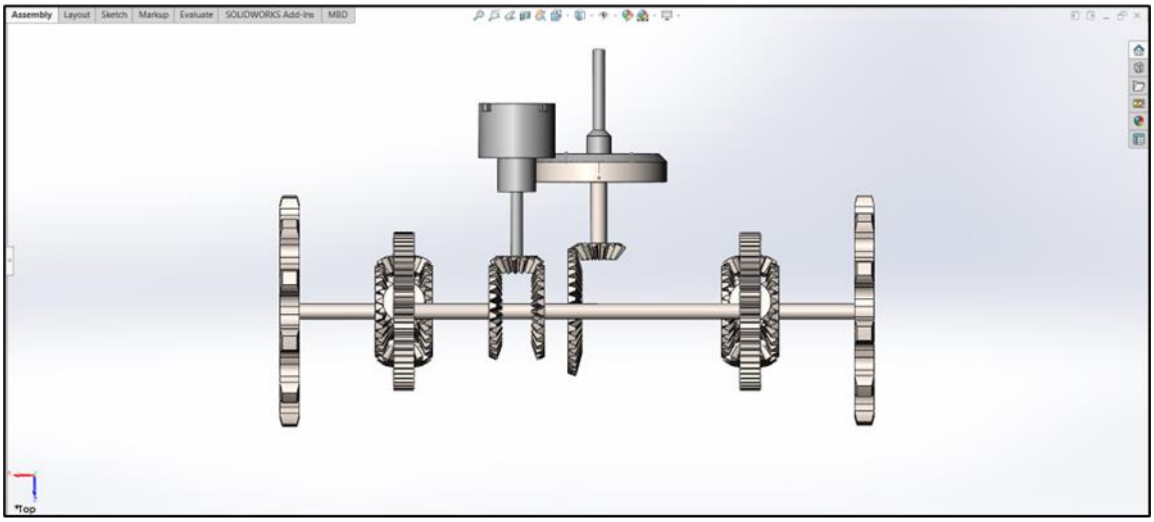

Fig. 4 - Steering system top view

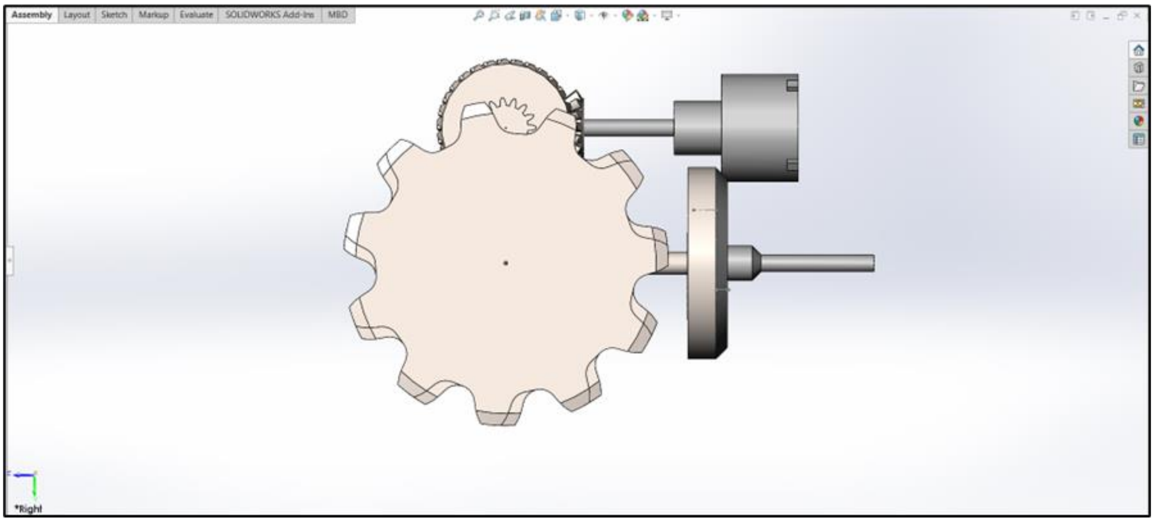

Fig. 5 - Steering system side view

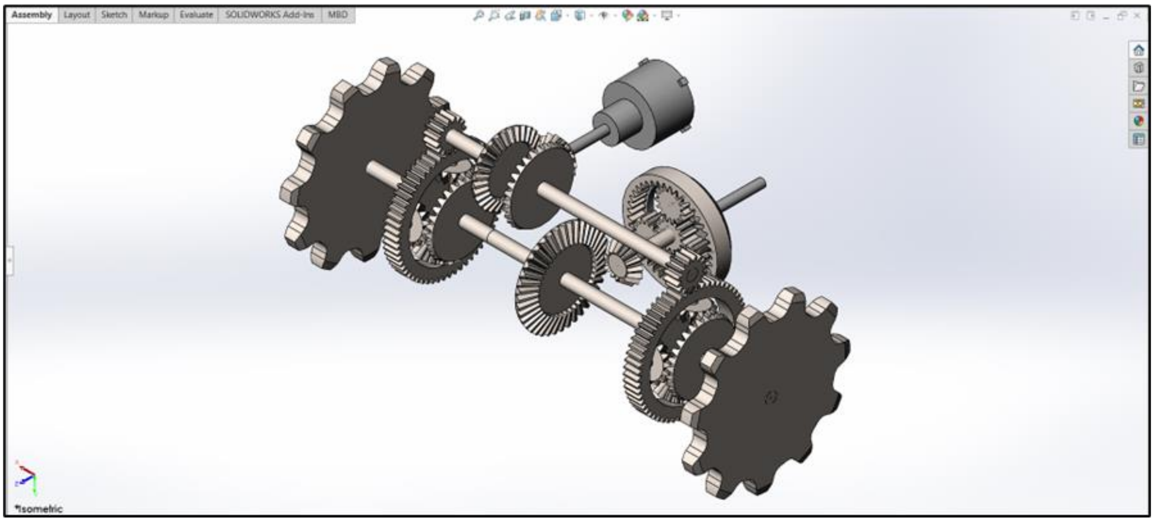

Fig. 6 - Steering system isometric view

As to achieve the omnidirectional capability, double differential steering system concept was selected and designed. The steering shaft is split into two output shafts that can revolve either forward, backward, or not at all using a clutch mechanism. This shaft is also receiving torque directly from the attached electric motor. For this idealised setting, the next crucial steps in the analysis will be focused on investigating the torque transfer from the electric motor to the driven gears. A neutral gear must also be included, which will allow the vehicle to remain stationary even when the electric motor is operating. Space limitation on board the vehicle will also affect the final optimum dimensions for the gearing systems, in addition to the allowable vehicle mass that can operate on oil palm plantation.

4. Conclusions and Recommendations

Throughout this study, the BEV concept for use in the oil palm plantation had been identified that would be suitable to meet the outlined operating requirements (travel and load needs). For the primary energy provider, Li-ion based battery pack had been chosen as the suitable power source with a suitable DC to AC converter to operate the brushless electric motor. In supporting the movement and manoeuvrability of the BEV an omnidirectional mechanism had been designed and presented in this paper. This mechanism includes double differential system connected to continuous track that would enable the BEV to rotate and navigate in any direction as well as navigating soggy, narrow and undulating terrains. The development of such an omnidirectional vehicle holds significant promise for the oil palm industry, as it offers a reliable means to transport goods and overcome the challenges posed by challenging landscapes. This study paves the way for future advancements in agricultural transportation, enhancing productivity and sustainability in the field of oil palm cultivation.

Based on the current omnidirectional agricultural vehicle steering system design, there are multiple areas that can be improved to deliver an exceptional user experience. Recommendations for future work are:

- Amending the existing design by implementing a neutral gear where the vehicle remains stationary when the power is supplied;
- Optimising the vehicle's dimensions focusing the vehicle's weight distribution;
- Simulating the equivalent elastic strain, Von-Misses stress and total deformation for the whole assembly using ANSYS Workbench simulation;
- Fabricating a dimensional-scale model to detect operational and design flaws; and
- Conducting total energy and road load analysis to ascertain the conceptual BEV will be having sufficient energy to cover the selected plantation plots.

Acknowledgement

The authors grateful acknowledged the supports given by Universiti Tun Hussein Onn Malaysia (UTHM) and APT TOUCH Sdn. Bhd. (www.apttouch.com) to conduct this research.

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