Development of a hybrid drive, energy sustainable wheelchair

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Abstract- This work presents a novel, energy-sustainable wheelchair with a hybrid drive system, addressing limitations of traditional models, such as quick battery depletion and high energy consumption. The hybrid wheelchair enhances mobility, promotes inclusivity, and improves user well-being. The wheelchair can be operated with the battery as well as manually. Furthermore, for energy sustainability, the battery charging is obtained with the main electric line, solar energy, and kinetic energy harvesting. By integrating a solar panel and solar charge controller, harnessing renewable energy, minimizing reliance on conventional power sources, and reducing environmental impact. The devised wheelchair can also harvest kinetic energy from hand motion with the manual mechanism. The wheelchair's performance under various load conditions was rigorously evaluated, providing key insights for further optimizations.

Index Terms- energy harvesting, hybrid wheelchair, kinetic energy, solar power, sustainability

I. INTRODUCTION

As we navigate the 21st century, a demographic shift towards an increasingly aging global population presents a unique set of challenges. Among these is the consequential rise in individuals afflicted with physical disabilities due to age, disease, or accident-related injuries, leading to impairments in motor function and balance, reduced mobility, and the pervasive challenge of maintaining a dignified and quality life [1]. To alleviate these issues, wheelchairs have evolved as indispensable mobility aids. However, despite their widespread utilization, traditional wheelchair models possess inherent limitations that restrict their efficiency and usability.

Manual wheelchairs, while offering potential health benefits, such as, promoting oxygen consumption and enhancing the respiratory exchange ratio, demand substantial physical exertion from the user. This often results in strain and fatigue and, in more severe cases, can lead to strain-induced injuries. These challenges arise predominantly due to the low mechanical efficiency of manual wheelchairs, often ranging from a mere 2% to 13.8%. This efficiency is contingent on several factors, factoring in the gravity of the user's injury, the movement strategy used, modifications to the wheelchair interface, and the rigor of the activity pursued.[2].

Electric-powered wheelchairs (EPWs) were introduced as an innovative response to these challenges, and over the past few decades, they have witnessed escalating popularity. By diminishing the manual exertion demanded of the user and lessening the likelihood of injuries from strain, EPWs mark a significant advancement in assistive mobility technology. Nevertheless, these EPWs also have their distinct drawbacks. EPWs often necessitate prolonged charging times, are typically larger and heavier, and present high costs. Their intricate mechanical and electrical components can be challenging to maintain, and their size and lack of disassembly or foldability make them inconvenient for storage and transportation [3]. These limitations often discourage potential users, preventing EPWs from gaining a market share commensurate with their potential benefits.

Emerging from these constraints, recent developments have heralded the advent of hybrid wheelchairs like push rim-activated power-assist wheelchairs (PAPAWs). PAPAWs, integrating human power and electric power, aim to strike a balance between user physical exertion and electrical assistance [4]. This innovative blend significantly reduces the risk of upper limb injuries while ensuring user energy conservation. However, even these models are not devoid of challenges, as their intricate design requires complex tuning tailored to each user, making them relatively difficult for individuals to interact with and adapt to [5].

Addressing these persisting energy and usability issues, researchers have begun investigating the potential of renewable energy, particularly solar power, as an alternative energy source for wheelchairs. Solar power-assisted wheelchairs offer a promising approach to overcome the frequent battery recharging and limited travel range issues inherent to battery-powered wheelchairs. However, existing solar-powered wheelchair models are often compromised by their rigid solar panel placement, inability to be disassembled, and loss of manual operation capability [6].

Set against this backdrop, this study introduces a novel, energy-sustainable wheelchair featuring a hybrid drive system that ingeniously combines the advantages of manual motion and electric power [7]. This wheelchair mitigates the key limitations of conventional models, such as rapid battery depletion and high energy consumption, significantly enhancing user mobility and promoting inclusivity.

The cornerstone of this innovative wheelchair lies in its energy sustainability, achieved by integrating a solar panel and solar charge controller. This harnesses renewable solar energy, reducing reliance on traditional power sources and diminishing the environmental impact. Further complementing this energy-efficient design, the wheelchair captures and converts kinetic energy from manual motion into electrical power, supplementing the solar energy system [8]. This design effectively bridges the gap between the health benefits derived from manual wheelchairs and the ease of use characteristic of electric-powered wheelchairs. Moreover, a comprehensive evaluation of the hybrid wheelchair's performance under various user's weight conditions is also performed, providing key insights for further enhancements. These findings pave the way for the iterative development of a new generation of sustainable, user-friendly, and efficient wheelchairs. By doing so, we hope to significantly improve the quality of life for those reliant on these vital assistive devices, contributing meaningfully to a more inclusive and accessible future [9].

II. PROTOTYPE ARCHITECTURE AND WORKING PRINCIPLE

The side-view and solid model of the developed hybrid drive energy sustainable wheelchair (HDESW) is shown in Fig. 1. and Fig. 2 respectfully.

The proposed energy-sustainable wheelchair integrates the practicality of a conventional manual wheelchair with the convenience of an electric wheelchair, thus resulting in a versatile hybrid model. Its design utilizes the structure of an existing commercially available manual wheelchair, ensuring ease of assembly and retraction while providing familiar comfort to the user. The electric drive system, comprising a primary battery pack and two electric motors (each for a drive wheel), augments the chair's capabilities, alleviating user effort during movement.The most groundbreaking feature of this hybrid wheelchair is the incorporation of a supplementary solar energy source.A strategically positioned solar panel acts as a roof, providing not only an environmentally friendly secondary power source to extend the wheelchair's travel range but also serving a protective role against weather elements such as sun and rain. This dual-purpose solution is the cornerstone of the wheelchair's architecture and working principle, enhancing user experience while increasing energy sustainability.

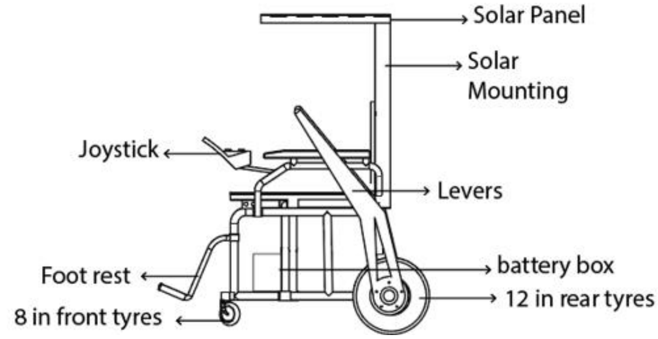

Fig. 1. Conceptual Line Diagram of HDESW

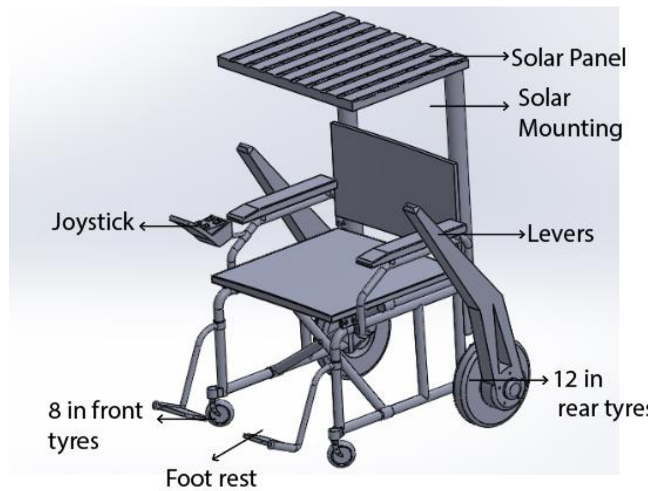

Fig. 2. Conceptual 3D model of HDESW

III. FABRICATION OF THE PROTOTYPE HDESW

The image of the developed prototype is depicted in Fig. 4. As previously stated, the wheelchair's base structure is derived from the chassis of a readily available manual wheelchair, with a weight of 17.4 kg. The supplementary components of the wheelchair, including the solar panel, battery set, and the Kinetic-based harvester, collectively weigh 21.6 kg. Therefore, the total weight of the wheelchair is approximately 39 kg. The solar panel mounting and support on the wheelchair are constructed using mild steel with a diameter of 23 mm.

We have chosen to use a prefabricated frame as the framework for the wheelchair design. Another crucial element of the wheelchair design is the choice of wheels. When selecting the right tires, we will carefully consider the needed requirements, such as size, traction, and durability.

The battery and solar panel are interconnected via a 12/24V PWM Solar Charge Controller. In the electric propulsion mode, the battery delivers power to the motor drivers and the Arduino Uno-R3 ATmega16U2. The Arduino then dispatches instructions to the BTS7960 43A motor driver, which rotates the two wheels' motors as per the direction and speed inputs provided by the user through a 4-axis Joystick Potentiometer.

A. Manual Drive Mode of Wheelchair

For the mechanical drive we use the chain drive system. The chain drive system is a dependable and effective way to transfer power from the wheelchair's operator to its wheels. We give the user a practical and simple control system for using the wheelchair by including a lever. The user's input is transfered to the wheelchair's wheels by a chain loop in the chain drive system. When the user pulls the lever, the chain drive is engaged, the wheels turn and wheelchair moves ahead. The user can change the speed and direction of movement in accordance with their well and need..

Overall, our mechanical drive's incorporation of the chain drive system and the lever mechanism marks a significant development for wheelchair technology. In order to empower wheelchair users and enhance their overall mobility, we offer a simple, effective, and user-friendly control mechanism. The photograph of manual drive can be seen in Fig. 3.

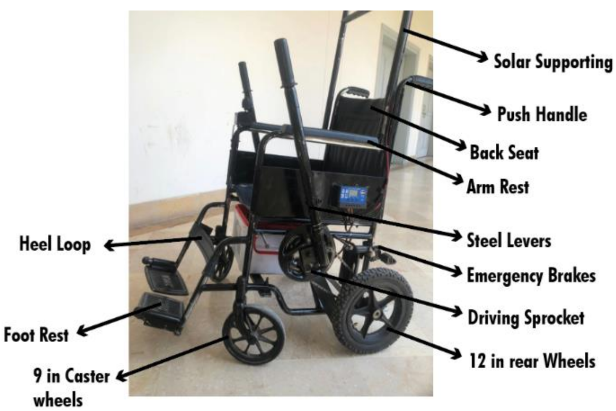

Fig. 3. Photograph of mechanical drive

B. Electric Drive Mode of Wheelchair

Typically, EPWs are designed to transport users at a speed not exceeding the stipulated speed limit (6-12 km/h), as mandated in most countries. Furthermore, they should be equipped to transport an individual weighing up to 90 kg, not just on level ground, but also on uphill ramps with an inclination of 7° (equivalent to a slope gradient of 1:8). In the devised HDESW, the electric propulsion is facilitated by two 59 mm DC worm gear motors, these motors are powered by BTS7960 43 A motor drivers. The selected gear motors have a rated speed and torque of 220 rpm and 24 N/m respectively.

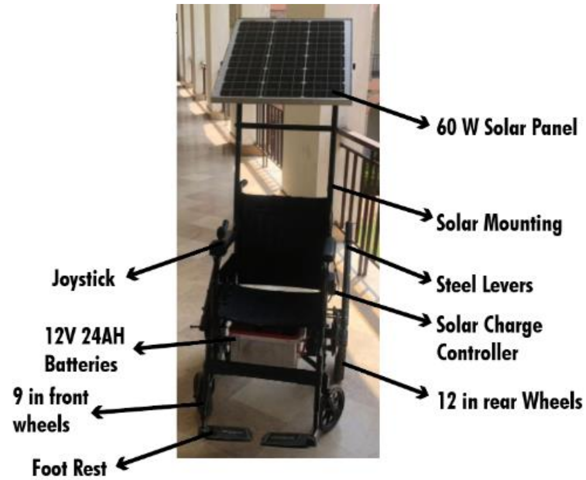

Fig. 4. Photograph of solar/lever drive wheelchair

1) Power Sources

The main power supply for the wheelchair was provided by two 12 V_{DC} (24Ah) multi power. We employed a series of rechargeable lead-acid batteries, arranged in a parallel configuration, to power a wheelchair. To augment the energy source, the wheelchair is integrated with a photovoltaic solar panel. During operation in its electric mode, the kinetic energy is jointly sourced from the lead-acid batteries and the solar module. Notably, the energy contribution from the solar module is contingent upon two primary factors: the prevailing solar irradiance and the residual voltage of the batteries. When in manual mode or exposed to sunlight, the solar energy system replenishes the battery pack for subsequent utilization.

2) Solar Panel

The primary power supply for the wheelchair is provided by a battery set that delivers a combined output potential of 12.6 VDC. Consequently, in determining the supplementary power source, a solar panel unit rated at 60 W is selected, with a standard voltage of 12.6 V. This solar panel is linked to a battery charge controller that regulates the output voltage to 12.6 V DC. The solar panel measures 540 × 620 mm.

As shown in Fig 4, the orientation of the solar panel is made adjustable through a support mechanism that comprises 24 mm stainless steel rods and a series of positioning holes also made from 24 mm stainless steel. These components allow the solar panel to be adjusted within a range of 0-330 degrees, based on various influencing factors.

3) Steering Joystick and Controller

Our electric wheelchair incorporates an efficient and straightforward navigation system by synergistically combining components, such as, a joystick, controller, microcontroller, motor drivers, and motors. This allows the user to navigate the wheelchair effortlessly in various directions. The microcontroller and motor drivers in the wheelchair facilitate meticulous motor control, rapidly converting user instructions into movements.

Physical connections were established between specific pins on the Arduino Uno and the H-bridge motor driver module using jumper wires. This connection is constructed based on the pinout diagram and specifications of the motor driver module. The detailed schematic is displayed as:

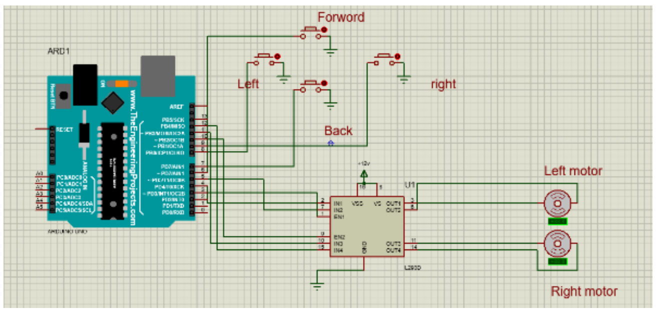

Fig. 5. Electric Drive Schematic in Proteus

The programming code incorporated the details of the pin connections, along with motor direction and speed control as well as other necessary functionalities to operate the wheelchair.

To integrate the joystick with the microcontroller, the joystick potentiometer's X and Y output pins are connected to the Arduino Uno's analog input pins. The Arduino Uno then processes this input data derived from the joystick potentiometer and generates the essential control signals for the H-Bridge Motor Driver Module. As a result, the wheelchair is able to move in the preferred direction and at the chosen speed. Fig. 6 Shows the connection of battery with BTS7960 Motor controller.

Fig. 6. Photograph of BTS7960 Motor Driver Connections with Battery

TABLE I.

DETAILED SPECIFICATION OF HYBRID DRIVE WHEELCHAIR

Metric	**Parameter**
Battery voltage	12 V
Battery ampere hours	24 A
Specifications for the Back Wheel (×2)	12 in.
Castor Wheel Specifications (×2)	8 in.
Solar panel	60 W
Solar charge controller	12 V
Motors torque	17 Nm
Motors Voltage	24 V
Motors rated current	12.5 A
Max Load Capability	80 Kg
Top Speed	0.8 m/s

4) Kinetic Based Harvester

In order to implement the energy harvesting technique [10-44] in the developed wheelchair, a 12 V electric generator is utilized as a kinetic based harvester. This delineates a novel approach in wheelchair design, aiming to harness the mechanical energy during the wheelchair's mobility. This process involves the integration of a 12 V dynamo, an electric generator, into the wheelchair's drivetrain and wheels. As the wheelchair moves forward, the rotating wheels spin the dynamo, thereby producing an electric current via electromagnetic induction. The dynamo, comprised of a magnet and a wire coil, exploits Faraday's law of electromagnetic induction to transform mechanical motion into a 12 V electrical energy output. This harvested kinetic energy is then captured and stored in batteries.

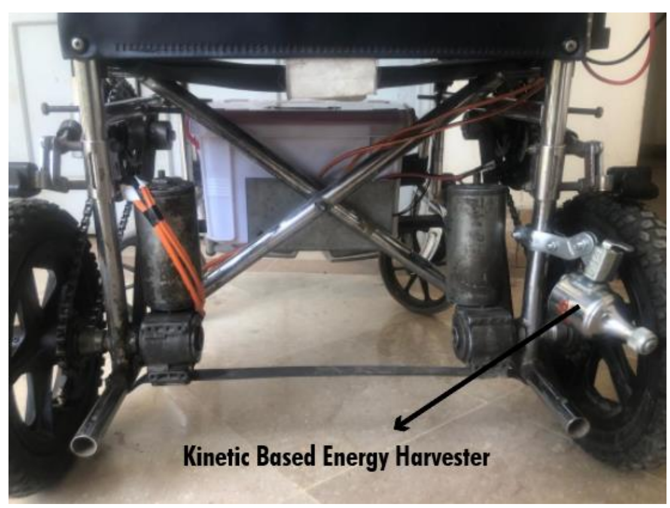

Fig. 7. Photograph of motion based kinetic harvester

IV. TESTING OF PROTOTYPE WHEELCHAIR

A. *Charging Behavior*

we examine the in-depth testing process for our prototype wheelchair to assess its usefulness, performance, and safety.

1) *Battery Charging Using Main Supply and Solar Energy*

Both solar energy and the main supply is used as charging sources. The graph in Fig 6 shows a consistent and steady increase in voltage over the course of 25 min when charging with the main source. On the other hand, the graph shows a similar pattern over a longer time frame of 55 min while charging using solar energy. The prolonged charging time is a result of the solar panels' reliance on sunshine to collect and convert energy.

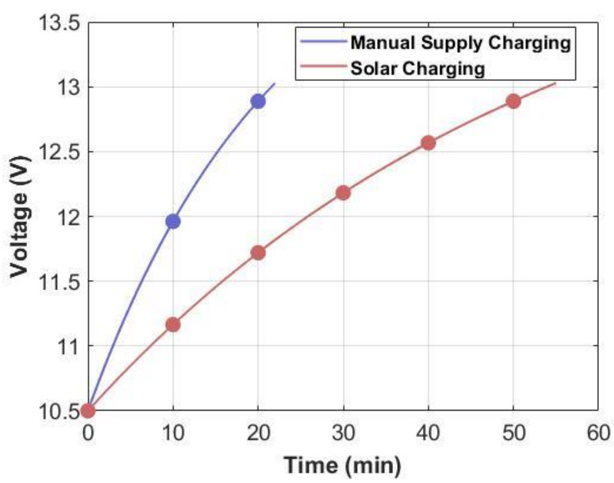

Fig. 8. Charging Behavior of Battery with Time (min)

2) *Battery Charging Using Kinetic Based Energy Harvesting*

3)

Utilizing a kinetic harvester for charging necessitates approximately 4.6 h is taken (Fig 7) to fully replenish the battery. The charging methodology involving a dynamo is notably more time-consuming when contrasted with alternative charging techniques. This extended duration is attributable to the dynamo's dependency on the conversion of mechanical energy into electrical energy, which is entirely contingent on the individual's capacity to manually operate the wheelchair.

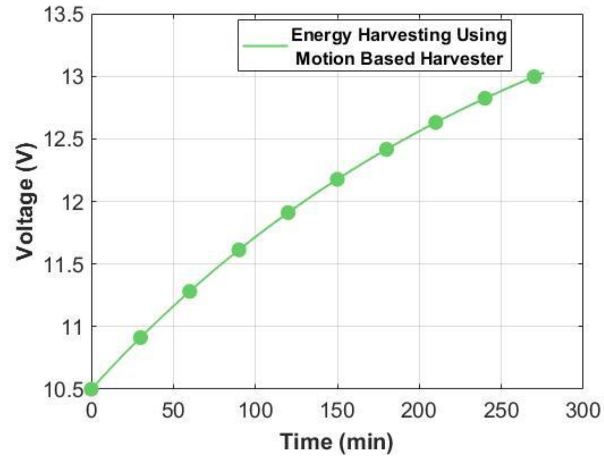

Fig. 9. Charging Behavior of Kinetic Based Harvester with Time (min)

B. *Discharging of Battery During Operation*

The correlation between weight and discharge duration of a battery is exemplified in the discharge curve shown in Fig. 8. Statistical data demonstrates that as weight increases, the discharge time correspondingly decreases.

For instance, a load of 45 kg results in an estimated battery life of approximately 59.7 min. This signifies that lighter weights necessitate extended periods to completely deplete the battery's energy reserves. On the other hand, with a load of 60 kg, the discharge time is reduced to around 37.6 min. This reduction in time indicates that a moderate weight causes the battery's energy to be consumed at a faster rate.

When the weight escalates to 81 kg, the discharge duration dramatically drops to roughly 20 min. This highlights that greater weights significantly expedite the discharge process, leading to a more rapid depletion of the battery's charge.

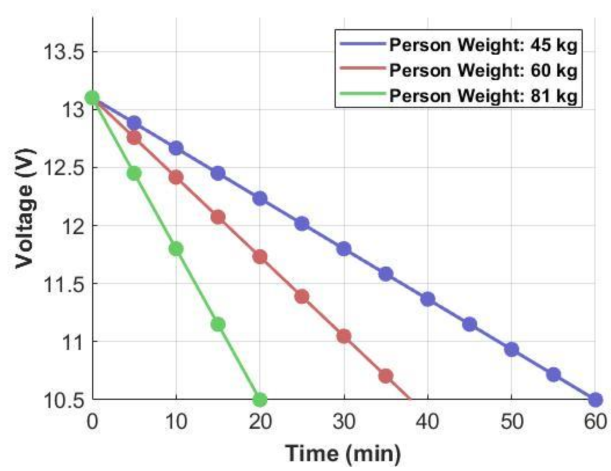

Fig. 10. Discharging Behavior of Battery with Time (min)

C. Load vs Speed in Electric and Manual Drive

The relationship between subject load and travel speed of wheelchair in both electric and manual drives is of significant interest in mobility aid design and is listed in Table II. In electric drive mode, the wheelchair exhibits a negative correlation between load and speed. As load increases from 45 kg to 81 kg, the speed drops from 0.88 m/s decreasing to 0.63 m/s. This reveals that as the weight the wheelchair has to carry rises, its movement speed correspondingly decreases due to the increased power demand and mechanical resistance.

A similar trend is evident in manual drive mode, albeit with a slower speed overall. Within the same weight bracket, the velocity drops from 0.55 m/s to 0.42 m/s. This slower speed, even with lighter loads, reflects the physical effort required from the user in manual mode.

These results underscore the importance of considering load variability in wheelchair design, particularly in scenarios where users may be carrying additional items or varying body weights, and the effect it can have on wheelchair speed and user effort.

TABLE II.

LOAD VS SPEED & CURRENT BEHAVIOR OF DEVELOPED WHEELCHAIR, EPWs and LDWs

Subject Load (kg)	Wheelchair Speed (m/s) (Electric)	Wheelchair Speed (m/s) (Manual)	Current(A)
81	0.63	0.42	15
63	0.74	0.48	11
45	0.88	0.55	8

EPWs = electric-powered wheelchair, LDWs = Lever Drive wheelchairs.

V. CONCLUSION

The study used was focused on designing and developing wheelchair prototype with both manual and electric drive systems, achieving energy sustainability through the utilization of solar energy and energy harvesting techniques. The integration of a solar panel, coupled with a solar charge controller, enabled the charging of batteries, thus providing a renewable and environmentally friendly power source. Additionally, the kinetic energy generated during manual wheelchair operation was harnessed using levers, further contributing to the charging of the batteries. Furthermore, the charging of the batteries was evaluated using different energy sources, including solar energy, the main power supply (WAPDA), and the harvested energy from manual wheelchair operation. To assess the overall performance of the wheelchair, measurements were taken of the electric and manual drive speeds under varying load conditions. These measurements provided valuable data on the wheelchair's operational capabilities, efficiency, and user experience.

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