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Enhancing Inclusive Mobility with Solar-Powered Assistive Technology: Design and Development of a Hybrid Smart Wheelchair with Multi-Modal Control

Rohit Sharma[1*], Anuj Srivastava [2], Avinesh Kumar[1]

[1] Department of Computer Science and Engineering, Dr Ambedkar Institute of Technology for Divyaangjan, U.P., India
[2]Department of Mathematics, Dr Ambedkar Institute of Technology for Divyaangjan, U.P., India

Email: rohit6615@rediffmail.com*, anuj_srivas1984@rediffmail.com, kumaravinesh1080@gmail.com

Abstract

People with disabilities also face many different types of physical issues. Examples include nerve or muscle degeneration, decreased motor function, and loss of balance and/or mobility. Modern powered wheelchairs are generally electrically powered and run on rechargeable batteries. An obstacle that individuals with electric wheelchairs may encounter is the continuous need to recharge their wheelchair batteries, the limited lifespan of wheelchair batteries, and reliance on electricity. In addition, there may be times when it is difficult for an individual to locate a place to recharge their wheelchair battery while traveling outdoors or to remote locations. Therefore, we set out to create a solar-powered wheelchair with joystick controls, head motion controls, and/or another type of control system used to direct the wheelchair's forward/backward (X) direction as well as its left/right (Y) direction. The backup power of solar energy is stored in a lead-acid battery. The solar wheelchair mainly consists of a solar panel, DC motor, Battery, Charge controller (MPPT), Throttle, and DC-DC converters to ensure that the collected energy is used efficiently and safely. This is a doubly powered device that operates on solar and electric energy. Overall, this solar-powered setup not only makes the wheelchair more reliable and convenient but also supports cleaner and more sustainable energy use, particularly in sunny outdoor settings.

Keyword

Solar-powered Wheelchair, Assistive Mobility Technology and Renewable Energy Integration

Introduction

Individuals with motor impairments face challenges in their daily lives and rely on others to move from one place to another. Thus, wheelchairs are essential devices for improving the mobility and quality of life of elderly and physically challenged individuals. Generally, existing wheelchairs can be categorized as manually or automatically operated wheelchairs. Manual

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wheelchairs are an affordable option, but as we know, normal wheelchairs require physical efforts to move, and the user will surely be tired after some time and have a limited range. Although there are advantages to using electric wheelchairs compared to manual ones, they have many drawbacks, including high cost, heavy weight for transport, and long periods of time required to recharge batteries. The reliance of electric-powered wheelchairs on reliable electrical charging systems is often difficult in locations where the power supply is unreliable. Our wheelchair includes two components: an input device (joystick, throttle, or head motion) and a microcontroller IC (Input/Command Processor). These devices allow the user's input commands (input source) to be processed into control signals for the motor driver to run the system. Additionally, we utilize solar panels and a charge controller to act as an auxiliary power source. These products not only recharge the battery but also protect it by controlling the amount of energy fed back to the battery so that it does not overcharge and exceed its rated capacity. Electromechanically, the wheelchair uses DC geared motors connected to a motor driver. The motor driver drives the motor, that is, FORWARD, BACKWARD, LEFT, and RIGHT, based on the input signals. The wheelchair frame was built from lightweight metallic steel sheets and was carefully welded to provide a strong structure that supported both the battery and control units. Additionally, a mount is included at the back and top of the seat to fit solar panels.

Background and Literature Review

Table 1: Literature Review Table

S.no.	Author(s) & Year	Title	Country/ Journal	Key Focus	Summary
1	Ahluwalia et al. (2017)	Designing and making a wheelchair that runs on solar power and has sensors	IJETT, India	Sensor fusion + solar	Integrated PIR, ultrasonic, accelerometer and solar panels
2	(Kim et al., 2024)	Creating a lightweight powered wheelchair via participatory action design	Actuators, South Korea	User-centered design	Lightweight participatory design for people with disabilities
3	Sattar et al. (20XX)	Voice-Controlled Autonomous Wheelchair That Is Smart and Cheap	Journal of Mobile Multimedia, Pakistan	AI + voice + solar	Voice recognition + solar charging + obstacle avoidance
4	PubMed authors (2015)	Making and designing a manual or electric wheelchair that can use solar power	PubMed, China	Hybrid solar/manual-electric	26% increased range; foldable & modular
5	Riaz & Aamir (2014)	Electrical Wheelchair with Retractable Solar Panels	ICESP Conf., Pakistan	Retractable solar panels	Convertible-panel design inspired by cars
6	Dixit et al. (2024)	Solar-Powered, Voice-Automated & Gesture-Controlled Wheelchair	Journal of Propulsion Technology, India	Multi-modal assistive control	Voice, gesture, RF comms + solar
7	Ogbonna et al. (2021)	Electric wheelchair driven by solar energy for people with disabilities	IJISRT, Nigeria	Energy-efficient solar assist	Prototype cost-effective solar design
8	Venkatesh et al. (2024)	Solar-Powered Tricycle for Enhanced Mobility	IJITCE, India	Solar tricycle for accessibility	Lightweight frame with adaptive seating

9	CN Patent (2020)	Intelligent Wheelchair of Solar Energy Power Supply	CN112587324A, China	Modular solar control panels	Foldable panels, communication controller
10	Leaman & La (2017)	A Comprehensive Review of Smart Wheelchairs	arXiv, Global	Smart wheelchair trends	Systematic international review

Wheelchairs are essential pieces of equipment for individuals with disabilities that make it difficult for them to move around. Individuals suffering from mobility impairment experience difficulties on a daily basis. However, these same individuals often find it difficult to move from one area to another. They also face challenges in operating wheelchairs, especially quadriplegic patients (Cleveland Clinic, n.d.). Modern smart wheelchairs incorporate various control mechanisms that allow for intuitive and effective operation. These include methods such as Eye Movement or Electrooculogram signals, which detect the direction of the user's gaze for control purposes (Amer et al., 2021). Voice recognition systems that recognize voice commands (Hou 2020). Tongue-based control systems that sense tongue movements using sensors (Lund et al., 2010). Systems utilizing joysticks for navigation of devices by users themselves (Saharia et al., 2017) and head-controlled systems (Machangpa & Chingtham, 2018) are examples of how movement can be translated into a system that will navigate through space based upon tilt or head orientation. These technologies have been developed to provide user-centered, effective, and adaptable solutions to help individuals with mobility issues achieve efficiency and independence. Many modern wheelchairs operate on an AC-powered electrical outlet to charge their batteries. While many parts of the world continue to evolve toward being reliant upon renewable forms of energy, some rural areas still experience electrical shortages. Therefore, it may be necessary to integrate solar panels into the wheelchair design to serve as a supplementary form of generating power source. The integration of these solar panels will eliminate the need to recharge traditional battery-powered wheelchairs by harnessing renewable energy from the sun, thus increasing the amount of time each day the wheelchair can be used without having to perform plug-in charging frequently, which is especially useful in both outdoor and remote environments. This sustainable energy addition not only supports eco-friendly operation but also ensures higher reliability for users throughout the day. This literature review focuses on studies that have investigated the Design and Development of Solar-Powered, manual, and head-gesture-controlled wheelchairs.

(Metkari et al., 2024) designed a wheelchair for orthopedic persons that uses solar power for operation. The wheelchair is controlled using voice commands, which can be complicated in a noisy environment. The system is programmed to support English and four other local Indian languages. The design also focuses on extending the operating range of wheelchairs. Aswathy et al. (2017) presented a solar-powered smart electric wheelchair that included a health monitoring system. This design integrates sensors to track the user's vital signs, thereby improving mobility and health. The system aims to offer a sustainable solution for individuals with physical challenges, particularly in areas with abundant sunlight. Oyekola et al. (2020) developed a wheelchair for those living with lower body disability. The system utilizes a joystick to determine the direction of travel of the wheelchair, as well as a 12 V battery and 80 W solar panel to provide the necessary power to operate the wheelchair. People with lower body disabilities may have difficulty operating a wheelchair. Those who suffer from quadriplegia may also find it difficult to control a wheelchair.

Methodology

Design of the solar electric wheelchair

The design of the wheelchair was largely influenced by three factors: load-bearing capability, amount of torque produced when in motion, and total dimensions of the wheelchair. The designed wheelchair can carry an average person with their own body weight included at approximately 160-170 kg. Therefore, it will be limited in terms of how fast the wheelchair can move. Several unconventional changes were made to enhance the overall function of the wheelchair.

Main Frame

The frame is the body structure of a wheelchair. The frame for this project was created using hollow cast iron rods with a diameter of 35 mm. This basic skeletal system carries all of an individual's weight plus additional items on the wheelchair (such as batteries, motors, and solar panels) to operate. The wheelchair measured 190 cm tall and 60 cm wide and had ample room under it for the user at 48 × 48 cm. The major prototype of the solar-assisted electric wheelchair is depicted in Figure 1. The frame is shown in Figure 1.

Figure 1. Frame of solar wheelchair

Motor

A motor is an electrical device that transforms electrical power into mechanical power. We used two PMDC-type motors to drive an electric wheelchair. These motors feature a gearbox with a 1:3 ratio, which decreases the output speed to one-third of the input speed, thereby increasing the torque. The motors were fitted with an electronic brake system that was automatically activated when the motors were not moving.

Motor Controller

For our helmet-controlled wheelchair project, we created a custom motor driver tailored to the specific needs and operational characteristics of the system’s motors. We carefully analyzed the voltage requirements, current draw, and load-bearing capabilities of the motors to ensure that the driver delivered the peak performance. A customized motor drive is an important part of developing wheelchairs, as it enables accurate operation and effective function. As the drive was created to be complementary to our motor, and based on the specifications of that motor, it provided a fluid motion for the user. A custom-designed drive was developed to meet the specific needs of our wheelchair designs, fulfill their unique operational characteristics, and ultimately increase their functional effectiveness.

Wheels

The Solar-Powered Smart Wheelchair employs 12-inch Polyurethane (PU) wheels because they are durable, have high load capacities, low friction loss, and good absorption of shock loads. They allow the wheelchair to operate smoothly over different surfaces, and will reduce maintenance. A 12-inch wheel diameter was selected based upon minimizing the torque that the drive motor needs to produce. The amount of torque needed to move a wheelchair is directly related to the radius of its wheels; therefore, using smaller wheels requires less torque to develop the same level of thrust. Using smaller wheels also results in lower mechanical loading on the DC motor which provides both lower power usage and higher energy efficiency. Smaller wheels are especially useful in the case of a solar assisted wheelchair as it is critical to be able to efficiently utilize the stored batteries along with the collected solar energy. Additionally, a smaller wheel allows greater maneuverability and control when operating within confined areas while still providing adequate grip and ride stability. In summary, employing 12 inch PU wheels greatly improves the reliability, comfort, efficiency, and performance capabilities of the wheelchair.

Power Supply

The Battery System in the Smart Wheelchair Design provides primary energy storage, which supplies all the electrical energy for motor use and additional auxiliary electronic components. Two 12V lead-acid batteries were used because of their reliability, cost-effectiveness, and ability to supply high surge currents necessary to accelerate the wheelchair and handle variable loads. When there is no sun available or sufficient sunlight available from the solar panel, the stored energy can be supplied continuously to the wheelchair. The selection of the lead-acid battery was based on its well-known performance characteristics (robust), low maintenance requirements, and widespread availability. The double-battery system resulted in a greater total energy capacity, resulting in longer operating times and better reliability than would have been possible with a single battery. Additionally, they serve as a backup power source, allowing the wheelchair to operate without interruption during periods of reduced sunlight (e.g., during cloud cover) and at night. Together with the solar charging system, they also allow for effective energy management, extended autonomous operation, and expanded user independence, thus enabling users to take advantage of this device indoors and outdoors.

Control mechanism

Joystick Controlled Mechanism

A joystick-controlled wheelchair is important for physically challenged people, especially paraplegic patients. Paraplegia is an impairment of motor or sensory function in the lower extremities. They cannot move anywhere like a healthy person can. Therefore, they always depend on other people for assistance. However, a joystick-controlled wheelchair can remove this problem and help them move anywhere. Because paraplegics have control over their arms and fingers, a joystick is the best device for controlling the movements of a wheelchair. . A single joystick controls both the speed and direction of motion of the dc-motor. The motor is stationary (i.e., resting) when the joystick is centered. As the joystick moves forward or backward, the motor turns. In addition, if the joystick is moved farther from the center position, either toward the front or rear of the joystick, the motor turns faster.

The joystick sends a command to an Arduino Board that processes the commands. Once processed by the Arduino board, it sends a digital signal to a Motor Driver, which then controls the operation of the wheelchair. The flow chart of the joystick-controlled system is shown in figure 2.

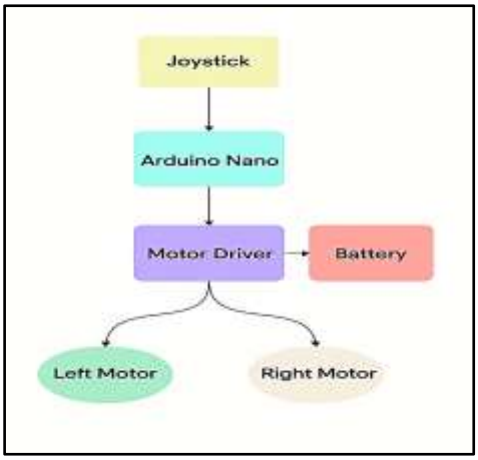

Figure 2. Block diagram of Joystick control

Head gesture control mechanism

The head gesture control mechanism is designed for the people with disabilities who can not have control over their legs as well as their legs. This type of disability is known as quadriplegia. The proposed wheelchair system uses head gestures to control wheelchair movement. The system has two main parts, one is Inclination detection module which is mount on the helmet/headband, another one is signal processing unit, this part of the system is mount on the wheelchair which is further connected with the motor driver. The Inclination Detection Unit has an Accelerometer Sensor that detects Head Tilt in four different directions (front, back, left, and right). Real-time processing of the sensor output was performed using an Arduino Nano, which determined the direction of the head tilt. Based on the detected head-tilt direction, a wireless command was transmitted via a Bluetooth Module, from an Arduino Microcontroller at the Sender's Device, to the Receiver. The Receiver Unit contained two separate modules; one being a Bluetooth Receiver Module that received Movement Commands from the Sender's device, and another being an additional Arduino Nano microcontroller that processed the received commands, and then sent the proper Signal(s), to either Turn On/Off the Motor Driver, or Change Speed as required. The motor driver drives the motor, that is, FORWARD, BACKWARD, LEFT, and RIGHT, based on the user's head movements. It stops when the person does not tilt their head in any direction. The function of this mechanism is illustrated in Figure 3.

Used components-
Arduino nano Accelerometer & Gyroscope Bluetooth module Battery Motor driver

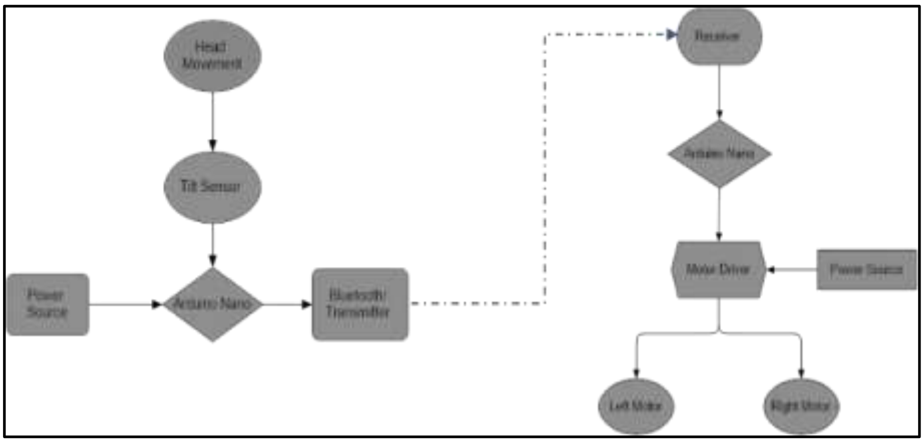

Figure 3. Working diagram of head gesture control mechanism

Solar integration

The drive-train of the solar-powered wheelchair receives energy from the primary source, which is the solar-charged battery. A Solar Panel (Photovoltaic Panel) mounted at an angle onto a Foldable Frame was positioned directly above the seat of the bicycle. Photovoltaic Cells convert solar Energy into Electricity. As long as sunlight hits the Solar Panel, it generates Direct Current (DC). The generated DC Power is then sent to a Battery for Storage. A Charge Controller Regulates the Flow of Electricity from the Solar Panel to the Battery. It Stabilizes the Unpredictable Fluctuations in the Current and Maintains a Consistent Source of Electrical Power to the Battery.

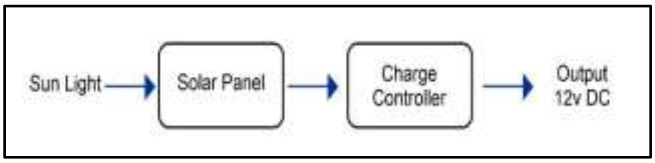

Figure 4. Block Diagram

Solar Panel
Photovoltaic (PV) cells on a solar panel capture sunlight and use it to create an electrical current by exciting the electrons inside the cells. When these electrons move freely, they create a direct current (DC). This DC current can then be fed directly into the electrical system of a home or stored in rechargeable battery systems for later use.

Charge Controller
This study provides a basic calculation for selecting a suitable solar panel to charge the wheelchair batteries by calculating the daily power consumption and assists in designing a custom wheelchair system by calculating the motor power requirement and suitable battery pack to power the wheelchair. The expected weight of the wheelchair was assumed to be approximately 70 kg, and the user's weight was assumed to range from 80 to 100 kg. Therefore, the total weight of the wheelchair was considered to be 170 kg (including the weight of the user).

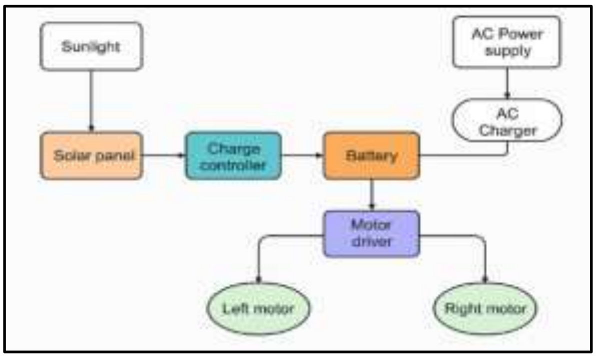

Figure 5. Charging flow chart

Calculation

This study provides a basic calculation for selecting a suitable solar panel to charge the wheelchair batteries by calculating the daily power consumption and assists in designing a custom wheelchair system by calculating the motor power requirement and suitable battery pack to power the wheelchair.
The expected weight of the wheelchair was assumed to be approximately 70 kg, and the user's weight was assumed to range from 80 to 100 kg. Therefore, the total weight of the wheelchair was considered to be 170 kg (including the weight of the user).

1)Power of the Electric Motor

It is important to calculate the power requirement of an electric motor that should be used to drive the wheelchair (10).

Power (watts) = Total weight × g × speed × gradient

Where,

Total weight = 170 kg
Gravitational force = 9.81 m/s
Speed = 6 kmph = 6 × 1000/3600 m/s = 1.66 m/s
Gradient = slope (assume 3%)
Power = 170 × 9.81 × 1.66 ×0.03 = 83.05watt
Therefore, the power required is approximately 85 watt (for a single motor).
As we are using two motors, the power required is approximately 170 W.
Thus, a 24 Volt, 170 W motor is sufficient for the wheelchair.

2)Battery Pack

The System voltage 24 Volt and load is 170watt
Then,
Load current = 170w/24v= 7.08 amps
It is estimated that the wheelchair shall be run for 6 hours continuously per day
Load current = 6 ×7.08 ×1.2 = 50.97 Ah/day ≈55 Ah/day
Assume 20% overall losses,
Size of battery = 55 ×1.2 = 66 Ah/day
Energy required for the motor
= 55 ×24 =1320 Wh/day.
Therefore, 55 Ah/day and 24 Volt power are required for the system.

3) Solar Panel

It is important to calculate the minimum power requirement of solar panel (in wattage) to charge the battery pack-

Assuming that we obtain approximately 5 peak sun hours/day (typical in sunny locations).

Required Panel Wattage = Required Energy / Peak sun hours

Solar panel (wattage) = 1320 / 5 = 264watt ≈ 270watt

We need at least a 270watt solar panel to fully charge a 24V, 55Ah battery pack in one day (with 5 h of good sunlight).

Conclusion

The Solar Wheelchair Prototype has several advantages for consumers, as well as external and internal operation. This wheelchair was designed to accommodate individuals that are quadriplegic or paraplegic. Paraplegics will use a joystick to control the wheelchair while quadriplegics will have the ability to use their heads (tilt) by an accelerometer. In order to address the issue of limited access to electricity in remote/rural areas, we implemented solar panels on the wheelchair to provide power. Designing the Solar Wheelchair provides a benefit to those with disabilities and will make a significant difference in their lives. Low cost components were used during prototyping to create a working model using the concept of circular economics.

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