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Training on the manufacturing of a BLDC motor-based hybrid wheelchair with an adaptive assistance system to support the independent mobility of students at SLBD YPAC

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ABSTRACT

Paraplegic and diplegic students at the YPAC Bandung Special Needs School (SLBD) face physical fatigue when navigating uphill paths in manual wheelchairs. Conversely, using fully electric wheelchairs can lead to neuromuscular degradation. To address this, a community service project provided practical training in constructing a hybrid wheelchair equipped with a Brushless Direct Current (BLDC) motor and an adaptive assistance system. Designed in accordance with WHO standards, the system automatically activates additional BLDC motor torque on inclines of 3° or greater, while preserving active manual propulsion on flat surfaces. Through Community-Based Participatory Research (CBPR) and Service Learning methodologies, school staff participated in co-design, assembly workshops, and field testing. Results showed a significant increase in staff technical competency from 23.3% to 82.6%. The resulting prototype reduced manual propulsion effort on inclines by 20%–35%, safeguarding users' neuromuscular health and effectively improving safe, independent mobility for students.

Keywords *: The hybrid wheelchair, adaptive assistance, community-based participatory research, capacity-building, special education*

1. INTRODUCTION

For students with physical disabilities, achieving independent mobility is fundamental to their personal development, learning process, and social integration. Freedom of movement empowers students to actively participate in academic sessions, therapy routines, and peer interactions within the school environment with increased self-confidence. For students with paraplegia and diplegia, wheelchairs serve as the primary mobility aid. Beyond acting as a transport medium, wheelchairs directly influence user safety, postural balance, and psychological independence. According to the mobility guidelines of the World Health Organization (WHO), personal mobility devices must be specifically adapted to both the user's physical capabilities and the structural characteristics of their surrounding environment **(Abdan, Siti, & Rahayu Yuliana, 2021; World Health Organization, 2023).**

In recent years, the paradigm of wheelchair development has shifted from basic mechanical durability toward adaptive assistance systems that dynamically adjust to varying terrain conditions **(Cowan et al., 2012; Sudrajat, Setiadi, Tohir, Habinuddin, & Supriyanto, 2023; Supriyadi, Setiadi, & Prasetyo, 2023).** At SLBD YPAC Bandung, located on Mustang 46 Street, Sukawarna, Sukajadi, Bandung City (as shown in Figure 1a), 68 students with physical disabilities were registered as active learners. Approximately 40 of these students rely on manual wheelchairs as their primary aid for independent mobility or require assistance from school staff. Field observations revealed that the internal school layout features several connecting ramps and pathways with inclines (uphill) ranging between 3° and 7°, particularly on access routes leading to classrooms and physical therapy facilities.

In terms of curriculum, students from grades 1 to 12 receive theoretical and practical training in Orientation and Mobility (OM) under the national special education curriculum (DIKNAS). However, practical experience demonstrates significant physical constraints when students navigate pathways with slopes of ≥3°. Operating a manual wheelchair under these inclined conditions requires an additional 20% to 35% pushing force, depending on user weight and tire characteristics (Figure 1b). Sustained manual pushing against gravity induces severe upper-limb fatigue and elevates the long-term risk of rotator cuff and shoulder joint injuries **(Bertocci, Frost, & Smalley, 2016; Kim, Lee, Kwon, & Chung, 2014).**

Although the school previously received an anti-crash electric wheelchair through a 2023 community service grant from Politeknik Negeri Bandung, exclusive and prolonged reliance on fully automated electric propulsion introduces secondary health concerns. Continuous use of passive electric transport reduces user neuromuscular engagement by 15% to 25%, gradually degrading muscle tone and active motor habits **(Mercuri et al., 2018).** This passive reliance directly undermines the objectives of OM rehabilitation training, which seeks to preserve and enhance active physical capabilities.

(a) (b)

Figure 1. (a) Partner Location at SLBD YPAC Bandung (b) Manual Wheelchair Activity on School Pathway

To bridge these contrasting challenges, a hybrid wheelchair design presents an ideal solution. A hybrid system combines traditional manual pushrim drive with intelligent electric assistance that activates only when required by terrain conditions, enabling users to maintain active muscle engagement without suffering excessive physical strain **(Wieczorek, Warguła, & Kukla, 2023; Wieczorek, Warguła, & Rybarczyk, 2020).** BLDC hub motors were selected for the propulsion drive due to their high power efficiency, rapid torque response, low maintenance demands, and minimal freewheeling rotational resistance when turned off **(Ahmadi, Anam, & Widjonarko, 2020).**

Beyond the technical requirements, the partner school faced limitations in technical knowledge regarding the maintenance and development of such adaptive systems. Consequently, this community service project provided structured capacity-building training on the manufacturing, maintenance, and operation of a BLDC motor-based hybrid wheelchair with an adaptive control system. By transitioning away from a passive donation model, this program transformed school teachers and vocational staff into active co-creators and self-reliant caretakers of their assistive infrastructure, ensuring long-term institutional sustainability at SLBD YPAC Bandung.

2. METHOD

This program formally implemented an integrated Community-Based Participatory Research (CBPR) and Service-Learning framework. This dual approach ensured that school partners were systematically involved across all development stages, optimizing local technical capacity building.

The methodology was executed in five collaborative phases: (1) Participatory Needs Assessment, (2) Collaborative System Co-Design, (3) Service-Learning Training Workshop, (4) Joint Field Implementation, and (5) Sustainable Evaluation.

2.1 Identification

The initial stage involved field observations, measuring school environmental conditions, and structured discussions with the principal and OM teachers. This activity aimed to obtain a comprehensive overview of:

1. Number of wheelchair-using students
2. Characteristics of the school path
3. Type and condition of wheelchairs used
4. Technical challenges when navigating uphill paths

The identification results indicated that the majority of students with disabilities, including paraplegia and diplegia, use wheelchairs as their primary means of mobility. Some access points to classrooms have slopes between 3° and 7°. At a minimum slope of 3°, users with a total mass of approximately 45kg - 60kg require additional propulsion to counteract gravity, potentially causing fatigue if used repeatedly.

Findings related to the use of manual wheelchairs on uphill paths can cause fatigue. These findings were used as a baseline in designing an adaptive assistance system that only activates when needed.

2.2 System Design and Prototype

The design phase was conducted collaboratively between the implementation team and partners. The approach adopted adhered to the principles of mobility assistance, safety, and ease of maintenance within the school environment.

2.2.1 Mechanical Design

The basic mechanics of the main system frame and wheels were based on finished products, as shown in Figure 2. Both left and right wheel sections were modified by replacing the standard wheel hubs with 6.5 inch BLDC motors. The drilling and integration of the BLDC motors for the spoke mounts, matched to the original rim, was carried out manually. The BLDC motors were then integrated into the chair frame. The process details are shown in Figure 3.

Figure 2. Mechanical Frame

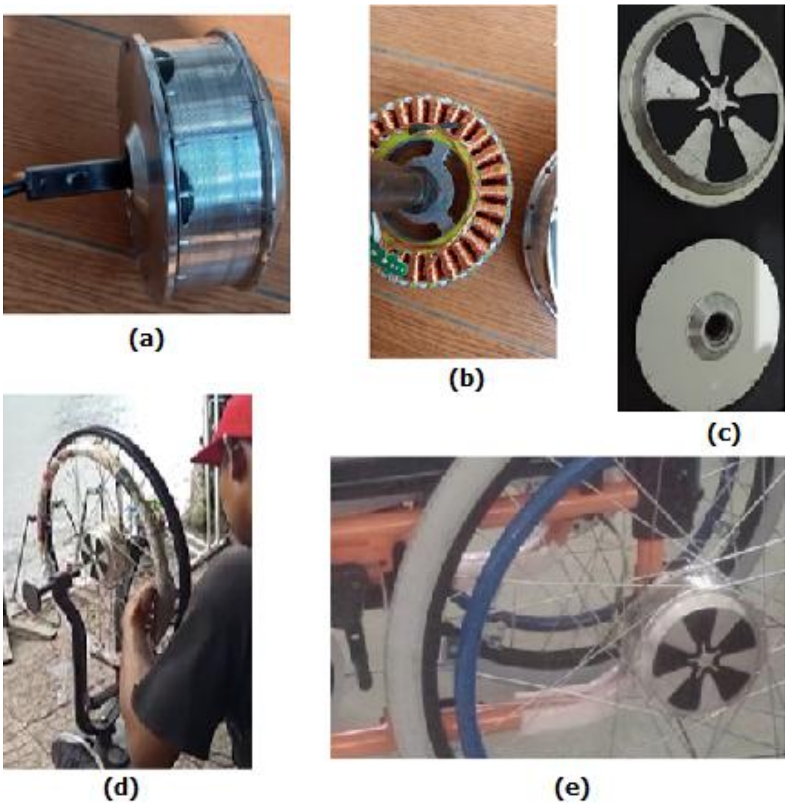

Figure 3. (a) BLDC Motor (b) Casing Separation (c) Marking the Spoke Holes (d) Integration of the Rim-Spoke-BLDC (e) Integration of the Wheel into the Frame

The reason for using a BLDC motor instead of a standard wheel hub is due to their similar characteristics when free. The wheelchair can still be used manually when the electrical system is off, and the design is designed to not increase rolling resistance in manual mode.

2.2.2 Electrical Design

The electrical design of the BLDC-based hybrid wheelchair system used in this community service activity was designed to ensure stable power availability, consistent control performance, and an automatic assistance mechanism based on the slope of the track. The system uses an Arduino Nano as the control center, two BLDC motors to drive the left and right wheels, and supporting devices, including a motor driver, a DC-DC converter, a 36 VDC battery, a main switch, and an accelerometer sensor. The hardware and control configuration is shown in Figure 4. Structurally, the electrical circuit is divided into three parts: a 36 VDC supply line for the motors, a 5 VDC line for the logic circuit and sensors, and a signal line as the control communication medium between the microcontroller, sensors, and drivers. Table 1 explains the use of input and output (I/O) on the Arduino Nano microcontroller.

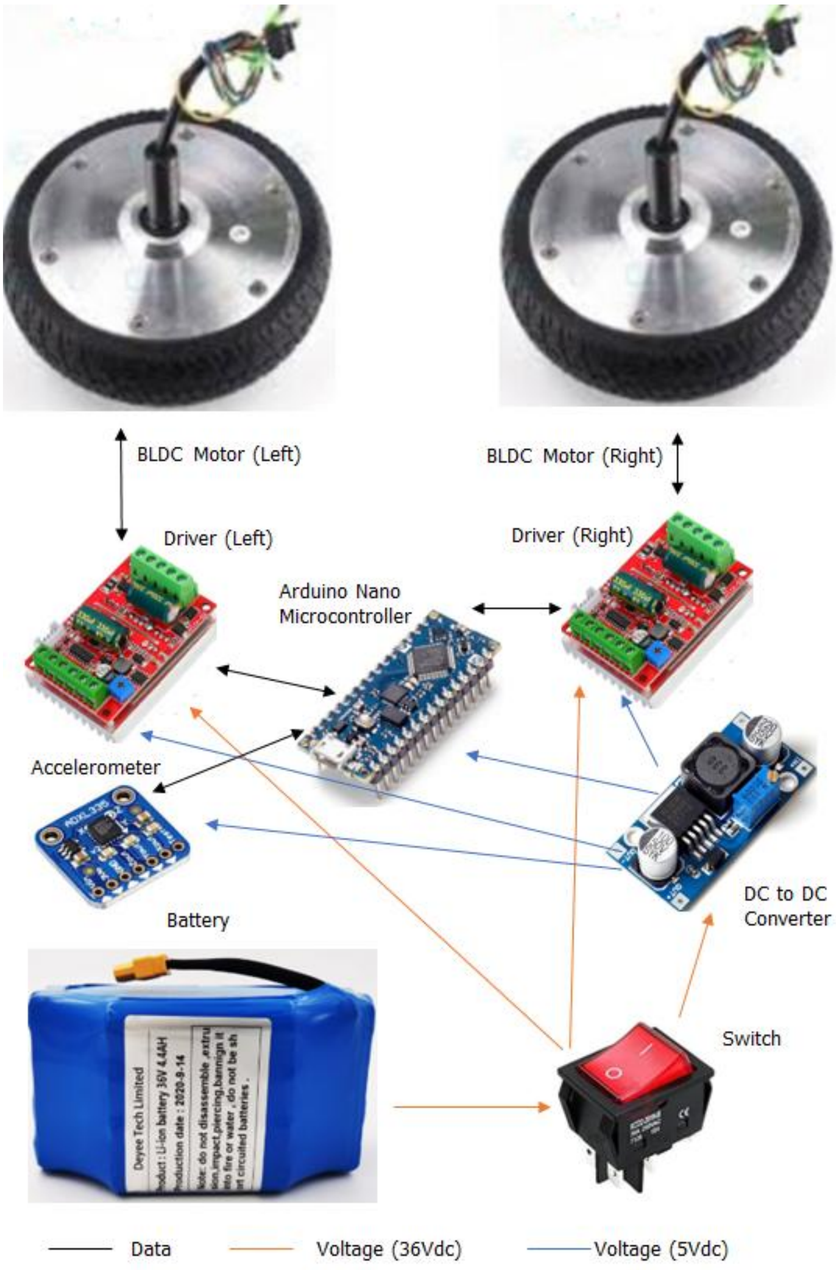

Figure 4. Hardware and Control System Diagram

The 36 VDC battery serves as the primary energy source, which first passes through the switch before being distributed to the motor driver and voltage reduction module. The 36 VDC voltage is used directly for the BLDC drive, while a buck-type DC–DC converter steps the voltage down to 5 VDC to power the Arduino Nano, accelerometer sensor, and logic components in the driver. This converter was chosen based on conversion efficiency and reduced power losses during operation.

Table 1. Input and Output on the Arduino Nano Microcontroller

No	Arduino Nano Pins	Connections to Components	Information
1	5V	5 V Output, DC to DC Converter	Powers the Arduino
2	GND	DC to DC Ground, Motor Driver, Sensor	System Voltage Reference
3	D5 (PWM)	Left BLDC Motor Driver (Speed)	Left Motor Speed Control
4	D4	Left BLDC Motor Driver (Direction)	Left Motor Rotation Direction Control
5	D2 (Interrupt)	Left Motor Hall Sensor	Left Wheel Speed Reading
6	D6 (PWM)	Right BLDC Motor Driver (Speed)	Right Motor Speed Control
7	D7	Right BLDC Motor Driver (Direction)	Right Motor Rotation Direction Control
8	D3 (Interrupt)	Right Motor Hall Sensor	Right Wheel Speed Reading
9	A4 (SDA)	Accelerometer Sensor (SDA)	Tilt Data Communication
10	A5 (SCL)	Accelerometer Sensor (SCL)	Communication Synchronization

The adaptive control process is executed by the Arduino Nano, which generates a PWM signal to regulate the speed and direction of the motor rotation. This signal is forwarded to each driver, allowing the left and right wheels to be controlled separately. Feedback from the Hall effect sensor in the motor is used to maintain the synchronisation of the rotation of the two wheels. This configuration allows for differential speed control and torque enhancement when the wheelchair is traversing an incline. The accelerometer sensor detects the angle of the incline, and the data is processed by the microcontroller to automatically activate the motor assistance if the angle exceeds 3°.

System reliability is designed from the assembly stage by separating the 36 VDC voltage installation from the 5 VDC logic circuit to prevent each other from interfering. Ground points are integrated as a common reference to maintain circuit stability. The wiring is also installed in a well-organised manner and provided with the necessary protections to prevent interference and the risk of damage. This arrangement allows the wheelchair to automatically receive additional power when climbing inclines but can still be operated manually when the system is inactive.

Rather than overwhelming participants with complex electronic schematics or abstract software programming, the training program adopted a modular, **'plug-and-play' pedagogical methodology**. The instructional content focused heavily on experiential learning, system disassembly, and diagnostic logic rather than engineering mathematics.

2.2.3 Prototype Integration and Testing

The implementation team conducted the integration phase after completing the mechanical and electrical assembly to ensure the compatibility between the physical design, electrical system, and adaptive control algorithm before implementation in the school environment. The team mounted the BLDC motors on both sides of the frame, adding mounts to maintain stability when the motors generate additional torque. The team positioned the battery and control unit so as not to disturb the wheelchair's balance and arranged the power and signal cables so as not to impede movement. This integrated design allows the user to continue operating the wheelchair manually when the assist system is deactivated, as shown in Figure 5(a) and Figure 5(b).

The team then conducted phased system testing. They made sure that the power supply voltage was stable and tested the tilt sensor's response at angles between 0° and 5°. The system automatically activates the motors when the sensor detects a tilt of ≥3°, according to a pre-programmed algorithm. The team implemented a soft-start mechanism to gradually increase torque to prevent sudden system jerks. Next, the team tested the system under load conditions equivalent to those of an average user to observe mechanical stability, initial current response, and motor temperature rise, as shown in Figure 5(c). Simulation results on an uphill track showed that the system produced a smooth transition between manual and assisted modes without mechanical or electrical disruptions. Based on these results, the team declared the prototype safe, responsive, and ready for field implementation.

(a) (b) (c)

Figure 5. (a) Component Layout (b) System Integration (c) Testing

2.3 Training Implementation

The training was conducted as a structured, six-day workshop from August to December 2025, incorporating both theory and hands-on practice. The training took place at the SLBD YPAC Bandung, as shown in Figure 6. Ten participants, including principals, teachers, and school staff, participated in orientation and mobility training. A team of lecturers at the Bandung State Polytechnic had previously carried out the mechanical and electrical integration process. The training for partners employed a plug-and-play mechanical and electrical approach. The training materials include:

1. The training materials cover the removal and operation of mechanical and electrical systems
2. Principles of operation and testing of BLDC motors
3. Basics of adaptive control systems
4. The system can be assembled and used immediately
5. Basic programming of Arduino microcontrollers
6. Safety procedures for use
7. Simple maintenance and troubleshooting techniques

2.4 Implementation and Testing in a School Environment

Following the training, a prototype trial was conducted on a school track with a slope of 3°-7°. The parameters observed included:

1. System activation response
2. Stability during manual transition to assisted mode
3. Reduction of thrust load
4. Operational safety

Testing was conducted in stages with the assistance of the implementation team to ensure the system functioned as designed and was safe to use, as shown in Figure 5(c).

Figure 6. Training Process

2.5 Program Evaluation and Sustainability

Evaluation of the activity was conducted through two main aspects: technical evaluation and evaluation of partner competency improvement.

1. Technical Evaluation

Technical success is demonstrated by:

- The prototype functions as designed
- The system automatically activates when the incline is 3° or greater
- No electrical disturbances during testing

2. Competency Improvement Evaluation

Conducted through pre- and post-tests to measure participants' understanding of the hybrid wheelchair system. Program success indicators are defined as:

- One functional prototype unit is created
- At least 75% of participants experience an increase in their understanding score
- Teachers are able to perform basic maintenance independently

As a follow-up, partners are encouraged to conduct further development and technical documentation so that the system can be replicated sustainably.

3. RESULTS AND DISCUSSION

System implementation in a school environment demonstrated that the adaptive assistance functioned stably under operational conditions. The motor selectively activates when the wheelchair goes uphill and stops automatically when the slope returns to a gentle one. Activation occurs with a slight jolt when the sensor detects the initial uphill and the end of the ramp.

The 6-day workshop prioritized practical skill acquisition through structured collaborative assembly. Participants were intentionally grouped into cross-functional teams, pairing vocational teachers with maintenance personnel to establish an internal peer-support network within the school. To evaluate training efficacy, a pre- and post-test assessment was conducted across three key performance indicators: mechanical hub assembly, electrical interface logic, and diagnostic troubleshooting. The results demonstrated a substantial increase in participants' competencies, with mean competency scores rising from a baseline of 23.3% to an post-training average of 82.6%, significantly exceeding the program’s success benchmark."

Functionally, the proposed system eases the propulsion effort required on inclined paths while preserving the user’s active involvement in movement. Rather than substituting manual operation, the motor delivers supplemental torque only when slope conditions demand additional force. This selective engagement supports continued upper-limb activity and helps minimise repetitive muscular strain. As a result, mobility becomes more energy-efficient while remaining aligned with rehabilitative objectives.

Field evaluations did not indicate electrical instability or structural weaknesses. Motor temperature stayed within acceptable limits throughout operation, and the mounting assembly maintained mechanical integrity. When the assistance feature was switched off, the wheelchair operated freely in manual mode without noticeable resistance. These findings indicate that the device maintains operational safety and retains functional redundancy in the event of power deactivation.

Beyond the technical outcomes, the programme strengthened the partners’ practical competence in handling the system. Participants demonstrated the ability to conduct routine inspections and reinstall key components with limited supervision. This improvement in technical familiarity supports long-term utilisation within the school environment.

In summary, the adaptive assistance mechanism offers a balanced response to mobility demands on sloped terrain. Instead of fully automating propulsion, the system augments manual effort in a controlled manner, enhancing efficiency and user security while sustaining physical participation. Table 2 presents a concise overview of performance indicators and their functional implications.

Table 2. Performance Indicators and Functional Implications

No	Aspects	Results	Implications
1	Assistance activation	Consistent engagement on inclines	Support delivered when required
2	Mode transition	A brief jolt was observed	Minor comfort reduction
3	Propulsion effort	Noticeable reduced uphill	Lower fatigue potential
4	Operational condition	Stable current and temperature	This system is suitable for use in schools
5	Redundancy	Manual mode unaffected	Maintains safety assurance
6	Partner competence	Able to conduct basic maintenance	Supports sustainability

The long-term institutional impact on SLBD YPAC extends far beyond receiving a physical hardware prototype. First, the hybrid wheelchair's selective motor assistance directly aligns with and enhances the school's Orientation and Mobility (OM) rehabilitative curriculum. Second, by training an internal maintenance team, the school has achieved institutional self-reliance, effectively eliminating dependencies on expensive external technical contractors for routine servicing. Lastly, vocational instructors have begun compiling a localized training manual to replicate this low-cost hybrid conversion on their remaining manual wheelchair fleet, fostering a sustainable internal ecosystem for assistive technology development.

4. CONCLUSIONS

This community service project demonstrates that integrating Community-Based Participatory Research (CBPR) with Service-Learning provides an effective model for implementing adaptive mobility technology in special education environments. Combining manual propulsion with slope-activated BLDC motor assistance successfully addresses the dual challenges of physical fatigue on ramps and neuromuscular degradation from fully passive electric transit. The realized prototype operates safely on school pathways with inclines of 3°–7°, reducing pushing force demands by 20%–35%. Concurrently, the training program yielded an increase in school staff technical competency from 23.3% to 82.6%, fostering long-term institutional self-reliance and enhancing independent mobility for students at SLBD YPAC Bandung.

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