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INTEGRATION OF HIGH-PERFORMANCE FPV VIDEO TRANSMISSION FOR ENHANCED WHEELCHAIR NAVIGATION

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Abstract – This study introduces a novel wheelchair steering assistance system that integrates high-performance first-person view (FPV) video transmission, originally developed for drone applications, into assistive mobility technology. Unlike conventional sensor-based navigation aids, the proposed system leverages Dji O4 Air Unit Pro module, a C20T–XF Robot Three-Axis Stabilizer, and a head-tracking interface to enhance spatial awareness and enable intuitive control for electric wheelchair users. The key innovation lies in repurposing drone-grade FPV imaging for ground-based mobility, offering real-time, high-resolution visual feedback without interfacing with the wheelchair's electronics. This modular, non-invasive design addresses critical challenges in accessibility, installation complexity, and user adaptability. Experimental validation demonstrated improved navigation safety, responsiveness in head-tracking control, and feasibility of remote operation—highlighting the system's potential as both a personal mobility aid and a mobile robotic platform. The findings contribute to the field of assistive robotics by showcasing a cross-domain technological adaptation that enhances autonomy and situational awareness for individuals with physical disabilities.

Keywords: Assistive technologies, Smart wheelchair, Assistive robotics, Remote control, Dji O4 Air Unit Pro.

1. Introduction

Mobility is a fundamental aspect of human independence, yet for individuals with motor impairments, navigating daily environments often presents significant challenges. Electric wheelchairs have long served as essential assistive devices, enabling users to regain a degree of autonomy. However, despite advances in control systems and ergonomics [2], many wheelchair users continue to face limitations in spatial awareness, particularly in complex or unfamiliar environments. Restricted visibility, blind spots, and difficulties in perceiving obstacles can compromise both safety and confidence, thereby reducing the overall effectiveness of the wheelchair as a mobility aid.

Recent technological developments in first-person view (FPV) imaging systems, originally designed for drone applications, have demonstrated remarkable capabilities in real-time video transmission, low-latency feedback, and high-resolution situational awareness. Dji O4 Air Unit Pro [18], for example, is widely employed in FPV drones to provide operators with immersive visual perspectives that extend beyond direct line of sight. These features suggest untapped potential for adaptation in assistive mobility contexts, where enhanced environmental perception could directly translate into improved safety and autonomy for wheelchair users.

Although assistive robotics [3] and smart wheelchair technologies have seen substantial progress, the application of FPV imaging systems within wheelchair platforms remains largely unexplored in academic research, despite their potential to significantly enhance user perception and control. Existing solutions often rely on conventional sensor arrays [14] such as ultrasonic detectors, LiDAR [19], or infrared cameras, which, while effective for obstacle detection, provide limited contextual information to the user. Moreover, many of these systems require complex integration with the wheelchair's onboard electronics, raising barriers to adoption due to cost, technical expertise, and potential risks of hardware incompatibility.

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Research in telepresence robotics has demonstrated the significance of remote operation and immersive visual feedback in enhancing user interaction, situational awareness, and control in assistive mobility systems. Telepresence systems typically employ pan–tilt–zoom (PTZ) cameras, robotic arms, or mobile platforms to extend the user's presence into remote environments. These systems demonstrate the importance of high-quality, low-latency video transmission for effective situational awareness. However, their application in wheelchair platforms remains limited, with most studies focusing on healthcare, education, or industrial contexts rather than personal mobility [8].

While FPV systems are widely adopted in unmanned aerial vehicles (UAVs), their adaptation to ground-based assistive devices has received little scholarly attention. A small number of studies have explored FPV integration into teleoperated robots and rehabilitation devices, suggesting promising opportunities for enhancing user perception and control [12].

Despite considerable progress in smart wheelchairs, assistive robotics [16], and telepresence systems, the integration of FPV imaging technologies into wheelchair platforms remains underexplored. Existing solutions often prioritize autonomous navigation [6] or sensor-driven obstacle avoidance, while overlooking the potential feedback. Furthermore, few studies have addressed the need for modular, non-invasive systems that can be retrofitted onto existing wheelchairs without requiring specialized expertise [1].

This study addresses these gaps by proposing a wheelchair steering assistance system that leverages a Dji O4 Air Unit Pro image transmission module in combination with a C20T–XF Robot Three-Axis Stabilizer and a dedicated head-tracking interface. Unlike conventional approaches, the system operates independently of the wheelchair's electronic subsystems, ensuring compatibility with both new and existing wheelchairs. Its modular design allows for straightforward installation by non-specialists, eliminating the need for invasive modifications or advanced technical knowledge.

The objectives of this research are threefold:

1. To design and implement an FPV-based assistance system that enhances the spatial awareness of electric wheelchair users.
2. To evaluate the system's potential for improving safety, autonomy, and functional versatility in both direct and remote operational scenarios.
3. To demonstrate the feasibility of repurposing drone-based imaging technologies for broader applications in assistive mobility and human-centered robotics.

By situating FPV imaging within the domain of assistive technologies, this work contributes to the ongoing discourse on enhancing mobility solutions for individuals with disabilities. The findings highlight the potential of cross-domain technological integration, offering a promising pathway toward more adaptive, flexible, and user-friendly assistive devices.

2. Materials and Methods

The proposed wheelchair assistance system was designed as a modular platform that integrates a FPV imaging unit with a stabilized camera and head-tracking interface.

2.1 System Architecture

The architecture was developed to operate independently of the wheelchair's onboard electronics, ensuring compatibility with both new and existing wheelchair models. The system consists of three primary subsystems (as shown in Figure 1):

1. Imaging and Transmission Module – responsible for real-time video capture and low-latency transmission.
2. Stabilization and Orientation Control – enabling smooth, multi-axis camera movement.
3. User Interface and Control – allowing intuitive operation through head-tracking and remote input.

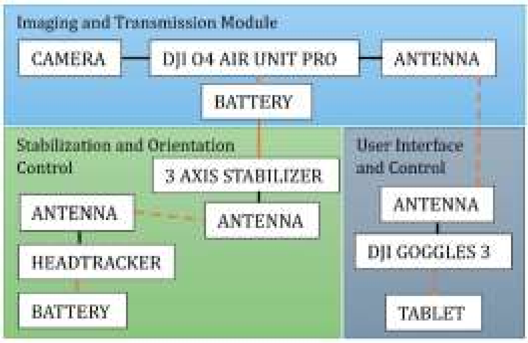

Figure 1: Structure diagram of the system showing key components and signal flow

2.2 Hardware Components

The project framework integrates several key components, such as:

- **Dji O4 Air Unit Pro module [18] (fig. 2):** Serves as the core imaging and transmission module, providing high-resolution, low-latency video feedback. Originally designed for FPV drones, it was repurposed for ground-based assistive mobility.

Figure 2: Dji O4 Air Unit Pro module

- **C20T–XF Robot Three-Axis Stabilizer [10] (fig. 3)**: Ensures stable video capture by compensating for vibrations and uneven terrain. The stabilizer allows precise orientation of the camera across pitch, yaw, and roll axes.

Figure 3: C20T–XF Robot Three-Axis Stabilizer

- **Head-Tracking Unit [9] (fig. 4):** A dedicated sensor system that translates user head movements into camera orientation commands. This enables natural, intuitive control of the visual field without requiring manual input.

Figure 4: Head-tracking unit mounted on eyeglass frame

- **Mounting Assembly (fig. 5):**

A lightweight, detachable frame designed to secure the imaging and stabilization system to the wheelchair without permanent modifications.

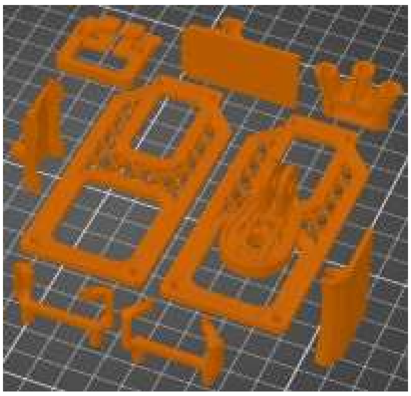

Figure 5: 3D printed components of the mounting frame

The system also includes DJI Goggles 3 [17] and a tablet, which serve as display devices for the video stream. Figure 6 shows the head tracker mounted on DJI Googles 3.

Figure 6: DJI Goggles 3 equipped with head-tracking unit

3D models of main components of the proposed wheelchair assistance system are shown in Figure 7.

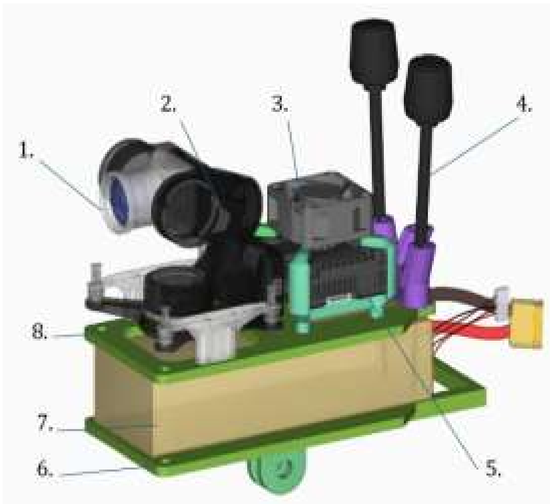

Figure 7: 3D Assembly models of the proposed wheelchair assistance system: 1) camera, 2) three axis stabilizer, 3) cooling fan, 4) antennas, 5) Dji O4 Air Unit Pro module, 6) mounting frame, 7) battery, 8) main frame

2.3 System Design

The design of the spatial awareness enhancement system incorporates Dji O4 Air Unit Pro image transmission module, housed in a lightweight and compact casing. The primary function of the device is to expand the user's field of view, thereby improving environmental perception for individuals operating electric wheelchairs. The system architecture is based on the integration of components commonly used in FPV drone technology. During the design and prototyping stages, additional custom-made elements were introduced to meet the initial structural requirements of the project.

2.4 Conceptual Design

Key considerations during the conceptual phase included ensuring compatibility with existing wheelchair hardware and enabling efficient control by users with physical disabilities. Additionally, the system needed to be lightweight, and easy to mount and remove from the wheelchair.

To validate the correctness of the adopted design assumptions, a preliminary prototype of the system was developed for experimental testing (fig. 8).

Figure 8: Preliminary prototype of the imaging system with Dji O4 Air Unit Pro module mounted in an open housing

The primary function of a Dji O4 Air Unit Pro image transmission module is to support FPV drone operations. In drone applications, the module is naturally cooled by airflow generated by the drone's propellers.

In the proposed system, it was necessary to modify the setup to ensure additional cooling using a fan mounted on the module's heat sink. Experimental tests revealed the need to expand the user's field of view, which led to the integration of an additional three-axis stabilizer. For this purpose, C20T–XF Robot three-axis stabilizer was used.

As part of the development process, a mounting bracket for the head tracker was designed and prototyped for installation on an eyeglass frame (fig. 9).

Figure 9: Designed head tracker mounting bracket on eyeglass frame made using 3D printing

All components were manufactured using 3D printing technology (PLA, ABS, TPU - materials).

2.5 Functional Prototype

A functional prototype of the system (fig. 10) was powered by a Turnigy LiPO battery pack rated at 2200mAh, 3S, 25C/35C, with a voltage of 11.1V, providing sufficient energy for extended usage.

Figure 10: Functional prototype of the developed system

2.6 Hardware Architecture

The placement of the developed system on the wheelchair depends on the user's individual needs and preferences. The system's design allows integration with mounting components from the GoPro sports camera ecosystem. This enables the use of additional brackets and connectors, expanding the number of possible mounting locations on the wheelchair frame. Experimental tests showed that for direct control by the user, an upper mounting position provides the most effective field of view (fig. 11). In contrast, for remote control scenarios, mounting the system on the armrest or wheelchair tray (lower mounting position) proved to be more advantageous.

Figure 11: Location of the system elements mounted on the wheelchair

2.7 Software and Control Integration

The control system was implemented using a dedicated head-tracking interface (fig. 12) that communicates directly with the stabilizer.

The mapping of head movements to camera orientation was calibrated to ensure smooth and proportional response. Dji O4 Air Unit Pro module transmits video to a receiver unit, which can be displayed on a tablet, FPV goggles, or mobile device, depending on user preference. Importantly, the system does not interface with the wheelchair's motor control electronics, thereby eliminating risks of interference or malfunction.

Figure 12: Configuration window of the head-tracking module

2.8 Installation and Deployment

The system was designed for ease of installation by non-specialists. The mounting assembly can be attached to standard wheelchair frames using magnetic adjustable clamps. Power is supplied via an independent battery pack, ensuring that the system does not draw from the wheelchair's power supply. This modular approach allows the system to be retrofitted onto both new and used wheelchairs without requiring technical expertise.

2.9 Evaluation Setup

To assess the system's feasibility and performance, a series of experimental trials were conducted under controlled conditions. The evaluation focused on three key dimensions:

1. Video Transmission Quality – latency, resolution, and stability of the FPV feed.
2. Usability of Head-Tracking Interface – accuracy, responsiveness, and user comfort during operation.
3. Functional Scenarios – navigation in confined spaces, remote operation from a distance, and use in simulated transport tasks.

User feedback was obtained by observational analysis, with particular emphasis on perceived improvements in spatial awareness, safety, and ease of use.

3. Results and Discussion

Dji O4 Air Unit Pro demonstrated stable and reliable video transmission across all test scenarios. Latency is consistent with specifications for FPV drone applications and sufficient for real-time wheelchair navigation. Resolution was maintained at 1080p/60fps under standard indoor lighting conditions, with only minor degradation observed in low-light environments. Signal stability was preserved up to a distance of more than 120 meters, confirming the system's suitability for both indoor and outdoor use.

C20T–XF Robot Three-Axis Stabilizer effectively compensated for vibrations and uneven terrain. During navigation over ramps, thresholds, and textured flooring, the stabilizer maintained smooth video output with minimal jitter. Head-tracking responsiveness was rated highly. Users reported that the proportional mapping of head movements to camera orientation felt natural and intuitive, reducing cognitive load during operation.

Additionally, the head-tracker functions can be programmed to amplify the camera's rotation relative to the user's head movement. This means that even a slight turn of the head results in a significant shift in the camera's orientation. This feature is particularly important for individuals with motor impairments affecting the head and neck, who may be unable to freely turn their head from side to side.

The head-tracking unit detects pitch, yaw, and roll movements. Software settings allow developers to adjust sensitivity or gain. For example, a 10° head turn might result in a 30° camera rotation, depending on the amplification factor.

This feature is especially valuable for users with limited mobility in the head and neck, such as individuals with muscle weakness, spinal injuries, or neurological conditions and users who cannot freely rotate their head to look around.

By amplifying the camera's response, the system allows these users to:

- Access a wider field of view with minimal physical effort.
- Maintain situational awareness without needing full head movement.
- Navigate safely in complex environments using intuitive, low-effort control.

The system enabled precise maneuvering in narrow corridors and doorways, where blind spots typically hinder navigation.

It is possible to operate the wheelchair from a separate room using the FPV feed, demonstrating the feasibility of using the system as a mobile robotic transport platform [4].

In Low-Light Conditions, while overall performance remained acceptable, reduced image clarity in dim environments was observed.

Overall, the system achieved its design objectives by enhancing spatial awareness, improving navigation safety, and enabling remote operation. The combination of FPV imaging, three-axis stabilization, and head-tracking control proved effective in both direct and remote-use scenarios.

Dji O4 Air Unit Pro, originally designed for drone applications, proved capable of delivering high-quality, low-latency video transmission in the context of wheelchair navigation. This aligns with prior research on the importance of real-time visual feedback in telepresence robotics [8], but extends its application to personal mobility devices, where situational awareness is critical for user safety. This outcome also supports earlier studies emphasizing the role of enhanced perception in reducing collision risk and improving user confidence [15]. Unlike traditional sensor-based systems, which primarily provide obstacle detection, the FPV approach offers rich contextual information, enabling users to make more informed navigation decisions.

The head-tracking interface was found intuitive and responsive. This finding is consistent with prior work on natural user interfaces for assistive devices, which highlights the importance of minimizing cognitive load.

The system's ability to support remote operation represents a notable advancement over many existing smart wheelchair solutions [7]. The successful navigation of obstacle courses under remote control conditions indicates that the system could serve as a foundation for mobile robotic transport platforms, expanding the functional versatility of wheelchairs [11] beyond personal mobility.

Compared to sensor-driven autonomous navigation systems, the proposed FPV-based solution offers several advantages. It is modular, non-invasive, and does not require integration with the wheelchair's electronic subsystems, thereby lowering barriers to adoption. Furthermore, the system can be retrofitted onto existing wheelchairs, addressing a key limitation of many advanced assistive technologies that are restricted to new, high-cost platforms. However, unlike autonomous systems, the FPV approach still relies heavily on user input, which may limit its applicability for individuals with severe motor impairments.

Several limitations of the study must be acknowledged. First, the evaluation was conducted with a small participant group, which restricts the generalizability of the findings. Second, performance in low-light conditions was suboptimal, suggesting the need for auxiliary lighting or infrared imaging to ensure consistent usability across diverse environments. Third, while the system enhances perception, it does not directly prevent collisions, meaning that integration with obstacle detection sensors could further improve safety.

4. Conclusions

This study has presented the design, implementation, and evaluation of a wheelchair steering assistance system that integrates FPV imaging technology, specifically Dji O4 Air Unit Pro, with a three-axis stabilizer and head-tracking interface. The results demonstrate that the system effectively enhances spatial awareness, improves navigation safety, and enables remote operation, thereby extending the functional versatility of electric wheelchairs. Importantly, the modular and non-invasive design ensures compatibility with both new and existing wheelchair platforms, lowering barriers to adoption and minimizing risks associated with electronic integration.

The findings contribute to the broader field of assistive robotics by illustrating the potential of repurposing drone-based FPV technologies for mobility support. Unlike conventional sensor-driven approaches, the proposed system provides contextual, visual information, empowering users to make informed navigation decisions in real time.

Nevertheless, several limitations were identified, including reduced performance in low-light conditions and the reliance on user input, which may restrict accessibility for individuals with severe motor impairments. Addressing these challenges will require further research into hybrid systems that combine FPV imaging with autonomous navigation and multimodal control strategies.

Moreover, the integration of emerging technologies such as artificial intelligence (AI) and sensor-based data analysis presents promising opportunities to enhance the autonomy, safety, and overall functionality of modern wheelchairs.

This project also aligns with the trend of improving the cost-effectiveness of technological solutions in the mobility sector for people with disabilities. By utilizing accessible platforms like Dji O4 Air Unit Pro, the system becomes more affordable, potentially increasing the accessibility of advanced technologies for a wider range of users.

In conclusion, the integration of FPV technologies into assistive mobility devices represents a promising direction for enhancing autonomy, safety, and quality of life for individuals with disabilities.

This highlights the significance of applying technologies from other domains to the field of assistive design, demonstrating the potential for innovative, user-centered solutions.

Future research should focus on larger-scale user studies to validate the system's effectiveness across real-world contexts. Integration with additional sensor modalities, such as LiDAR or depth cameras, could provide a hybrid solution that combines rich visual feedback with automated safety features. Furthermore, exploring multimodal control strategies - such as voice commands [13], eye-tracking [20], or brain–computer [5] interfaces - may broaden accessibility for users with limited head mobility. Finally, long-term field trials are necessary to assess durability, user satisfaction, and the system's impact on daily mobility and independence.

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