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Integrating Computer Vision and Dynamic Control for Environmental Perception and Navigation

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***Abstract*—This study introduces a novel mechatronic system that integrates computer vision and dynamic control to optimize lower limb exoskeleton support across various terrains. This work introduces a motorized chest mount camera mount that dynamically adjusts to maintain an optimal field of view (FOV). This setup ensures that terrain features crucial for navigation are continuously centered, achieving an accuracy rate of 83%. Our framework employs an algorithmic suite for terrain classification, step measurement, and staircase detection. Using the YOLOv3 model, it detects ascending stairs with 98.1% accuracy, while an edge detection approach refines descending stair navigation with minimal errors. An integrated Inertial Measurement Unit (IMU) and RGB-D camera precisely capture step lengths, facilitating accurate predictions of the transitional step with 95% accuracy. Furthermore, point cloud analysis is utilized to measure staircase dimensions with a high degree of accuracy, demonstrating an average absolute error of 0.84 cm. This integration of advanced sensing, processing, and control technologies significantly enhances the functionality and adaptability of exoskeletons, paving the way for more effective and versatile assistive devices.**

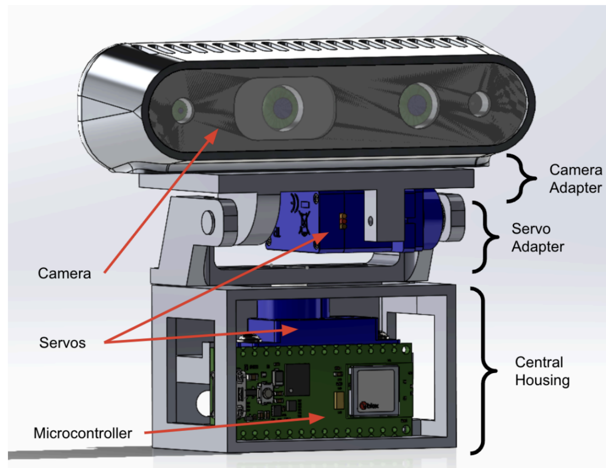

Fig. 1: Wearable pan-tilt camera.

I. Introduction

Vision is paramount to navigating the world. As humans, we rely on sight to maneuver around obstacles within a path. New promising approaches to gathering information about the environment makes use of inexpensive depth and RGB cameras, given their capability of measuring the distance of objects in each frame. With deep learning, these sensors have been implemented for robust vision-based robot control systems, allowing them to have a perception of the environment [1, 2, 3, 4]. While machine vision has proven to enhance the automatic control of robotic devices, applications to wearable robotics have not advanced as rapidly [5].

II. Methodology

The device is targeted to weigh under 1 kg to ensure ease of mobility, with the design necessitating a quick donning time of less than 30 seconds to enhance usability. It must operate effectively within normal human walking speeds, specifically at an average speed of 1.4 m/s, while drawing less than 0.9 Amps of current to accommodate the limitations of standard USB Type C protocols.

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The system also includes a motorized camera setup to adjust the field of view (FOV) dynamically, ensuring an effective FOV of over 90°, which allows both the ground near the subject and the horizon to be visible, enhancing navigation. This setup facilitates precise terrain obstacle identification and tracking.

III. Results

The device's total weight measured 0.285 kg, well below the target of 1 kg, with each component's weight meticulously detailed. Donning time was efficiently short, averaging 10.51 seconds, and the system exceeded the target average human walking speed, functioning effectively up to 2.05 m/s against a specification of 1.4 m/s. Power consumption was also within limits, with a peak draw of 0.625A against a maximum allowable of 0.9A, confirming the device's efficiency.

The Effective Field of View (EFOV) was increased as intended by the servo motors' range of motion, despite physical constraints, which was methodically verified using a goniometer. System success rate tests across various locations revealed an overall success rate of 83%. The terrain characteristic such as staircase detection, step length, staircase dimensions were each validated separately, showing an accuracy of 98%, 95%, and less than 0.84cm error, respectively.

These results underscore the device's potential in enhancing mobility and navigation across varied terrains, demonstrating its viability while highlighting areas for future refinement to meet all targeted specifications.

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