Project 1

CEG5303: Intelligent Autonomous Robotic Systems

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1 Lower Limb Rehabilitation Exoskeleton Robots

Introduction

Lower limb rehabilitation exoskeletons integrate robotics, information science, and control systems to help patients with motor impairments caused by stroke, spinal cord injury, or cerebral palsy. These wearable devices can improve rehabilitation outcomes while reducing the workload of therapists.

1. Specific Applications

These robots help patients with lower limb dysfunction regain a normal gait. Hospital exoskeletons such as Lokomat help control gait training, while devices such as ReWalk and Indego support daily walking.

2. Operations

The robot is operated either by a preset gait trajectory or by real-time adjustments using an IMU, force sensors, and plantar pressure sensors, as demonstrated in LOPES. Active control modes include trajectory tracking (ReWalk, Rex) and force-based impedance control (Lokomat), which adjusts the level of assistance by measuring deviations in joint angles.

3. Usefulness of the Design

Exoskeletons enable repetitive, stable training, accelerate movement recovery, and reduce reliance on therapists, thereby improving rehabilitation efficiency. They also provide real-time gait data, allowing doctors to assess progress and optimize rehabilitation plans.

4. System Architectures for Safety

Safety mechanisms include limit control to prevent overextension, force control to regulate torque, and emergency stop functions based on abnormal plantar pressure. Algorithmic safeguards such as finite state machines (FSMs) prevent unexpected transitions, while predictive control (MPC) enhances gait stability.

5. Efficient Operations

Modular design simplifies maintenance and upgrades. Dynamic gait adjustment algorithms, such as MPC, adjust training in real time, while optimization strategies, such as Lokomat, reduce hospital stays and increase efficiency.

6. Economic Values

Exoskeleton robots reduce rehabilitation costs by automating training and minimizing human resources. Driven by an aging population and technological advances, the exoskeleton robot market has great potential and is a valuable investment in healthcare.

2 Autonomous Underwater Vehicle (AUV) Sentry

Introduction

Sentry is a fully autonomous underwater vehicle designed for deep-sea exploration, capable of operating at depths up to 6,000 meters. It is equipped with advanced sensors that can generate high-resolution bathymetric, side-scan, seafloor, and magnetic maps to help study seafloor geology. It can also navigate complex terrain such as mid-ocean ridges and hydrothermal vents while capturing thousands of digital images for scientific analysis.

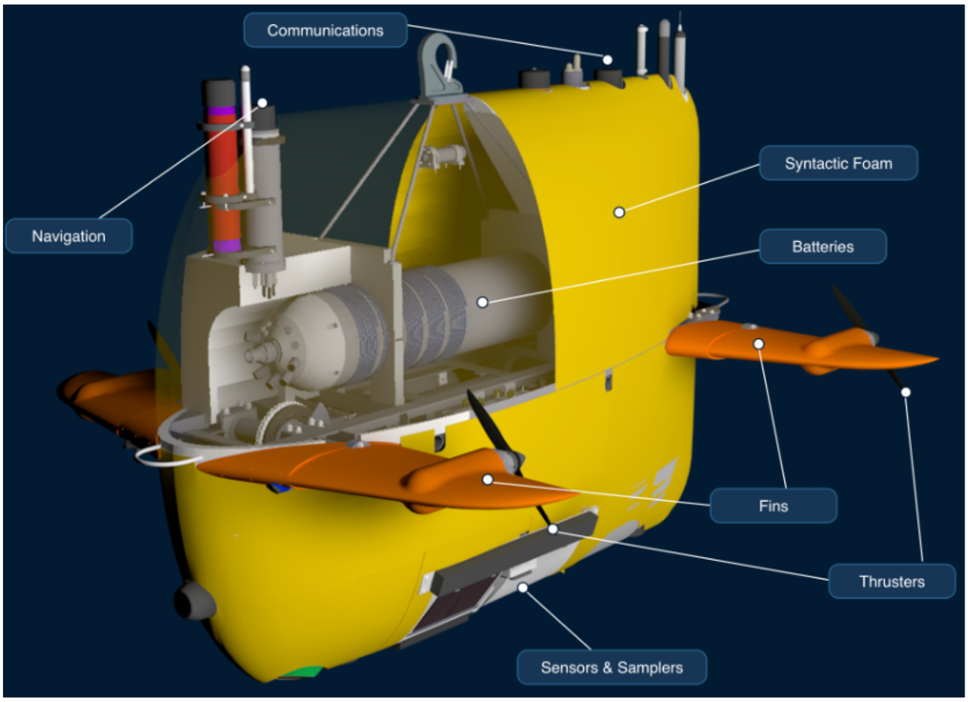

Figure 1: Key components of the AUV Sentry.

1. Specific Applications

Sentry supports ocean mapping, hydrothermal vent exploration, deep-sea topography surveys, and biological and chemical sampling. Provides critical data for understanding the morphology of the sea floor, locates hydrothermal fluxes for ecosystem studies, and surveys mid-ocean ridges and underwater scarps. Its customizable payloads allow for in situ chemical analysis and biological sampling.

2. Operations

Sentry uses the Doppler Velocimeter (DVL), the Inertial Navigation System, and Acoustic Tracking for autonomous navigation, while relying on GPS on the surface for navigation. Communicates via an underwater acoustic modem and a satellite link on the surface. It is powered by lithium-ion batteries to sustain operations for long-duration missions. Its four reversible thrusters and optimized fin layout ensure precise maneuverability for altitude control.

3. Usefulness of Design

Sentry's hydrodynamic structure minimizes drag for efficient movement, and its synthetic foam structure ensures buoyancy at high pressures. Its modular sensor payload can be customized for different scientific missions. A powerful battery system supports extended deployments, making it a durable and adaptable exploration tool.

4. System Architectures for Safety

Multiple navigation systems, including DVL, USBL, and inertial sensors, improve positioning accuracy and prevent failures. Pressure-resistant components ensure safe operation at extreme depths. Acoustic communications enable real-time monitoring and mission adjustments underwater, improving operational safety and reliability.

5. Efficient operations

Equipped with high-capacity batteries and optimized energy consumption, Sentry supports long-duration missions while maintaining navigation accuracy. Its advanced thruster system improves stability in challenging underwater conditions. It can be deployed in a single location for mapping, sampling, and monitoring, maximizing ocean research efficiency.

6. Economic Values

By replacing manned submersibles, Sentinel reduces operating costs while improving safety. Its versatile design optimizes resource utilization and reduces deployment frequency. As part of the National Deep Submersible Facility, it remains accessible to researchers worldwide, promoting collaboration and innovation in ocean science.

3 Robotic System for Post Office Package Handling

Introduction

The post office parcel handling robot system uses AI-driven automation to meet the growing needs of logistics by simplifying parcel sorting and placement. Using Universal Robots UR5 and AI gripping and detection systems, the system improves parcel handling efficiency while reducing reliance on manual labor. By integrating computer vision and robotic control, the system plays a vital role in the modernization of postal logistics.

1. Specific Applications

The robotic system automates parcel sorting by accurately identifying, picking up and placing parcels. Using advanced grip quality networks such as Dex-Net 4.0, it can adapt to various parcel sizes and shapes in cluttered environments. It can operate efficiently in logistics centers without retraining and has improved adaptability to different materials and weights, making it suitable for a variety of industrial applications.

2. Operations

The system is equipped with a high-precision RGB depth camera that captures 3D images for package identification and orientation detection. An AI-based model calculates the optimal gripping point for precise robotic arm control. The system follows a state machine-based workflow that synchronizes vision, motion planning, and execution through the Robot Operating System (ROS), ensuring real-time response and seamless task coordination.

3. Usefulness of the Design

The robotic system significantly improves productivity by automating repetitive tasks, reducing errors and increasing sorting speeds. Its adaptability ensures consistent performance despite varying parcel attributes. It features an advanced vacuum gripper design that adapts to varying surface textures, while an integrated error recovery mechanism enables corrective gripping to prevent workflow disruptions.

4. System Architectures for Safety

Safety features are embedded into the system architecture, including collision avoidance through motion planning frameworks such as MoveIt!. Hand-eye calibration maintains alignment between the sensor and the robot arm, minimizing positioning errors.

Real-time monitoring enables instant adjustments for increased reliability, while emergency stop capabilities ensure safe operation in the event of unexpected errors.

5. Efficient Operations

The system uses efficient motion paths and parallel processing to optimize energy consumption for computer vision and control to avoid bottlenecks. Its modular design based on ROS facilitates seamless integration with future hardware upgrades. The system is designed for scalability, supporting high-speed operations while maintaining performance consistency in large logistics environments.

6. Economic Values

Automating labor-intensive processes reduces operating costs and improves efficiency, especially during peak shipping periods. The system's high return on investment (ROI) is achieved by reducing reliance on manual labor and increasing throughput. As a scalable ROS-based solution, it can be expanded from postal logistics to other industrial sectors, thereby expanding its commercial potential.

4 Football Training Assistant Robot

Introduction

The football training assistant robot uses robotics, artificial intelligence and computer vision to improve training efficiency by automating tasks such as passing, shooting and catching the ball. It reduces human input while providing players with personalized and adaptable training sessions.

1. Specific Applications

The system improves passing accuracy by analyzing pass trajectories and simulating real game scenarios. It assists in shooting practice by launching the ball at different speeds and angles, helping goalkeepers improve their reaction and positioning abilities. As an autonomous goalkeeper, it can dynamically block shots and conduct realistic forward training. In addition, it automatically collects the ball using vision-based object detection and storage mechanisms, ensuring a seamless workflow.

2. Operations

The robot uses LiDAR, GPS and SLAM technology to navigate the field, avoid obstacles and maintain precise movement. High-resolution cameras detect the ball, players and goal posts in real time. Customizable training plans allow coaches to tailor training to match the player's skill level by adjusting ball speed, trajectory and repetition frequency.

3. Usefulness of the Design

By automating repetitive training tasks, the robot increases efficiency and saves time. It can adapt training sessions to each player, ensuring targeted skill development. Its versatile design reduces reliance on additional training equipment, making it a versatile tool for a variety of practice scenarios.

4. System Architectures for Safety

The system uses proximity sensors to avoid collisions, ensuring safe operation around players and obstacles. Fail-safe mechanisms such as emergency stop buttons and automatic safety protocols prevent injuries. Made of weather-resistant materials, the robot can still be used reliably outdoors in different conditions.

5. Efficient Operations

The robot is powered by a high-capacity battery to support long training sessions. It can handle multiple tasks such as passing, catching and shooting simultaneously to optimize training time. The mobile app interface allows coaches to remotely control settings and analyze player performance metrics in real time.

6. Economic Values

By reducing reliance on human coaches, the system reduces labor costs while maintaining high training quality. Its automated, data-driven approach improves player performance and ensures a strong return on investment. The system is scalable for use in professional clubs and community training centers, with wide applicability and long-term value.

References

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