Surface Water Vehicle (SWV)

An autonomous robot on water surface

Abstract -

A Surface Water Vehicle (SWV) is a type of vessel designed for autonomous navigation and serves a range of purposes. The present design emphasizes seafloor mapping, an activity that requires significant resources and benefits greatly from automation. This SWV has been specifically designed to launch an autonomous vehicle responsible for capturing intricate scans of the ocean floor. The system enables the deployment and tracking of the remotely operated vehicle (ROV) by utilizing GPS for location monitoring and a magnetometer for directional guidance.

Considering the long-term aspects of the SWV project, it was structured to be modular, facilitating easy adjustments to meet the changing needs of future teams. The platform enables waypoint navigation and incorporates continuous developments in autonomy. Initiatives aimed at enhancing its features encompass the use of sonar technology for obstacle detection and the optimization of heading and speed control systems.

Purpose -

A Surface Water Vehicle (SWV) is fundamentally an autonomous water vehicle created to perform tasks and carry out missions on its own. These vehicles enable automation across a variety of water-related operations, including port monitoring, emergency rescue missions, environmental studies, cargo transport, and waste management in aquatic environments. By integrating SWVs into these activities, organizations can significantly lower costs, improve efficiency, and safeguard human lives by minimizing direct involvement in dangerous scenarios. Furthermore, SWVs are capable of functioning in extreme environments, operating for long periods without tiring, and delivering reliable data for further analysis.

Goals -

The project began with the development of a Surface Water Vehicle (SWV) using an aluminum extrusion frame as the foundation. The initial design included hardware and software for waypoint-to-waypoint navigation based on a pre-set mission file. Building on this foundation, the following goals were outlined for the project's advancement:

1. **MOTION MASTERY** Implementation of holonomic motion systems for omnidirectional maneuverability
2. **AQUA-DYNAMIC EXCELLENCE** Structural refinement to minimize water resistance and maximize operational efficiency
3. **SUSTAINABLE POWER SOLUTIONS** Incorporation of solar panel arrays for autonomous energy generation
4. **SUBSURFACE INTELLIGENCE** Deployment of sonar technology for subsurface mapping and obstacle avoidance
5. **DEEP VISION INTEGRATION** Integration of underwater monitoring systems for enhanced data acquisition
6. **PRECISION CONTROL MATRIX** Implementation of heading and speed feedback mechanisms for precise operational control

This strategic framework propels the SWV platform toward enhanced operational capabilities and technological sophistication.

Design Overview -

Chassis/Frame -

The chassis of the Surface Water Vehicle (SWV) is built with 20x20 aluminum extrusions, securely joined using corner brackets to form a strong cuboidal frame. This frame structure ensures the SWV is rigid and balanced, optimizing its payload capacity while keeping the overall weight low. The simplicity of this design also helps in reducing fabrication costs and making the assembly process straightforward.
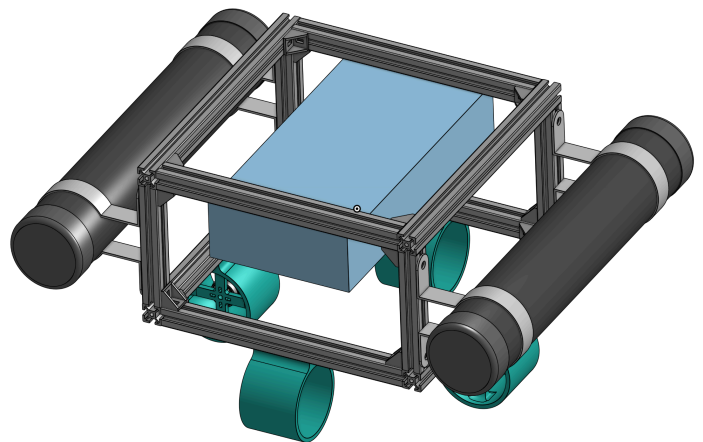
The entire chassis is designed with future adaptability in mind, allowing easy upgrades or modifications as the project progresses. The lightweight and modular design helps keep the vehicle functional, cost-effective, and ready to handle the demands of autonomous water operations.

Buoyant Tubes:

For buoyancy, PVC pipes are mounted on two sides of the frame. These pipes are sealed airtight, waterproof, and filled with air, providing just the right amount of lift to keep the vehicle afloat. They are easily attachable and detachable, making maintenance or adjustments simple without complicating the overall structure.

Thrusters:

Container:

On top of the aluminum frame, an acrylic sheet is used to create a protective enclosure for the electronic sensors and circuits. This enclosure keeps the electronics safe from water and external elements, while also being lightweight and durable. Acrylic was chosen for its balance of strength and low weight, ensuring the components stay protected without adding unnecessary bulk.

Controls for SWV Motion and Waypoint Navigation

The motion control of the Surface Water Vehicle (SWV) is achieved using two high-thrust BLDC motors mounted on the frame with custom 3D-printed mounts. These motors provide the necessary thrust and turning capabilities through differential thrusting, a method where the motors operate at varying speeds to achieve both linear and angular motion. Independent directional control is achieved by adjusting the speed of each motor, enabling precise maneuverability. The motors, capable of delivering significant torque, ensure excellent controllability and stability even in challenging water conditions.

Autonomy Overview -

The Surface Water Vehicle (SWV) achieves autonomy through a seamless integration of its sensors and control system. The GPS provides real-time positional data, identifying the vehicle's current location and comparing it to the target coordinates, much like how the eyes track a destination. The magnetometer determines the vehicle's orientation and calculates the necessary angle for alignment, ensuring accurate direction toward the target. A WiFi-enabled microcontroller, ESP32, serves as the central processing unit, analyzing the input from the GPS and magnetometer and employing a PID (Proportional-Integral-Derivative) controller to regulate speed and direction. This ensures precise and efficient navigation by dynamically adjusting to changes in position and heading. Additionally, a laptop is used as a ground station to monitor the status of the vehicle, providing real-time updates and insights. By continuously processing data from the sensors and utilizing the ground station for monitoring, the SWV dynamically corrects its course and propels itself toward its destination with precision.

Waypoint Navigation with Two Motors

To autonomously navigate to a waypoint (x, y), where 'x' and 'y' stand as the geographical coordinates on the water's surface, the SWV uses differential drive principles with the following key steps and formulas:

1. **Calculate Distance to Waypoint**:

   The distance between the current location and the waypoint is computed as:

   $$d = \sqrt{(x_{tar} - x_{curr})^2 + (y_{tar} - y_{curr})^2}$$

2. **Determine Heading Angle (θ):**

The desired heading angle to the waypoint is calculated using:

$$\theta \; = \; tan^{-1}(\frac{y_{tar} - y_{curr}}{x_{tar} - x_{curr}})$$

3. **Angle Correction (Δθ\Delta \theta):**

To align the SWV with the target heading, the deviation from the current orientation is computed as:

$$\Delta\theta = \theta_{tar} - \theta_{curr}$$

4. **Motor Speed Control:**

The SWV adjusts its motor speeds for both linear and angular motion using the following equations:

- **Linear Speed** (v) for forward motion:

$$v \; = \; r^2(\omega L \; + \; \omega R)$$

- **Angular Speed** (ω) for turning:

$$\omega \; = \; rL(\omega R \; - \; \omega L)$$

Where:

- ωR and ωL are the right and left motor angular velocities.
- r is the propeller radius.
- L is the distance between the two motors.

5. **Navigation Logic:**

- If $\Delta\theta > 0$, the SWV increases the right motor speed to turn left.
- If $\Delta\theta < 0$, the SWV increases the left motor speed to turn right.
- Once aligned with the target heading, both motors maintain equal speeds for forward motion toward the waypoint.

By continuously adjusting motor speeds based on real-time feedback from sensors, the SWV achieves precise alignment and efficient navigation to any designated waypoint on the water, ensuring robust performance in autonomous operations.

Electronics:

Applications of a Surface Water Vehicle (SWV)

1. **Seafloor Mapping**:
   SWVs equipped with sonar systems can create detailed bathymetric maps, aiding in underwater exploration and research.

2. **Environmental Monitoring**:
   Used to monitor water quality, measure pollution levels, and track biodiversity in lakes, rivers, and coastal areas.

3. **Search and Rescue Operations**:
   Deployed in emergency situations to locate missing individuals or objects in water bodies without risking human lives.

4. **Ocean Cleanup**:
   Utilized to collect floating debris and pollutants, contributing to maintaining cleaner water bodies.

5. **Marine Infrastructure Inspection**:
   Inspects underwater structures such as bridges, dams, pipelines, and offshore rigs for maintenance and safety assessments.

6. **Data Collection for Climate Studies**:
   Collects data on temperature, salinity, and other parameters to support climate change research and weather predictions.

7. **Defense and Surveillance**:
   SWVs can patrol harbors and coastal areas, detecting unauthorized vessels or underwater threats.

8. **Autonomous Ferrying**:
   Transporting goods or small payloads between points in coastal regions or water-locked areas.

9. **Aquaculture Management**:
   Assists in monitoring and maintaining fish farms, ensuring optimal water conditions and detecting anomalies.

10. **Hydrographic Surveying**:
    Supports navigation by identifying underwater hazards and ensuring accurate charting of waterways.

Conclusion

The primary goal of this project is to create an innovative and adaptable Surface Water Vehicle (SWV) capable of serving a wide range of applications for years to come. While the current model meets basic functional requirements, it is designed with a modular structure, enabling extensive potential for future upgrades and application-specific modifications. Through rigorous testing and research, we have identified areas for improvement and are steadily moving toward developing a fully functional product. The SWV's versatility and broad usability across various domains make it a project with boundless potential, and we remain committed to making significant advancements to expand its applications and effectiveness.