TEKNOFEST 2024 · UNMANNED SURFACE VEHICLE (FINALIST)

Autonomous Catamaran Unmanned Surface Vehicle (USV)

A twin-hull unmanned surface vehicle with autonomous navigation and drone-assisted communication.

Catamaran / USV · Autonomy · MAVLink · LIDAR + GPS Fusion · Image Processing · UAV Relay · Pixhawk

Team: Başkent Autonomous Marine Vehicle Team (Team ID: 558211 · 7 members)
Competition: TEKNOFEST 2024 Unmanned Surface Vehicle Competition — Finalist · Mersin
Application ID: 2233843 · Founded: 2023

Critical Design Report (Summary) 2024

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1. Project Summary

The catamaran-type Unmanned Surface Vehicle (USV) project aims to develop an autonomous surface craft for marine research, environmental monitoring and security applications, exploiting the advantages of high stability, large payload capacity and low water resistance. With a 1.2 m hull length, the vehicle is equipped with LIDAR, camera and navigation systems, and can establish a communication relay with an accompanying UAV. The project reached the finals of the TEKNOFEST 2024 competition.

Key Capabilities

- Twin-hull (catamaran) high-stability platform — Ø1.2 m hull
- Artificial-potential-field-based autonomous route following
- GPS + LIDAR fusion for precise positioning and obstacle detection
- Ground-station and UAV communication over the MAVLink protocol
- Accompanying rotary-wing UAV (Pixhawk + NVIDIA Jetson TX2)

Team Information (Official Registration)	
Team name	Başkent Autonomous Marine Vehicle Team
Team ID	558211
Application ID	2233843
Founded	2023
Members	7
Result	TEKNOFEST 2024 — Finalist (Mersin)

2. Design Approach

Three hull types were evaluated before design; the catamaran was chosen for its high payload capacity (to carry various sensors/equipment), fast and efficient motion with low water resistance, and high stability from two parallel hulls. Hull sizing followed the proportional formulas in “How To Dimension a Catamaran” and was modelled in SolidWorks.

Hull length (L)	1200 mm
LBR (length/beam)	4 (reasonable catamaran range: 4–12)
BTR (beam/draft)	1.9 (minimizes water resistance: 1.5–2.8)
Hull connection	30 × 30 mm Sigma profiles
Modelling	SolidWorks · Analysis: ANSYS (structural + CFD)

3. Manufacturing Method

For cost advantage and adequate strength, the hulls were produced from fibreglass. One layer of woven fabric + three layers of felt (450 g/cm²) were laid layer by layer into a plastic mould and shaped with CE 92 general-purpose polyester resin. After each layer cured, the hulls were removed from the mould, capped with MDF, and micro-holes/cracks were filled with plaster and painted. Finally the hulls were joined with sigma profiles and the motor and rudder were mounted.

- Fibreglass: 1 woven + 3 felt layers (450 g/cm²) + CE 92 polyester resin
- Top cover: MDF (flat base → prevents water pooling, bonds well to epoxy)
- Surface repair: plaster filler + paint; corners rounded to reduce collision damage
- Assembly: 30×30 sigma profile → easy, modular assembly

4. Electronic Design

The vehicle contains many sensors working together for autonomy, providing 360° situational awareness, obstacle detection and monitoring of position/speed/mission progress.

Component	Task
3S Li-Po battery	Main power source
12 V → 5 V regulator	Voltage regulation
Raspberry Pi 4	High-level processing / image processing
Pixhawk	Flight/navigation control unit (autopilot)
LIDAR	Ranging / obstacle detection
Camera module	Imaging / object detection
BLDC motor + drivers	Propulsion system
XBee Pro	Wireless communication with the ground station

5. Autonomy & Algorithms

Algorithms were developed across areas for the USV's autonomous motion and situational awareness: object detection and colour sensing in image processing, MAVLink for communication, and GPS + LIDAR fusion for navigation. An artificial-potential-field algorithm was designed for route following.

5.1. Image Processing — Colour-Based Object Tracking (OpenCV)

Frames from the camera are converted to HSV space; a mask is built for the chosen colour range, contours are found, and objects above a certain area are marked with a rectangle.

```
import cv2
import numpy as np

cap = cv2.VideoCapture(0)
lower = np.array([30, 150, 50]); upper = np.array([255, 255, 180])

while True:
    ret, frame = cap.read()
    if not ret: break
    hsv = cv2.cvtColor(frame, cv2.COLOR_BGR2HSV)
    mask = cv2.inRange(hsv, lower, upper)
    contours, _ = cv2.findContours(mask, cv2.RETR_TREE, cv2.CHAIN_APPROX_SIMPLE)
    for c in contours:
        if cv2.contourArea(c) > 500:
            x, y, w, h = cv2.boundingRect(c)
            cv2.rectangle(frame, (x, y), (x+w, y+h), (0, 255, 0), 2)
    cv2.imshow("Frame", frame)
    if cv2.waitKey(1) & 0xFF == ord("q"): break
cap.release(); cv2.destroyAllWindows()
```

5.2. GPS + LIDAR Fusion

The global position from GPS is combined with LIDAR's precise short-range measurements for a more accurate position estimate; the fused path is compared against the GPS path on the graph.

5.3. MAVLink Communication

Communication between the vehicle and ground station uses MAVLink, which carries reliable data at low bandwidth. A connection is opened with pymavlink, verified with HEARTBEAT, commands such as ARM are sent, and telemetry is listened to.

```
from pymavlink import mavutil

def start(conn):
    master = mavutil.mavlink_connection(conn)
    master.wait_heartbeat()
    print("MAVLink connection successful!")
    return master

def send(master, cmd, params=[]):
    master.mav.command_long_send(
        master.target_system, master.target_component, cmd, 0, *params)

master = start("udp:127.0.0.1:14540")
send(master, mavutil.mavlink.MAV_CMD_COMPONENT_ARM_DISARM, [1, 0])
```

6. Accompanying UAV (Aerial Vehicle)

A rotary-wing UAV accompanies the system, providing a communication relay and aerial mission support. A ready-made F450 frame (ABS arms, copper-trace carbon-fibre plates) was used mechanically; carbon-fibre mounting plates for the electronics were cut with a CNC router.

UAV Specifications	
Dimensions (L×W×H)	50 × 50 × 41 cm
Mass	2070 g
Material	ABS, carbon, carbon fibre, plexiglass
Propeller	10 inch
Flight control	Pixhawk autopilot (GPS, IMU, airspeed, altimeter, US range)
Mission computer	NVIDIA Jetson TX2 (CUDA-capable, high processing capacity)

The UAV has two parts: flight control (Pixhawk) and mission control (Jetson TX2). Sensor data is collected at the Pixhawk over serial; the autopilot manages the vehicle based on commands from the mission computer and the USV.

7. Ground Station & Communication Protocol

- **Protocol:** MAVLink — carries command, status and telemetry data at low bandwidth.
- **Software:** ground-station software such as QGroundControl / Mission Planner.
- **Flow:** connect → HEARTBEAT verification → send commands (e.g. ARM) → monitor periodic telemetry.
- **Hardware:** wireless data exchange via an XBee Pro radio module.

8. Performance Tests

The design underwent extensive structural and computational fluid dynamics (CFD) analysis in ANSYS. Catamaran resistance is characterized by dominant viscous resistance at low Froude numbers and lower wave-making resistance than a single hull at high Froude numbers; the interaction between the two demi-hulls affects total resistance. In addition to mechanical tests, communication and navigation tests were run with the prototype, and autonomous motion along a given route was verified.

> *Test runs/navigation are documented with video recordings (test videos in the project archive).*

9. Safety

- Before production, the whole team received 16 hours of basic Occupational Health & Safety training.
- Fire extinguishers were kept near flammable materials (epoxy, XPS); warning/instruction signs in the workshop.
- On signal loss or emergency, the vehicle enters fail-safe mode and returns to a predefined point.
- Electronics are in waterproof enclosures; an easily accessible emergency power-cut fuse is provided.
- A 12 V motor was chosen for safety, efficiency and ease of maintenance.

10. Conclusion

The USV is an integrated system designed and built end-to-end — from catamaran hull design to autonomy algorithms, and from vehicle–UAV communication to safety procedures. Reaching the TEKNOFEST 2024 finals validates the design's field performance.

> *This document is compiled from the TEKNOFEST 2024 Unmanned Surface Vehicle Competition Critical Design Report.*