A novel Multi-Axis Load Cell System for Force Distribution Analysis in Paddles and Oars

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Summary

This study presents a novel load cell-based system for measuring force distribution on blades of paddles and oars, which is integrated into a controlled test bench. Unlike conventional methods that capture force at a single point and axis, this system records forces across multiple points and all three orthogonal axes, offering a detailed view of blade-water interactions. A neural network processes the collected data, refining force distribution predictions and generating precise force maps. This innovation advances the understanding of propulsion mechanics in nautical sports, paving the way for performance optimization and improved equipment design.

Introduction

Accurate measurement of force distribution on paddle and oar blades is essential for optimizing performance in nautical sports. Studies aiming to simplify the analysis of reaction forces on the blade often assume that the force acts at its center of mass and within a single plane, disregarding variations in other planes [1]. Some authors have embedded sensors into the blade's surface to better understand the behavior of these forces [2]. This study presents a load cell-based system that measures force distribution across the blade in a controlled environment.

Methods

The system was built using Minitec aluminum profiles (40x40 mm), with an aluminum base supported by four vertical (TSTM 500 N, VETEK) and four lateral (TSTM 200 N, VETEK) load cells to measure forces along the Z, X, and Y axes (Figure 1). A flexible expansion chamber with adjustable internal pressure simulates real water conditions at the blade interface. The base was divided into 18 sections, with 29 calibration points, including midpoints, intersections, and the center of mass. A screw-driven feed assembly applies static forces via a load cell (TSTM 500 N, VETEK) and a 5 mm pointer system, replicating gradual force application in canoeing and rowing. The system is calibrated by applying forces ranging from 0 to 500 N at discrete positions to maximize data points for training the neural network. Data is acquired at 10 Hz via an NI 9219 system and processed in MATLAB to generate force distribution maps and improve force prediction. Validation was performed through analytical modeling, comparing expected and measured deformations based on force position, magnitude, and load cell location.

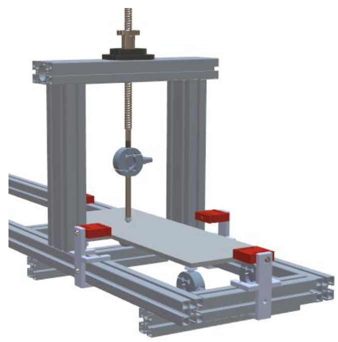

Figure 1: 3D representation of the force measurement system during calibration.

Results and Discussion

The results show that the relative error between the analytical and measured values is approximately 1% for higher loads (above 100 N) and up to 5% for lower loads (below 100 N). The increased error at lower loads is likely due to sensor sensitivity limitations and signal noise, highlighting the need for further refinement in low-force measurements.

Conclusions

This load cell-based system significantly improves force distribution measurement on blades of paddles and oars, offering a more detailed and accurate analysis than traditional methods. Integrating a neural network enhances predictive accuracy, contributing to a better understanding of propulsion mechanics and supporting advancements in performance optimization and equipment development.

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