Summer Research Proposal

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1 Overview

The project involves building a square-shaped reaction-wheel based 3D inverted pendulum and developing the control algorithms necessary to make it stand on its tip without any external support. If this turns out to be successful, proceed to make a cube/pyramid object that can stand on its edges and vertices.

2 Project Basis

Similar research was conducted in ETH Zurich and succeeded. The result was the Cubli – a cube that stands on edges and vertices. As the Cubli project was open-sourced, we will be able to base our design on their research.

3 Goal of Project

Replicate the prototype, which is essentially one side of the Cubli. Considering that the original impact-based braking mechanism causes deformation, a new mechanism will be designed. Upon completion, the prototype will be tested. If the test is successful, the control algorithms will be altered to accommodate a tetrahedron shape, and a subsequent test will be conducted on the tetrahedron prototype.

4 Technical Requirements

- Mechanics
- Control theory
- Electronics design
- Programming of the evaluation board
- Manufacturing

5 Previous Research

The research was originally conducted in ETH Zurich. More resources, including firmware for the Cubli, are on GitHub.

M. Muehlebach, R. D'Andrea, Nonlinear Analysis and Control of a Reaction-Wheel-Based 3-D Inverted Pendulum, in IEEE Transactions on Control Systems Technology, 2016 (early access)

M. Muehlebach, G. Mohanarajah, and R. D'Andrea, Nonlinear Analysis and Control of a Reaction Wheel-based 3D Inverted Pendulum, in Proc. Conference on Decision and Control, CDC 2013 (Florence, Italy)

M. Gajamohan, M. Muehlebach, T. Widmer, and R. D'Andrea, The Cubli: A Reaction Wheel-based 3D Inverted Pendulum, in Proc. European Control Conference (Zurich, Switzerland), pp. 268-274, July 2013.

M. Gajamohan, M. Merz, I. Thommen, and R. D'Andrea, The Cubli: A Cube that can Jump Up and Balance, in Proc. IEEE/RSJ International Conference of Intelligent Robots and Systems (Algarve, Portugal), pp. 3722-3727, October 2012.

6 Roadmap

- Research and understand the original papers
- Design a basic layout in Solidworks.
- Use conservation of angular momentum and equations of motions to determine the relative mass of the flywheel to the entire structure, the necessary angular velocity, and the required power of the motor.
- Test impact-based brake system, and come up with something else if it deforms too much (as suggested in the original paper)
- Research whether damping is required
- Approximate required battery capacity. Choose material for the frame, flyer wheel, and manufacture.
- Develop the closed-loop control system or use the existing code
- Program the STM32 NUCLEO-L432KC evaluation board and motor controller.
- Connect the board with the IMU (currently looking at LSM9DS1) and the motor
- Complete and test the prototype

If the prototype works, aim to make a cube/pyramid that stands on any edge/point

- Researching the 3D control logic and mathematics
- As nonlinear control is expected, finding a way to make it happen
- Reprogram the board and controller (rather luckily, it's a 4-channel, so it can work with 4 motors)
- Design 3D layout
- Prototype and test

7 Budget Estimation

Part specification comes from the original research papers. Shipping Cost is not included.

In theory, this will not exceed the £2500 limit.

Parts	Specification	Price
Motors x4	EC 45 flat Ø42.8 mm, 50 Watt, with Hall sensors	€126.09 x4
Motor Control	ESCON Module 50/5, 4-Q Servocontroller for DC/EC motors	€187.27
STM32 Board	NUCLEO-L432KC	$10.12
Sensory Stick	SparkFun 9DoF Sensor Stick	$17.50
Battery		£60
Manufacturing	Outer shell	£200
	Total	£860