The Helicopter: A Demonstration of Control Theory Methods

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Abstract: I propose to build a freely rotating armature/helicopter system under the direction of Professors Cheever and Orthlieb in order to examine various Multiple Input Multiple Output (MIMO) control theory methods and techniques for achieving stable position control. The successful completion of this project would result in my achieving a greater level of comprehension of basic control theory methods, MIMO systems, data acquisition and function creation in MATLAB, dynamic systems modeling and practical experience with electronic circuit and mechanical construction. Just as importantly, the helicopter system could be implemented as an advanced control theory experiment or demonstration for future students in the Swarthmore College Engineering department. Acquisition of parts and preliminary testing of components followed by system construction will begin in the winter of 2004, while research and implementation of MIMO systems control practices will take place in the spring of 2005. The total cost of this project should total less than $150.

Introduction

This project is concerned with the design and creation of a fixed-helicopter system and the components necessary to its operation and control. The following proposal begins with a **Technical Discussion** of the system's physical parameters and construction, the associated electronic components (motors, power amplifier, and data acquisition setup), and a brief introduction to MIMO control techniques. The **Project Plan** subsection includes a detailed timeline which is organized according to a Critical Path Method of project planning. I then list the qualifications I hold with regards to the successful completion of this project. Finally, a detailed summary of the costs that will be required to procure the necessary system components and materials is provided.

Technical Discussion

The primary domains of relevance with regards to the construction and design of a fixed-helicopter system control project are as follows: 1) mechanical, 2) electrical and data acquisition, 3) software processing and implementation of control algorithms. In this section, I present a detailed schematic of the proposed device to be constructed. This includes an illustration of the components and construction of the apparatus. Finally, a brief discussion of the available data acquisition tools library in MATLAB is supplied. The goal of this project is to be able to control or adjust the helicopter's position in its theta- and phi-directions of freedom. Given time and resources, a tactile user interface may be added at the successful completion of the basic project.

Figure 1 illustrates the completed apparatus:

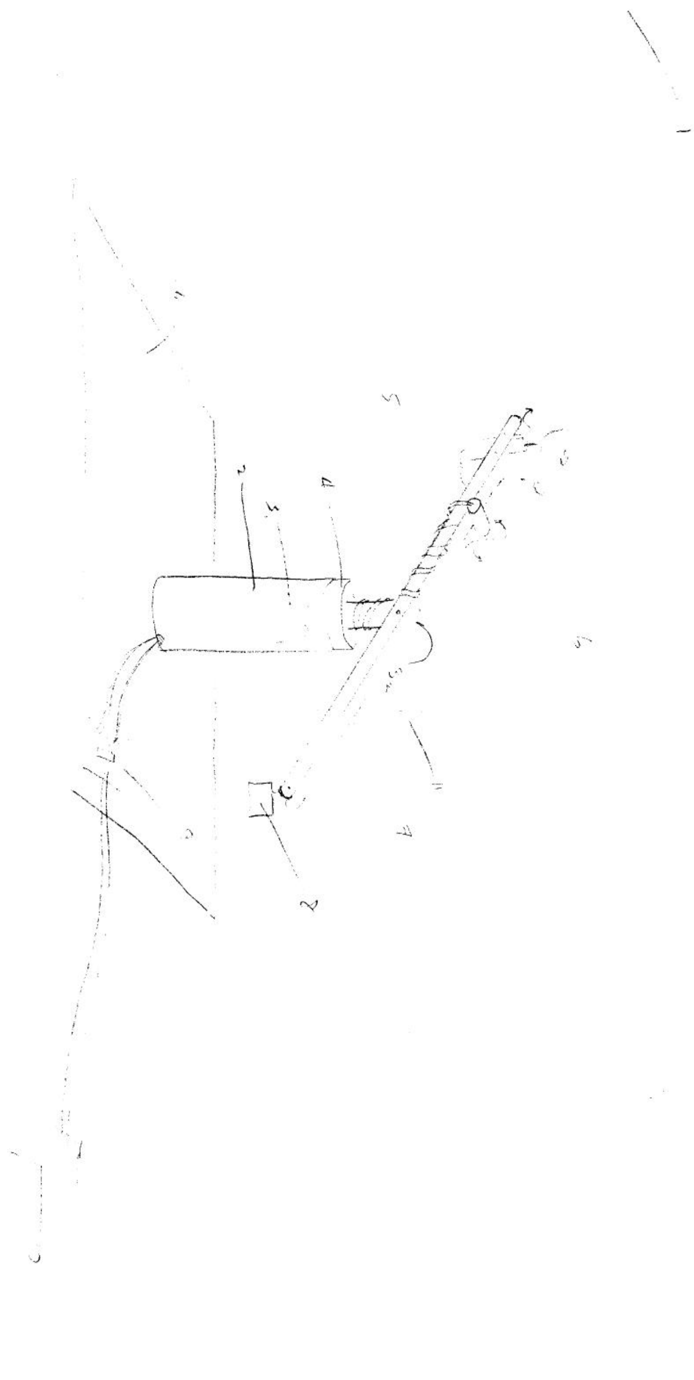

Figure 1 – The Apparatus

Legend:

1	Plexiglass safety barrier
2	Primary support shaft
3	digital encoders measure rotation in theta (1) and phi (2) directions
4	ball-bearings to permit rotation
5	DC motors
6	propellers
7	primary swinging arm
8	counterweight mass
9	amplifier circuirtry
10	Data Acquisition Board
11	Optional Safety post
12	Padding to prevent damage upon emergency shutoff
13	Computer
14	Tactile Interface
15	Visual display

Very simply, the motors will rotate the propellers to generate lift and yaw. The angles of rotation of the helicopter arm will be measured by rotational encoders (3_1, 3_2) which produce a voltage that is input to the computer. The ball-bearing (4) permits rotation in the horizontal plane, while a pin over a metal V-support will allow for tilt. An optional safety beam (11) preventing rotation beyond 360 degrees may be implemented during the initial testing stages of the project.

In order to reduce design constraints, the mass of counterweight (8) will be chosen to balance the torques created by the weight of the motors, propellers, and physical arm, such that the natural tendency of the arm will be to rest on the floor. However, the amount of torque required to lift the 'helicopter' side of the arm will be chosen to match the vertical force the phi-direction motor/propeller will be able to provide. This ensures that motion can be produced regardless of the amount of force the motor/propeller/amplifier system is able to generate. The force/weight ratio will be maximized to preclude any static friction concerns. Preliminary measurements of amount of force generated by the motors and propellers will be conducted to determine their capabilities.

The specifications of the amplifier will be determined in accordance with the requirements of the motor/propeller system. Both initial motors that have been purchased require direct current of up to 12V, though they vary in terms of current consumption. The power supply to the amplifier has already been constructed for a previous experiment; it should be able to provide ample current to the motors. The amplifier will need to supply a varying amount of power to the motors which is controlled electronically by the computer.

The data-acquisition and processing will take place through the use of the software suite MATLAB. The resources for developing the necessary data acquisition code, with which I have had experience, are available by typing ‘help daq’ at the command prompt. Although I have not yet researched MIMO control practices, basic control theory for SISO systems will form the basis of my approaches.

Project Plan

The success of my proposed project will be subject to the completion of the following table of activities. The dependencies and resultant actions that are enabled by a given activity are also included:

Activity	Needs	Feeds	Duration	Effort	Action
A	-	B,C,D	1d	2h	Research, obtain motors and propellers
B	A	E, H	1d	1h	perform preliminary lift calculations
C	B	A	1d	1h	Re-Order motors/propellers if necessary
D	C	E, H	1d	1h	Finalize motor/propeller choice, order ball bearings and encoders
E	-	G, H	1d	3h	Design Electrical Circuits
F	D	H	4d	12h	build apparatus (balanced)
G	E	H	1d	3h	Assemble and Test Electrical Circuits
H	F,G	I, J	2d	6h	System Modeling
I	H	L, M, N, (O)	1d	3h	Write Data Acquisition Code
J	-	K	2d	6h	Research MIMO Theory
K	J	L	1d	3h	Implement MIMO Code
L	I, K	M, N	1d	3h	Test Code
M	L	N	0-2w	0-40h	Re-Evaluate Methods, try different techniques
N	M	P	3d	10h	Finalize Demonstration
O	N	P	1w	10h	Optional: Add Tactile User Interface
P	N	graduation	1d	1h	Perform Demonstration

Table 1 – CPM Network Diagram

The next table shows a summary of a projected timeline of activities and effort:

Week	Activities In Progress	Activity Effort (Hrs)	Total Week's Effort (Hrs)	Total Project Hours
0	A, B, C, D	6, 1, 3, 2	12	12
1	F, E, G	12, 2, 2	16	28
2	F, E, G	4, 4, 4	12	40
3	G, H	4, 16	20	60
4	G, H, I	3, 3, 14	20	80
5	H, I, J	16, 2, 2	20	100
6	J, K	6, 14	20	120
7	K, L	2, 18	20	140
8	L, M	4, 20	24	164
9	M, J, K	3, 15, 2	20	184
10	J, K,	10, 10	20	204
11	K, L, M	5, 5, 10	20	224
12	M, O	5, 20	25	249
13	N, O	20, 5	25	274
14	N, O (K, L)	10, 5, (10, 10)	15 (25)	289
15	N, P	20, 1	21	310

Table 2 – CPM Network Diagram

The final graphic combines the two above sets of data into an integrated CPM Network flow chart, with earliest and latest start times listed above each activity:

<u>Figure 2</u> – CPM Network Flow Chart

Project Qualifications

As a senior engineering student at Swarthmore College, I have had the opportunity to take numerous electives and gain extra-curricular experience with the tools and resources available here. I have spent numerous hours in the woodshop through the previous construction projects including the creation of a stereo set of loudspeakers and am shop-certified. My experience in the electronics labs through taking design-oriented courses such as *Electronic Circuit Application* have been built upon a strong foundation of fundamental electrical circuit principles acquired through classes like *Physical Electronics.* My background in data acquisition and processing through MATLAB is significant, having spent three summers working with this software suite. This programming knowledge is supported by the understanding of data acquisition and processing principles which I gained in courses such as *Digital Signal Processing* and *Communication Systems*. The course entitled *Control Theory and Design* gave me the tools and understanding of basic principles that will be necessary to achieve my goals in this project.

I feel I have a strong background in the area of my proposed project, and I am confident that I will be able to bring the project to a successful completed state. This includes the ability to take a number of outside factors into account. For my project, I will not need to take the following constraints into consideration: environmental, ethical, or political. The installation of the safety shield and rod fall under the health and safety category. After the project is completed, the parts may be reused or taken apart, thus taking sustainability into account. The economic aspect of the project is not strenuous enough to warrant serious concern. Lastly, the manufacturability of the project is well within the capabilities of the available wood/metal shop.

Project Cost

The primary costs of this project consist of the required materials of the apparatus:

Item to be Purchased	Cost
Motors	$100
Propellers	$25
safety barrier	$20
apparatus construction materials	$20
cabling and basic electrical circuit components	Free
High Current Operational amplifier chip(s)	$10
ball bearings	$20
Tactile User Interface	$10
Total	$205

Table 3 – Bill of Materials

In addition, I estimate that I will require regular technical support and advice of approximately 2 hours per week.