A Neural Network Based Observer Design for the Aerobeam System

Eren Çakmak
Department of Control and Automation Engineering
Istanbul Technical University
Istanbul, Turkey
cakmaker@itu.edu.tr

Serhat Şeker
Department of Electrical Engineering
Istanbul Technical University
Istanbul, Turkey
seker@elk.itu.edu.tr

***Abstract*— In real-world applications, non-linear systems such as quadcopters are difficult to implement. In this regard, the Aerobeam system built to convey the problems of the quadcopter physics and control. The Aerobeam system in Cyber Physical Systems Laboratory (CPS Lab) at Istanbul Technical University (ITU) represents the problem of maintaining a balance of a beam, which is one of the most popular bench systems in control. However, the Aerobeam has a number of non-linearities. In that manner, a neural network observer is proposed that imitates the behavior of the Aerobeam system under a limited control history.**

Keywords—neural network, observer design, Aerobeam system.

I. Introduction

The Aerobeam is a laboratory set up system that represents the problem of maintaining a balance of a beam, which is one of the most popular bench systems in control. Also, with the strong correlation between beam balance control and quadcopter stability control, it simulates the essential concepts of quadcopter physics and control. In a typical quadcopter, there are four rotors equally placed corners of frame, and six degrees of freedom (3- translational and 3-rotational motion). A quadcopter can move longitudinally (forward and backward), vertically (upward and downward), and laterally (right and left). It can also move rotationally among each axis to produce roll, pitch, and yaw movements. With the additional aerodynamic effects and nonlinear behavior, quadcopter control is a difficult problem.

The Aerobeam system is a two-propeller test-bed with similar hardware features as the quadcopters, which consist of brushless DC motors, Electronic Speed Controllers (ESC), and an Inertial Measurement Unit (IMU) to detect changes in rotational attributes. The Aerobeam is fixed on the ground. That eliminates the translational motion. As well the propellers at both ends cause rotational movement on the single axis. Since the mathematical concepts are more complex in quadcopter modeling because of 6-DOF, the Aerobeam system with 1-DOF is a convenient system to fundamentally examine the stability problem, besides it is a novel approach to beam balance bench systems. Aerobeam is given in the Figure 1.

In the beam balance systems, the most important signal is the feedback signal, like all control applications. If the measurement of the states is not accurate, the closed-loop controlled system may be unstable. In this study, the speed of the motors reaches 5000 rpm to 6700 rpm. The vibrations of the motors at that speed are very high that enough to disrupt the Bosch BNO055 FusionLib software. Hence, accuracy the measurement is the key point. In this context, a very accurate Kalman Filter fusion algorithm designed by CPS Lab is applied to the system.

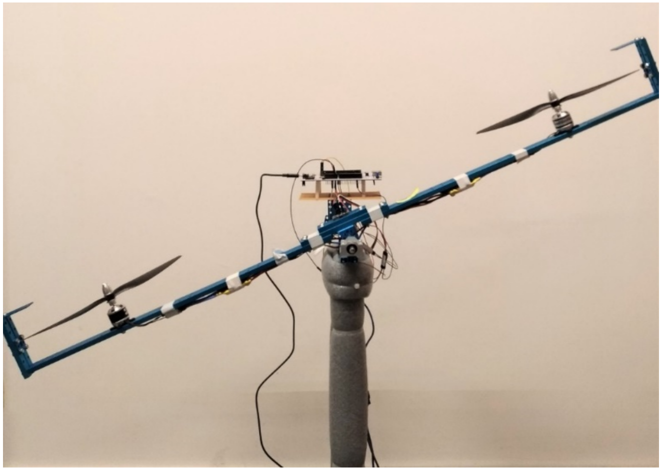

Figure 1: The Aerobeam system in CPS Lab at ITU.

At the moment, the Aerobeam system is driven by a PD+ controller. The PD+ controller is designed with a simple model that is derived by using Newtonian physique under some assumptions. The Aerobeam, however, has a number of non-linearities. For instance, the lifting force of air are not directly proportional to velocity of motors; the position and orientation of the motors with respect to ground is also significant. For that reason, the model is not accurate. Therefore, the PD+ controller is not too. In that manner, a neural network observer is designed that imitates the behavior of the Aerobeam system under a limited control history. Hence in the future, a more accurate controller can be designed.

The paper is organized as follows: After the introduction in Section I, an overview of the system is provided in II. This is followed by neural network based observer design in Section III. Section IV presents training results. Finally, Section V provides the conclusions and future direction.

II. System Overview

The The Aerobeam system consists of five main parts. The first one is the main body, which is the skeleton of the Aerobeam. The second part is the microcontroller. Next part is brushless direct current motors (BLDCM) and propeller. The fourth part is the electronic speed controllers (ESC). Finally, the last part is the inertial measurement unit (IMU).

A. Main Body of the Aerobeam

The model of the Aerobeam is depicted in Figure 2. The main body of the Aerobeam system consists of the Makeblock beams, which are mounted perpendicularly with a hinge at the beam's center of mass. Brushless DC motors with 10 inches propellers positioned in each side of the balance beam. An Inertial Measurement Unit (BNO055 IMU) is placed above the pivot point to measure the angle orientation around the pivot point. The shaft was designed to tilt ±55° from the horizontal position. Speed control of brushless dc motors achieved through PWM technique using electronic speed controllers. Controller signal is generated through variation of duty cycle.

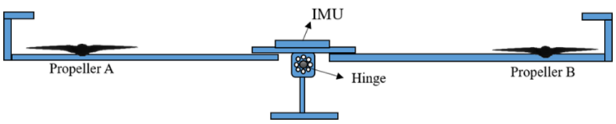

Figure 2: The model of the Aerobeam.

B. Nucleo F767ZI Development Board

The STM32 Nucleo board offers an affordable and flexible way for users to test new concepts and build prototypes with the STM32 microcontroller, choosing from the various combinations of performance, power consumption and features. The STM32 Nucleo-144 board does not require any separate probe, as it integrates the ST-LINK/V2-1 debugger/programmer and it comes with the STM32 comprehensive software HAL library, together with various packaged software examples, as well as a direct access to the ARM®mbed™online resources. The development card is shown in Figure 3.

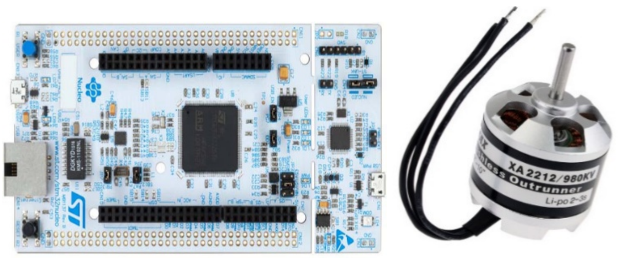

Figure 3: The STM micro controller and BLDCM respectively.

C. BLDCM and Propeller

Brushless DC motors are synchronous motors with high efficiency and controllability that powered by DC electric and supplied with AC voltage via inverters or switching power supplies. BLDCMs are convenient for aerobeam system due to their high power-to-weight ratio. BLDC motors can be controlled with feedback mechanisms to deliver the desired torque and rotation speed. EMAX 2212 / 980 KV brushless DC motor used in Aerobeam system is given in Figure 3.

Table 1: BLDCM test record with 10" propeller

Voltage (V)	Current (A)	Thrust (G)	Power (W)	Efficiency (G/W)	RPM
12	15.1	880	181.2	4.9	6960
8	9.5	550	76	7.2	5470

EMAX 2212 / 980 KV brushless DC motors are combined with 10inches propellers. The motor-propeller system provides the required thrust force for balancing the beam. BLDCMs create the torque, and propellers transform the torque into thrust. Test records of EMAX 2212 are given in Table 1.

D. Electronic Speed Controller

Electronic Speed Controller (ESC) is an electronic circuit with the purpose to vary a DC motor's speed, its direction and might act as a dynamic brake. Fully programmable ESC, which is shown in Figure 4, controls and regulates the speed of BLDC motor in the system. The electronic speed controller follows the speed reference signal derived from the microcontroller. By adjusting the duty cycle or switching the frequency of the reference signal, the motor speed is controlled.

E. Inertial Measurement Unit

Inertial Measurement Unit (IMU) is an electronic device that uses accelerometers, gyroscopes and magnetometers to measure orientation, speed and gravitational strength. In the Aerobeam, 9-DOF BNO055 IMU in Figure 4 is used.

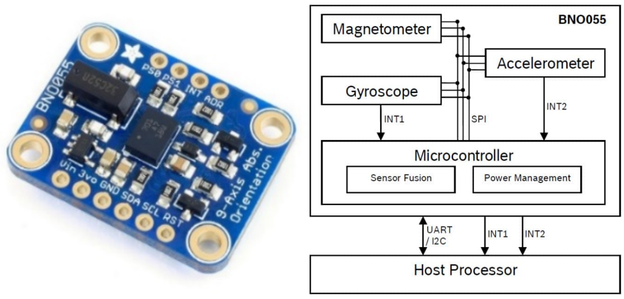

Figure 4: Adafruit 9-DOF BNO055 IMU and its system architecture respectively.

III. Neural Network Based Observer Design

The block diagram for the observer is depicted in Figure 5. To get the training and test data, the Aerobeam system is run by the PD+ controller. After that, the control history and Kalman filtered angular position data are recorded. Finally, the data is processed as in Figure 5. The neural network has seven inputs that first four inputs are control history and last three inputs are the history of trajectory. Therefore, the observer estimates the output by looking a limited history of inputs and outputs.

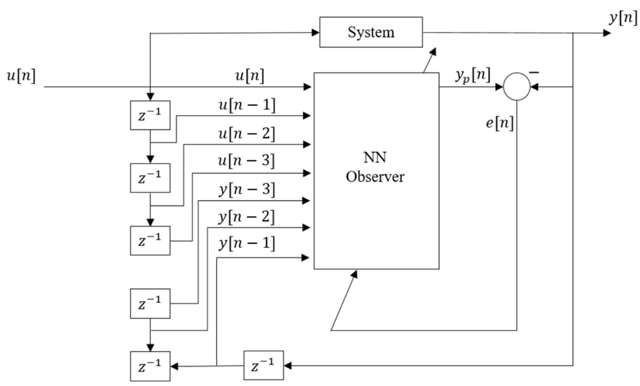

Figure 5: The block diagram of the neural network based observer system.

The topology of the neural network is depicted in Figure 6. The network has four hidden layers that each one has eight nodes, and one output.

The code of the algorithm is written withm keras using tensorflow as framework in python language. The RMSprop optimizer of the tensorflow framework is used. The loss function is selected as mean square error (MRE). The code is available at https://github.com/erenleicter/ANN-Sys-IdenCont.

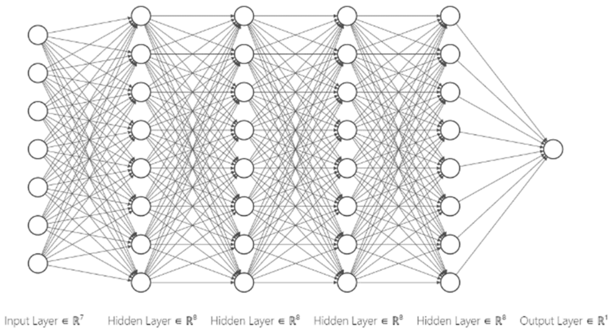

Figure 6: Topology of the neural network.

IV. Training Results

The algorithm is run for 500 iterations. The MRE of the training is 0.44826. The test results are given in the Figure 7. As it is seen in the figure, the observer predicts the real output successfully.

V. Conclusion and Future Directions

This paper proposes a neural network observer design for the Aerobeam system in CPS Lab at ITU. The observer successfully imitates the real system that cannot identified accurately via classical methods. This study also shows that non-linear systems, which are hard to identify, can be identify with that philosophy. Even if the designed observer in this study do not represents a mathematical expression for the system, it can be still used for different areas, such as observing the system if it is faulty, or designing controllers by using tune algorithms of neural network controller.

The Aerobeam system still does not have a well-designed controller. In that respect, at the next development stage, the neural network will be used to model the system with mathematical expressions and design a different types of controllers.

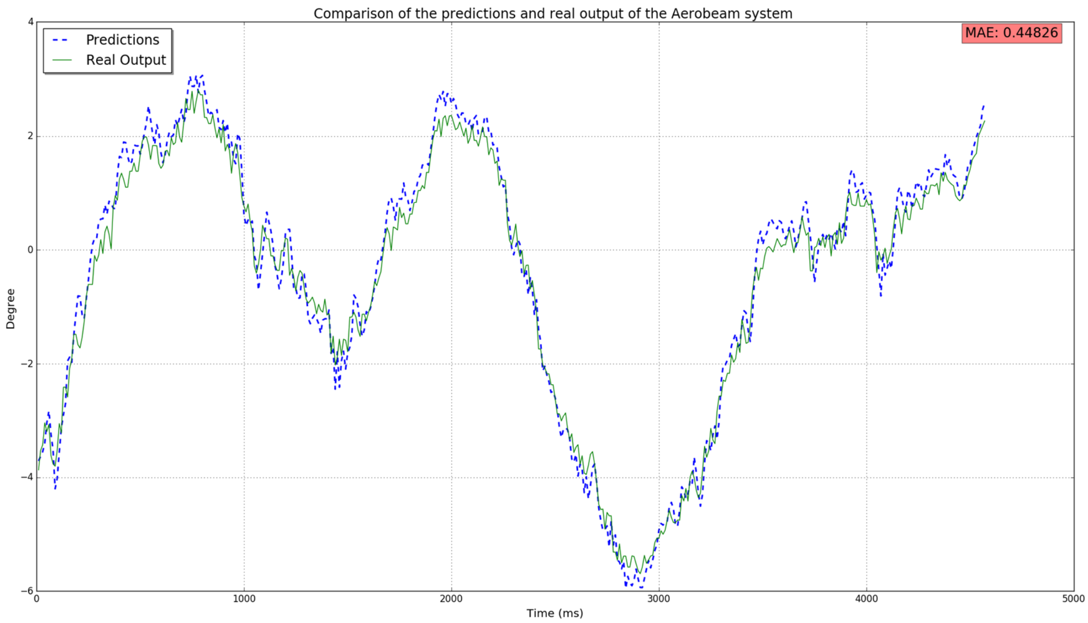

Figure 7: Comparison of the neural network based observer's predictions and the real data.