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14. ABSTRACT

This paper presents the initial results of a research project which investigates the application of the Direct Inverse Control technique to the problem of the Autonomous Hover of a quadrotor UAV Helicopter. The goal of the project is to investigate the effectiveness of the Direct Inverse Control technique using an Artificial Neural Network to learn and then cancel out the Hover dynamics of the quadrotor UAV Helicopter under various environmental conditions during a hover mode. The project is to evaluate how robust the control technique is to uncertainty and

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Direct Inverse Control using an Artificial Neural Network for the Autonomous Hover of a Helicopter

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Keywords—Direct Inverse Control, Neural Network, Flight Control, and UAV helicopter.

I. INTRODUCTION

Research in the area of UAVs has grown in importance over the last two decades as the operational requirements for such vehicles have increased in both military and civilian sectors [2]. As the role of the UAV increases, the need for improved autonomous guidance, navigation, and control (GNC) algorithms has become increasing crucial. Additionally, the need for system identification of nonlinear dynamics has grown in importance when designing a control law for the system [3&4]. Controllers for helicopters have been designed predominantly by classical control techniques [4&5]. While this tradition has produced many highly reliable and effective control systems, recent years have seen a growing interest in the use of robust, nonlinear adaptive control theory for flight control [2, 5&6]. A particularly important area of interest is the application of robust nonlinear control techniques to flight dynamics and control of rotorcraft UAVs [7-9]. Nonlinear control techniques are appealing because of their ability to address the highly nonlinear and coupled nature of the rotorcraft's dynamics [4].

In response to this need, the University of the Incarnate Word Autonomous Vehicle Systems (AVS) Laboratory is investigating new techniques or extending existing nonlinear design techniques to flight controls on unmanned rotorcraft dynamics. The overall mission of the AVS Laboratory is to determine the effectiveness of the stabilizing and robustness properties of nonlinear control design techniques on autonomous rotorcraft vehicles. A major focus of the rotorcraft UAV research at the AVS Laboratory will be the development, simulation, system integration, and flight testing of GNC algorithms. The flight dynamics of a helicopter is by its very nature nonlinear and sensitive to control inputs and external disturbances such as wind and ground effect.

This research was partially support by grant Proposal No. 64685-EG-REP from the Air Force Office of Scientific Research.

II. DIRECT INVERSE CONTROL

Direct Inverse Control (DIC) is a simple technique to implement and control nonlinear dynamics [11]. The flight dynamics of a helicopter is by its nature very nonlinear and sensitive to inputs and disturbance. The DIC was coupled with an Artificial Neural Network (ANN) in order to design a control system which could adjust and adapt to changes in the system dynamics and be robust to uncertainty in its environment. For this research project, the ANN was taught the correct dynamics of a helicopter in a hover hold using flight test data from the X4-P helicopter. The DIC control objective was to attempt to cancel out the dynamics of the hover motion such that the only command left was the hover command.

The DIC technique coupled with an ANN was chosen as a controller because it is simple to implement within the software constraints of the flight control computer and the controller can be tuned to changing state parameters using the ANN. Additionally, the DIC can be optimized for specialized missions such as a hover hold and can be adjusted to handle time varying systems, as seen in helicopter dynamics [11].

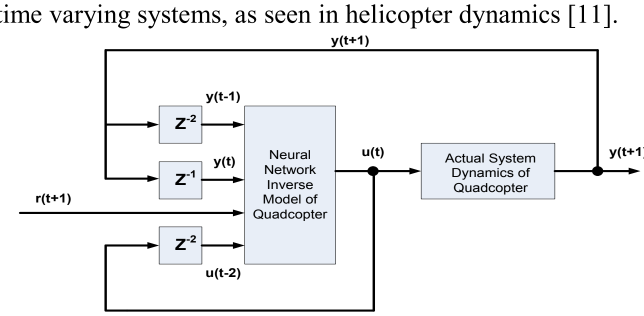

Figure 1. Direct Inverse Control Used for Hover Hold.

The actual dynamics **y(t+1)** of the helicopter can track an input command **r(t+1)** if it is driven by a controller **u(t)** whose model approximates the inverse of the actual helicopter dynamics as shown in Figure 1. A stable inverse model of the helicopter was obtained through the use of an ANN trained from actual dynamics of the helicopter in a hover hold. Feedback is used by employing the helicopter's output **y(t+1)**, which is utilized to change the parameters of the controller by using the ANN structure. The ANN is learning to approximate a desired reference hover hold through training by actual helicopter flight data.

The objective of this research was to create a tracking hover hold command. Therefore if the input is a hover hold, the helicopter will maintain a hover as it tracks the input command. To achieve this, the helicopter's output states were fed back into the ANN structure;

$$y(t) = g[y(t), y(t-1), \ldots, y(t-n), u(t), u(t-1)].$$

The output y(t) represents such physical parameters as acceleration, velocity and height of the helicopter and g(t) represents the nonlinear dynamics of the helicopter. An ANN was used to create a controller u(t),

$$u(t) = \hat{g}^{-1}[y(t) = g[y(t), y(t-1), \ldots, y(t-n), u(t), u(t-1)],$$

where $\hat{g}^{-1}(t)$ is the nonlinear inverse dynamics of the helicopter created by the ANN. The control objective is to have the inverse dynamics $\hat{g}^{-1}(t)$ and the actual dynamics g(t) cancel each other out; such that the input and output signal are equal,

$$y(t) = \frac{g(t)}{\hat{g}^{-1}(t)} r(t)$$

and therefore,

$$r(t) = y(t).$$

This means that if **r(t)** is the command to hover; the output **y(t)** will simply track the input command and hold a hover for the helicopter.

III. THE X-4P QUADROTOR HELICOPTER

The Draganfly X4-P quadrotor is an electric powered semi-autonomous UAV helicopter weighing 2.5 pounds (shown in Figure 2) and is being used to test the DIC techniques to simulate realistic flight conditions. The X-4P was instrumented with a number of sensors and a data recording device to collect flight data to compare the results from transfer functions with the flight data.

Figure 2. Draganfly X4-P Helicopter.

The CIFER (Comprehensive Identification from FrEquency Response) program developed by the U.S. Army, NASA, and Sterling Software has been used for our research [1] for system identification. The X-4P SISO transfer functions were developed by CIFER in order to compare results against the DIC control:

$$\frac{p}{\delta_{lat}} = \frac{277.7}{s^2+3.062s+420.8} \textbf{ (roll rate)}$$

$$\frac{q}{\delta_{lon}} = \frac{78.6}{s^2+3.062s+106.5} \textbf{ (pitch rate).}$$

IV. INITIAL RESEARCH RESULTS

This research is still ongoing; however the initial research is promising as shown in Figure 3. An ANN was trained using hover flight test data in MATLAB/Simulink. The DIC Control is able to hold a hover in simulation using flight test data. The next phase will be to test using the X-4P.

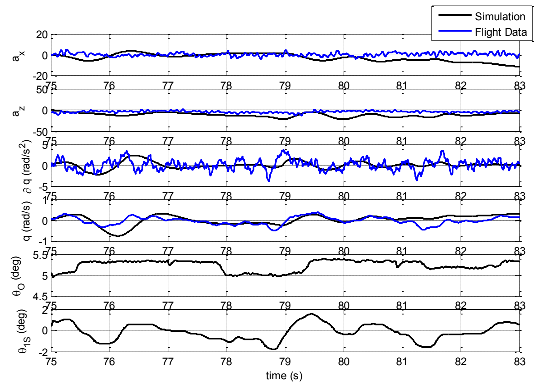

Figure 3. Simulation Results.

V. CONCULSION AND FUTURE WORK

This paper reviewed an application of Direct Inverse Control to the control of an Autonomous Helicopter in Hover mode. The initial results are promising and further research is being investigated to implement the DIC on the X-4P helicopter to test the hover envelope.

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