INVERSE NEURAL NETWORK CONTROLLER FOR CAMERA GIMBAL STABILIZATION

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Summary. In each regulation process, independently of the object of interest, we are trying to save as much energy as possible, and to achieve the highest possible quality of the control process. In order to decrease the time for the control algorithms proposal and tune, to increase quality, precision and to make control algorithms „smart“, several new approaches in cybernetics like fuzzy inference logic, artificial neural networks, hybrids systems, genetic algorithms, etc were invented. This article deals with the controlling of a camera gimbal aimed for Unmanned Aerial Vehicles (UAVs) using artificial neural networks and points out the main advantages of neural networks, like the simplicity of their application after training and their ability to control complex dynamic systems.

Keywords: neural network, camera gimbal, unmanned aerial vehicle

1. INTRODUCTION

The Department of Aviation Technical Studies at Faculty of Aeronautics, has been specialized on Unmanned Aerial Vehicles (UAVs) for several years. Initial attention was focused on the legislative frame and UAVs construction, then started works on onboard sensorics and electronics intended for the position angles and position determination that are important for the navigational purposes, and finally we dealt with the health monitoring, too [1,3,9]. Recently, our intention was to design the camera gimbal and to control it: stabilize and track the camera’s Line of Sight (LoS) to the object of interest [4].

2. CAMERA GIMBAL

In the market, there is a wide spectrum of camera gimbals that differ in a weight, dimensions, degrees of freedom, movement range and also in the precision. The top in the camera gimbals represents high quality gimbals with three degrees of freedom allowing rotation around all three axes. Based on the preliminary analysis and considering multirotor UAVs (that have been the main interest of the Department of Aviation Technical Studies) it is necessary to have the ability to compensate vehicle’s vibrations and to control gimbal, mounted on the multirotor UAV, in roll and pitch axis. Based on the afore mentioned requirements, the two degrees of freedom gimbal, powered by two high quality servomotors (MKDS18) with titanium gears and more than 5000 steps, were chosen, as presented in [5,6,10].

Figure 1 Quadrocopter during flight

Full movement range of the used camera gimbal is approximately ±30° in roll and pitch. Servomotors, as the classical modelers servomotors, are controlled by the PWM signal. As for the UAVs position determination, we have been using onboard electronics, based on the *mbed* or *Arduino* microcontroller for more than five years, and considering the fact that these microcontrollers are able to produce the PWM signal for servomotors needed for the camera gimbal mounted on the UAV, there will be no need to add any additional electronics, nor the sensors, so the previously used electronics can be reused only after the gimbal stabilization code upgrade [6].

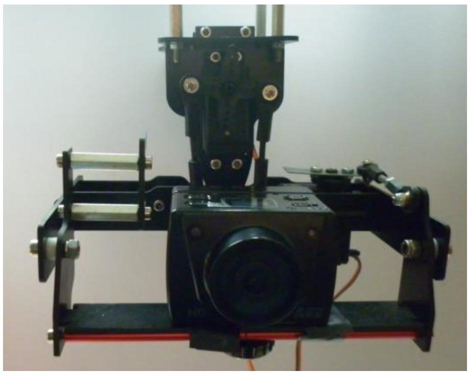

Figure 2 Camera gimbal with two degrees of freedom

Once servomotors were obtained, their dynamic characteristics and the precision on a specialized workstation were measured. Even though the high quality and fast actuators were chosen, after studies and precise analysis of the measured data, the transport delay was identified. The transport delay is really undesirable effect in many actuators, degrading their quality and usage, and affecting the controlling negatively. In some cases, the transport delay can even make the control impossible [4-6].

Even though there are many well known techniques for handling with the transport delay using the classical PID controllers, the quality of regulation process is highly dependent on precision of the mathematical model of the controlled system including the transport delay. Usually, and especially in application with high dynamics, control algorithms based on these techniques are not fast enough, causing oscillations in the regulation process and long regulation time. Due to these reasons, the decision to use a simple inverse control algorithm based on the neural network was made.

3. NEURAL NETWORKS

In the last decades, the usage of control systems based on the artificial neural networks has increased. Usually, the neural networks are successful in applications, where the classical PID controllers failed or their design is too complicated. The most important advantage of the neural network is a generalization - the ability of the neural network to predict output vectors for the inputs that the neural network has not been learned to [7-8].

Using the neural network for a system identification, it is possible to obtain a neuro – model. For the controlling purposes, the inverse neuro model (controller) will be used. The inverse neuro controller takes the pitch or roll angle as an input signal and calculates the output PWM signal.

Inverse model algorithms are open loop algorithms, without feedback, so the delayed response from the controlled system doesn't have to be taken into consideration. The block scheme of the proposed inverse neuro controller is illustrated on Fig. 3 [5].

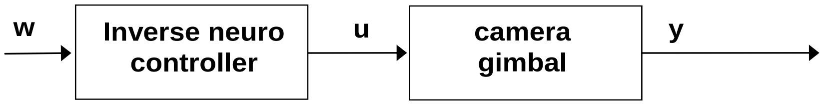

Figure 3 Block scheme of the inverse neuro controller

Inverse neuro controllers have several advantages that motivate users to implement them, for example:

- simple implementation as a controller,
- no need to know a functional principle of the controlled systems,
- no need to have a mathematical model of the controlled system [6-8].

The so called „life" cycle of the neural network consists of two parts. The first one is a learning process and the second part is its running in a real application. The precision of the inverse neuro controller depends on the learning process, so the high emphasis is put on the proper learning and validation data selection [5].

As the learning data, the special measured data consist of discrete steps (PWM varying from 1250 to 1700 μs, with a 20 μs step, staying in the steady state for 3 seconds) of the servomotor control PWM signal with measured roll and pitch angle (varying from –30° to +30°) of the camera gimbal. Learning data measurement took approximately 3 minutes [6].

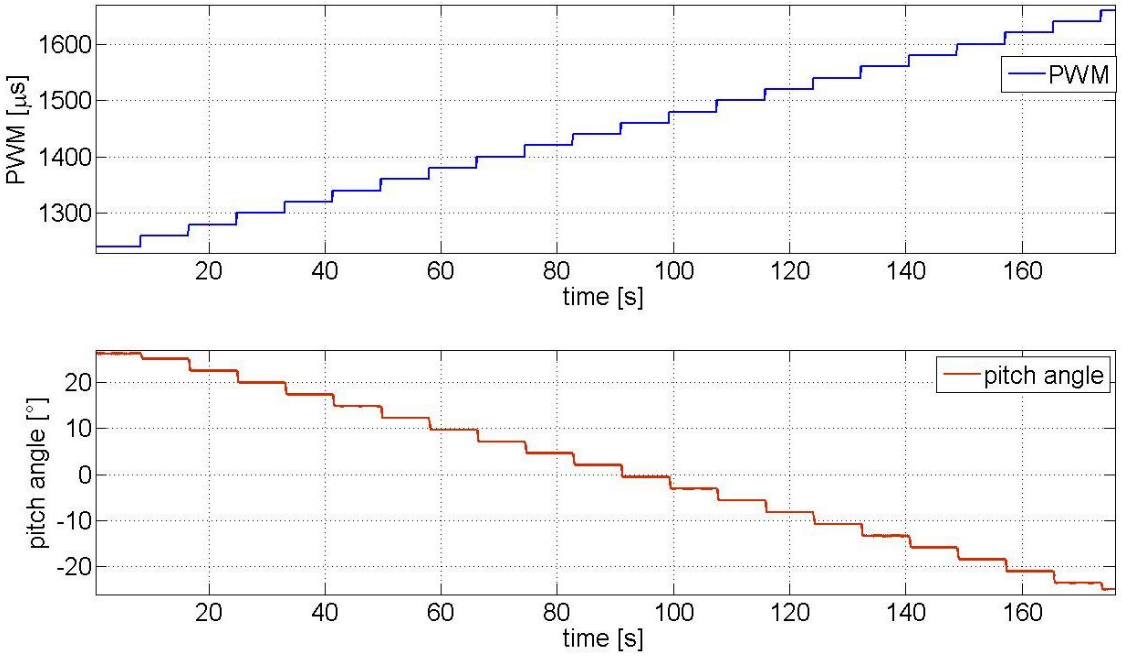

Figure 4 Learning data

4. INVERSE NEURAL CONTROLLER DESIGN

To create the learning and validation data, measured representative data for the learning process, consisting of the PWM signal and roll / pitch angle, were preprocessed and normalized. Several neural networks with different architectures were designed in a Matlab environment using the Neural Network Toolbox and the best inverse neural controller was selected and verified.

The proposed neural network consists of an input, one hidden and an output layer. The topology with a single hidden layer was selected as it is a sufficient topology in order to approximate an arbitrary continuous function. The input layer has 1 neuron, the numbers of neurons in the hidden layer was determined experimentally, where in each training session neurons were added up to the point where the precision for the given application was sufficient. This way we obtained 10 neurons in the hidden layer. Outputs from the hidden layer neurons are connected to the output neuron. For the learning of the neural network the scaled conjugate gradient method was used. This adaptive rule allows the neural network to converge to the searched solution faster. During the learning process, the synaptic weights were adapted using the conjugate gradient – a derivative of a gradient. Approximating the gradient gives the neural network the prediction ability [6, 8]. Proposed artificial neural network was efficient, not very large and can be implemented in embedded systems with lower computational power.

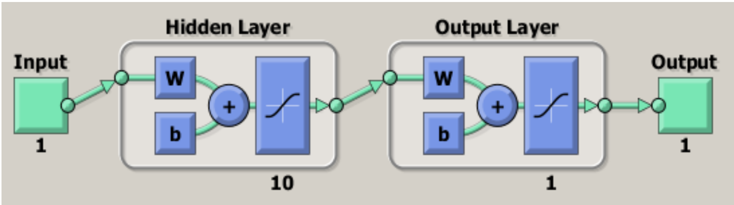

Figure 5 Used neural network architecture

4.1. SIMULATIONS AND RESULTS

After the neural network learning and validation processes were finished with satisfactory results, the inverse neuro controller was verified by a simulation. For the evaluation of reached results, the statistical errors: MAAE, MAE, MAPE were computed [6, 7]. During the verification, while changing the pitch angle in a range of 30°, the maximal steady state error of 1.69° and the maximal time delay between required and simulated camera gimbal pitch of 0.19 seconds was achieved.

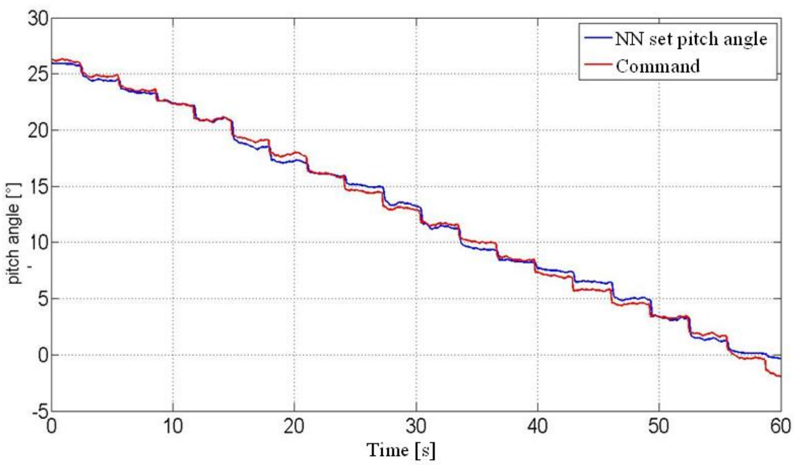

Figure 6 Verification of the proposed inverse neuro controller

MAAE=1.6916° MAE=0.3681° MAPE=0.9411 %

Considering the simulation verification results, the inverse neural controller is a suitable alternative for the camera gimbal control and stabilization. As the inverse neural controller is an open loop controller, it has some small steady state errors, but its biggest advantage is its speed, causing really small time delay in the process of regulation.

CONCLUSION

As UAVs are nowadays widely used for monitoring purposes, proposing and development of stabilized camera gimbals is really necessary. Since the majority of actuators are nonlinear systems with the transport delay, design of a precise mathematical model is time consuming and complex, similarly the proposal of a stable control algorithm is a difficult task and sometimes the results achieved with classical PID controllers are unsatisfactory. New progressive algorithms, such as artificial neural networks are predetermined for such complex applications. The main advantage of the control algorithms based on the neural networks is their design without the need of a mathematical model of the controlled system. For the camera gimbal stabilization, the open loop inverse neuro controller with the simple architecture, containing one input and one output neuron and 10 neurons in the hidden layer was designed in the Neural Network Toolbox of Matlab environment. Based on the simulation verification results, the proposed inverse neural controller achieved satisfactory results: maximal steady state error reached 1.69° in pitch angle, the controller was fast enough, as the maximal time delay reached only 0.19 seconds.

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