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UDC 621.865 **AUTOMATION AND CONTROL SYSTEMS**

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DESIGN OF CONTROL SYSTEMS OF UNMANNED AERIAL VEHICLES VIA A VICON MOTION CAPTURE SYSTEM

In the paper, an approach to the design of control systems of Unmanned Aerial Vehicles (UAVs) using the Simulink graphical package and the Vicon Motion Capture (MOCAP) System is discussed. The practical experiments were conducted on the basis of a Parrot Ar. Drone 2.0 at the Aerial Robotics Laboratory of National Polytechnic University of Armenia. Data transfer of the Parrot control system was implemented via Wi-Fi and the Vicon MOCAP system. The proposed approach allows implementing real-time selection of parameters of Proportional-Integral-Derivative (PID) regulators.

Keywords: control system, unmanned aerial vehicle, Wi-Fi signal, PID regulator, Vicon system, Parrot Ar. Drone 2.0.

Introduction. With the development of modern technology, UAVs have become more popular [1]. They have a simple structure and a very broad area of application. Nowadays the main problem connected with UAVs is the design of accurate flight control systems. The main objective of this paper is to design and implement an indoor autonomous flight control system for Unmanned Aerial Vehicle (UAV) on the basis of Parrot AR.Drone. Autonomous flight is achieved when the AR Drone is capable of following a predefined trajectory without any human interaction. For this purpose, a control algorithm for Parrot AR Drone designed by Mathworks under software Matlab/Simulink was used and enhanced. As a part of the control model development and enhancement, a Vicon Motion Capture (MOCAP) system [2] consisting of a set of cameras was integrated in real time with the AR Drone Matlab/Simulink dynamic model. Vicon MOCAP System was used to capture the position of the drone and compare it with the estimated position obtained from Parrot drone onboard sensors. It was noticed that the Vicon cameras’ position estimation was closer to the real position than the sensors’ estimation.

Vicon system. The Vicon MOCAP system belongs to the so-called passive systems [2]. The optical cameras of that system are accomplished with 12 LEDs which are distributed uniformly around the objective and emanate infrared light impulses. The positions of cameras are chosen so that the investigated object can be seen from all sides. On the other hand, special markers are placed (fixed) in the nodal points of the moving object (that is the object whose motion is to be captured). The markers are small plastic cores (having diameters from 0.5 *cm* to 2.5 *cm*) covered by a substance (paint) reflecting well the infrared radiation. The minimal number of markers fastened to a rigid body is three. The light impulses emanating from the optical cameras are reflected by the markers and registered by the sensitive to infrared radiation elements located in the focal planes of the cameras. All the output signals of active cameras are synchronized and fed to a special Vicon MOCAP work station which processes these signals in real time and creates a 3-D model of the moving object (as well as the 3-D virtual model of the working space), which shows the nodal points connected with straight lines by the Vicon software.

The Vicon MOCAP system is an integrated set of Vicon's devices and accompanied items (Fig. 1).

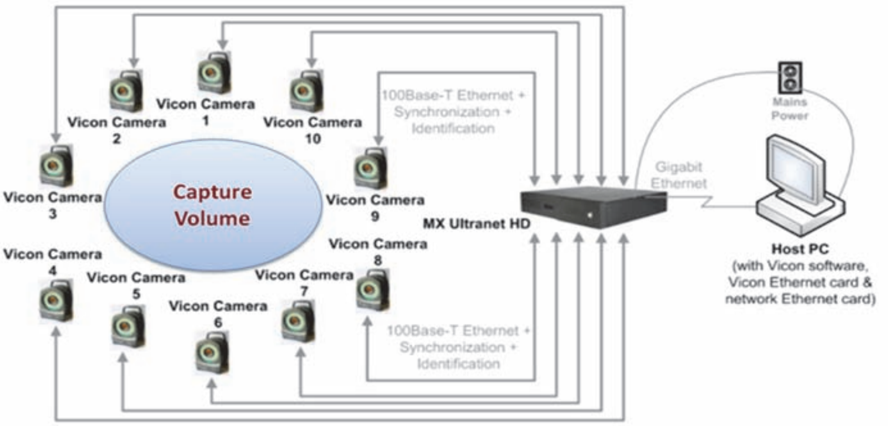

Fig. 1. Vicon Motion Capture system

The Vicon MOCAP system of the Aerial Robotics Laboratory at NPUA consists of 20 Vero V2.2 optical cameras (Fig. 2), a special Vicon MOCAP work station, powerful computers for processing the digit signals and other complex devices, which are placed in a special room and provide a working (capture) area of 10x10x3*m* for testing various moving mechanical objects.

Fig. 2. Vicon Vero V2.2 optical camera

In case of development and dynamics investigation of mechanical objects (UAVs, mobile robots, etc,) the output data stream of the Vicon system is transferred to an application computer, where MATLAB, LabVIEW and other specialized engineering software programs are installed (Fig. 3). These programs seem to allow embedding the application computer into the feedback loop of the control system of the moving mechanical object and perform all the necessary changes of control algorithms of the object in real time. As a result, the efficiency of developing UAVs and other objects' control systems is increased as many as ten times. Besides, the developer has an opportunity to implement such approaches and methods which would be impossible to use without the Vicon MOCAP system.

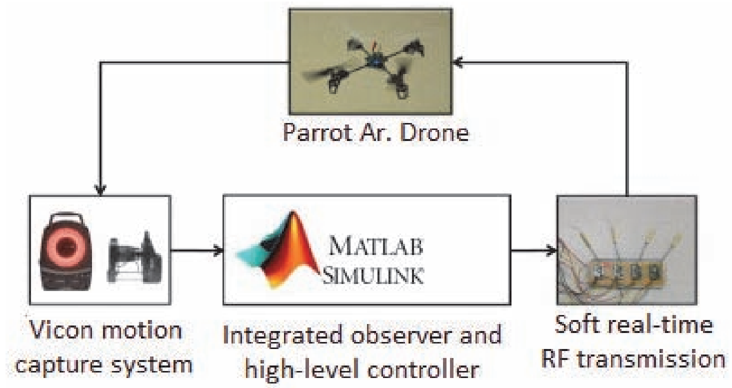

Fig. 3. UAV Control System

Structure of Parrot Ar. Drone 2.0 and its components. The Parrot AR Drone 2.0 is one type of UAV where AR stands for Augmented Reality. It is considered to be a multi-copter UAV or basically a quadrotor UAV. Parrot AR. Drone 2.0 was built by a French company called Parrot. Parrot AR. Drone 2.0 is typically composed of four propellers with four electric motors, one cross beam, two cameras, two electrical boards, a base house which is the place where all the above-mentioned components are connected to one another, two top covers (indoor and outdoor hulls) used to protect the UAV. Fig. 4 shows a Parrot AR Drone 2.0 with an indoor hull and an outdoor hull.

Fig. 4. AR.Drone 2.0 with Indoor and OUT hulls

There are four different types of sensors available in the AR Drone 2.0 which are: an accelerometer, a 3-axis gyroscope, a magnetometer, and an ultrasound altimeter sensor. The Parrot AR Drone 2.0 moves based on six degrees of freedom (DOF) which are the translational movement along the X, Y and Z axis and the rotational movements around the Pitch, Yaw, and Roll angles. The drone has four basic movements which are roll, yaw, upwards and pitch movements [3].

Control System. The control system of the drone along one axis has the following block diagram (Fig. 5).

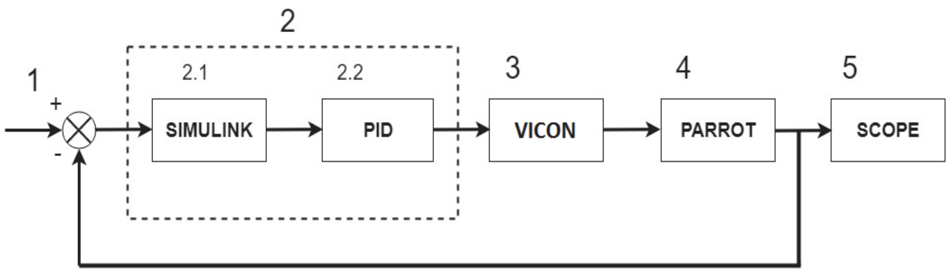

Fig. 5. Block diagram of the Parrot control system

where 1. Input signal, which is created by the computer.
2. Control part which consists of 2 subparts.
2.1. Simulink module.
2.2. PID regulator.
3. Converter, which sends signals to the drone via Wi-Fi and Vicon system.
4. Parrot AR Drone 2.0.
5. Graphical outputs.

The first objective of the work was to control the drone autonomously along a predefined path. The Simulink model in Fig. 6 consists of many blocks which are integrated together to control the drone and actually contains two programs.

The first program is used for Wi-Fi control code which receives the real sensor measurements from the drone, compares them with the desired waypoints given by the user and calculate the required control inputs which are sent as commands to the drone. This model requires having an AR Drone connected to the PC via Wi-Fi during execution.

The other program is used for simulation and includes all mathematical equations representing the behaviour or the model of the drone. The feedback from the drone is estimated here using its dynamic model.

Fig. 6. Program block in SIMULINK

The PID regulator block in the Simulink model is shown in Fig. 7.

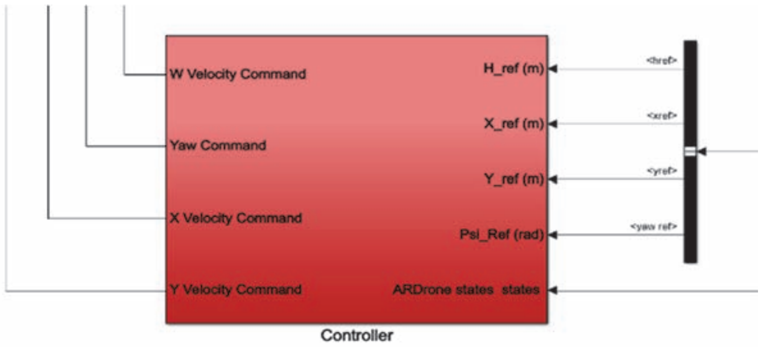

Fig. 7. Regulator block

Design of PID regulator. In one of the standard forms of PID regulators, the output signal ($U_{PID}(t)$) is associated with the error signal $\varepsilon(t)$ in the following way [4]:

$$U_{PID}(t) = K_e\left[K_P\varepsilon(t) + K_I\int\varepsilon(t)dt + K_D\frac{d\varepsilon(t)}{dt}\right]. \quad (1)$$

Applying the Laplace transform to (1) yields:

$$U_{PID}(s) = K_e\left[K_P + \frac{K_I}{s} + K_D s\right]\varepsilon(s)\,. \quad (2)$$

The PID regulator used in control systems of the Parrot drone has a more general form, which includes the low-frequency filter of the derivative term:

$$U_{PID}(s) = K_P + \frac{K_I}{s} + K_D s W_F(s)\,, \tag{3}$$

where

$$W_F(s) = \frac{1}{T_D s + 1}\,. \tag{4}$$

Equation (3) can be reduced to the following form:

$$W_{PID}(s) = K_P + K_I \frac{1}{s} + K_D \frac{N}{1 + N/s}\,, \tag{5}$$

where $N = 1/T_D$. The value of N in (5) was chosen equal to 100 due to the recommendation given in [3] . The four basic movements of the Parrot drone with respect to roll, yaw, upward and pitch axis are controlled independently by four separate PID regulators, as shown in Fig. 8.

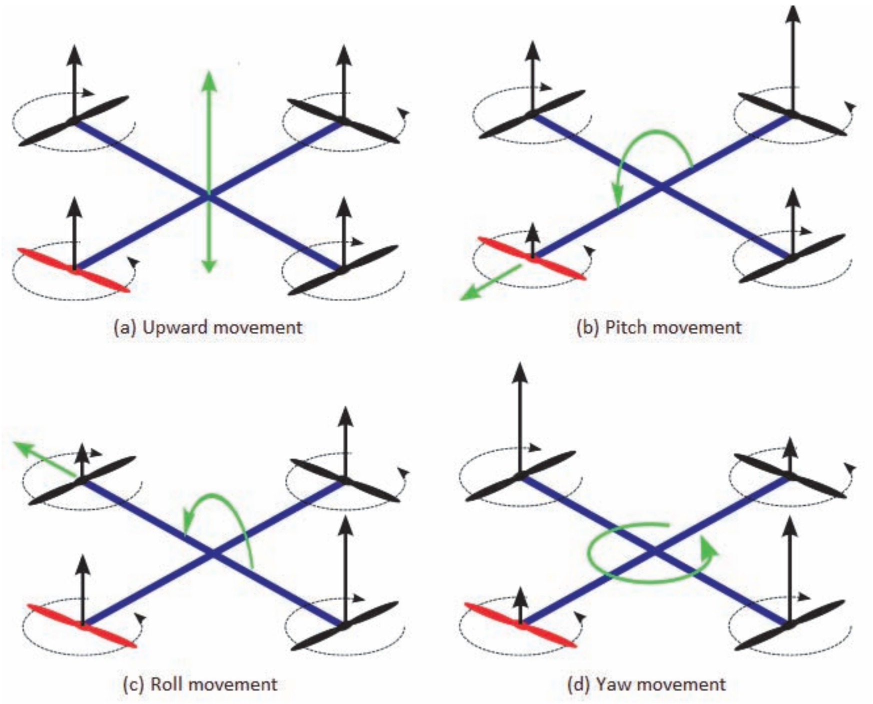

Fig. 8. UAV‘s directions of movement

The coefficients of the PID regulators of the above-mentioned separate control channels are presented in the Table.

Table

	Coefficients for upward movement	Coefficients for pitch movement	Coefficients for roll movement	Coefficients for yaw movement
K_P	-1	0.4	-0.5	1.2
K_I	0	0	0	0
K_D	0	0	-0.01	0

The experimental transient responses of the Parrot drone's vertical ascent (along the z axis) from the ground (zero) level to 0.6m are shown in Fig. 9, where the solid line depicts the signals of the Vicon MOCAP system, and the dotted line corresponds to signals from the drone's onboard sensors.

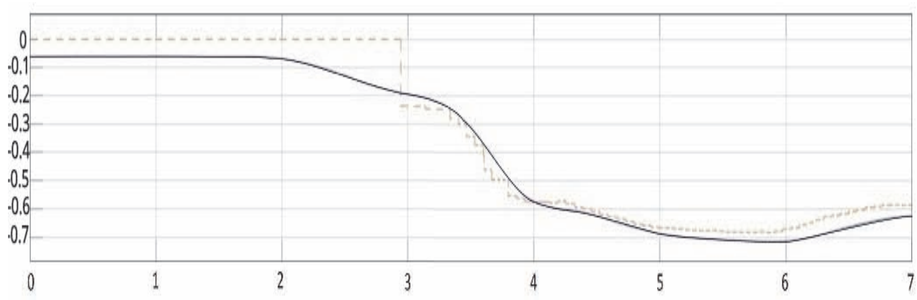

Fig.9. Transition graph for z-axis

Conclusion. Summarizing, the issue of designing the control system of UAVs using the Vicon MOCAP system and Matlab/Simulink software is discussed in the paper. The position of the Parrot AR Drone while hovering was measured by the drone's on-board sensors and transmitted wirelessly by Wi-Fi to the base workstation. The real position of the drone was measured by the Vicon system and also transferred to the same workstation. Such an approach allows one to implementing a real-time choice of parameters of the PID regulators. In perspective, the results of this work can be used in performing cooperative flight control of two or more drones.

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VICON ՇԱՐԺՈՒՄԸ ԳՐԱՆՑՈՂ ՀԱՄԱԿԱՐԳԻ ՄԻՋՈՑՈՎ ԱՆՕԴԱՉՈՒ ԹՌՉՈՂ ԱՊԱՐԱՏՆԵՐԻ ԿԱՌԱՎԱՐՄԱՆ ՀԱՄԱԿԱՐԳԵՐԻ ՆԱԽԱԳԾՄԱՆ ՄԱՍԻՆ

Դիտարկված է անօդաչու թռչող ապարատների (ԱԹԱ-ների) կառավարման համակարգի նախագծման մոտեցում՝ օգտագործելով Simulink գրաֆիկական ծրագրավորման միջավայրը և Vicon շարժումը գրանցող (MOCAP) համակարգը: Գործնական փորձարկումները կատարվել են Parrot Ar. Drone 2.0 ԱԹԱ-ի հիման վրա Հայաստանի ազգային պոլիտեխնիկական համալսարանի «Օդային ռոբոտատեխնիկա» լաբորատորիայում: ԱԹԱ-ի կառավարման համակարգի տվյալների փոխանցումները կատարվել են Wi-Fi-ի և Vicon MOCAP համակարգի միջոցով: Առաջարկվող մոտեցումը թույլ է տալիս կատարել համեմատական ինտեգրա-դիֆերենցող (ՀԻԴ) կարգավորիչի պարամետրերի ընտրությունը իրական ժամանակում:

Առանցքային բառեր. կառավարման համակարգ, անօդաչու թռչող ապարատ, Wi-Fi, Vicon համակարգ, Parrot Ar. Drone 2.0:

А.В. ДАВТЯН

К ПРОЕКТИРОВАНИЮ СИСТЕМ УПРАВЛЕНИЯ БЕСПИЛОТНЫХ ЛЕТАТЕЛЬНЫХ АППАРАТОВ С ПОМОЩЬЮ СИСТЕМЫ ЗАХВАТА ДВИЖЕНИЯ VICON

Рассмотрен подход к проектированию систем управления беспилотных летательных аппаратов (БПЛА) с использованием графического пакета Simulink и системы захвата движения Vicon. Практические эксперименты были осуществлены на основе дрона Parrot Ar. Drone 2.0 в лаборатории "Воздушная робототехника" Национального политехнического университета Армении. Обмен данных от системы управления дрона осуществлялся посредством сигналов Wi-Fi и системы Vicon. Предложенный подход позволяет производить выбор параметров пропорционально-интегрально-дифференцирующих (ПИД) регуляторов в реальном масштабе времени.

Ключевые слова: система управления, беспилотный летательный аппарат, Wi-Fi, пропорционально-интегрально-дифференцирующий (ПИД) регулятор, система Vicon, Parrot Ar. Drone 2.0.