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INFLUENCE OF SLOPE SURFACE ON TAKEOFF AND LANDING IN UNMANNED QUADROCOPTER FLIGHT

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The necessity of analyzing and modeling process of the takeoff unmanned quadrocopter from the inclined plane and landing it on an inclined plane is described. Through mathematical modeling the basic features of influence of slope the start and landing unmanned quadrocopter on the process output to the desired waypoint are considered. The methods of the takeoff and the landing unmanned quadrocopter which is on an inclined plane are proposed.
Key words: quadrocopter, altimeter, 3-axis gyroscope, 3-axis accelerometer, 3-axis magnetometer, control.

Introduction. Traditionally mathematical quadrocopter model is describing the dynamic processes in the system as a whole at zero initial conditions [1-7]. This means that quadrocopter is standing on a horizontal plane at takeoff. The landing is down on the same horizontal plane. Profile places of quadrocopter takeoff / landing consists of individual sections of the rise or of descend and less with of the horizontal sections. The steepness of the ascent or descent of areas are characterizing by longitudinal and transverse biases. Movement of quadrocopter is done on three axes: of longitudinal, transverse and vertical. The quadrocopter constructions axis, which was laid about the design, is used as the longitudinal axis. When rotating around it the quadrocopter does down at the one side and lifts the other side of the console with attached to it by motor. This movement is called a Roll. The transverse axis - the axis is perpendicular to the plane of quadrocopter symmetry directed toward the right console, complementing thus coordinate system related to the right system of three vectors. The quadrocopter lowers or raises the nose, when rotating around this axis. This movement and the angle between the longitudinal axis and the horizontal plane of quadrocopter are called a Pitch. There pitch with increasing angle - pitch up, and with decreasing angle - dive. The rotation around the vertical axis and angle, which means the housing quadrocopter angle in the horizontal plane, measured from the direction north is called a Yaw. The three corners, roll, pitch and yaw are for determinate the slope of the aircraft about its center. It is important to know a influence the dynamics of quadrocopter the non-zero values angles roll, pitch and yaw, which are caused by slope place of the takeoff / landing unmanned (UAV) of quadrocopter.

Block diagram of quadrokopter with regulator. Quadrocopter constructively is a combination of two subsystems: the actual quadrocopter like electromechanical subsystem and board flight control how electronic subsystem.

Electromechanical subsystem is implemented as a crosswise-beam structure, which at each end of the same length beams are attached electric DC motors with immutable angles of attack the air propellers. Tractions of all four pairs of electric motor-propeller of quadrocopter are directed perpendicular to the beam construction, with engines on adjacent ends of beams with different propellers, one of them - right propeller, another - left. Rotor speed motors and therefore thrust propeller are changed by changing the voltage that supplies to windings of electric motors [4-7].

Electronic subsystem is implemented as a control board of power traction motors by determining the voltage to be submitted to the respective electric coils to move the quadrocopter at given trajectory. The process of calculating the value of microcontroller control signals occurs after measurements sensors.

In fig. 1 shows a block diagram model of quadrocopter together with the control board and sensors, where Z – quadrocopter altitude, V_z – vertical velocity component, γ, θ, ψ – corresponding angles of roll, pitch and yaw, ω_γ, ω_θ, ω_ψ – angular velocities of quadrocopter, U_1, U_2, U_3, U_4 – voltages submitted for engines of quadrocopter. The block of sensors are consists altimeter, 3-axis gyroscope, 3-axis accelerometer and 3-axis magnetometer.

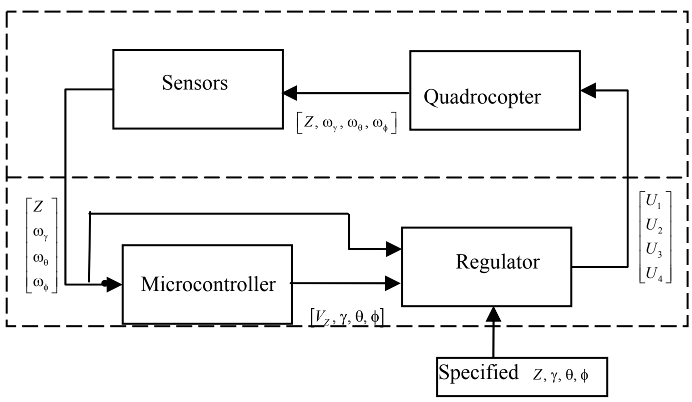

Fig.1. Block diagram of quadrocopter with regulator

Mathematical model of quadrokopter. Mathematical model of quadrocopter in flight, taking into account characteristics of sensors is considered as two essentially different mathematical models. Actually in a mathematical model quadrocopter as UAV inputs are connected to the power supply voltage of electric motors. Its outputs are the angled shaft rotational speeds of electric motors. And a mathematical model of PD regulator whose input is fed from the sensors the measured values and microcontroller implements the algorithm PD controller and displays values the output voltages of engines.

The system of differential equations 16th manner in the form of Cauchy describes mathematical model of quadrocopter in flight [5-7].

The regulator, which sets the required voltages to the engines of propellers, is used for flight control of the quadrocopter. In this paper selected proportional-differential regulator (PD). Controller regulates the altitude and angles of quadrocopter by changing the vertical component thrust and torque of engines.

The height Z is determined by the altimeter. We are computing vertical speed by numerically differentiating the quadrocopter altitude. The angular velocities (ω_γ, ω_θ and ω_ψ) determines 3-axis gyroscope. It is appropriate changes in the state model of quadrocopter. Using numerical integration formula we are calculating the angles of pitch, roll and yaw. The gyroscope has offset Δ. Obtain the formula for calculating the angle of heel at time t_{i+1} based on the values of these angles at time t_i

$$\gamma_{i+1} = \int_{t_i}^{t_{i+1}} \omega_\gamma(t)\,dt + \int_{t_i}^{t_{i+1}} \Delta_\gamma dt + \gamma_i \approx \gamma_i + \omega_{\gamma,i} \cdot (t_{i+1} - t_i) + \Delta_\gamma \cdot (t_{i+1} - t_i)$$

Similarly had been calculated angles of pitch and yaw. Due zero error of the gyro (third summand) the error of the angles of pitch, roll and yaw will accumulate. This leads to deviations from the set trajectory.

To corrected angles of calculation of quadrocopter position is using amendment of these angles through accelerometer. 3-axis accelerometer provides projections (A_{xo}, $A_{yo,}$ A_{zo}) of values of the vector acceleration of gravity and of the vector absolute acceleration on the axis X_o, Y_o, Z_o of coordinate system coupled with the object. When stationary object or when uniform motion the above titles of projections are projections of the vector acceleration of gravity $\vec{G}$ on the axis X_o, Y_o, Z_o of quadrocopter. To correct the yaw angle use magnetometer. 3-axis magnetometer determines the projection of magnetic induction on the axis X_o, Y_o, Z_o of quadrocopter (according B_{xo}, B_{yo} та B_{zo}).

For analysis and mathematical modeling used implicit method Runge-Kutta TR-BDF2.

Для аналізу та математичного моделювання використовувався неявний метод Рунге-Кутта TR-BDF2. In the first phase the equation is integrating by trapezoidal rule and on the second stage is using of the formula of differentiation of second order back [8].

Mathematical modeling takeoff of quadrocopter from of inclined surface. The takeoff of quadrocopter with horizontal surface is done vertically [1-7, 9]. This is because in this case the reaction of support is equal zero. Attempted of vertical takeoff quadrocopter with of the inclined surface can lead to unpredictable consequences. The main reason this is sliding friction. It is impossible to predict the means of the coefficient of friction under the surface of the chassis quadrocopter. However, from a practical point of view it is clear that at rest, in the static, quadrocopter should not slide down of the inclined plane slope. In the dynamics at engines inclusion the situation looks different. On slick surfaces quadrocopter moves over the surface in uncontrollable direction without takeoff in of the sky. On of the rough surface the quadrocopter or uncontrollably rises in the any direction, or is flipped at hitting to the surface by propellers.

It is proposed to carry out the quadrocopter rise with the inclined plane in the direction perpendicular to the plane from of the mute control. The traction of all four pairs an electric motor-propeller also are directed perpendicular to the plane of the beam construction, it is sufficient at all the four electric motors energize the same voltages. After quadrocopter flied away on a certain distance from the plane the controller is included and flight program continues running from regulator.

The simulations of autonomy quadrocopter rise to a height of 3.5m above the portion by size 25x20m were done. The horizontal section contains a domed mountain by height of 2.0m with center coordinates X = 0m, Y = 0m and 6.28m in diameter.

On fig. 2 listed quadrocopter trajectory at various angles longitudinal slope of inclined plane. Initial placement of quadrocopter is characterized by angles of the inclined plane:

pitch=0°, yaw=90°, roll=-30° ÷ +30°. Trajectory # 1 shows the takeoff of quadrocopter with inclined surface for roll #1 – -30°, #2 – -15°, #4 – +15°, #5 – +30° . The trajectory # 3 – 0° of the traditional vertical takeoff of quadrocopter with of horizontal plane is listed for comparison. For all points of takeoff the coordinate X = 0m, and coordinates Y and Z comply to elected roll angles.

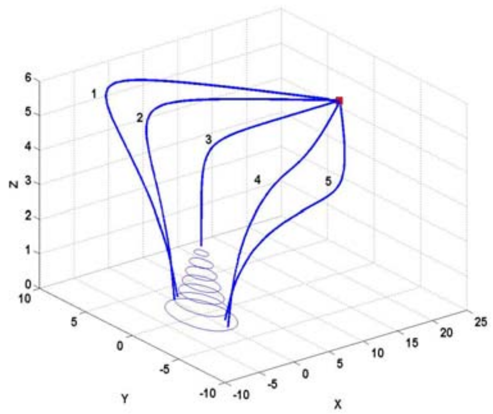

Fig.2. Quadrocopter flight trajectories
from different angles of the longitudinal inclination of inclined plane.

In fig. 3 listed quadrocopter trajectory on various angles of the cross slope of inclined plane. Initial placement of quadrocopter is characterized by angles of the inclined plane: roll =0°, yaw =90°, pitch =-30° ÷ +30°. Trajectory # 1 shows the takeoff of quadrocopter with inclined surface for #1 – -30°, #2 – -15°, #4 – +15°, #5 – +30°. The trajectory # 3 – 0° of the traditional vertical takeoff of quadrocopter with of horizontal plane is listed for comparison. For all points of takeoff the coordinate Y = 0m, and coordinates X and Z comply to elected pitch angles.

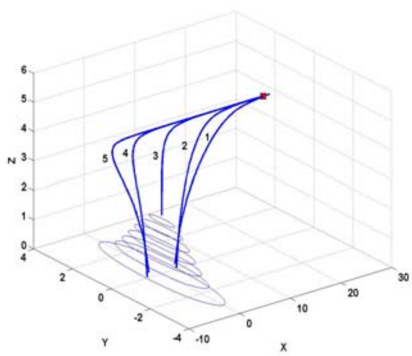

Fig.3 .Quadrocopter flight trajectories
from different angles of the cross inclination of inclined plane.

Mathematical modelling of the quadrocopter landing on an inclined surface. Implementation of the quadrocopter landing to an inclined plane is heavier than implementation its takeoff from an inclined plane. In fact, after landing quadrocopter should be ready for a new start with the same nonzero initial conditions as in the take-off of an inclined plane.

It is proposed to carry out the quadrocopter landing to an inclined plane in two stages. When approaching to the landing point the regulator sets height 0.5m. So the quadrocopter is backed at the point takeoff on a height of 0.5m. Then the regulator is switched off and quadrocopter is landed on inclined plane as with manual control [9].

In fig. 4 listed the trajectory of the quadrocopter landing on an inclined plane for approaching it from four different sides of the world. All trajectories converge at a height of 0.5m at the same point site of the landing.

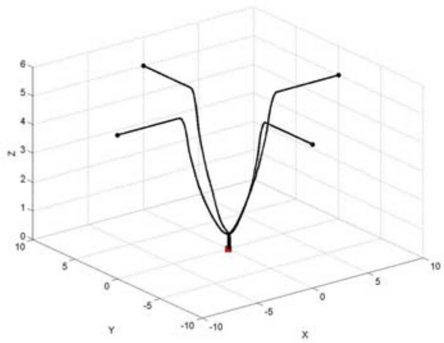

Fig.4. Trajectory of the quadrocopter landing on an inclined plane
for approaching it from four different sides of the world.

Conclusions. The studies determine the effectiveness and practical significance of the proposed methods takeoff of quadrocopter from the inclined plane and landing it on the inclined plane. It is proposed to carry out the quadrocopter rise with the inclined plane in the direction perpendicular to the plane from of the mute control. After quadrocopter flied away on a certain distance from the plane the controller is included and flight program continues running from regulator. It is proposed to carry out the quadrocopter landing to an inclined plane in two stages. When approaching to the landing point the regulator sets height 0,5 m. Then the regulator is switched off and quadrocopter is landed on inclined plane as with manual control.

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ВПЛИВ УХИЛУ ПОВЕРХНІ НА ЗЛІТ І ПОСАДКУ КВАДРОКОПТЕРА У БЕЗПІЛОТНОМУ ПОЛЬОТІ

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Обгрунтована необхідність аналізу та моделювання процесу злету безпілотного квадрокоптера з похилої площини і приземлення його на похилу площину. За допомогою математичного моделювання розглянуті основні особливості впливу ухилу місця старту і приземлення безпілотного квадрокоптера на процес виходу до потрібної точки маршруту. Запропоновано методи злету та приземлення безпілотного квадрокоптера, який знаходиться на похилій площині.

Ключові слова: квадрокоптер, висотомір, 3-осьовий гіроскоп, 3- осьовий акселерометр, 3- осьовий магнітометр, управління.