QUATERNION-BASED CONTROL OF A MULTIROTOR HELICOPTER: ITS APPLICATION TO PLANETARY SCIENCE.

J. Petényi[1] and A. Gucsik[2], [1]Buki sor 12, Vác, Hungary 2600; jozsef.petenyi@gmail.com, [2]Wigner Research Center for Physics, Hungarian Academic for Sciences, Konkoli Thege út 29-33, 1121 Budapest, Hungary sopronianglicus@gmail.com.

Introduction: Quadrotor helicopters have become increasingly important in recent years as platforms for both research and commercial unmanned aerial vehicle applications. This paper proposes a robust controller for the attitude tracking of quadrotors subjected to disturbances and parameter uncertainties. Multi-rotor vehicles utilize motors to control thrust forces, and resultant torques independently and thus are capable of simultaneous control over their rotational and translational motion [1]. In most cases, the quadrotors are symmetrical, which rotors located on the peaks of a square.

The problem of orientation control for multi rotor helicopters has been addressed by several researchers. Mellinger et al. [2], Bouabdallah and Siegwart [1], Beard [3], Li et al. [4] and others have used the Euler-angles orientation representation, which is the most widely used parametrization due to its simplicity. Lee et al. [5], Goodarzi et al. [6] have used rotation matrices on the special orthogonal group to avoid the singularities associated with Euler-angles. Guerrero et al. [7], Stingu and Lewis [8], Fresk and Nikolakopoulos [9], Abaunza et al. [10], Carino et al. [11] and many others utilized quaternion mathematics to solve this problem. In order to influence the motion all of the 6 degrees of freedom, the rotational and translational movements must be coupled [12].

This study presents a kinematics-based approach to control multi-rotor helicopters. The proposed algorithm calculates the shortest arc, which the craft should follow to reach its desired attitude. This helps achieving better convergence for orientation control. Furthermore the simplicity of the algorithm ensures real time capability for controlling crafts even with large angles as well.

It is also a purpose to utilize the above mentioned method in the planetary exploration missions, such as robotic missions in Mars, as well as asteroidal bodies.

Dynamic modelling: The calculations were based on Newton's second law as follows (see Figure 1.)

$$m\ddot{\mathbf{x}}(t) = \mathbf{F}_g + \mathbf{R}_q^T(\mathbf{q}(t))\mathbf{F}(t), \tag{1}$$

and

$$\mathbf{I}\dot{\boldsymbol{\omega}}(t) + \boldsymbol{\omega}(t) \times \big(\mathbf{I}\boldsymbol{\omega}(t)\big) = \mathbf{M}(t), \tag{2}$$

where m is the mass, $\mathbf{x}(t)$ is the position, $\mathbf{F}_g$ is the gravity vector, $\mathbf{R}_q^T(\mathbf{q}(t))$ is the rotation transformed from quaternion to rotation-matrix, $\mathbf{F}(t)$ is the resultant force, $\mathbf{I}$ is the mass moment of inertia, $\boldsymbol{\omega}(t)$ is the angular velocity, and $\mathbf{M}(t)$ is the resultant moment.

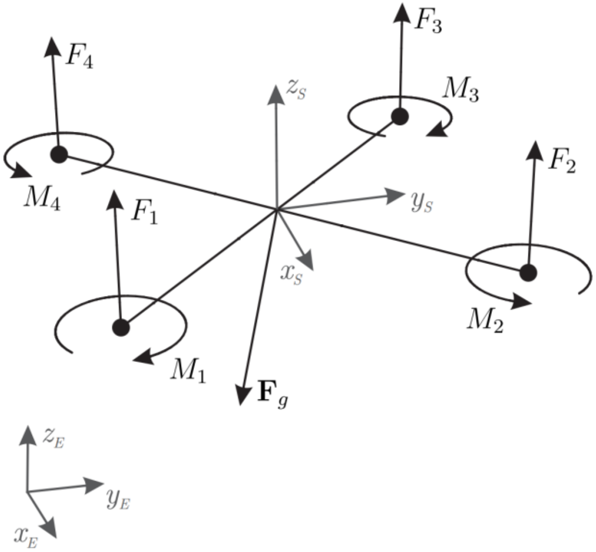

Figure 1: Free-body diagram of the quadrotor

Furthermore, the rotordynamics were approximated by a second order differential equation based on experimental results.

Control: Quadrotors usually have low mass moment of inertia along with propellers placed outwards, which result in high achievable angular accelerations, therefore tracking the body's rate can be done with low time delays. This is usually achieved by usinghigh-bandwidth controllers with the feedback from gyroscopes. Accordingly it is assumed that a nested controller is being used, where the angular velocity control loop is available to accurately track the desired body rates.

In the following a novel approach can be found to implement the orientation control layer, which applies quaternion algebra. In the proposed approach every calculation have been made by utilizing quaternions,

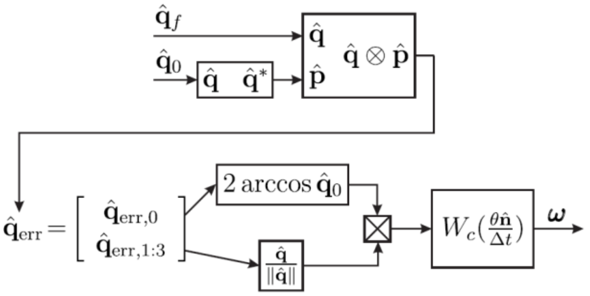

Figure 2: Schematic of the proposed control layer

without using Euler-angles. The controller can be easily implemented and has no problems with singularities.The output of the controller is the function of the desired orientation $\hat{\mathbf{q}}_f$ and the actual orientation $\hat{\mathbf{q}}_0$. The reference signal is the requirement of the pilot or an upper control layer, which is easily computable. The rotation difference between the two orientation is the error, which we want to minimize.

Results and discussion: The simulation is done in Matlab. Throughout the simulation a PID controller is applied with the same tuning parameters in case of the novel and the Eulerian method as well.
The initial condition is
$\mathbf{X}_r = [0, 50, 50]^T$deg.
Here the nonlinear behavior of theEuler-angle method is expected. The result is shown in Figure 3., where the advantage of the proposed method is clear. The controller brings the orientation to the desired value fast and a robust manner.

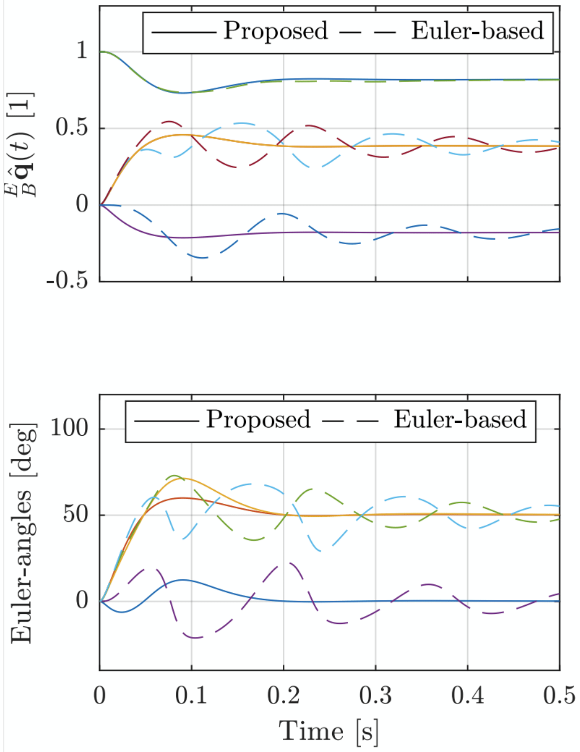

Figure 3: Spatial step response with large angles

In this paper a novel control method presented for multirotor helicopters. The dynamic model is derived in quaternion form, which simplied the resulting equations. The algorithm is simple, computationally effective and can be easily implemented, so it is suitable for on-board real-time controllers as well. In order to make visible the advantage of the method, a numerical simulation is performed.

Conclusion: In terms of planatory sciences this methodology shows some advantages as follows. It allows to control some aggressive movement against cross wind during landing for instance. It helps to have quadrotors into goorges as well as caves, which are important targets in the planatory exploration programs. Moreover quadrotors controlled by this method could carry some facilities including hyperspectral camera for the insitu rock and mineral anaysis on the planatory surfaces [13]. Furthermore the above mentioned technuque helps in the meteorite survey in Antarctica, too.

References: [1] Bouabdallah S. and Siegwart, R. (2007) In:Intelligent robots andsystems, IEEE/RSJ international conference. pp. 153-158. [2] Mellinger D. et al. (2010) In:Proceedings of the International Powered Lift Conference. pp. 205-225. [3] Beard R. (2008) Quadrotor dynamics and controlrev 0.1. [4] Li S. et al. (2017) In:Nonlinear Dynamics, pp. 1-11. [5] Lee T. et al. (2013) Asian Journal of Control 15.2, pp. 391-408. [6] Goodarzi F.A. et al. (2015) Journal of Dynamic Systems, Measurement, and Control 137.9, p. 091007. [7] Guerrero M.E. et al. (2016) International Conference on. IEEE. pp. 144-151.[8] Stingu E. and Lewis F. (2009) In:Control and Automation,pp. 1233-1238. [9] Fresk E. and Nikolakopoulos G. (2013) In:Control Conference (ECC), pp. 3864-3869. [10] Abaunza H. et al. (2015) In:Research, Education and De-velopment of Unmanned Aerial Systems (RED-UAS), pp. 195-203. [11] Carino J. et al. (2015) In: Unmanned Aircraft Systems (ICUAS), pp. 825-831. [12] Gabriel M.H. et al. (2007) In:Proc. of the AIAA Guidance, Navigation, and Control Conference. Vol. 2. 2007, p. 4. [13] Kalmár S. and Gucsik A., (2011) Preliminary Results of the Airborne Hyperspectral Remote Sensing Applied to the Antarctic Meteorite Survey.