Stjepan Bogdan[1], Matko Orsag[1], Marko Car[1], Antun Ivanović[1]

Aerial Robotics – Unmanned Aerial Vehicles in Interaction with the Environment

[1]Faculty of Electrical Engineering and Computing, University of Zagreb, Zagreb, Croatia

Abstract

Defined as technology that provides services and facilitates the execution of tasks (such as observation, inspection, mapping, search and rescue, maintenance, etc.) by using unmanned aerial vehicles equipped with various sensors and actuators, aerial robotics in one of the fastest growing field in research as well as in the industry. While some of the services provided by aerial robots have already been put into practice (for example aerial inspection and aerial mapping), others (like aerial manipulation) are still at the level of laboratory experimentation on account of their complexity. The ability of an aerial robotic system to interact physically with objects within its surroundings completely transforms the way we view applications of unmanned aerial systems in near-Earth environments. This change in paradigm conveying such new functionalities as aerial tactile inspection; aerial repair, construction, and assembly; aerial agricultural care; and aerial urban sanitation requires an extension of current modeling and control techniques as well as the development of novel concepts. In this article we are giving a very brief introduction to the field of aerial robots.

Keywords: *unmanned aerial vehicle, aerial robotics, aerial manipulation*

1. Introduction

A huge impact of Unmanned Aerial Vehicle (UAV) technologies evolution has been pointed out by several studies. According to the report [1], the total addressable value of UAV powered solutions in all applicable industries is estimated at over $127 billion (bn) in 2015 in the world (see Table 1).

Table 1. Value of UAV powered solutions (in $bn)

Infrastructure	45.2	Telecommunication	6.3
Transport	13	Agriculture	32.4
Insurance	6.8	Security	10.5
Media and Entertainment	8.8	Mining	4.3
Total			127.3

The industry with the best prospects for UAV applications is the infrastructure with total addressable value of just over $45bn. This includes investment monitoring, maintenance and asset monitoring. The study [2] is devoted to UAV inspection applications Beyond Visual Line of Sight (BVLOS) and has pointed out that in oil and gas a 1% change in downtime can result in $600,000 revenue lost in a day. In this industry any slight improvement in asset utilization can result in a significant gain in revenue and cash flow: Companies could lose up to 5% of production due to unplanned down. The average impact of unscheduled downtime caused process companies to lose more than $20 billion in production annually. UAVs reduce inspection costs by approximately 66%. For example, the cost with traditional methods is $80-$90 per well pad, with 5-10 inspected per day. The costs with drones in the Visual Line of Sight (VLOS) is $45-$60, with about 8-16 inspected per day. For BVLOS applications it is $30-$50 with 100-125 inspected per day. The SESAR UAV study [3] is very relevant concerning the impact in Europe. According to the study, the

European demand will be more than EUR 10 billion annually by 2035 and over EUR 15 billion annually by 2050. Particularly, government and commercial business applications will represent the majority with more than EUR 5 billion of annual value by 2035 (the estimated potential is over 100,000 UAVs by 2035). All these numbers clearly show that industries related to UAVs are one of the fastest growing market with huge potentials.

As many of potential applications require interaction of UAVs with the environment (contact between robotics arms or tools on-board the vehicle with infrastructure), one of the major research topics in the UAV research field is related to the analysis of phenomena once an UAV is in contact with the surrounding as well as the synthesis of the controllers that ensure the stable behavior of an aerial manipulator.

2. UAV related research in LARICS

Starting in 2006, research of aerial systems has become one of the major research lines of LARICS (larics.fer.hr) over the last 10 years. Mainly focused on multirotor systems, studies included i) UAV design [4, 5], ii) analysis of UAV dynamics and kinematics [6], iii) design of UAV controllers [7], iv) design and control of aerial manipulators [8], and v) mission planning and scheduling for cooperative teams of aerial and ground vehicles [9].

Currently LARICS researchers are involved in the following projects that are related to UAVs: AeroTwin – Twinning coordination action for spreading excellence in Aerial Robotics (H2020), ENCORE – ENergy aware BIM Cloud Platform in a COst-effective Building REnovation Context (H2020), MORUS – Unmanned system for maritime security and environmental monitoring (NATO), Specularia – Structured Ecological CULtivation with Autonomous Robots In Agriculture (HRZZ), EuRoC – Wind generator remote inspection system (FP7), and MBZIRC – Mohamed Bin Zayed International Robotics Challenge (Khalifa University). In the rest of the paper we shortly present our results of research on UAVs in interaction with the environment, namely, transportation of a package and an ultra-light ground vehicle and peg-in-hole insertion task.

3. UAV in interaction with the environment

The first example we present herein considers a system comprised of two distinct agents with specific capabilities – a mobile unmanned aerial vehicle (UAV) with a manipulator and a lightweight ground vehicle (L-UGV) [9]. This two-agent system has a task to find a package in an unknown environment and to deliver the package to the predefined position by executing a mission that is optimal from the energy point of view. UAV is the most versatile of the robot agents in the system (and the most energy expensive). It surpasses the ground vehicles with its four degrees of freedom enabling it to access every section of the environment. The UAV in this example goes beyond the well-known and rather simple concept of eye-in-the-sky since it has the ability to physically interact with its surroundings – both the parcel and the L-UGV – by using on-board dual-arm manipulator with two degrees of freedom.

To find and track both the package and the L-UGV,we designed two vision-based algorithms (UAV has on-board camera pointing downright), one based on AR marker tracking and the other based on tracking the IR LEDs placed on top of the L-UGV. In order to successfully find and pick up the L-UGV, an infrared LED tracking algorithm was designed. The final result, the UAV carrying the L-UGV and the package during mission execution, is shown in Fig. 1.

The second example is related to the experimental validation of canonical peg-in-hole manipulation task using an aerial robot [10]. The same as in the previous example, the robot consists of a multirotor platform equipped with a dual arm multi-degree of freedom manipulator. The research of aerial manipulators is often accompanied with use-case scenarios, ranging from single degree of freedom (DOF) grippers [11], [12], multi DOF grasping [13], [14], to more complex missions which require strong interaction with the environment. Such missions include valve turning [15], opening and closing a cupboard drawer [16] or surface cleaning [17]. In most cases the information about the applied force to the environment is not used. For instance, the authors in [18] performed an aerial robotic contact-base inspection without any knowledge about the applied force. Instead, they set the position reference of the UAV inside the environment. There is also a variety of the aerial manipulation tasks where the force information is not taken into account.

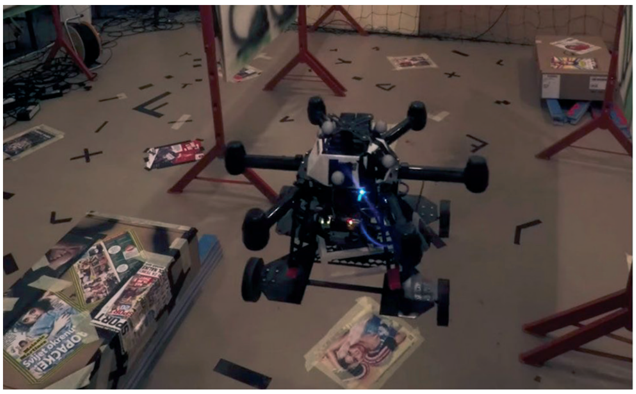

Fig. 1. Multirotor UAV in a mission of carrying an L-UGV and a parcel.

The objective of the proposed peg-in-hole experiment is to validate UAV controller whose purpose is to control UAV's end effector impedance in Cartesian coordinates in order to provide a stable physical interaction. The ba-

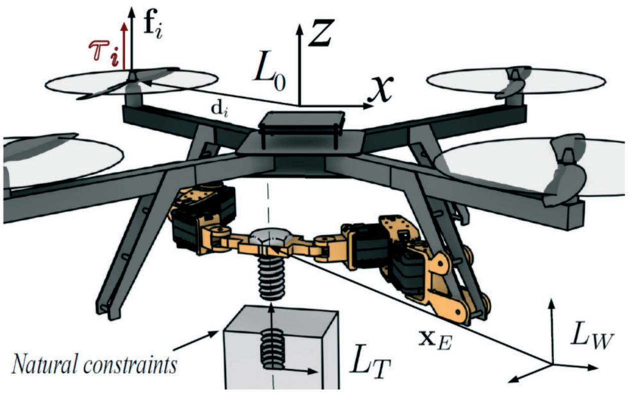

Fig. 2. Multirotor UAV with dual-arm manipulator executing peg-in-hole task.

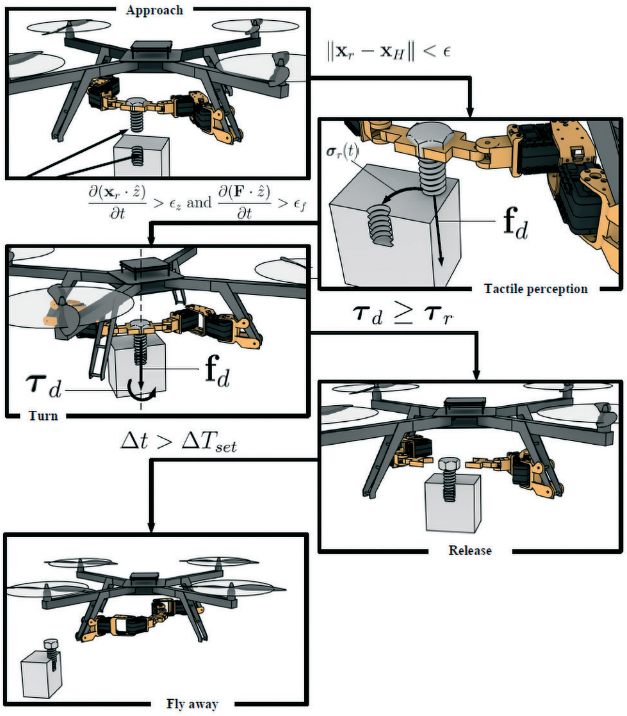

Fig. 3. Five-state automaton describing multirotor UAV with dual-arm manipulator executing peg-in-hole task.

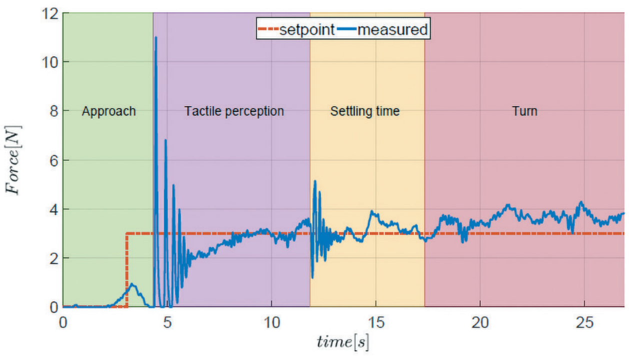

Fig. 4. Force setpoint in z-axis direction and response during each task frame. The oscillations in the forces are due to bouncing the multirotor during the contact.

sic impedance control concept is to establish a desired user-specified dynamical relationship between the contact force and position. Fig.2 shows the proposed aerial robot w.r.t. the task frame, the insertion point for the bolt. The image shows forces and torques produced from within a specific rotor and relates the defined coordinate systems.

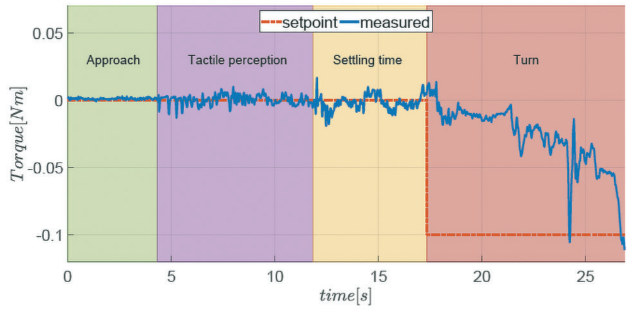

Fig. 5. The end-effector z-axis twist response on fastening a bolt. The bolt is released in the moment when the measured torque is bellow threshold value.

However, to drive the bolt in the hole, we humans seldom rely purely on vision, but rather choose to use our sense of touch. This personal experience teaches us to define the second state of automaton (Fig. 3), as touch perception. During this state, the impedance control is utilized to regulate a constant pressure force normal to the surface around the hole. Results of mission execution are presented in Figs. 4 and 5 in a form of responses of the transitions between each phase as well as triggers that ultimately drive the robot to tighten the bolt.

4. Conclusions

In this article we have very briefly introduced the field of aerial robotics. Details of the current trends in the research and on the market are presented together with an overview of the running projects in which LARICS – Laboratory for Robotics and Intelligent Control Systems is participating. Finally, two sets of results of experiments are given in order to present just a glimpse of various possibilities that are offered by this novel technology that belongs to the field of autonomous robotics systems.

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