

# UAV design and construction for real time photogrammetry and visual navigation

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**Abstract**—A unmanned aerial vehicles applications in photogrammetry have increased rapidly last years. A fast data gathering and processing in real time in some cases become crucial and desired in some application. In the paper, a real time solution is proposed. A real time photogrammetry from UAV is proposed, where image data are gathered and processed on board UAV and finally reconstructed 3D model and measurements are delivered. The paper presents the design of sUAV (small unmanned air vehicle) for real time photogrammetry, visual navigation, real-time spectral data processing. Construction is based on newly designed quadcopter frame based on the experience and previous research, using CAD/CAM. No image data are transferred out of the board and overall photogrammetry process is calculated on board. Finally three dimensional measurements are delivered to the user in the same time, as sUAV flies, or in specified time just after the sUAV has landed.

**Keywords**—unmanned aerial vehicles; navigation; computer aided manufacturing.

## I. INTRODUCTION

A typical digital aerial or UAV photogrammetry process is an offline, sequential process, based on data processing separated in time and location from measurement. Data are gathered in one time, downloaded from a camera data storage and passed to a photogrammetry station, which now is a relevant PC with photogrammetry software. If for some reason and applications a fast data gathering and processing is crucial and desired, an online photogrammetry can be engaged.

In The online photogrammetry process, image data are usually transferred wirelessly to online server and processed outboard the UAV, it is defined also as an internet photogrammetry [1]. That solution delivers measurements in relatively short time, if compared to offline photogrammetry. A resized images are transferred during the flight and the user can get initial data on the field. The calculation process is started just after few resized images were taken and uploaded to the online server. Moreover, online photogrammetry service delivers computing power and specialized software. Online photogrammetry delivers initial data on the field, however full

resolution and quality is delivered after full sized data are uploaded, like in offline process.

A real-time photogrammetry can deliver measurements in a shortest possible time and it requires simultaneous image acquisition and processing. A delivering spatial data in real time can be crucial for emergency and disaster situation, where there is no human access or the access is very dangerous. This means, that spatial data and measurements are delivered just after data acquisition is finished.

In a real time photogrammetry carried out from UAVs, image data are to be gathered and processed on board, and finally reconstructed 3D model and measurements are to be delivered just after landing. In a stationary real-time systems weight and power consumptions are not taken into account, however these both parameters are extremely important in aerial application. Due to that fact an embedding commuting are to be involved [2], preferably in conjunction with simultaneous photogrammetry task and UAV control [3].

The presented design of sUAV and its commuting power can be also engaged to process spectral data in real-time [4] [5], and any data processing based on artificial neural networks [6], especially for neural comparative navigation methods [7].

## II. SYSTEM

A proper sUAV design process has to be started with detailed payload specification, desired performance, endurance and other important parameters. In order to finish initial design assumptions and select suitable platform a methodology [8] was harnessed. As the initial analysis showed, the multirotor platform will be the preferred one for the application real-time photogrammetry, visual navigation developing and testing. The payload weight and desired flight time suggested four motor frame configuration, based on high efficient BLDC (Brushless Direct-Current) motor with low  $K_v$  constant.  $K_v$  is the motor velocity constant measured in RPM per volt or radians per volt-second (rad/V-s). The  $K_v$  rating of a brushless motor is the ratio of the motor's unloaded rotational speed (measured in RPM) to the peak voltage on the

wires connected to the coils. Low  $K_v$  motors enables to use high voltage lithium polymer (LiPol). Generally, a lower  $K_v$  motor that spins a larger and low-pitched propeller will be more efficient than a high  $K_v$  motor with a smaller and high-pitched propeller [9]. In this case 14 inch propellers are used in combination with 380  $K_v$  and 6 cells (6S) LiPol 10 Ah battery. Increasing the propeller's radius is generally more efficient [9]. Consequently, high voltage LiPol battery allows to use smaller ESCs (Electronic Speed Controller). The main parameter when selecting ESCs to consider is the maximum rated amperage. In order to generate the same power using 6S LiPol battery, a less current is needed, that allows to use lighter and smaller ESCs. In this case, a total current required to allow the vehicle to hover not exceeded 15 amps, for 4 kg vehicle.

#### A. sUAV Platform

sUAV platform (body) is considered as a mechanical structure, typically including a fuselage, wings (arms), a propulsion system and aviation electronics. The platform is designed for carrying specified payload like cameras, additional commutators, electronics or effectors. Platform's design is a field of aerospace engineering that combines aerodynamics, materials technology and manufacturing methods to achieve balances of performance, reliability and cost [8].

In the project, CAD (computer aided design) and CAM (computer aided manufacturing) technologies were employed (Fig. 1), on the every stage, including static and dynamic analyses. All platform's elements was manufactured using CNC (Computerized Numerical Control) milling machines and 3D print. This manufacturing method is relatively low cost, and delivers desired projecting phase flexibility and easily enables to implement all necessary changes.

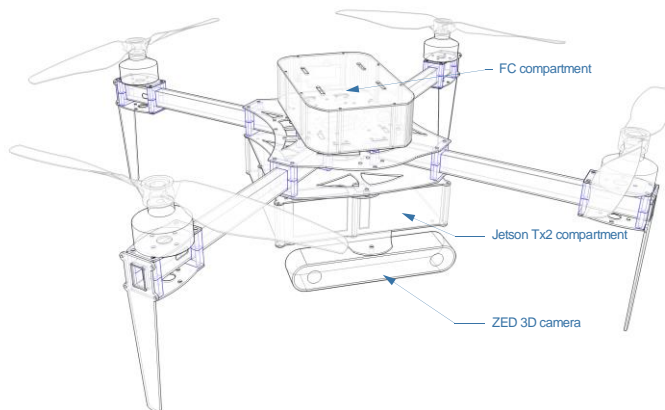


Fig. 1. CAD 3D project – drawing (source: own elaboration)

#### B. Sensors

Sensors installed on board platform have been divided on two groups. Embedded ones, already included in flight controller board (FC) including additional flight support sensors (current and voltage sensors), and attached ones – sensors which are carried out and can be changed depending

on mission or task. In this particular case, embedded sensors are responsible for platform's attitude (gyros and accelerometers for roll and pitch), direction (magnetometers for yaw), height sensing (barometers) and position (GNSS receiver) (Fig. 2). All sensors readings (including GNSS) are available and can be shared for all computations needs and other parts of the system.

The used GNSS receiver (Here GPS) is based on UBlox M8N GNSS module and supports GPS, GLONAS, BeiDou and Galileo satellite constellations. GNSS readings are distributed within FC to support GPS enabled flight modes. The sUAV has 20 flight built-in flight modes, 10 of which require GNSS lock prior take-off. GNSS position acquired on board presented platform enables system to record own trajectory and orientation for direct photo georeferencing. The paper [10] presents results of navigation accuracy of M8N module installed on board sUAV.

For a real-time photogrammetry tasks, as an attached sensor, the ZED 3D Stereolabs camera has been chosen. The sensor quality and performance for photogrammetry has been proved in the research [11], however authors used data gathered in the offline photogrammetry method. The ZED 3D camera is based on passive stereovision, and consists of two RGB cameras with fixed base distance to 120 mm, which allows to generate depth image up to 20 meters. The passive stereo cameras has ability to generate outdoor 3D images, while other depth cameras (RGB-D) based on active infrared (IR) pattern projecting (Kinect, PrimeSense) are optimized for indoor environment, and are not able detect depth on outdoor scenes containing objects illuminated by sunlight. The camera is optimized for real-time calculation using CUDA technology. CUDA is a parallel computing platform and programming model invented by NVIDIA. It enables dramatic increases in computing performance by harnessing the power of the graphics processing unit (GPU), consequently GPU computing enables run photogrammetry application in real time. ZED camera (among variety of options) can deliver already rectified stereo pairs in highest resolution (4416x1242) at 15 frames per second. The ZED camera provides data via high speed USB 3.0 interface. This processing speed enables to run visual stereo navigation algorithms [12].

For a visual navigation [13] a monocular camera with OmniVision OV5693 5M PLCC has been designated. The camera offers sensor size 5.400 x 4.850 mm and 1.4 x 1.4  $\mu\text{m}$  for each pixel, 2592 x 1944 active pixels, frame rate at full resolution is 30 fps, based on CSI Bus interface The CSI Bus interface is optimized in terms of CPU and memory usage for getting images processed and into memory, provides full advantage of hardware vision pipeline. SCI interfaced cameras enables low level control and allows to work in application which is extremely intensive and on the edge of camera performance (high FPS, high resolution, etc.), like in visual navigation cases.

### C. Commuting power

A real-time application for unmanned vehicles needs a reasonable commuting power, in order to run all needed calculations in the shortest possible time. For this reason a NVIDIA TX2 processor has been chosen. Jetson TX2 integrates 256-core NVIDIA Pascal GPU, a hex-core ARMv8 64-bit CPU complex, and 8GB of LPDDR4 memory with a 128-bit interface. The CPU complex combines a dual-core NVIDIA Denver 2 alongside a quad-core ARM Cortex-A57. The Jetson TX2 module fits a small size, weight, and power with footprint of 50 x 87 mm, 85 grams, and 7.5 watts of typical energy usage [14]. These features makes this credit card size processor a very suitable for MAV applications. Jetson TX2 is one of the most prominent GPU-enabled platforms marketed today for autonomous systems [15]. For the presented platform Jetson TX2 Developer Kit has been chosen, which is a basically comes with a mini-ITX size motherboard, and allows a developer to have full access to all supported hardware interfaces. For clearly defined application it is possible to use different, processor sized motherboard (carrier boards) which delivers a less number of hardware interfaces, however is size not exceeds processor size, and can be fitted a smaller and lighter sUAV.

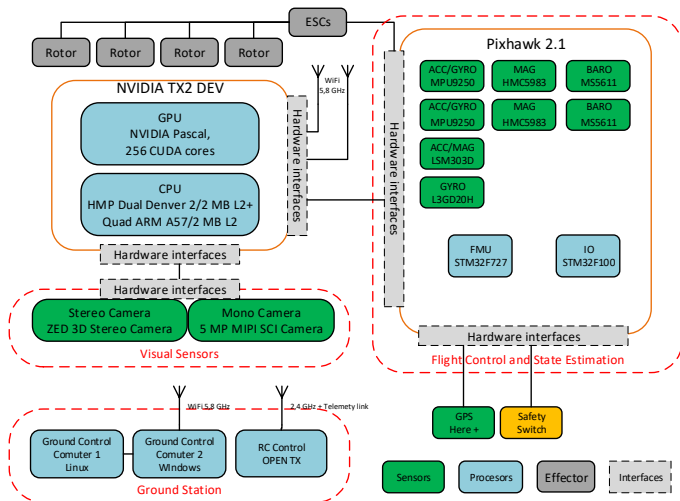


Fig. 2. Sensors, effectors and commuting power configuration (source: own elaboration)

### D. Effectors

An effector is defined as a device used to produce a desired change in an object in response to input. In the presented case, effector is a propulsion system consists of BLDC motor, ESC and propeller. Due to the fact that, the overall performance of the propulsion system depends on combination of motor, propeller and ESC. Any change in this configuration will contribute to change in system efficiency. Moreover, as the experimental results shows [16], the motor characteristics provided by the manufacturer is not correlated with the values measured in the laboratory. The propulsion system efficiency is calculated as: ratio of thrust to electrical

power ( $gf/W_E$ ) (the system efficiency is in grams per watts of electrical power). A result of propulsion system laboratory measurements are presented on Fig. 3. The manufacture data have been compared to real one, for used here ESC, BLDC and ESC configuration. Manufacture propulsion data is based on NM4006 380KV type motor with 14x4,8 inch carbon fiber (CF) propeller, tested configuration is based on the same motor with APC (advanced precision composite) 14x5,5 inch propeller. The tested propulsion system data shows differences between manufacture and presented configuration. This confirms assumptions stated in [16].

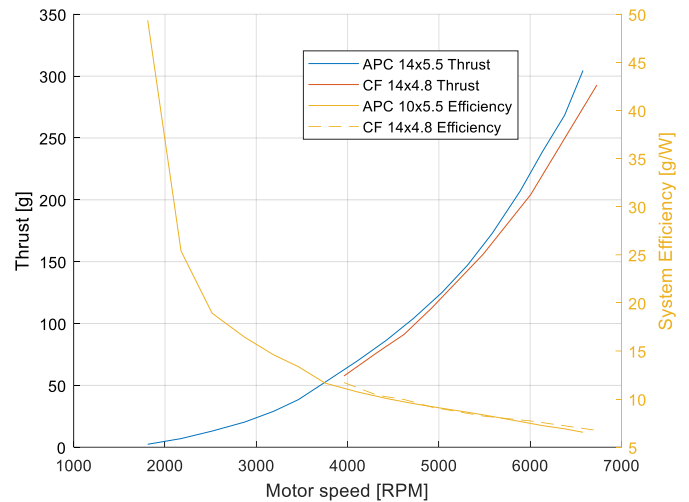


Fig. 3. Measured thrust and system efficiency (source: own elaboration)

## III. SOFTWARE

### A. Architecture

The done software architecture (Fig. 4) presents high level structures of the system, software elements and relations among them. The specific structural options from possibilities been chosen in order to enable real-time computing, compatible autopilot interaction possibilities, any custom payload integration.

The drone software is based on FC software (responsible for flight control and standalone flight parameters computation) and on the embedded computer software. Embedding commuting is responsible for highly demanding sensors data calculation. As a result of the calculations, simple MavLink command is sent to FC to command the UAV. Ubuntu operating system (OS) is used with Robot Operating System (ROS) for sensor data calculation. The ROS is a flexible framework for writing any robot software. It consists of collection of tools, libraries, and conventions. This enables to simplify the task of creating complex and robust drone behavior. On the top mentioned software, the Flyt Operating System was chosen. This OS allows for integration with external ROS/Linux libraries and custom data plumbing

between onboard and offboard applications. The custom applications, can be run on any operating system and hardware (smartphones, PC, MAC, tablets) in order to build interface between the drone and human operator.

### B. Internet Of Drones

The designed system architecture is Internet Of Drones compatible and ready to implement its full functionality. IoD is an architecture designed for providing coordinated access to controlled airspace for UAVs. IoD provides generic services for various drone applications such as package delivery, traffic surveillance, search and rescue and for real-time photogrammetry [17]. Implemented IoD system enables to transmit real-time measurements to a user, in any place in the World. The system is publishing calculation results on the local web server, which can be accessible via any web browser. The sUAV Internet connectivity can be enabled via local Wi-Fi access point (what reduces operational range to the access point signal range) or via GPRS modem (operation within mobile network range).

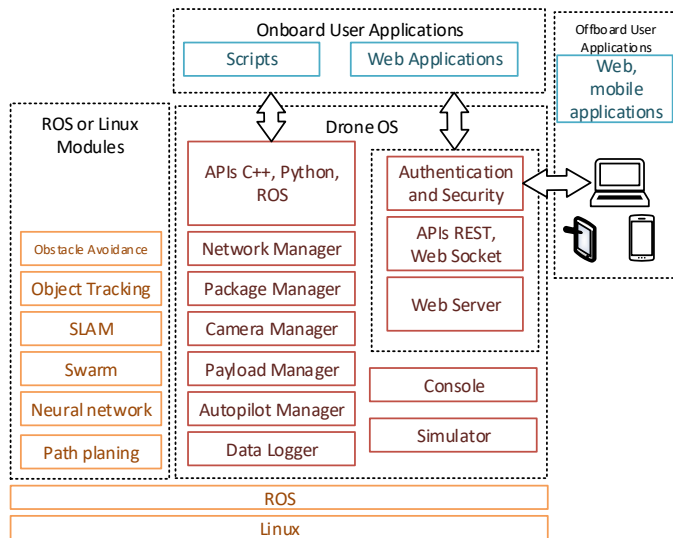


Fig. 4. Drone Operating System architecture (source: own elaboration based on FlytOS architecture)

### C. Web based interface

A basic interaction with user is built on web based interface. The web server is running on board companion computer, integrates all sensors data and advertise all necessary for user messages and calculation results. The web based communication is optimized, as for data transfer and available communication bandwidth. Interface is accessible via popular web browser and any operating system on PC, tablets or smartphones. That architecture enables user to access to the sUAV data from any computer with Internet access, including live 3D data visualization, raw camera stream and depth image (Fig. 5 and Fig. 6).

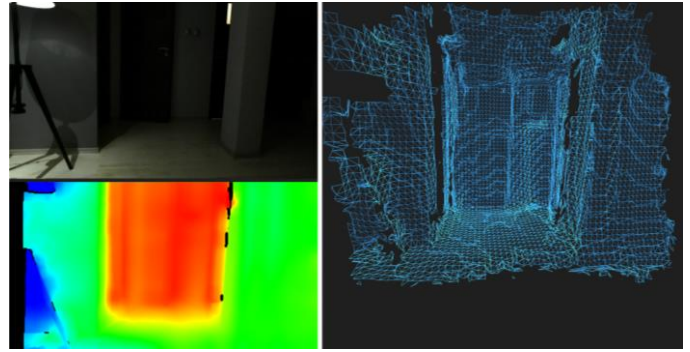


Fig. 5. Live raw image stream (left top), depth image (left bottom) and single triangular mesh for indoor environment (right) (source: own elaboration)

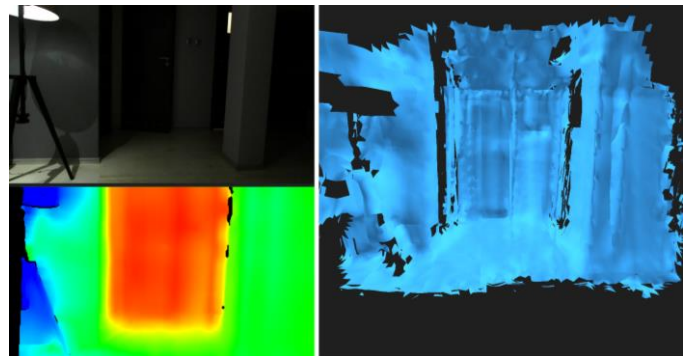


Fig. 6. Live raw image stream (left top), depth image (left bottom) and surface model (right) (source: own elaboration)

## IV. CONCLUSIONS

Presented sUAV was developed and build for real time UAV photogrammetry. Nowadays, technology available on the market made possible to successfully finish the project. Live 3D data are computed on board presented UAV and transmitted via communication link to the ground station and for the users. The spatial data are stored on board for future analysis and are accessible during the flight.

The sUAV has been tested in real environment, during the flight, what proves that the architecture and chosen configuration were correct.

The accuracy of photogrammetry measurements have not been considered in the presented paper, as this is planned for a future work.

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