

Development and Flight Test of a Multicopter for Medical Operations

Laura Novaro Mascarello, Fulvia Quagliotti

Politecnico di Torino

ITALY

laura.novaromascarello@polito.it

fulvia.quagliotti@polito.it

ABSTRACT

Flight test is a strategic phase in the development of an UAS (Unmanned Aerial System) in order to verify performances and the reliability of the system. In this paper, a multicopter for medical applications was developed and it was set with the aim of guarantee the autonomous navigation. Because this multirotor will be used in unfriendly scenarios where a professional operator could not be there, the automatic landing was tested and results demonstrated a good setting of the system.

1.0 INTRODUCTION

The paper deals with the development of an UAS able to operate in the specific cases of medical support to civil population, given by military or civilian organizations, in presence of natural disasters, like landslides, floods, earthquakes, or avalanches, when reaching victims is often almost impossible on the ground, or it would take too much time for their survival. In those cases, roads, bridges and other communication ways are usually not available and the unmanned platform is the most efficient way to help people. It can be launched from the nearest base and it could carry medication, necessities and everything that could support the first aid. Moreover, after a landslide or an enemy attack, communications could be cut off and UASs could be used as radio links to coordinate relief efforts.

In particular, the paper focuses on a multicopter that carries an AED (Automated External Defibrillator) or a box with medicines or therapies for chronically ill people. Actually, this kind of UAS is very efficient, cheap and it can intervene immediately and quickly after an accident.

For example, Sudden Cardiac Death (SCD) is the largest cause of natural death in the USA, causing about 325,000 adult deaths in the U.S. each year. It is a sudden, unexpected death caused by loss of heart function (sudden cardiac arrest). The intervention by operators must therefore be immediate because every minute that passes, the survival rate falls by 10%. According to the latest data from the World Health Organization (WHO), more than 20% of the worldwide mortality is caused by respiratory diseases that turn out to be the third leading cause of death; 210 million are victims, even irreversibly, of COPD (Chronic Obstructive Pulmonary Disease) and 300 million due to asthma. About 20% of the adult population suffer of OSAS (Obstructive Sleep Apnea Syndrome or Obstructive Sleep Apnea Syndrome), which is a risk factor for mortality, stroke and metabolic syndrome (hypertension, cardiovascular disease, obesity, diabetes) ^[1].

Therefore, multicopter can be used for *telemedicine* or *e-health*, that is define by the World Health Organization (WHO) like: “*The delivery of health care services, where distance is a critical factor, by all health care professionals using information and communication technologies for the exchange of valid information for diagnosis, treatment and prevention of disease and injuries, research and evaluation, and for the continuing education of health care providers, all in the interests of advancing the health of individuals and their communities*” ^[2].

Thus, the multicopter can be used in emergency situation when the intervention of medical operators is less efficient and slow. Therefore, UASs must be reliable, safe and accurate, especially because they do not fly in PIC (Pilot In Command), but in autonomous mode or CIC (Computer In Command). They must complete their missions without accidents both in terms of loss of payload and in terms of safety for the civilian population.

For these reasons, flying testing has an important role in the success of the mission. First, all pre-flight checks are defined. Considering a multicopter, an operator must calibrate and bind the radio, but also ESCs, compass module and accelerometers. After that, parameters are set and the balance of the vehicle is done. Finally, flying tests are performed, in particular in the automatic landing mode.

2.0 PARAMETERS SETTING

Parameters setting is a strategic phase of the development of a multicopter.

The autopilot uses an open source software and this option has considerable advantages. Indeed, the multicopter could be reset according to the payload, the configuration and the kind of mission. In this way, the multicopter is a multitasking and an all-around vehicle. For example, the UAS can carry an AED of 1.5 kg or medicines of few hectograms; resetting parameters is sufficient to complete the mission. This multicopter differs from commercial ones, which are now very fashionable, but they are set only for a specific mission that could not be the same wanted by the operator. As a matter of fact, some parameters are default ones, but others are set up by operators according to the “try and error” approach; actually, parameters are set during ground tests and then they can be modified during flight tests.

First, during ground tests PID gains are set. The operator should suspend the multicopter using cords, but due to some difficulties during the procedure, the pilot holds the vehicle in his hand, over his head. Furthermore, a second operator gives different inputs of pitch and roll setting consequently the PID gains of pitch, roll and yaw according to the pilot feedback.

Afterwards, the failsafe parameters are set up defining the minimum voltage of batteries from which the multicopter has to fly in failsafe mode, the flight mode used by the multicopter (Land or RTL, Return To Launch) in this phase and the rate of descent in event of an emergency land.

Finally, the operator plans the autonomous navigation setting waypoints, the speed of ascent and descent, the horizontal one and accelerations.^[3]

The most important parameters are reported in the following table.

Table 1 List of parameters

	Parameter	Description	Value
Flight Mode	FLTMODE1	Flight Mode	0 (Stabilize)
	FLTMODE2	Flight Mode	0 (Stabilize)
	FLTMODE3	Flight Mode	0 (Stabilize)
	FLTMODE4	Flight Mode	2 (AltHold)
	FLTMODE5	Flight Mode	0 (Stabilize)
	FLTMODE6	Flight Mode	5 (Loiter)

Fail safe	ARMING_CHECK	Pre-flight checks, accelerometer, barometer and compass	1 (on)
	FS_BATT_ENABLE	Voltage battery check	1 (on)
	FS_BATT_VOLTAGE	Minimum voltage of battery after that failsafe starts	14 V
	RTL_ALT	Altitude before beginning the RTL mode	500
	RTL_ALT_FINAL	Final altitude of the RTL mode	0
	LAND_SPEED	Speed of descent	50 cm/s
Thrust	THR_MIN	Minimum thrust for spinning engines	130
	THR_MID	Thrust value with halfway stick	500
	THR_MAX	Max value of thrust	1000
Gain	RATE_RLL_P	Proportional roll gain	0.15
	RATE_RLL_I	Integrative roll gain	0.1
	RATE_RLL_D	Derivative roll gain	0.004
	RATE_PIT_P	Proportional pitch gain	0.15
	RATE_PIT_I	Integrative pitch gain	0.1
	RATE_PIT_D	Derivative pitch gain	0.004
	RATE_YAW_P	Proportional yaw gain	0.2
	RATE_YAW_I	Integrative yaw gain	0.02
	RATE_YAW_D	Derivative yaw gain	0
Autonomous navigation	WPNAV_SPEED	Horizontal speed	500 cm/s
	WPNAV_RADIUS	Distance from WP for which WP is reached	2 m
	WPNAV_SPEED_UP	Speed of ascent	250 cm/s
	WPNAV_SPEED_DN	Speed of descent	150 cm/s

	WPNAV_LOIT_SPEED	Max horizontal speed	500 cm/s
	WPNAV_ACCEL	Horizontal acceleration	100 cm/s ²

Thus, the UAV is ready for flying tests.

3.0 FLIGHT TESTS

The concerned multicopter has eight rotors (four coaxial engines) and its characteristics are reported in the following tables.



Figure 1 The multicopter

Table 2 Weights

Weights	[g]
Structural weight	906,6
Electronic component weight	2427,8
Empty weight	3334,4
MTOW weight	4600

Table 3 Dimensions

Dimensions	[mm]
Height	304
Width	697
Diagonal wheelbase	985.7

During flying tests, autonomous landing is tested because it is a critical phase of the mission. Indeed, the scenario could be unfriendly or people could be near the site, therefore it is important that it is performed safely.

When the multicopter is at a sufficient altitude, the pilot switches on the “Land Mode” and the vehicle starts landing. Figure 1 represents the rate of descent (R/D).

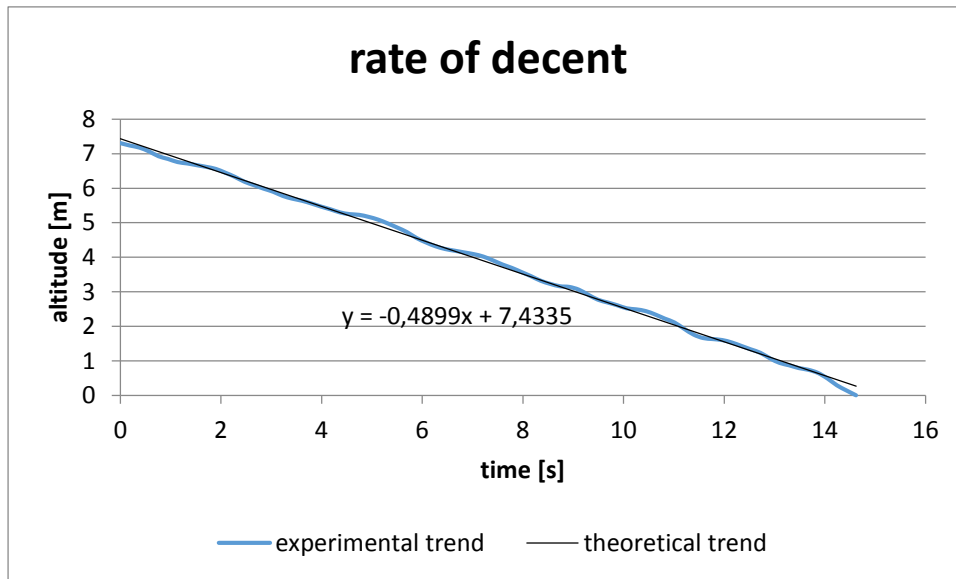


Figure 2 Rate of descent

As can be seen in the figure, the UAV switches to the autonomous landing mode when it is at 7.31m of altitude; in 14.62s, it lands according a R/D equal to -0.5 m/s, like it was set before by the operator. Data have a noticeable linear trend and this is confirmed by the equation of the black line.

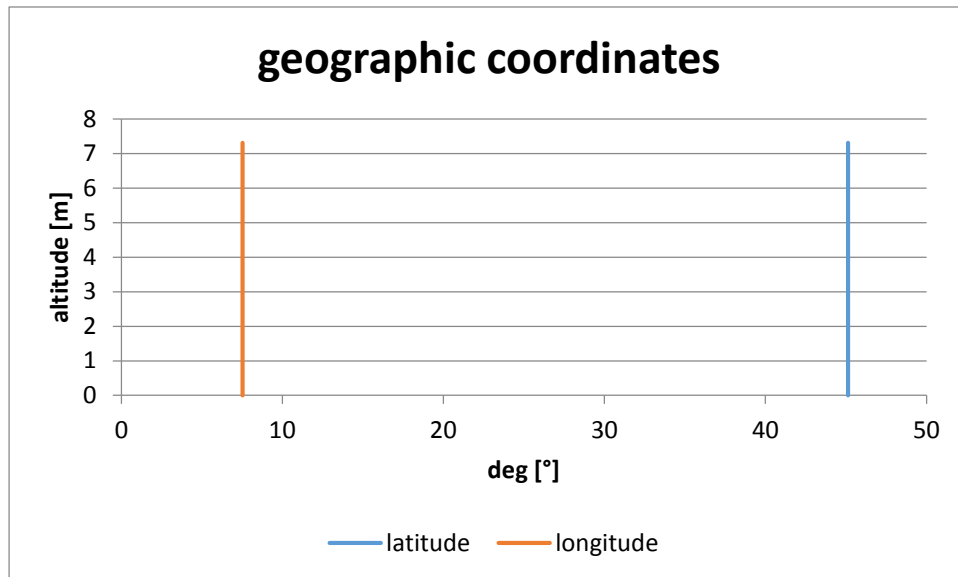


Figure 3 Geographic coordinates

Using the GPS data, the vehicle seems maintain the same geographic coordinates during the descent.

Latitude= 45.1233858° N

Longitude= 7.5251859° E

Actually, the multicopter does not maintain the vertical position but it has some little deviations, as shown in Figure 3 and Figure 4.

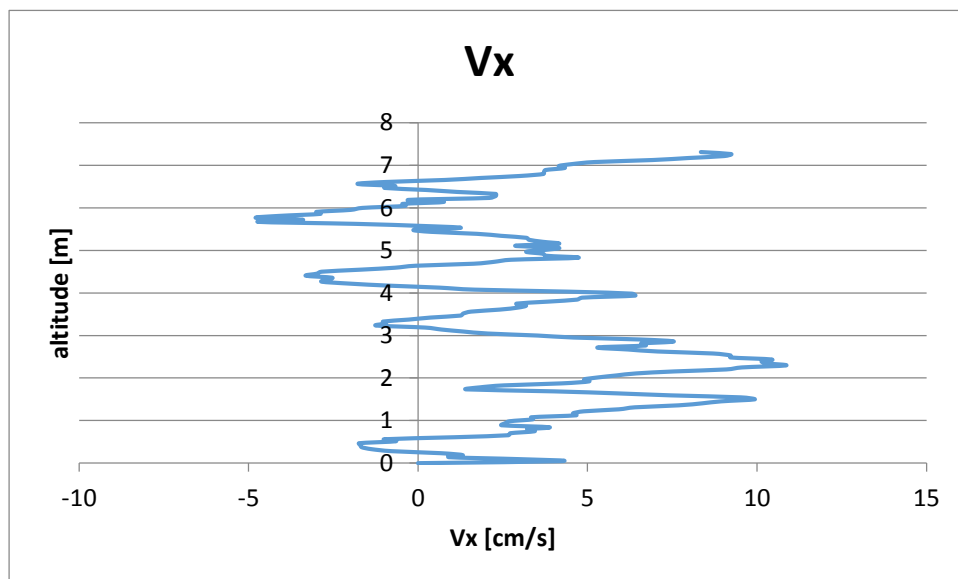


Figure 4 Vx

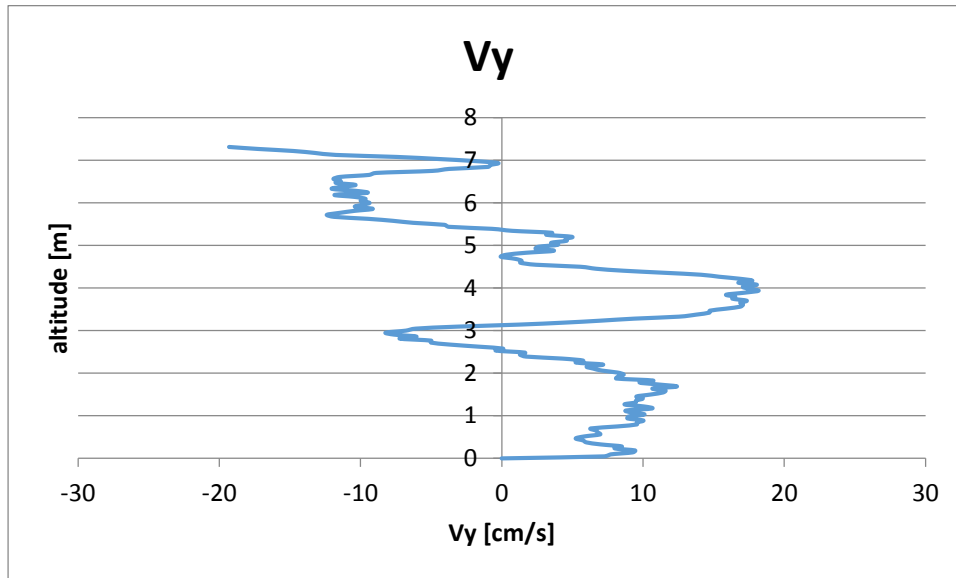


Figure 5 Vy

These deviations of the horizontal speeds V_x and V_y , are due to gusty crosswinds and to the control and stabilization systems, which compensate the external disturbances.

Using the time of landing and the deviations of speed, the deviations of position are calculated:

$$\Delta x = 41.16 \text{ cm.}$$

$$\Delta y = 41.75 \text{ cm.}$$

These results are very satisfactory, considering that the multicopter will be used in emergencies where the vehicle must be immediately available and sufficiently precise in its land, or rather, these little deviations are accepted.

Accelerations and angular velocities are measured by accelerometers and gyros on board. The measurements during the descent are represented in the following figures.

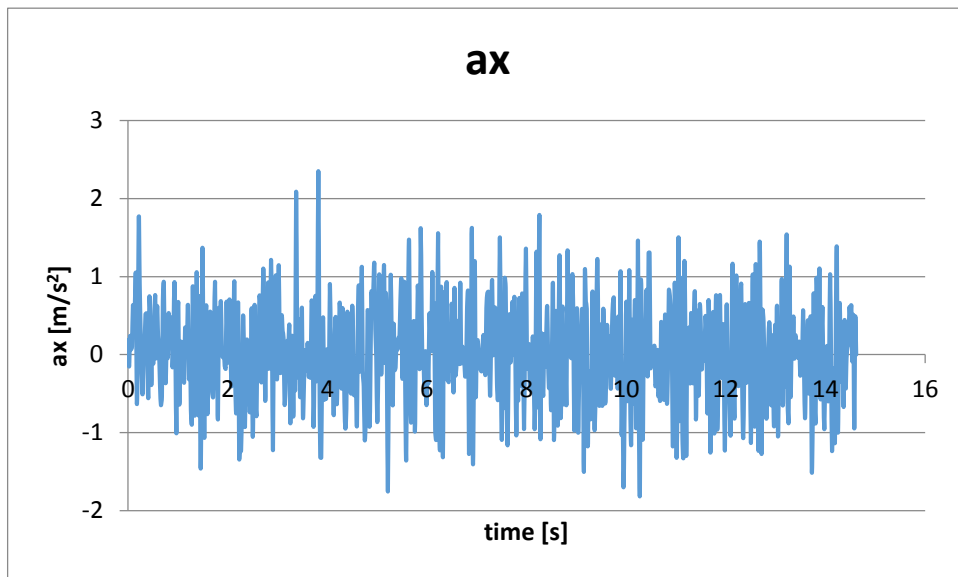


Figure 6 Acceleration: a_x

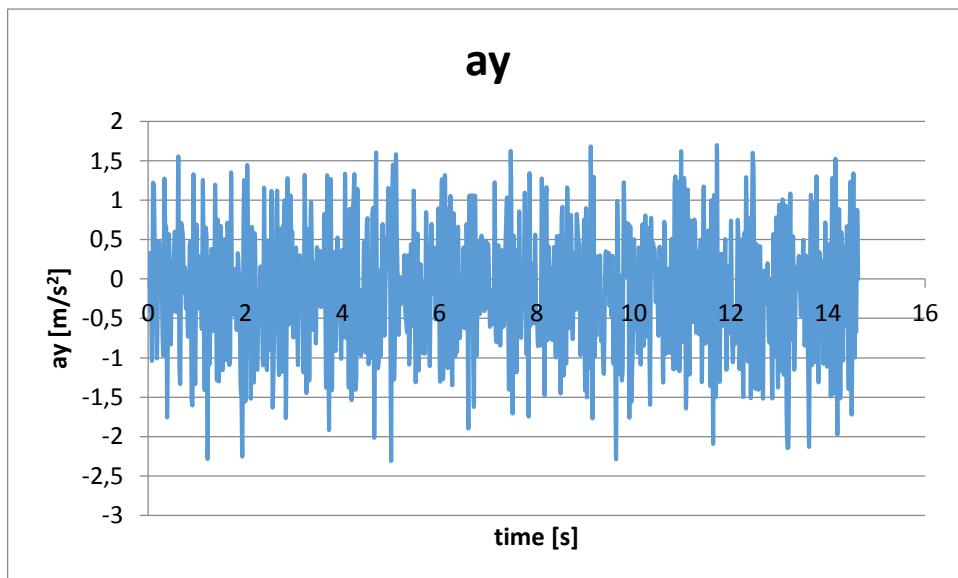


Figure 7 Acceleration: a_y

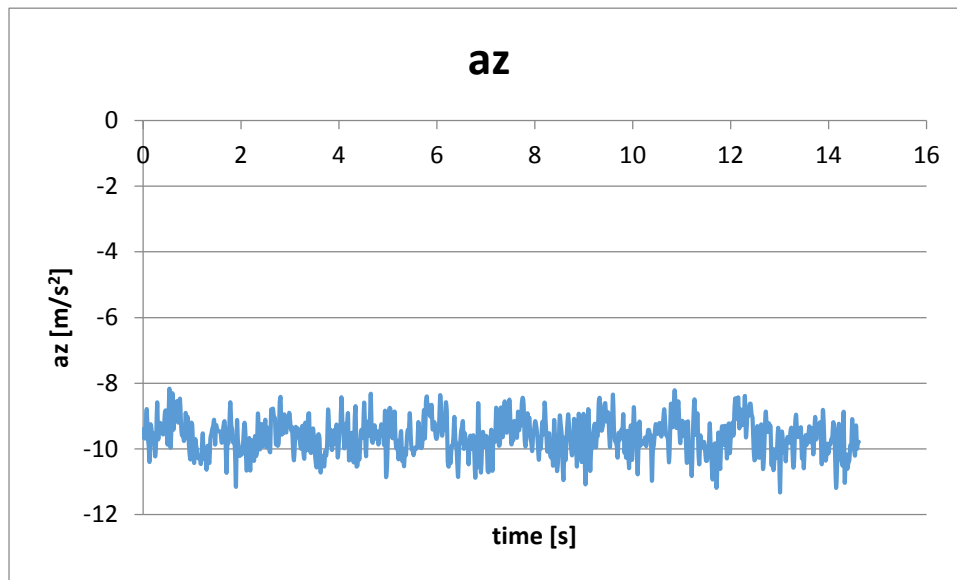


Figure 8 Acceleration: az

The average values are respectively:

- $a_{x_M} = 0.014277 \text{ m/s}^2$
- $a_{y_M} = -0.15421 \text{ m/s}^2$
- $a_{z_M} = -9.62845 \text{ m/s}^2$

a_{x_M} and a_{y_M} are near the null value due to the good performances of the control and stabilization system and to a good choice of PID gains.

a_{z_M} does not correspond to the acceleration of gravity because of the propulsion force that is directed upwards.

The angular velocities p , q and r can be observed in the next plots.

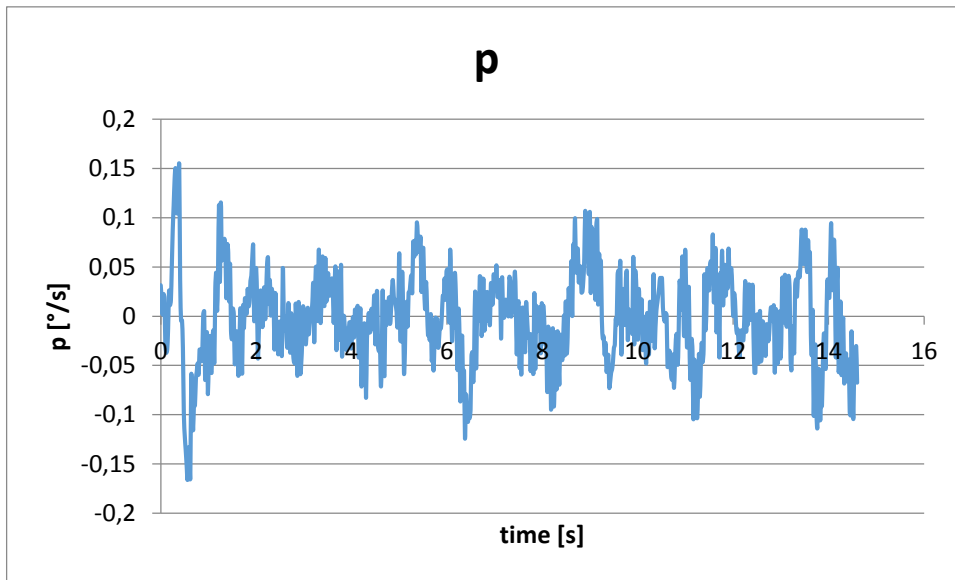


Figure 9 Angular velocity: p

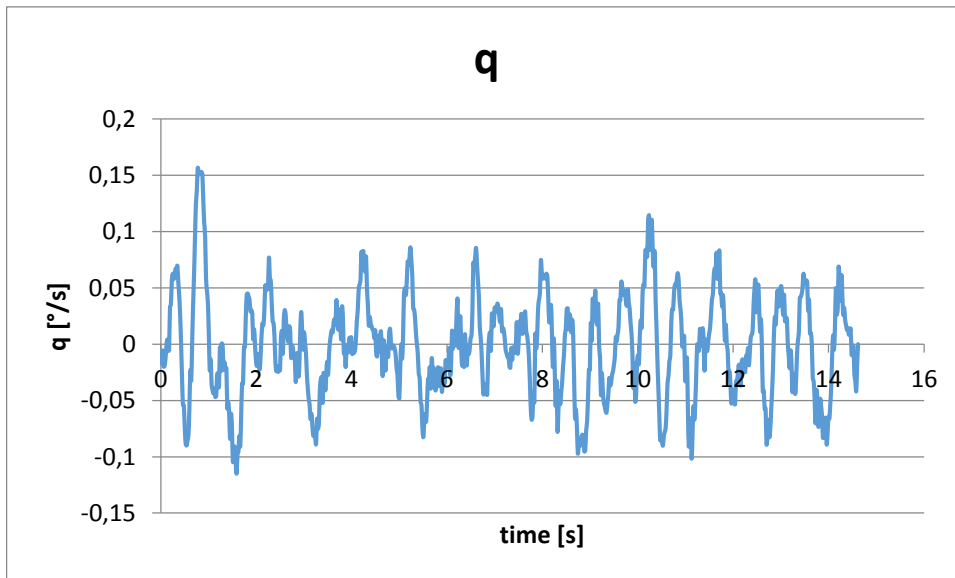


Figure 10 Angular velocity: q

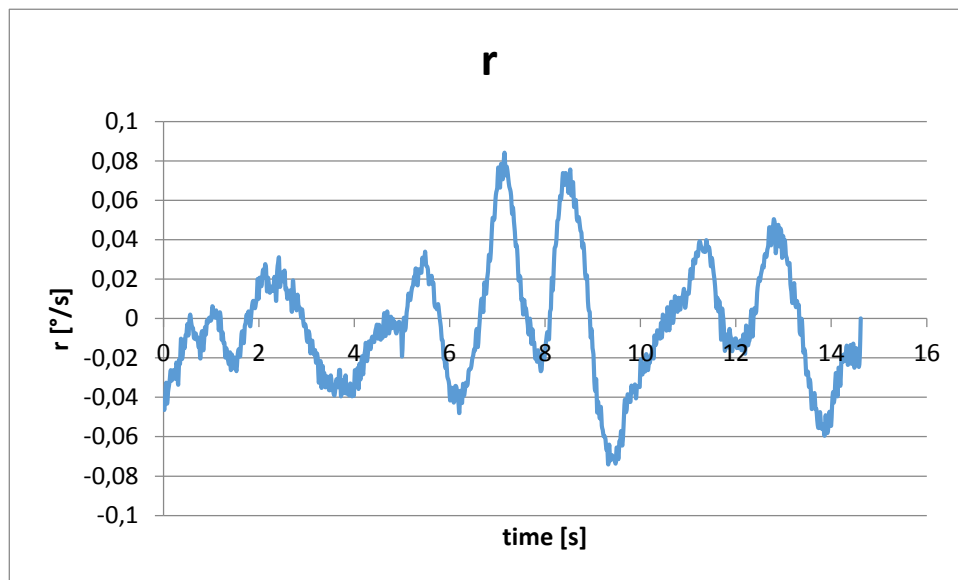


Figure 11 Angular velocity: r

The average values are respectively:

- $p = -0.00196 \text{ } ^\circ/\text{s}$
- $q = -0.00119 \text{ } ^\circ/\text{s}$
- $r = -0.00334 \text{ } ^\circ/\text{s}$

Also these results confirm the appropriate settings of PID gains.

Besides the accelerations and the angular velocities, the Euler angles are measured and their trends during the automatic landing are presented in the following. Each angle is reported varying the altitude and the time during the descent.

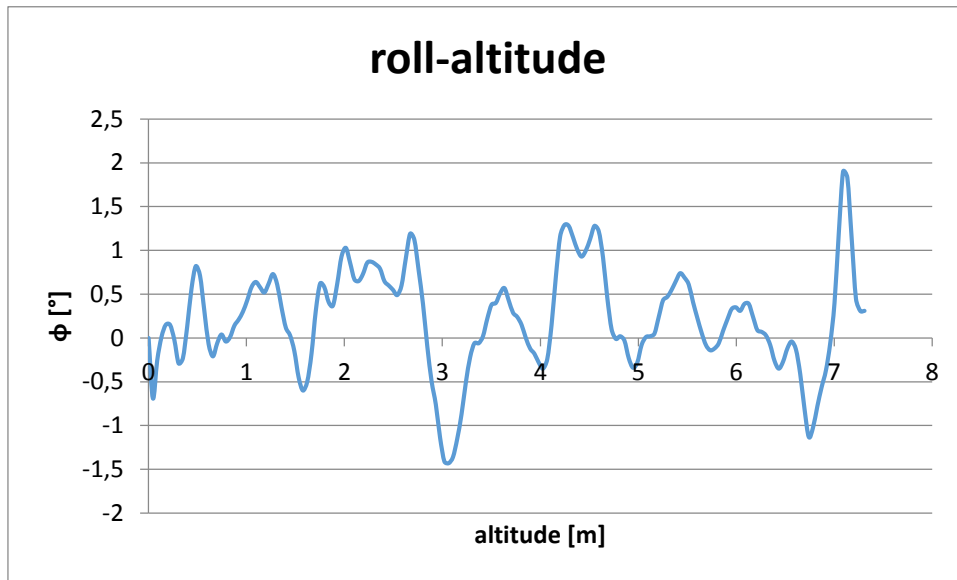


Figure 12 roll-altitude

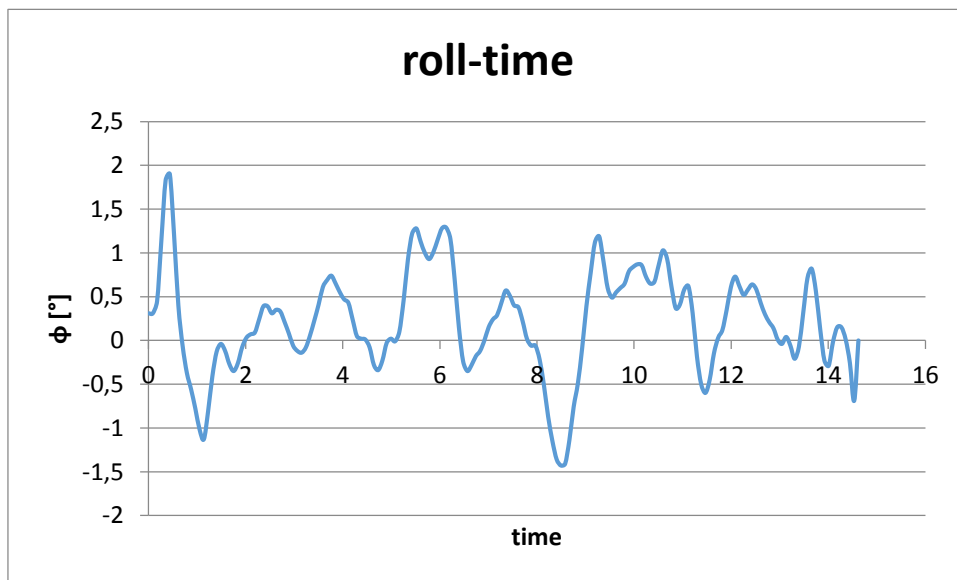


Figure 13 roll-time

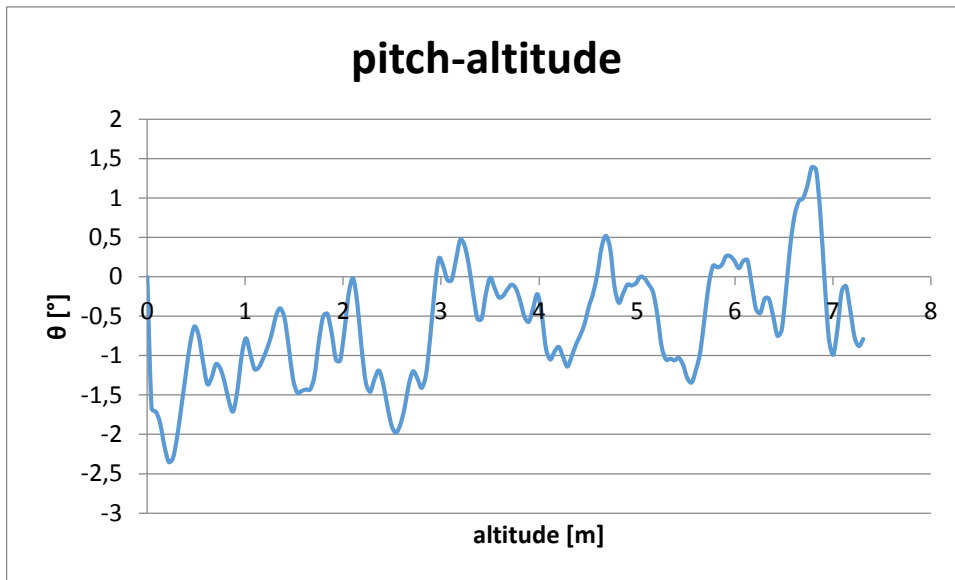


Figure 14 pitch-altitude

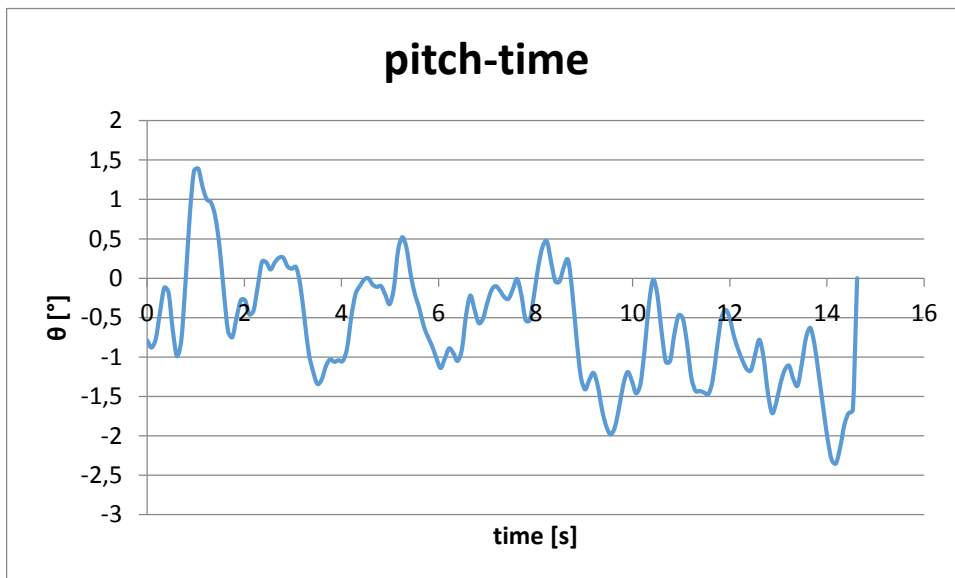


Figure 15 pitch-time

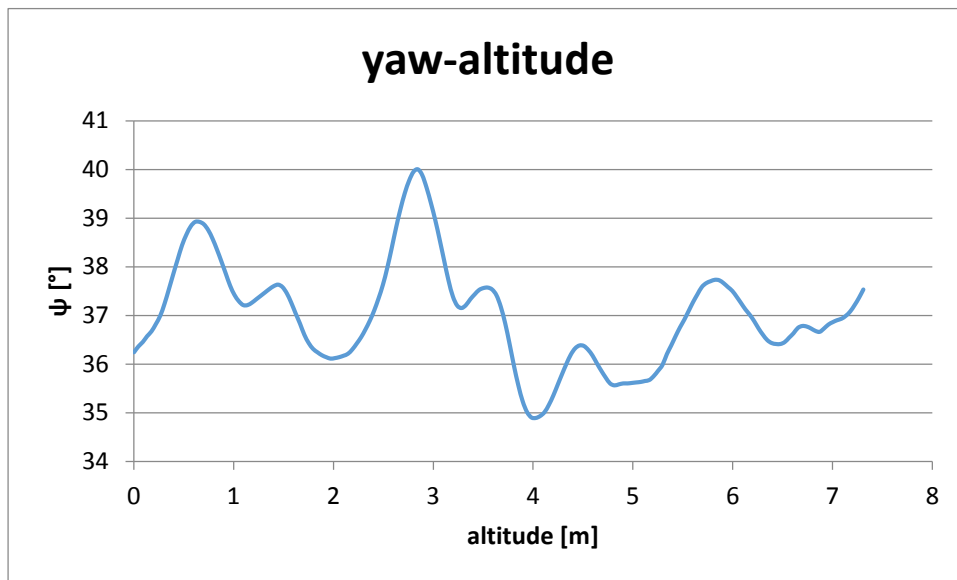


Figure 16 yaw-altitude

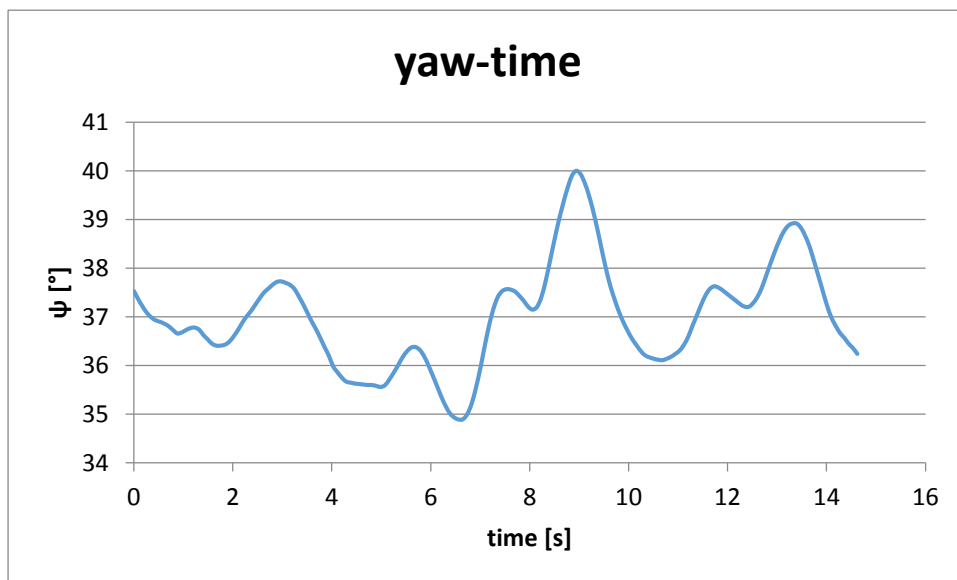


Figure 17 yaw-time

With decreasing altitude and then with increasing time of the descent, Euler angles have oscillations of few degrees because of the control and stabilization system. Indeed, the aim of this mission is the automatic landing on the vertical position. Therefore, this system continually corrects the attitude of the vehicle.

4.0 DISASTER RELIEF

The multicopter took part at the Disaster Relief I/2014, a joint exercise between Italian Army, National Emergency Service, Firefighters and National Civil Protection. It was an exercise for the control and management of emergency situation due to natural disasters. An earthquake was simulated in the Moncalieri city, near Turin, on the 28th May 2014 at 4:30 o'clock: there were some rubble of houses and a dam, which caused the flooding of the river Po.^[4,5]

Multicopter was used to assist people in the rescue. The operation commander, Colonel Moricca, ordered the take-off of the vehicle and the UAV carried out missions around ten minutes. It flew over the riverbank looking for any missing and it identified a suitable place for the preparation of the displaced camp. The ground station communicated GPS coordinates of the multicopter to the operating room.

Some people needed resuscitation and the multicopter must carry an AED (Automated External Defibrillator). The payload was fixed in the lower part of the vehicle using straps. When the UAV arrived at the site, it landed and turned off engines. Afterwards, a medical operator released the payload. Moreover, the multicopter patrolled the area to identify crashes and injuries in the rubble.

The vehicle had been under operation for about three hours. It had proved willing to intervene even if the endurance of each mission was only 15 minutes. Indeed, the readiness is an important characteristic for an UAV, which should intervene in emergency situations. The vehicle had proved to also be multitasking, carrying out different kinds of missions.

5.0 CONCLUSIONS

The multicopter will be used in emergency situation where it must be immediately available and ready to intervene. The operator is often not a professional-pilot, but a doctor or a rescuer and thus the UAV must not have any kind of problem. For these reasons, flight test has an important part in the project and development of the multicopter; parameters setting is done step by step according to the “try and error” approach until the optimum configuration. Results confirm the satisfactory setting of the control and stabilization systems that is possible only using an open source software.

6.0 REFERENCES

[1] <http://www.webmd.com/heart-disease/guide/sudden-cardiac-death>

[2] WHO. “Telemedicine. Opportunities and developments in Member States: report on the second global survey on eHealth”, Global Observatory for eHealth series-Volume 2, 2010

[3] <http://copter.ardupilot.com/wiki/flying-arducopter/>

[4] http://www.difesa.it/Primo_Piano/Pagine/Esercitazione_Protezione_Civile.aspx

[5] <http://www.lastampa.it/2014/05/28/multimedia/italia/disaster-relief-ecco-come-lesercito-interviene-in-caso-di-calamit-3PVJgWXIwB2hJIMDIWcMUK/pagina.html>

