The 11th International Conference on Mechanical and Aerospace Engineering

VIRTUAL CONFERENCE

DRONE AS A MEASUREMENT INSTRUMENT, HOW TO TEST IT?

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UNIVERSITÀ DEGLI STUDI DEL SANNIO Benevento

L.E.S.I.M.

OUTLINE

- L.E.S.I.M.: Who We are;
- Drones;
- Drone trends;
- Drone vs. measurements;
- Measurements for drone;
- Drone for measurements;
- Conclusions.

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L.E.S.I.M.: WHO WE ARE (1/3)

Where is Benevento?

L.E.S.I.M.: WHO WE ARE (2/3)

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Prof. I
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Ph.D
Tu
(Rese

Francesco
cariello

Dr. Imran
Ahmed
ı.D. student)

Contact us if you are interested to join our team.

L.E.S.I.M.: WHO WE ARE (3/3)

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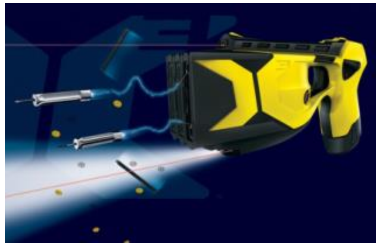
Laboratory of Signal Processing and Measurement Information

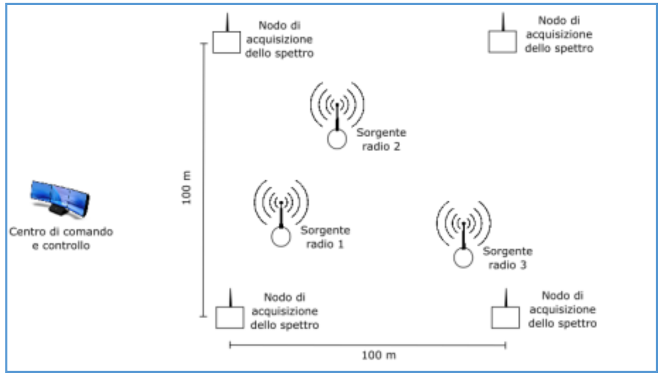
- ✓ LESIM is involved in
  - ✓ Definition of new measurement methods
  - ✓ Processing of measurement information
  - ✓ Development of new electronic measurement instruments
- ✓ Application field
  - ✓ Characterization of electronic components - ADC and DAC Testing
  - ✓ Telecommunication - Monitoring of the radio spectrum
  - ✓ Biomedical - Monitoring of patients (ATTICUS)
  - ✓ Aerospace - Drone-based measurement instrumentation

Project 2014-NIST-MSE-01
A phase measurement system for calibrating Electroshock-Weapons

NIST
National Institute of Standards and Technology
U.S. Department of Commerce



NIST financial assistance award:
$ 1.000.000,00



Z-Spectrum
Italian Ministry of Defence
€ 480.000,00

Italian Government Grant
€ 900.000,00

A/D L.E.S.I.M.

Educational for Drone (eDrone)
574090-EPP-1-2016-1-IT-EPPKA2-CBHE-JP

EDUCATIONAL FOR DRONE
eDrone

Prof. Pasquale daponte

6 European Partners

11 Partners

17 Associate Partners

Education, Audiovisual and Culture Executive Agency
Erasmus+ : Higher Education – International Capacity Building

This project has been funded with support from the European Commission. This publication (communication) reflects the views only of the author, and the Commission cannot be held responsible for any use which may be made of the information contained therein.

eDrone

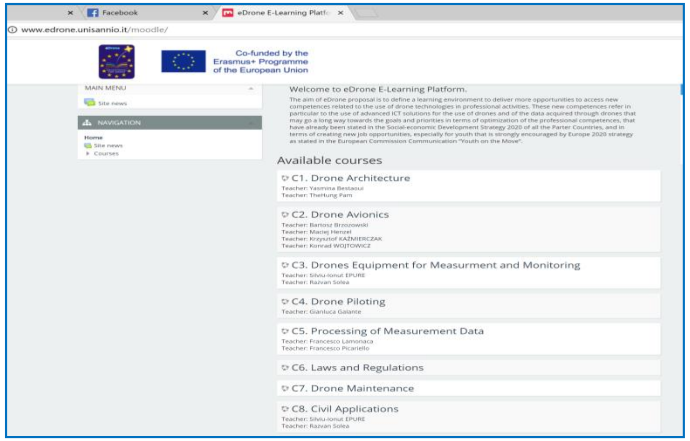
OUTPUTS

Contact us if you are interested to the Course for Training the Teachers (CTT) and Course to Instruct Attendees (CIA).

http://www.edroneproject.org/

Set up of four laboratories for drone educational activities: one for each Partner Country

Content management system



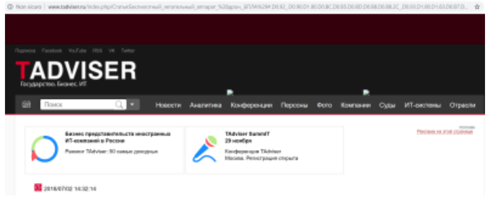
CTT accreditation


Ministerul Educației, Culturii și Cercetării al Republicii Moldova
Universitatea de Stat din Moldova

PROGRAMUL
de recalificare profesională „Educație pentru drone”
în cadrul proiectului Erasmus+ „Educație pentru Drone – eDrone”

CHIȘINĂU 2018

Disseminations



MetroAeroSpace

www.metroaerospace.org

8th IEEE International Workshop on
Metrology for AeroSpace
23-25 June 2021, Naples, Italy



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DRONES (1/3)

What are drones? ...for others...

- Drone is for making pictures;
- Drone is for military missions;
- Drone is a toy.

DRONES (2/3)

An Unmanned Aircraft System (UAS) comprises individual system elements consisting of an “unmanned aircraft”, the “control station” and any other system elements necessary to enable flight, i.e. “command and control link” and “launch and recovery elements”. There may be multiple control stations, command & control links and lunch and recovery elements within a UAS.”

European Aviation Safety Agency (2009)

DRONES (3/3)

Operation		Remote pilot competency (age according to MS legislation)	UAS				UAS operator registration
Subcategory	Area of operation (far from aerodromes, maximum height 120 m)		class	MTOM/ Joule (J)	Main technical requirements (CE marking)	Electronic ID/ geo awareness	
A1 Fly over people	You can fly over uninvolved people (not over crowds)	Read consumer info	Privately built	< 250 g	N/a	No	no
			C0		Consumer information, Toy Directive or <19 m/s, no sharp edges, selectable height limit		
		• Consumer info • online training • online test	C1	< 80 J or <900 g	Consumer information, <19m/s, kinetic energy, mechanical strength, lost-link management, no sharp edges, selectable height limit.		
A2 Fly close to people	You can fly at a safe distance from uninvolved people	• Consumer info • online training • online test • theoretical test in a centre recognised by the aviation authority	C2	< 4 kg	Consumer information, mechanical strength, no sharp edges, lost-link management, selectable height limit, frangibility, low-speed mode.	Yes + unique SN for identification	yes
A3 Fly far from people	You should: • fly in an area where it is reasonably expected that no uninvolved people will be endangered • keep a safety distance from urban areas	• Consumer info • online training • online test	C3	< 25 kg	Consumer information, lost-link management, selectable height limit, frangibility.		
			C4		Consumer information, no automatic flight	if required by zone of operations	
			Privately built		N/a		

MTOM: Maximum Take-off Mass

DRONE TECHNOLOGY

- Microprocessor
- Flight controller
- Electronic Speed Control
- FPGA

- Sensors to guarantee a safe autonomous navigation
- Real-time data processing

- Telemetry
- Radio communication

- Autonomous navigation
- Autonomous mission planning

- Image processing
- Artificial Intelligence

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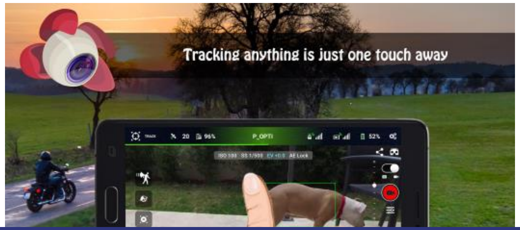
DRONE TRENDS



- One touch

Requirements:
- Autonomous navigation
- Real-time data processing
- Artificial Intelligence (AI)
- Sensors to guarantee a safe autonomous navigation

DRONE: ONE TOUCH

Today drones are controlled mostly by operator.

In the future more and more flights will be autonomously with the use predictive and prescriptive analysis.

Advances in AI, big data and machine learning will translate to collision detection, or “sense and avoid”.

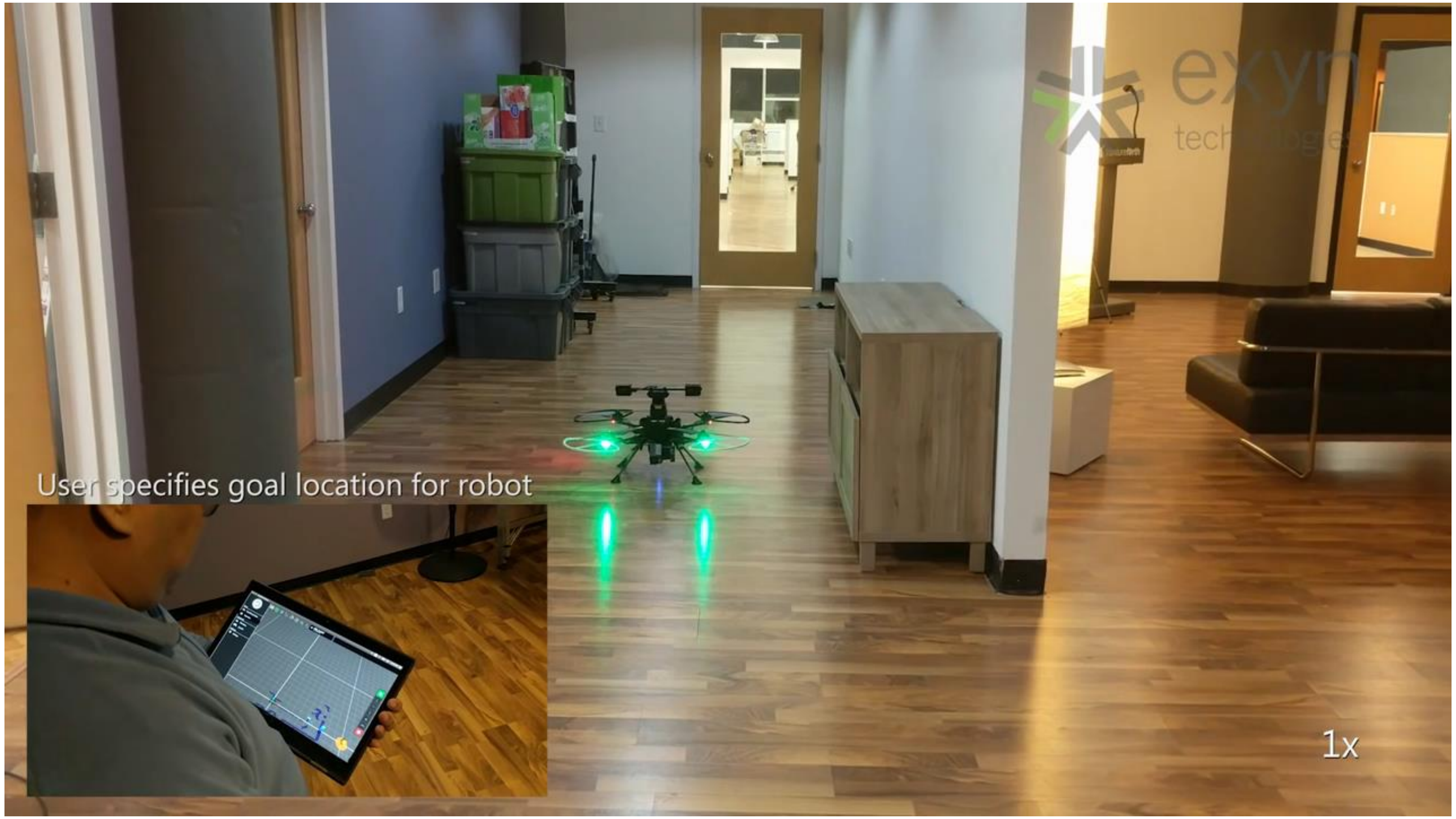
DRONE SWARMS

A swarm of drones will greatly reduce the time taken to perform some surveys, with parallel operation of imaging and sensor systems, all operating at maximum data transfer rates.

For example if a sensor on a drone fails it can return to base and another drone could continue with the work without much interruption.

DRONE: INDOOR NAVIGATION

- The drone needs to take measurements from different sensors to ensure safe navigation.
- The measurements must be processed in real-time and the drone has to take decisions during the flight.
- Applications: search and rescue operations and management of emergency situations.



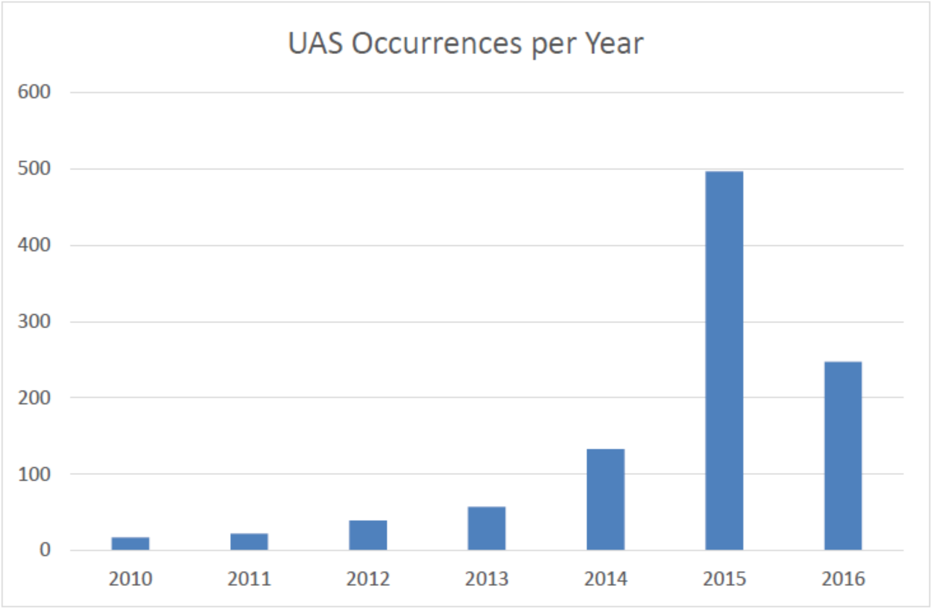
DRONE SECURITY

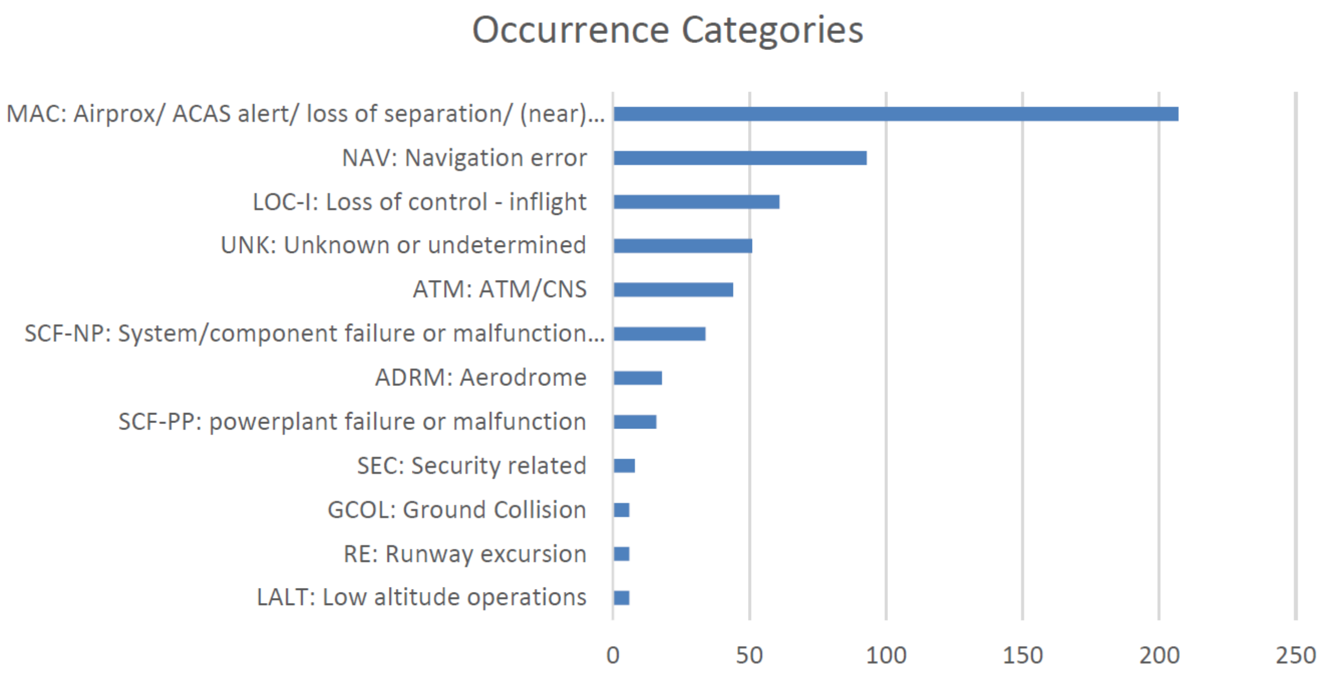
Liability Risk	War / Terrorism Perils	Cyber - Attacks	Privacy Issues
Liability risks associated with drone are completely different to those posed by manned aircrafts as there are no occupants onboard, and the size and weight of the drone are usually smaller.	*Similarly, to manned aircrafts, drone can be used for malicious acts like attacking key infrastructure or events where large crowds gather. in Sept 2019, a Saudi oilfield was the target of drone attacks, wiping out 5% of the world's oil supply.*	*The prospect of hackers taking control of a drone during flight is a real one. Causing a crash in the air or on the ground could result in material damage and loss of life.*	*There are many public concerns over drone around issues like privacy, trespass and nuisance.*

DRONE SAFETY (1/3)

- Small drones for civil use are becoming easily available to commercial entities for use in a range of purposes.
- They introduce new risks to people and property on the ground as well as to other parts of the aviation system where potential Mid-Air Collisions pose a threat to passenger aircraft.

DRONE SAFETY (2/3)





An increasing trend in the number of reported drone occurrences (both accidents and incidents) per year from 2010 to June 2016 that involve drone, with a clear and significant jump in 2014, has occurred.

DRONE SAFETY (3/3)

Risk factors to be considered:

- The Weight of the drone (<250g, >250g);
- The type of drone;
- Experience of the pilot;
- Purpose of usage;
- Air traffic congestion.

Remember EASA classification

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DRONE VS. MEASUREMENTS (1/3)

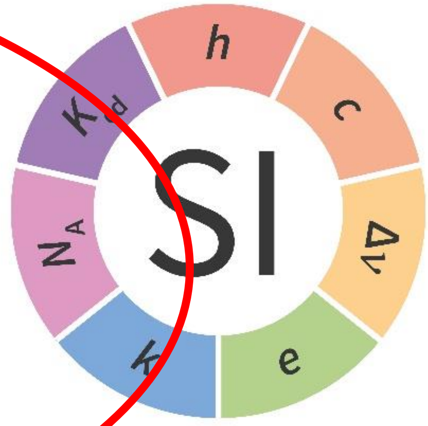
What are drones? ...for us...

1. Drones fly thank to the measurements provided by the navigation sensors embedded on them;
2. Drones must be tested with measurement systems for assuring their reliability;
3. Drones are mobile measurement platforms making measurements during flight.

DRONE VS. MEASUREMENTS (2/3)

- A drone needs to take the measurements provided by several sensors for flying;
- In several applications, the sensors embedded on the drone are used for taking measurements during flight.

Drone



Measurements

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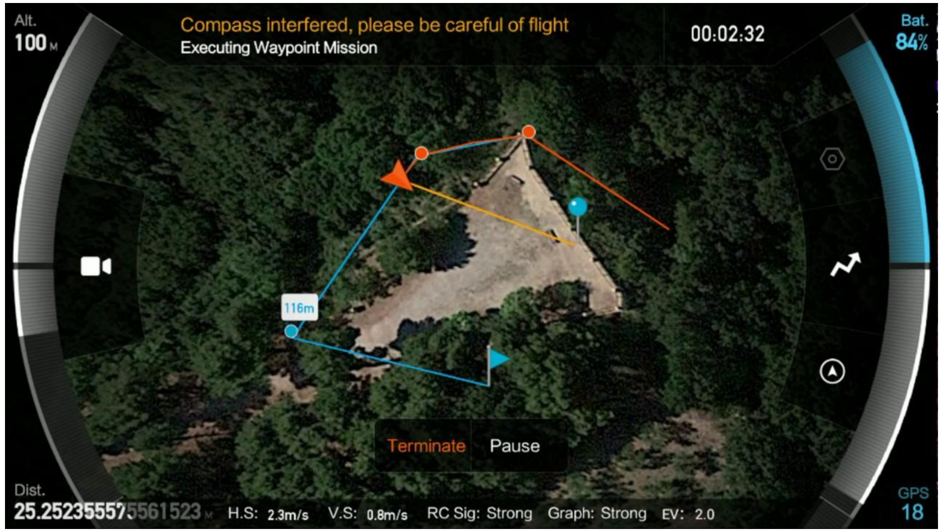
DRONE VS. MEASUREMENTS (3/3)

- Measurements for drone:
  - Measurements for drone navigation;
  - Measurements for security from drones;
  - Measurements for drone safety.
- Drone for measurements.



A/D L.E.S.I.M.

P. Daponte, L. De Vito, G. Mazzilli, F. Picariello, S. Rapuano, M. Riccio, “Metrology for drone and drone for metrology: measurement systems on small civilian drones”, Proc. of IEEE Workshop on Metrology for Aerospace, pp. 316-321, 3-5 June 2015, Benevento, Italy.

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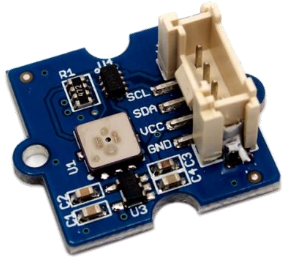
MEASUREMENTS FOR DRONE NAVIGATION (1/2)

The measurements used by drone for flying are:

1. Attitude;
2. Altitude;
3. Position.

Those measurements are provided by:

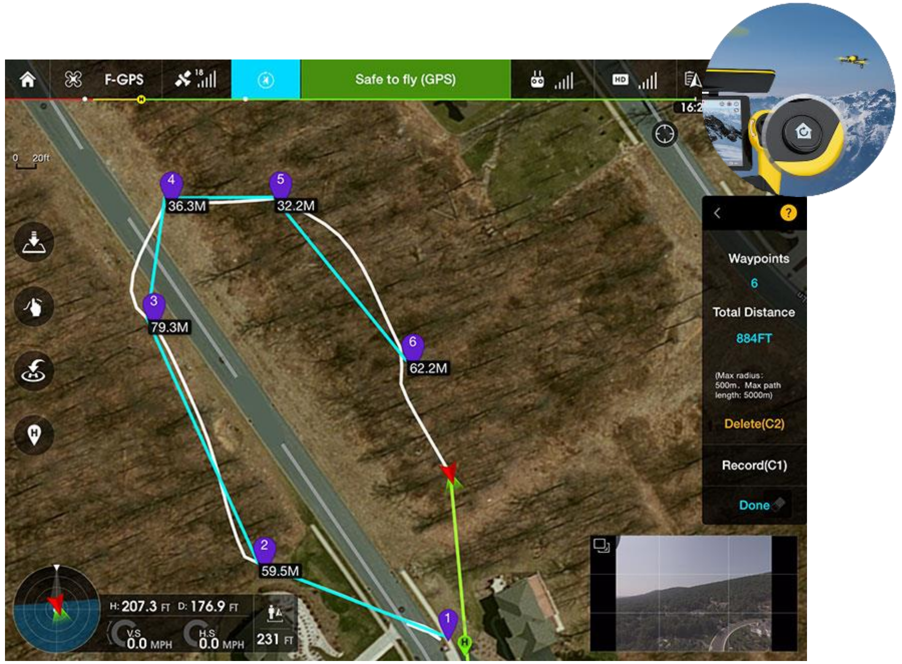
1. Inertial Measurement Unit (IMU);
2. Ultrasonic sensors;
3. Altitude LIDAR;
4. ToF-Camera;
5. GNSS-RTK systems.



MEASUREMENTS FOR DRONE NAVIGATION (2/2)

- The Inertial Navigation System (INS) aims to measure velocity and orientation of drone;
- The Global Positioning System (GPS) provides position measurements.

- The orientation and velocity measurements are used by the control board to assure drone stability during flight;
- The position measurements are used to perform preplanned missions and return home feature.



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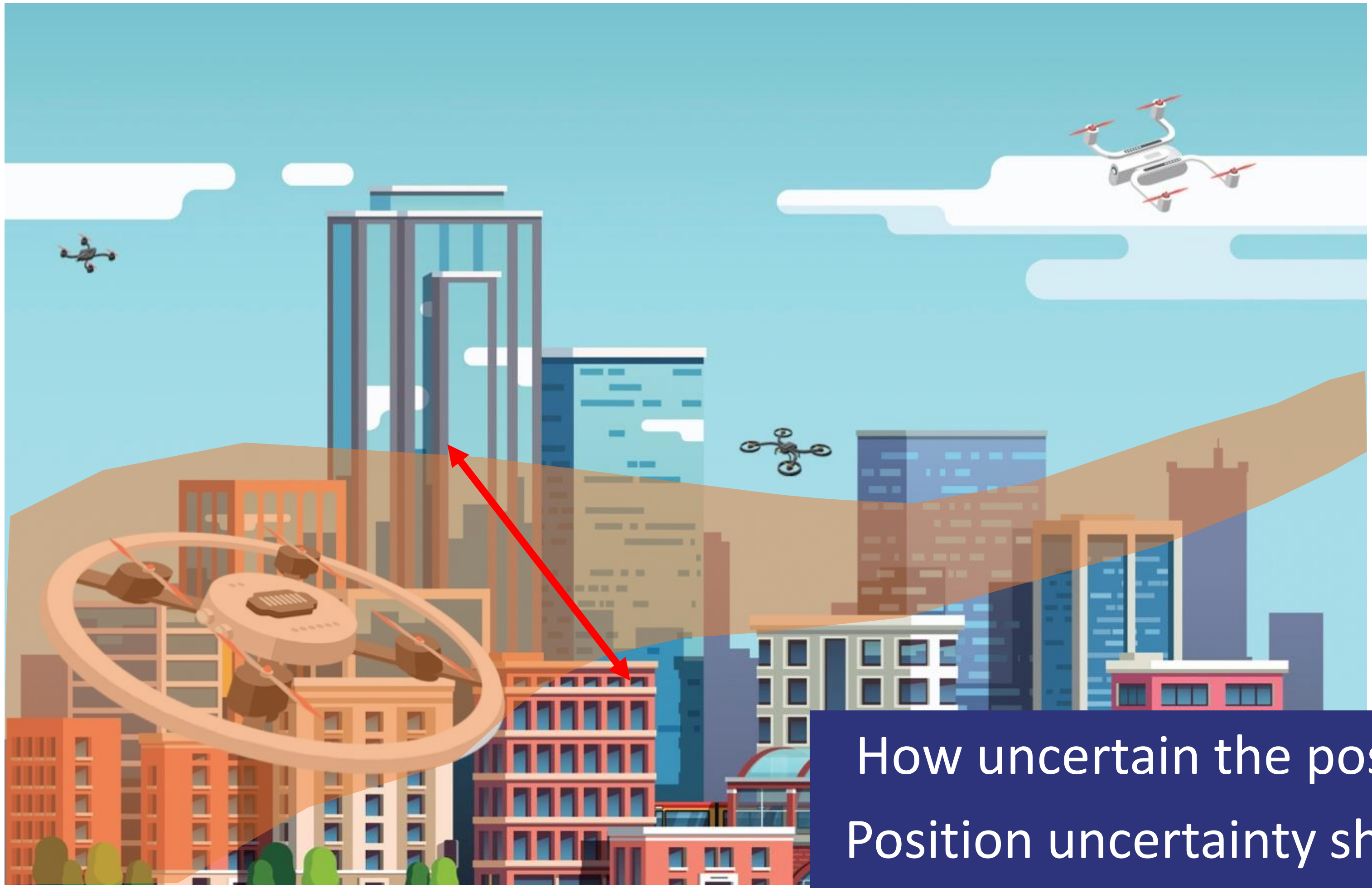
MEASUREMENTS FOR DRONE NAVIGATION: ACCURACY ISSUES (1/3)



How uncertain the position of the drone is?

Position uncertainty should be considered in allocating drone routes.

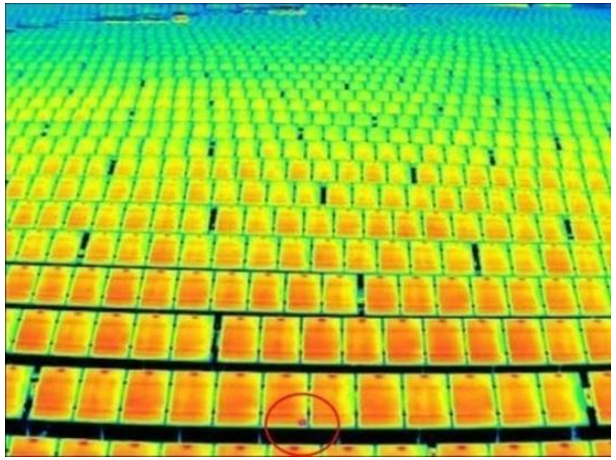
MEASUREMENTS FOR DRONE NAVIGATION: ACCURACY ISSUES (2/3)

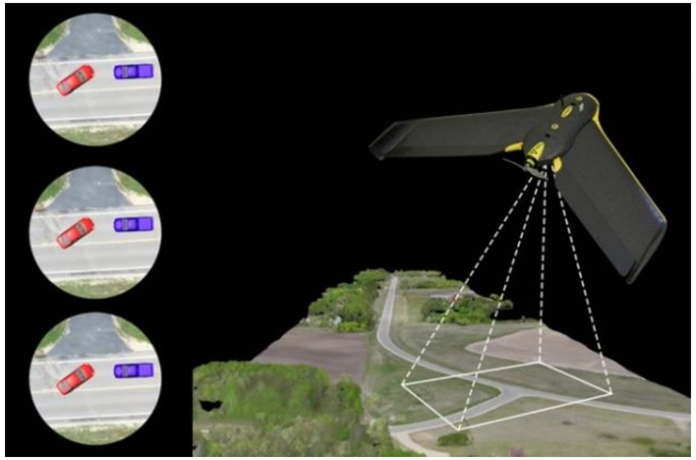
The orientation measurements are affected by:

- motor vibration (accelerometer);
- electromagnetic interference and ambient ferromagnetic influences (magnetometer).

Data fusion algorithms combining accelerometer, gyroscope, magnetometer and GPS measurements are used to improve the accuracy for position and orientation measurements.

Position and orientation are useful information to localize the measurements provided by drone.





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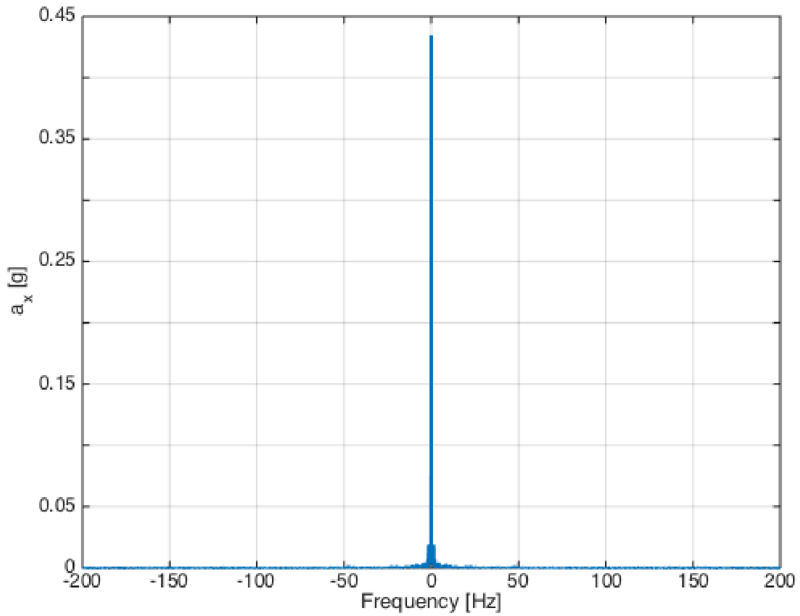
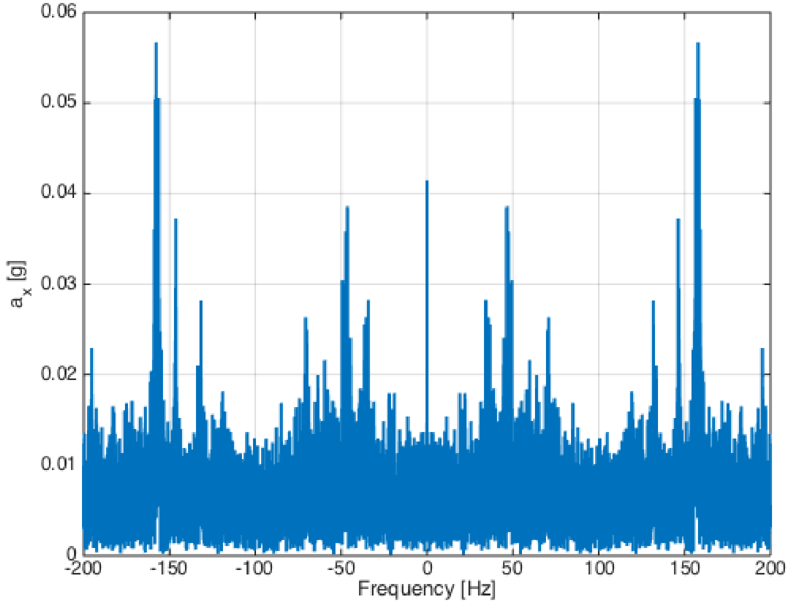
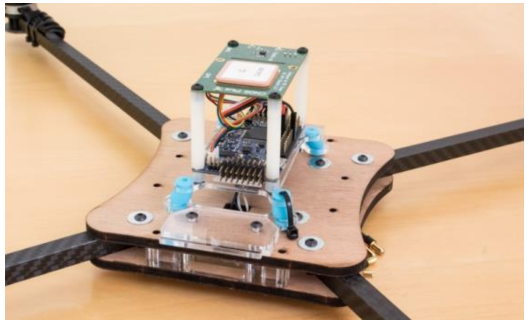
MEASUREMENTS FOR DRONE NAVIGATION: ACCURACY ISSUES (3/3)

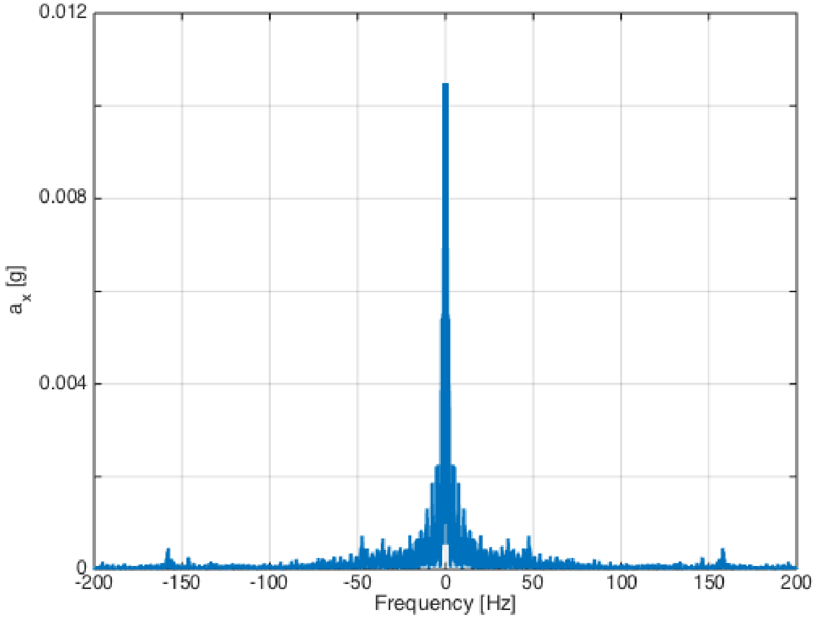


Measurements on ground in static conditions

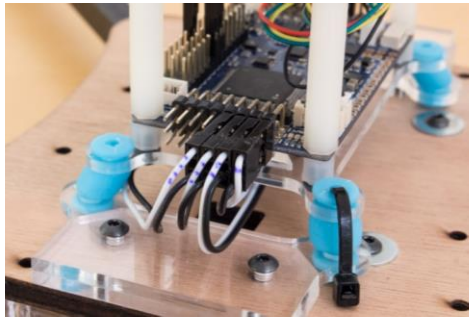


Static conditions measurements with propellers running





Static conditions measurements with damping platform

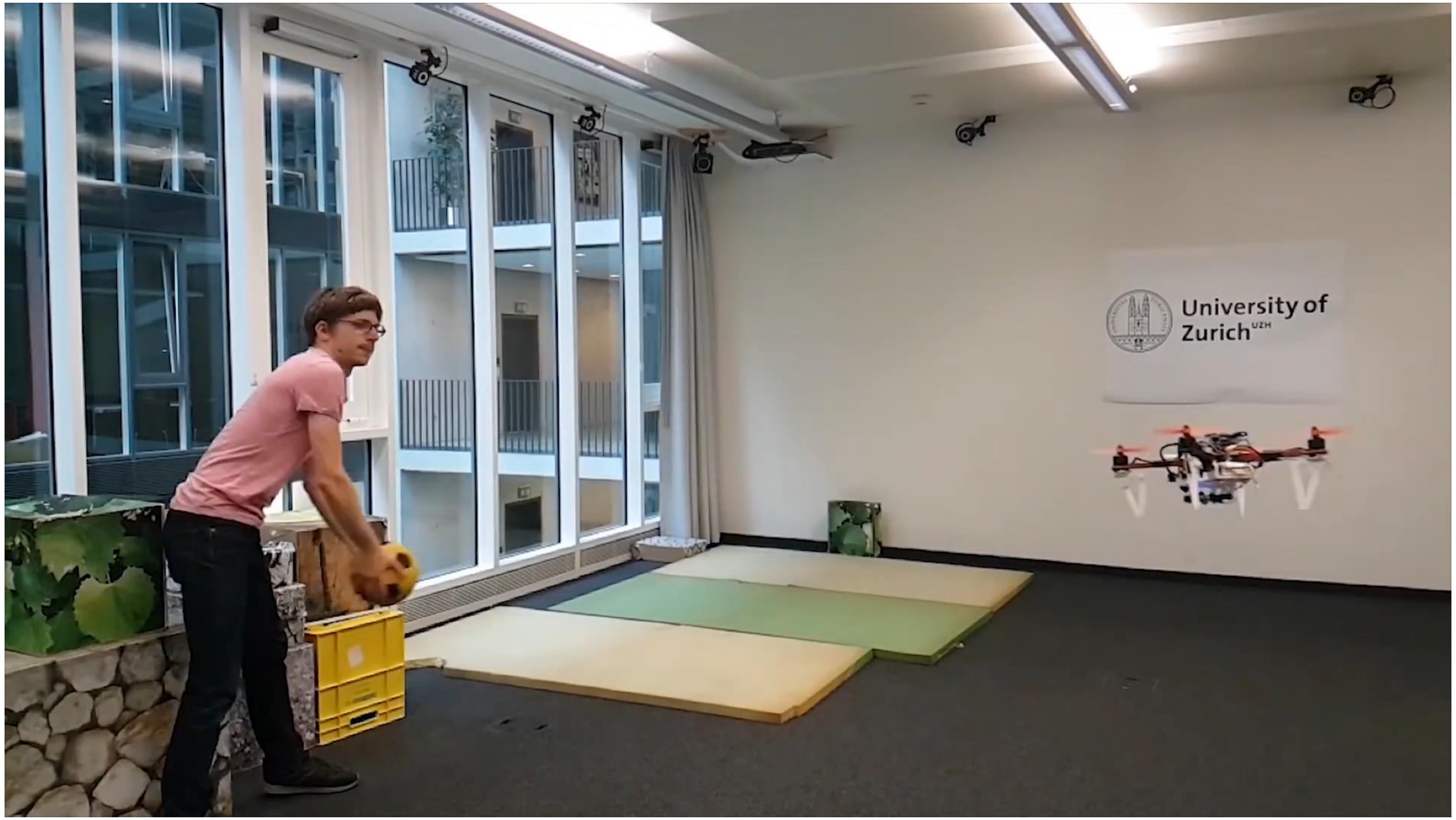


MEASUREMENT FOR DRONE NAVIGATION: SENSE AND AVOID

Sensors for sensing obstacles and other flying objects:

- Camera;
- LIDAR;
- RADAR;
- Ultrasonic.

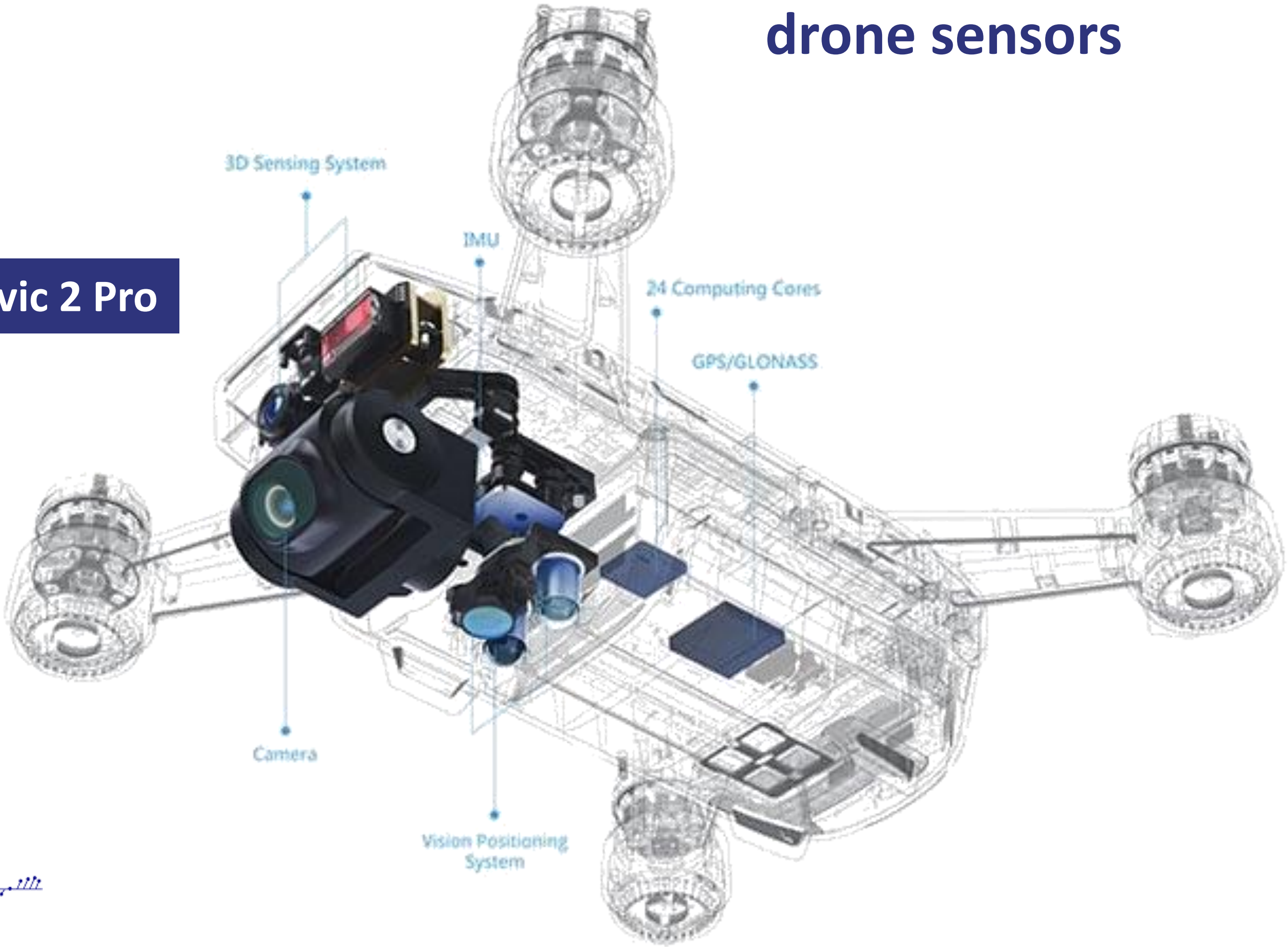
All the measurements must be processed by the drone as soon as possible.



MEASUREMENTS FOR DRONE NAVIGATION: FUTURE TRENDS

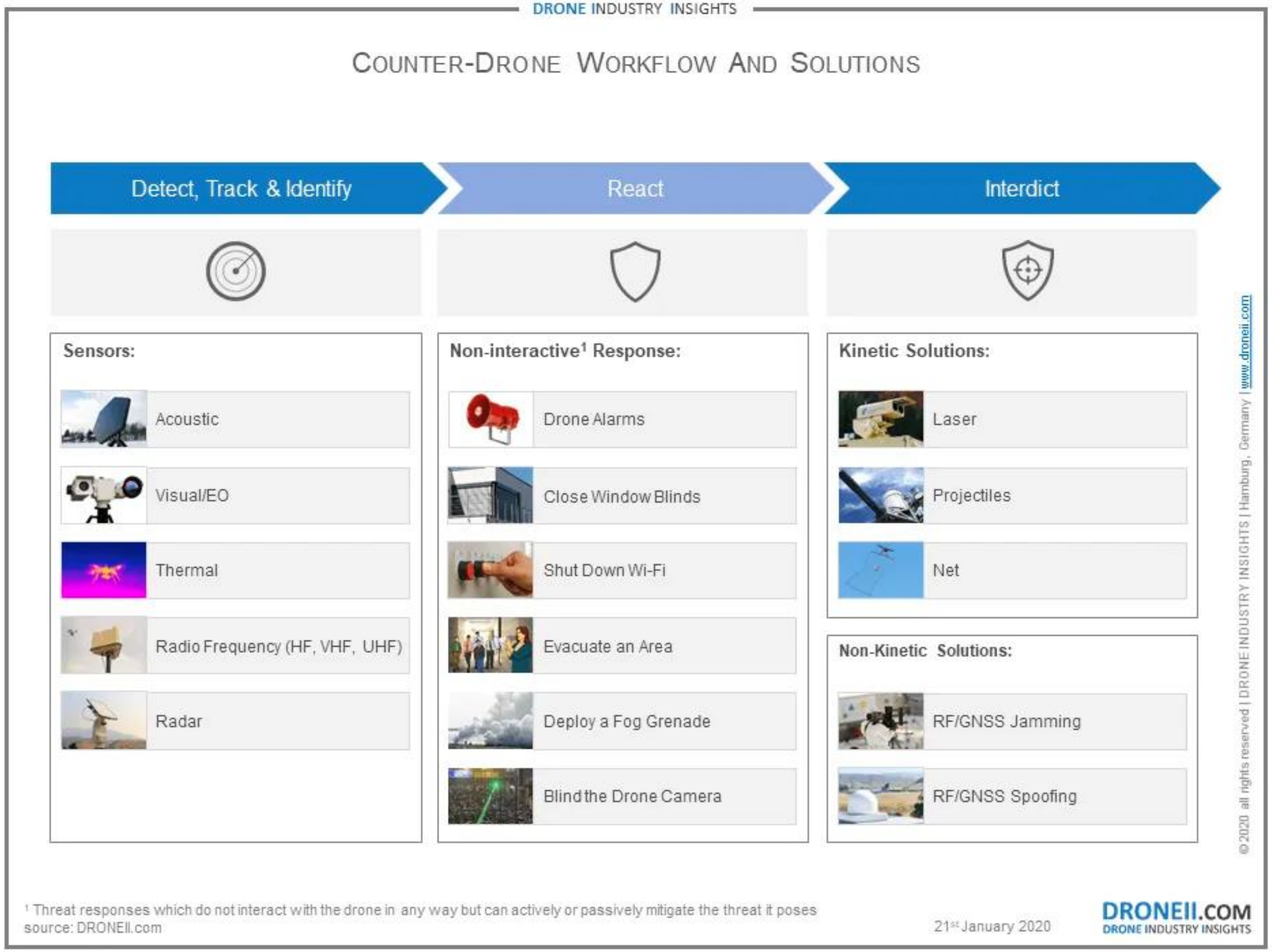
Drone manufacturers are constantly striving to improve the dizzying array of drone sensors

DJI Mavic 2 Pro



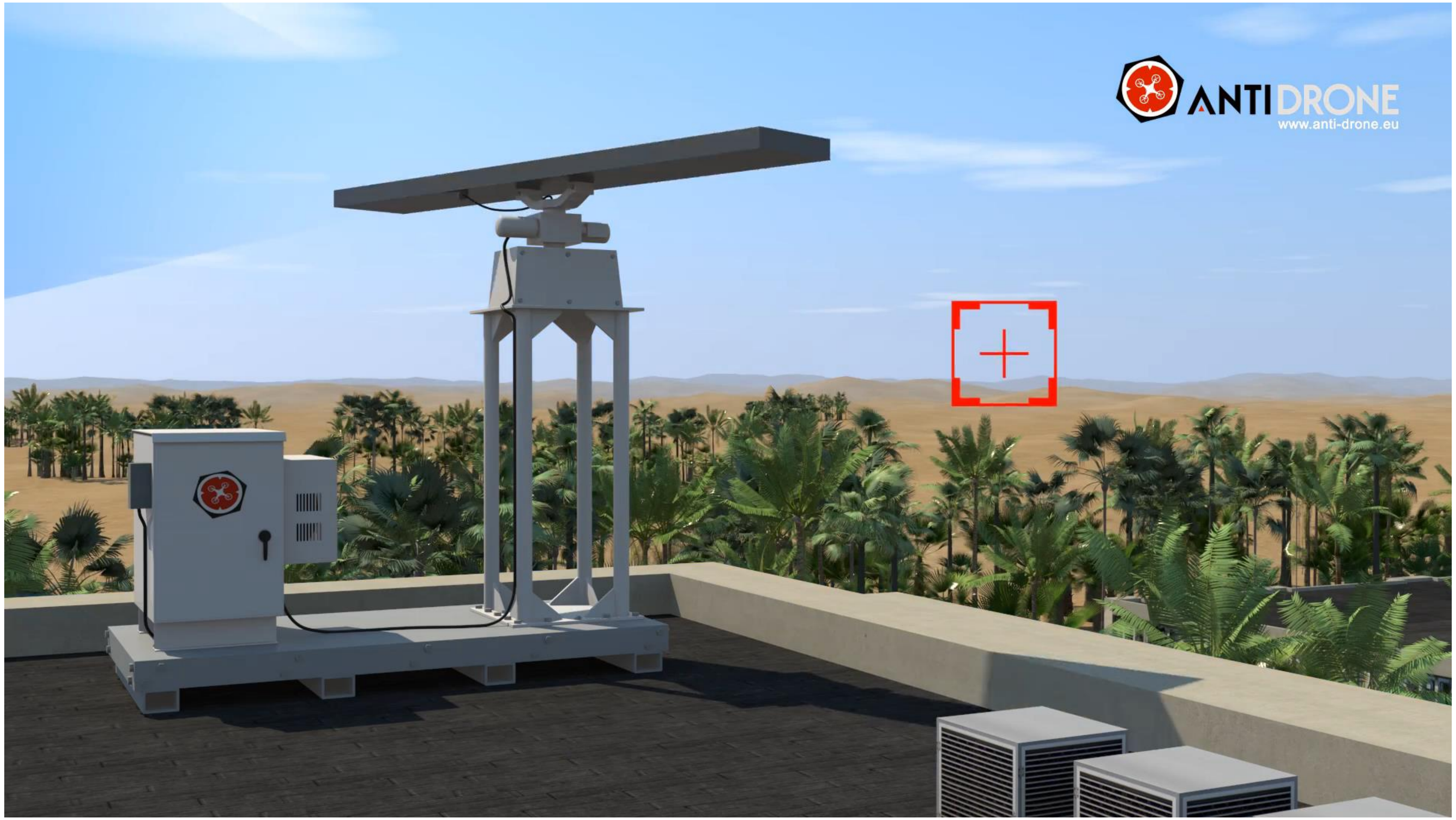
- Visual cameras;
- Infrared detectors;
- Multispectral and hyperspectral sensors;
- Light Detection and Ranging (LIDAR);
- Inertial measurement units;
- Sensors that measure electric current, magnetic fields, and acoustic sound pressure.

MEASUREMENTS FOR SECURITY FROM DRONES (1/2)



MEASUREMENTS FOR SECURITY FROM DRONES (2/2)

- Radar for detecting the drone;
- Camera for tracking the drone;
- RF spectrum monitoring.



MEASUREMENTS FOR DRONE SAFETY (1/3)

- For civilian applications, an important issue is to ensure an acceptable level of safety during drone operations;
- The reliability of the drone as a whole system must be performed periodically to assess the effects of aging and wear;
- Any company performs its own specific tests on drones; thus the tests are not standardized.

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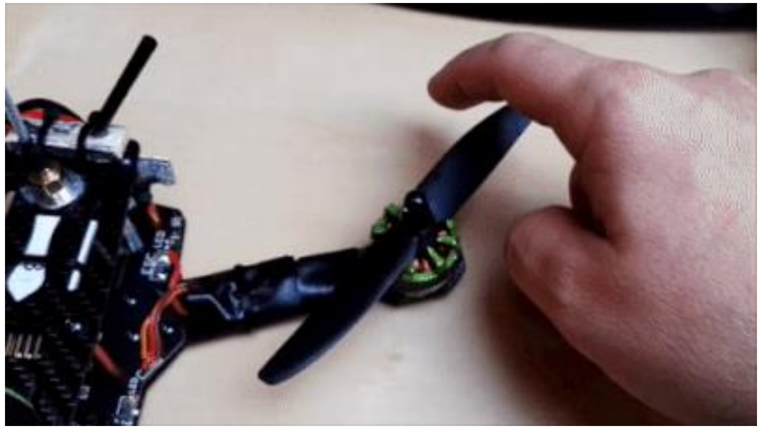
MEASUREMENTS FOR DRONE SAFETY (2/3)

System Failures:

- Engine Failure, which covers failure of the drone propulsion system
- Other System Failures which includes both electrical and control systems as well as software and data link failures.

Battery damage

Propeller damage



Motor damage

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MEASUREMENTS FOR DRONE SAFETY (3/3)

The safety and diagnosis methods for a drone-based measurement instrument can be classified into characterization methods performed:

- **on test benches:** the aim is to measure the parameters related to each drone's component for the following subsystems: (i) propulsion subsystem, and (ii) INS-control board.

- **during flight:** the aim is to characterize the mission measurements provided by drone, according to the application.

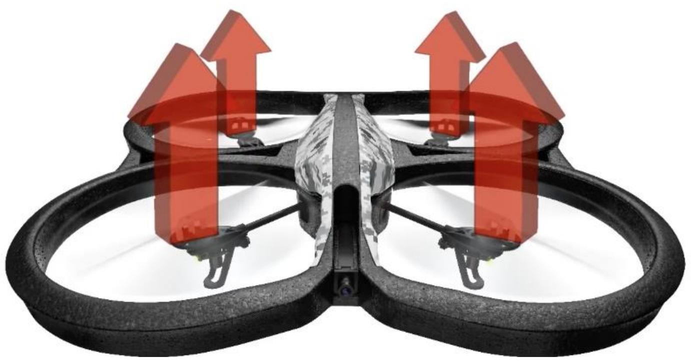
P. Daponte, L. De Vito, F. Lamonaca, F. Picariello, M. Riccio, S. Rapuano, L. Pompetti, M. Pompetti, "DronesBench: an innovative bench to test drones", IEEE Instrumentation & Measurement Magazine, vol. 20, No. 6, pp. 8-15, December 2017.

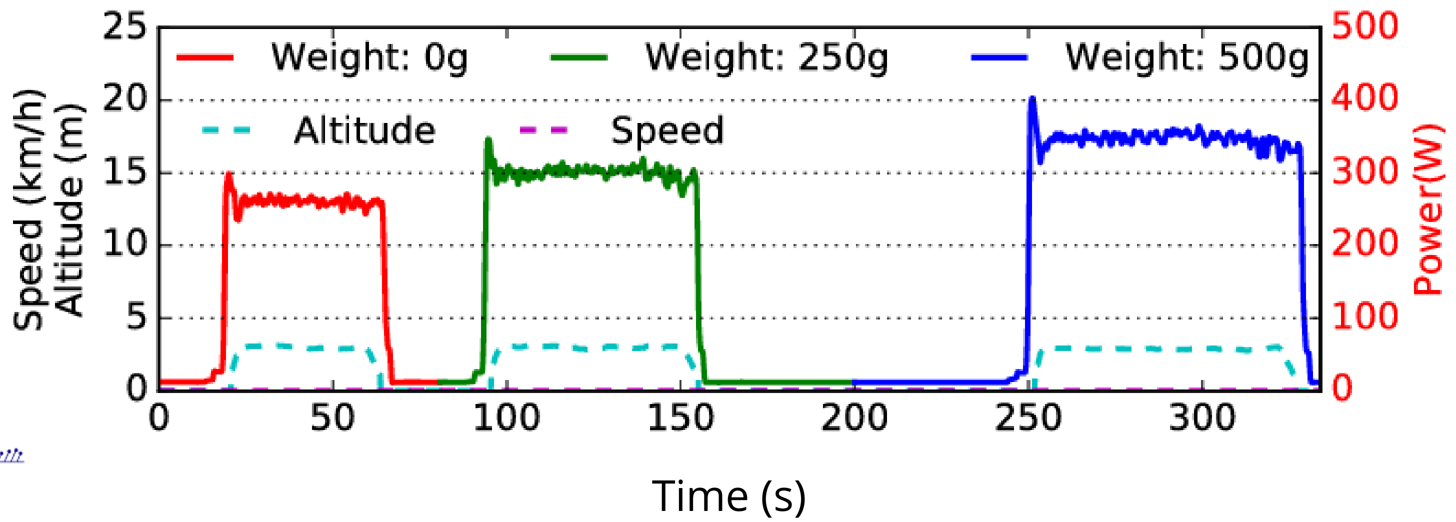
L.E.S.I.M.

CHARACTERIZATION PERFORMED ON TEST BENCH

The most important parameters to be measured are:

- the thrust forces in relation to the motor speeds;
- the motor speed response time;
- the power efficiency in terms of Newton per Watt, [N/W];
- Attitude stability.

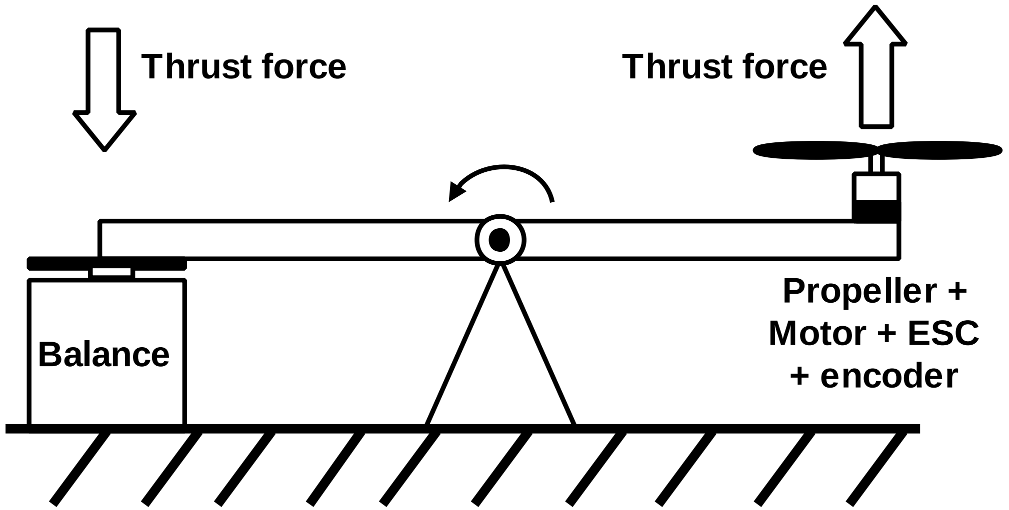


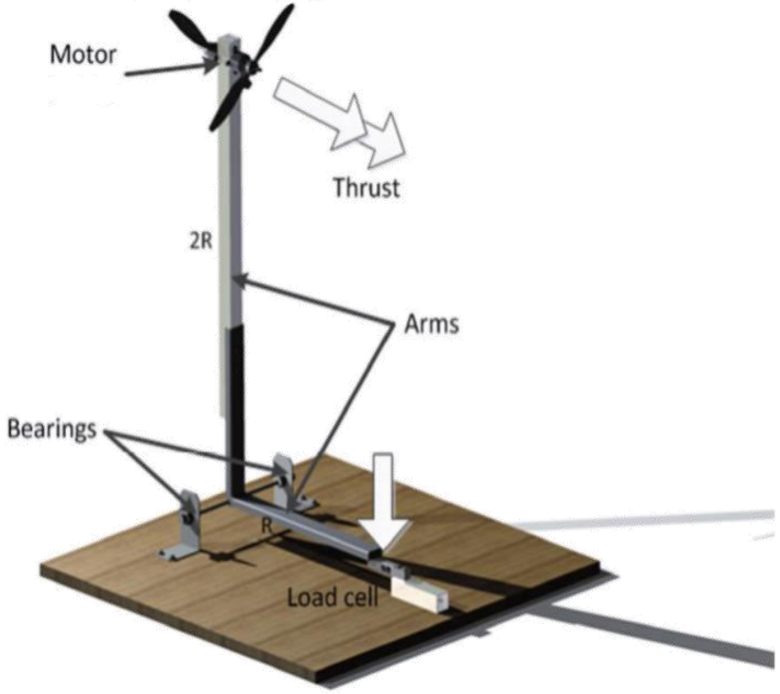


D. N. Faundes, V. Wunsch, S. Hohnstein, B. Glass, and M. Vetter, "Research paper on the topic of different UAV drive train qualification and parameter sets", In *Proceedings of the 32nd Digital Avionics Systems Conference (DASC)*, East Syracuse, NY, Oct. 6–10, 2013.

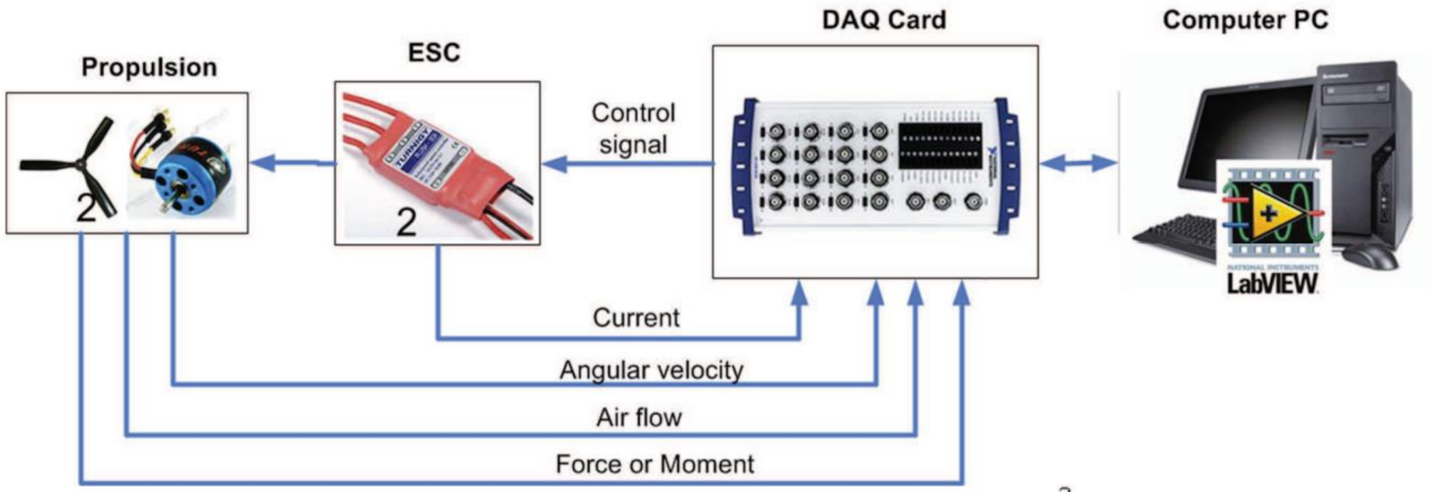
ELECTRONIC WEIGHT BALANCE (1/4)

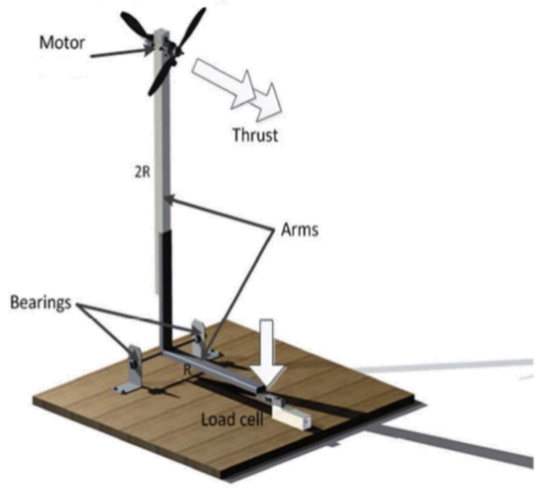
- The thrust force generated by the propeller due to the motor rotation is transmitted on the electronic balance;
- By using this test bench, it is possible to measure the thrust force exerted by propeller for each motor rotation speed and to determine the relationship between them.



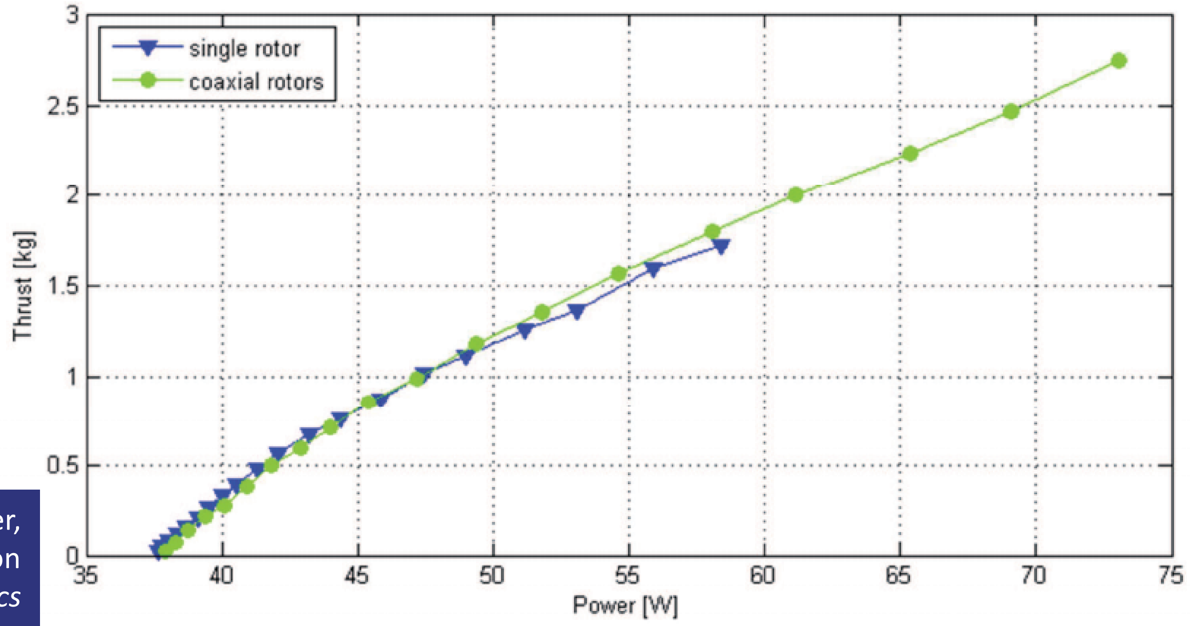


ELECTRONIC WEIGHT BALANCE (2/4)





- Despite the need for supplying two motors, the efficiency of coaxial system turned out to be very close to a single rotor.
- It can be seen that the higher values of thrusts depend linearly on a higher power of propulsion system.



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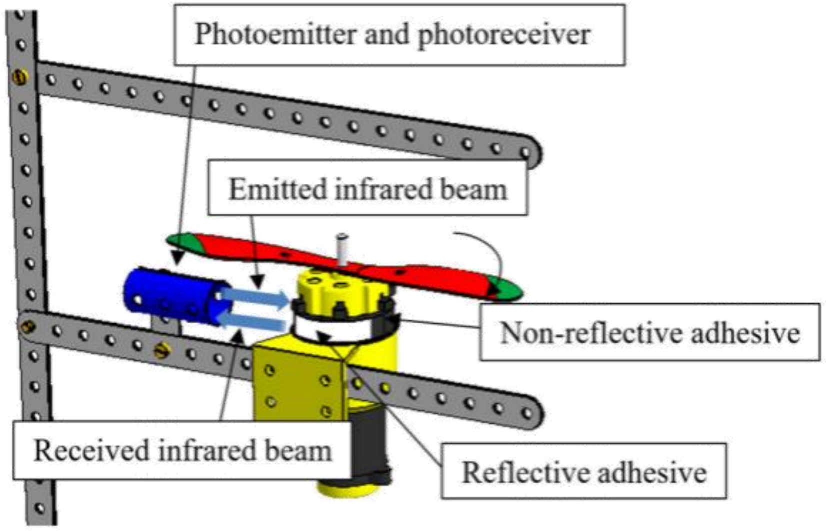
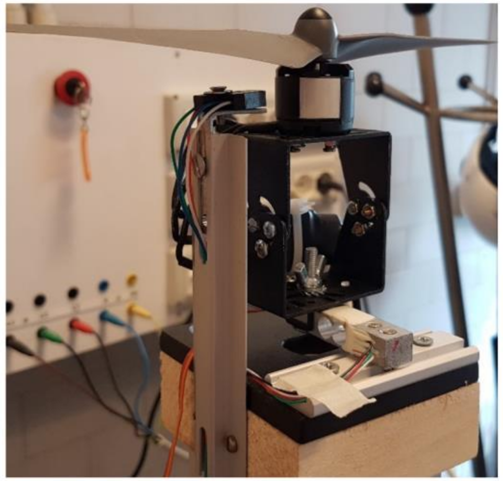
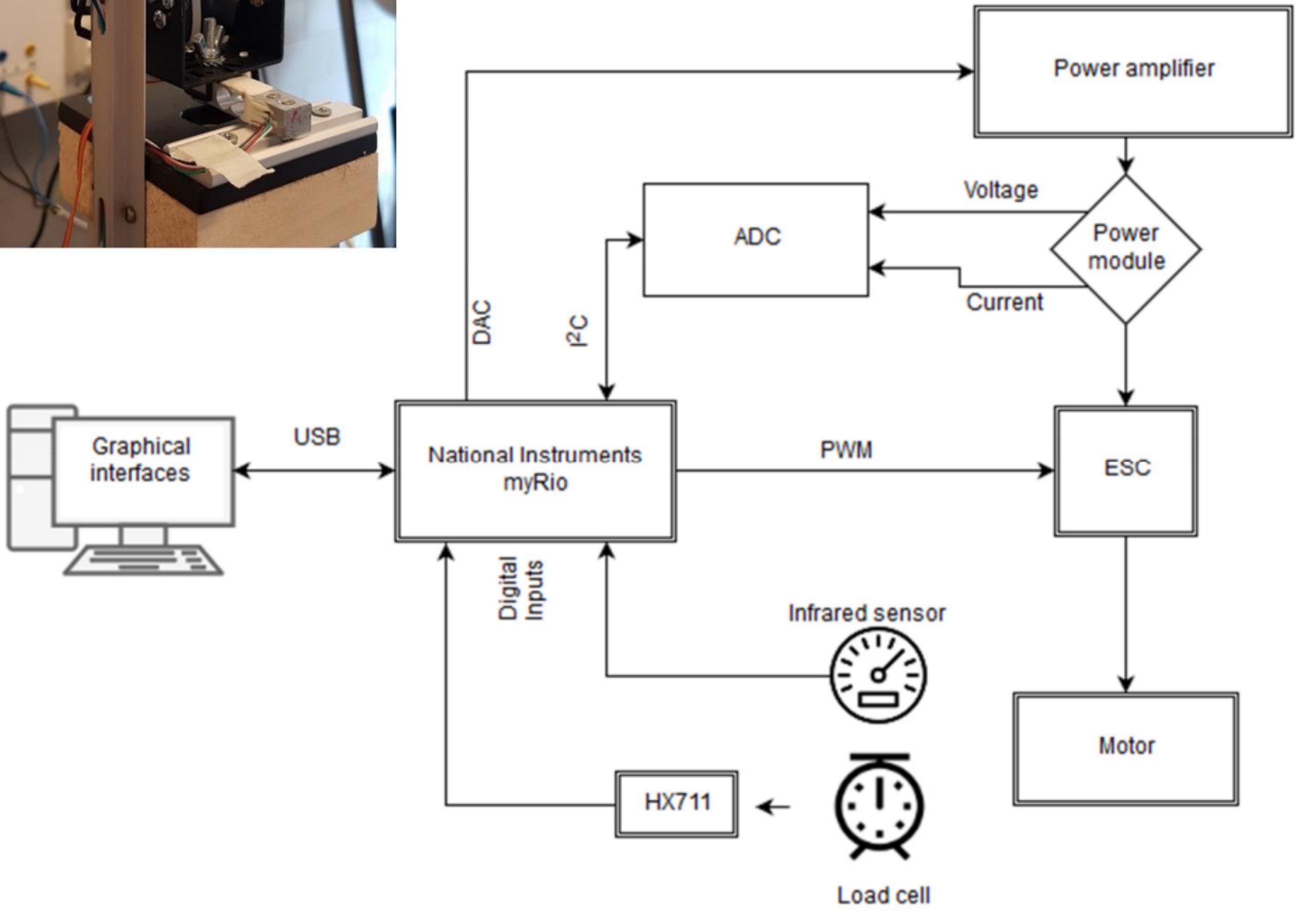
ELECTRONIC WEIGHT BALANCE (3/4)

- Measurement of propulsion force;
- Measurement of motor speed.





F. Adamo, G. Andria, A. Di Nisio, C. G. Calò Carducci, A. M. L. Lanzolla and G. Mattencini, "Development and characterization of a measurement instrumentation system for UAV components testing" 2017 IEEE International Workshop on Metrology for AeroSpace (MetroAeroSpace), Padua, 2017, pp. 355-359.

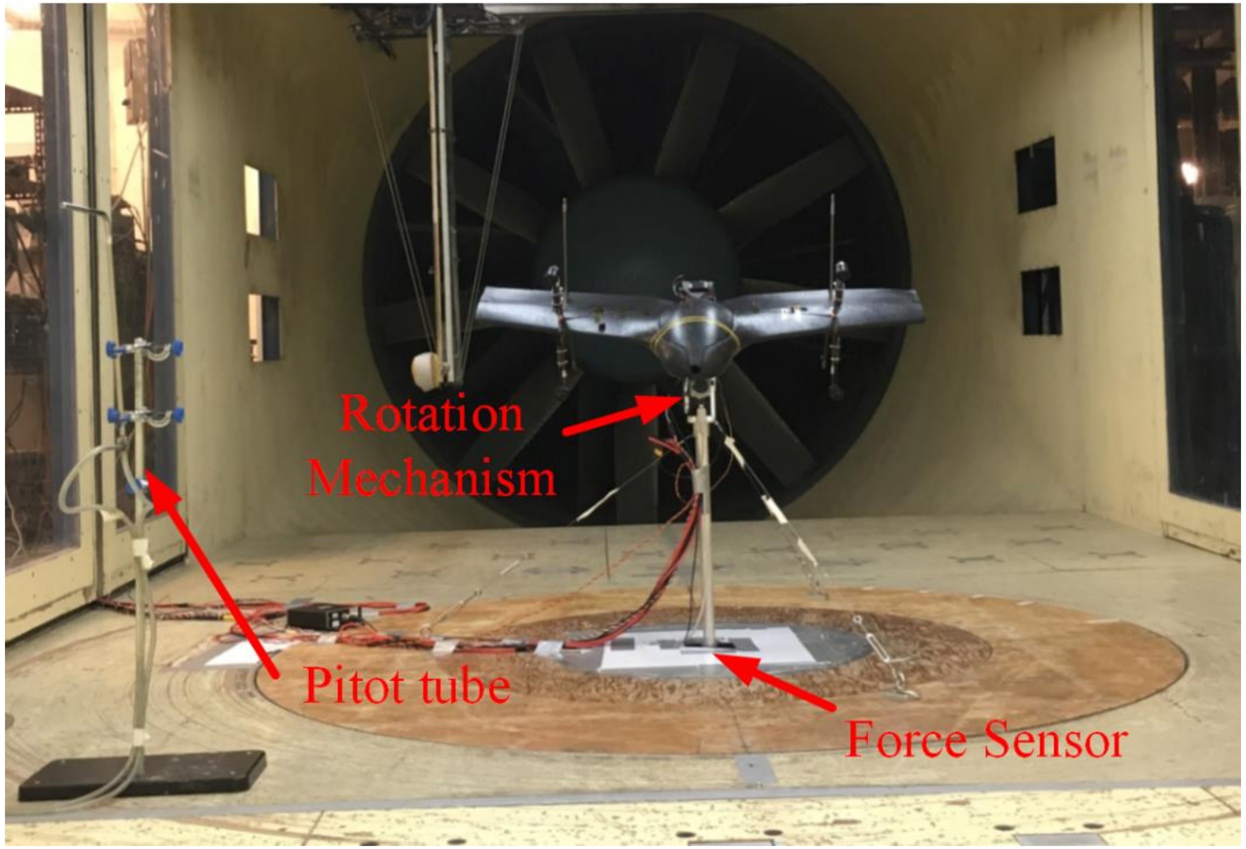


ELECTRONIC WEIGHT BALANCE (4/4)

The test bench is based on the balance method, but the measurement system is placed in a wind tunnel.

In this way, it is possible to take into account the effect of wind direction and speed on the thrust force and the motor speed.

X. Lyu, H. Gu, Y. Wang, Z. Li, S. Shen and F. Zhang, “Design and implementation of a quadrotor tail-sitter VTOL UAV”, 2017 IEEE International Conference on Robotics and Automation (ICRA), Singapore, 2017, pp. 3924-3930.



ATTITUDE STABILITY TEST

- The test bench allows to measure the roll, pitch and yaw angles.
- The test bench consists of a three degrees of freedom platform.
- The drone center of gravity is placed on a fixed height rod, allowing roll, pitch and yaw rotations.

Dr. Ahmet Kirli, Prof. Dr. V. Emre Ömürlü, Prof. Dr. Ata Mugan, " Ground Fixed Quadrotor Flight Control Test Bench for UAVs w/ Variable DOF"
link: https://journals.sagepub.com

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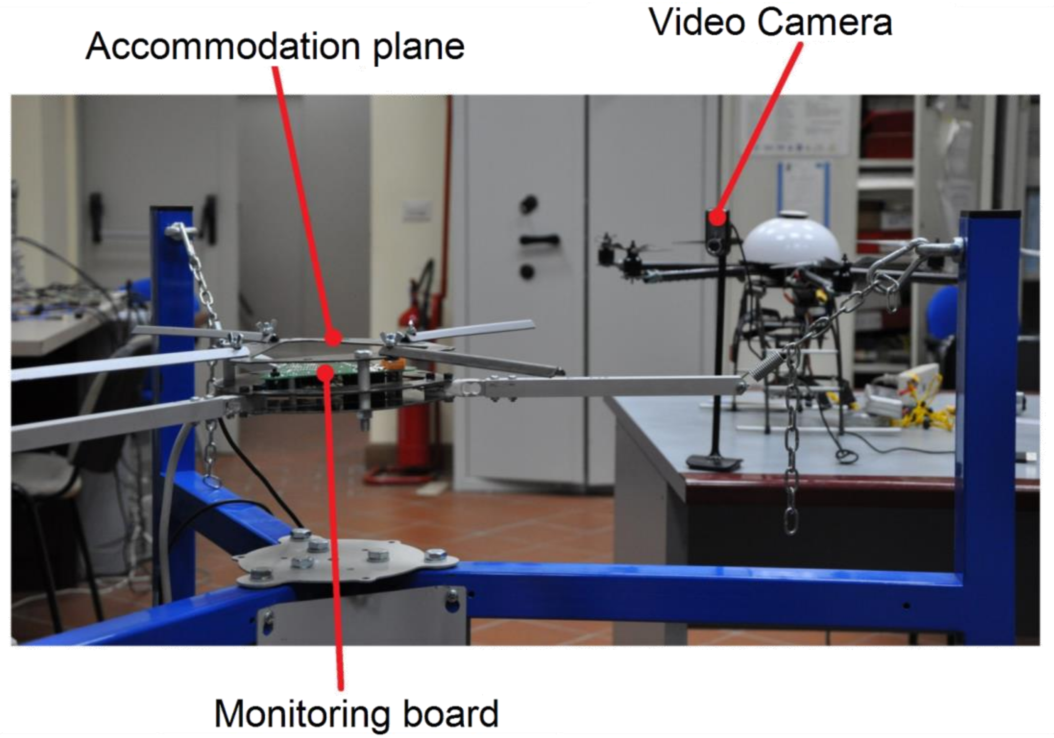
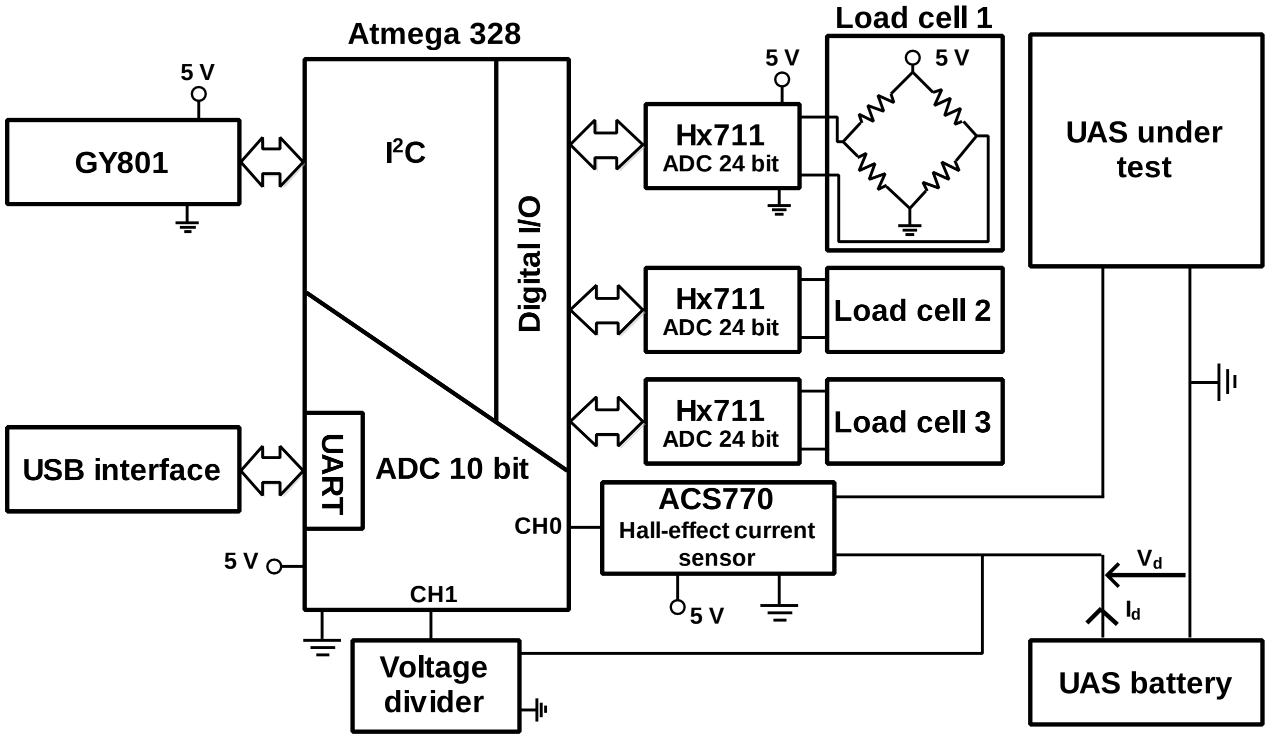
CHARACTERIZATION PERFORMED ON TEST BENCH: OPEN ISSUE

- In literature, the systems used for testing drones are mainly used for measuring parameters related to each component of the drone itself (such us control board, propeller, motor, and so on).

- These measurement systems are designed for testing each drone subsystem and they do not allow assessing the reliability of a drone as a whole system.

DRONESBENCH: A SOLUTION (1/3)





The system consists of: (i) the accommodation plane, where the drone is inserted, (ii) the monitoring board, which is used for acquiring the data of the sensors, and (iii) the video camera for online visualization and recording of the testing scenario.

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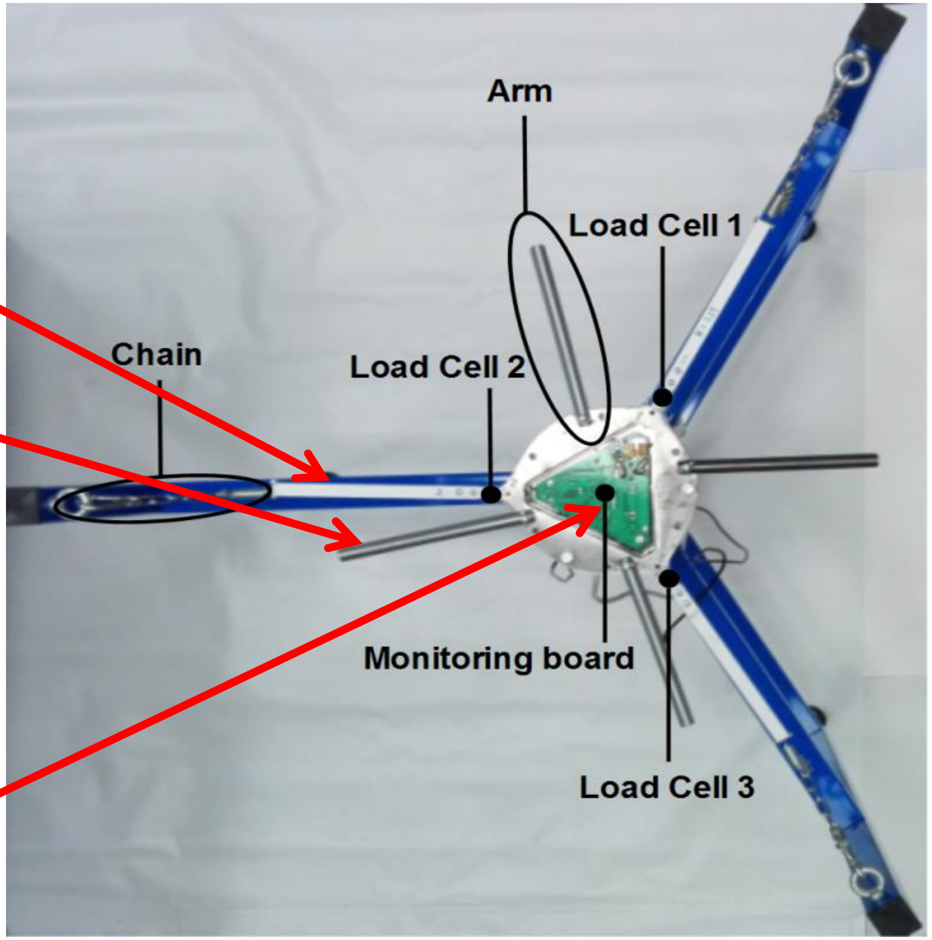
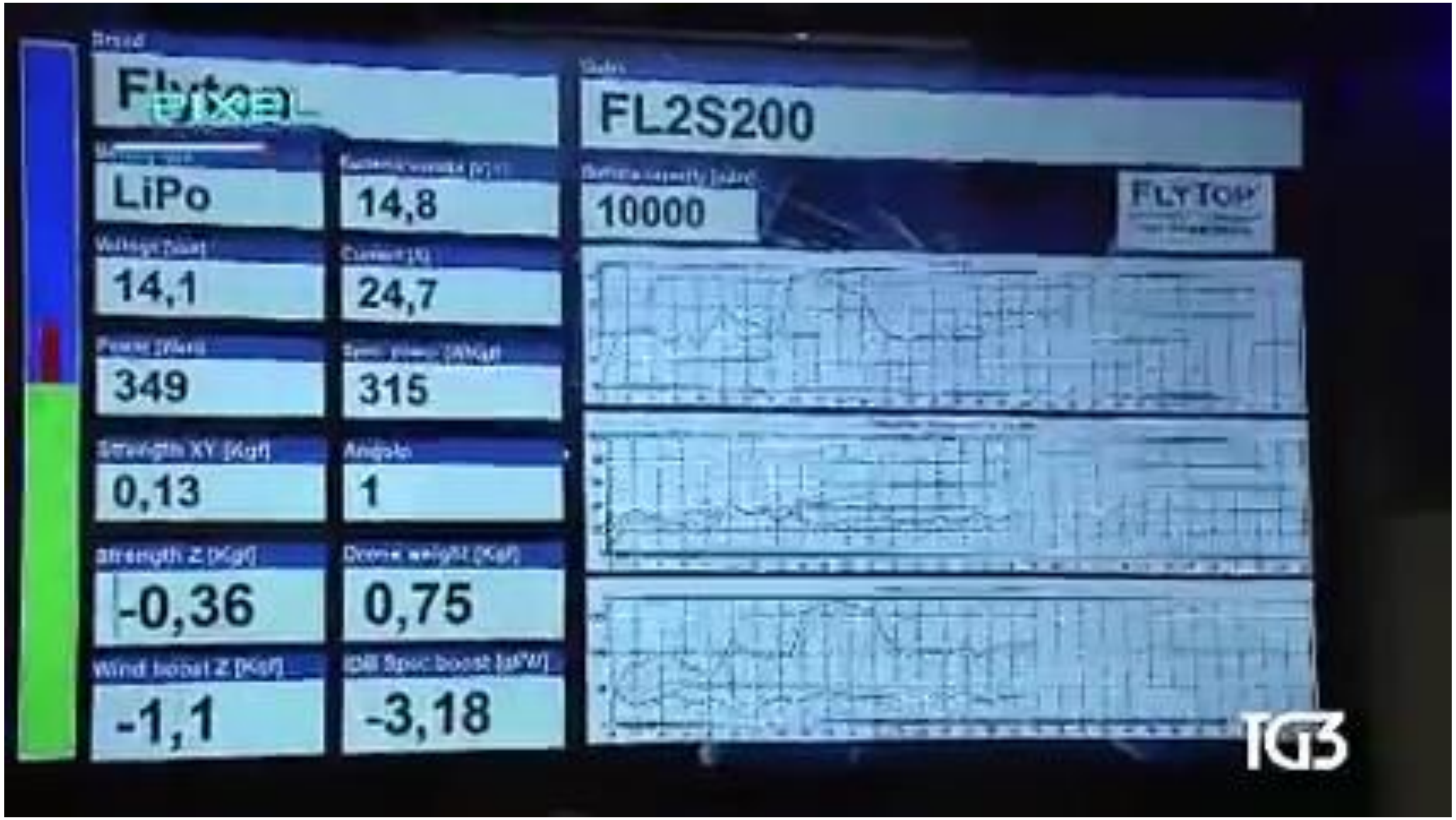
P. Daponte, L. De Vito, F. Lamonaca, F. Picariello, M. Riccio, S. Rapuano, L. Pompetti, M. Pompetti, “DronesBench: an innovative bench to test drones”, IEEE Instrumentation & Measurement Magazine, vol. 20, No. 6, pp. 8-15, December 2017.

DRONESBENCH: A SOLUTION (2/3)

- The load cells are placed at 120° to each other on the accommodation plane.
- The drone under test is fixed through the four arms that are attached on the accommodation plane and the monitoring board is placed under the accommodation plane.
- The measurements are acquired in real-time, from the monitoring board, on a PC by using a LabVIEW application.



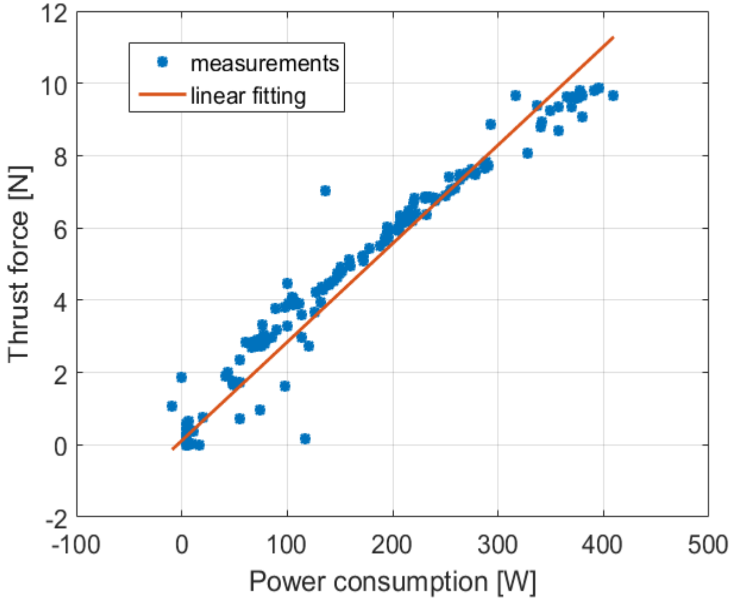
DRONESBENCH: A SOLUTION (3/3)

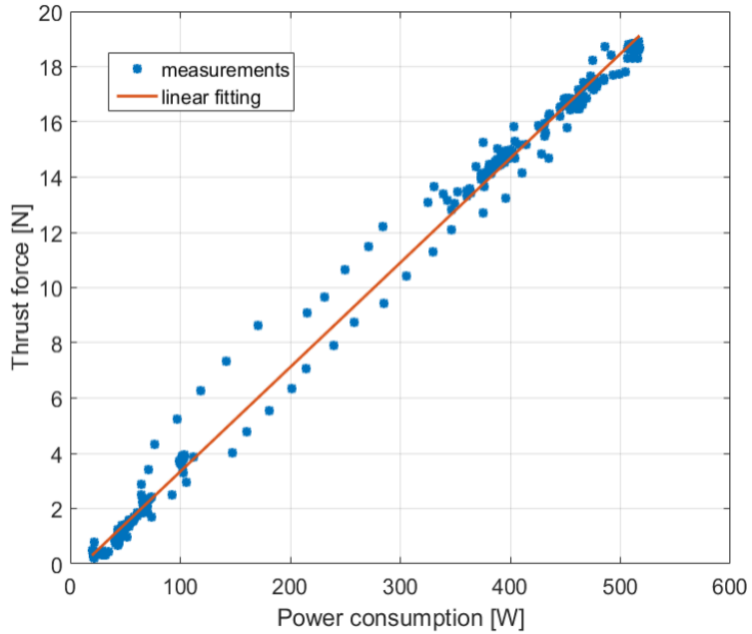


DRONESBENCH: PRELIMINARY RESULTS (1/2)

Quadrotor

FoM = 0.027 N/W





Hexarotor

FoM = 0.038 N/W

The testing procedure consists of driving the drone manually by using the ground control station. In particular, the test has been performed for about 45 s where the pilot executed one throttle variation from the minimum to the maximum values allowed by the drone.

	Quadrotor	Hexarotor
Motor	Sunnysky V3508	Pulso U22 M
Propeller	(28 × 12.5) cm	(28 × 12.5) cm
ESC	Opto 30 A	Opto 30 A
Control board	Pixhawk V2.4.8	DJI NAZA-M V2
Battery	Turnigy 3S, 5000 mAh	Fullpower 4S, 5000 mAh
Frame	wheelbase length 495 mm	wheelbase length 670 mm

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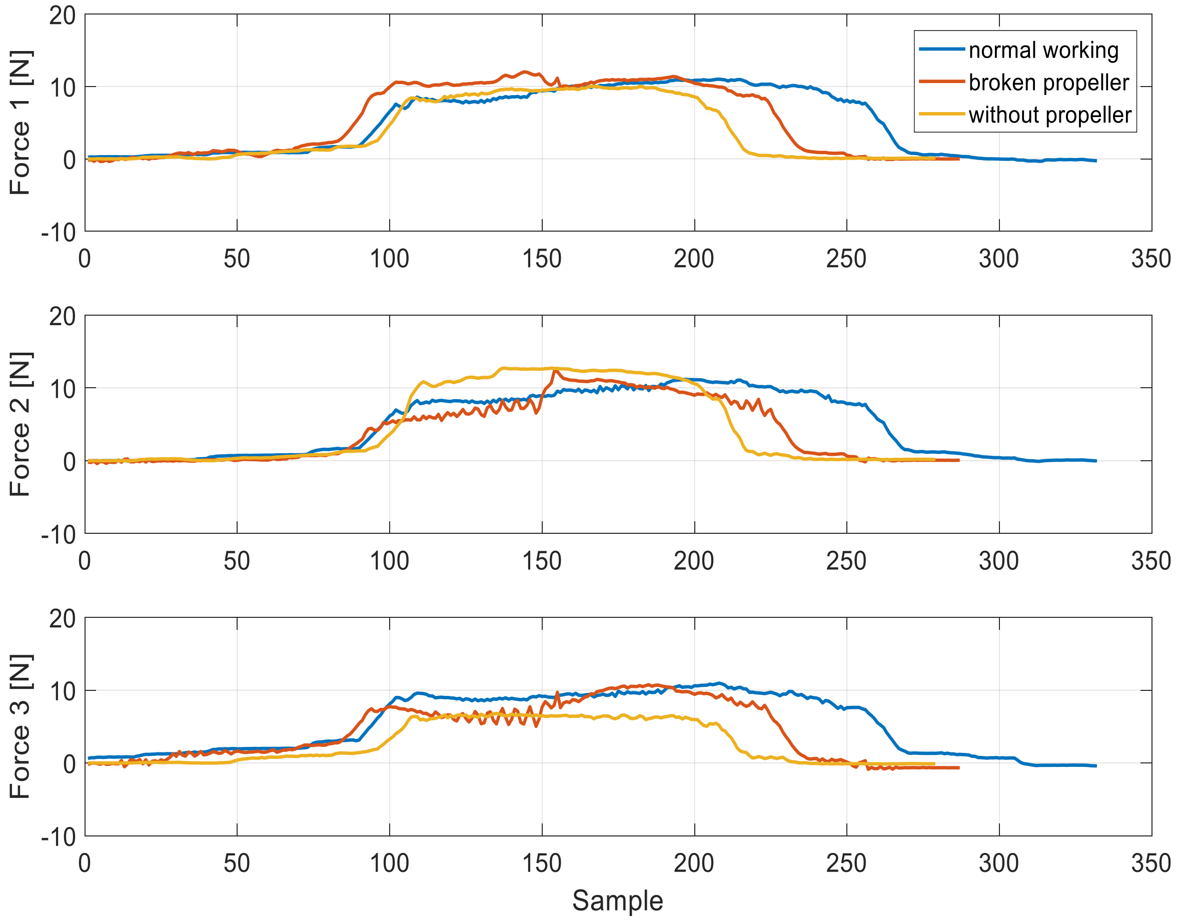
DRONESBENCH: PRELIMINARY RESULTS (2/2)

Test 1: the hexarotor was tested with all the propellers working (called normal working).

Test 2: the hexarotor was tested with one propeller damaged – missing about 1 cm of blade on one of the tips (called broken propeller).

Test 3: the hexarotor was tested without a propeller (called without propeller).

The obtained results show that the force measurements can be used for detecting and identifying faults or damages of drones.

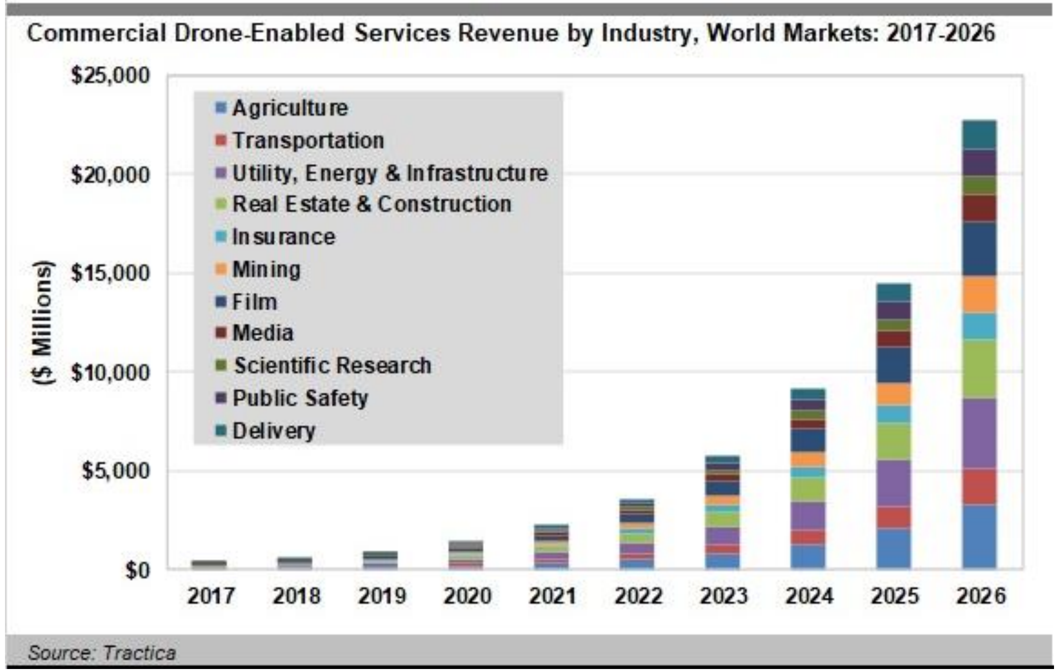


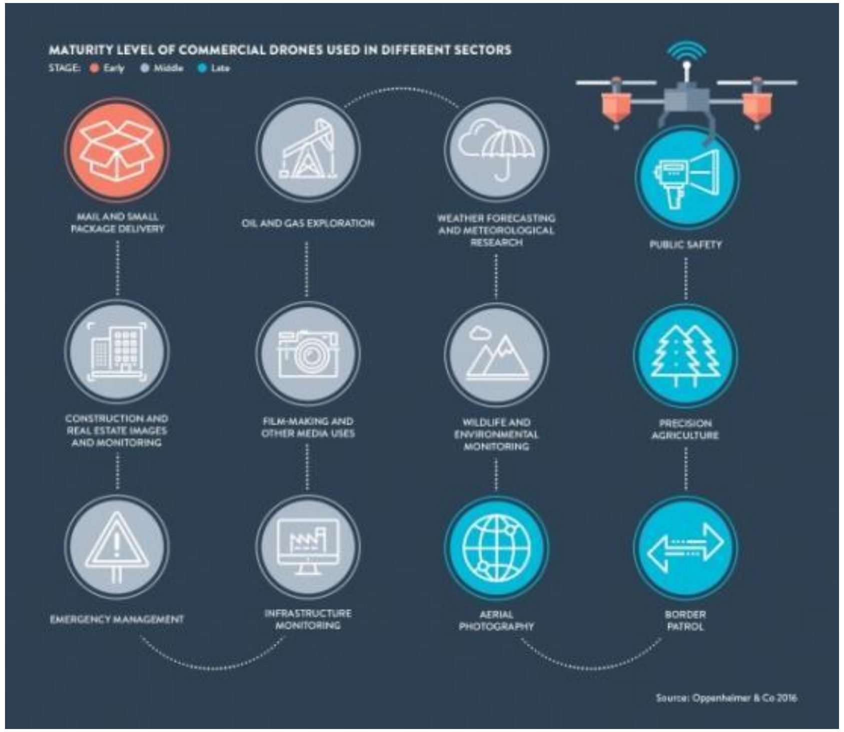
B. Brzozowski, P. Daponte, L. De Vito, F. Lamonaca, F. Picariello, M. Pompetti, I. Tudosa, K. Wojtowicz, “A remote controlled platform for UASs testing”, IEEE Aerospace and Electronic Systems Magazine, vol. 33, no. 8, pp. 48-56, August 2018.

OUTLINE

- L.E.S.I.M.: Who We are;
- Drones;
- Drone trends;
- Drone vs. measurements;
- Measurements for drone;
- Drone for measurements;
- Conclusions.

DRONE FOR MEASUREMENTS

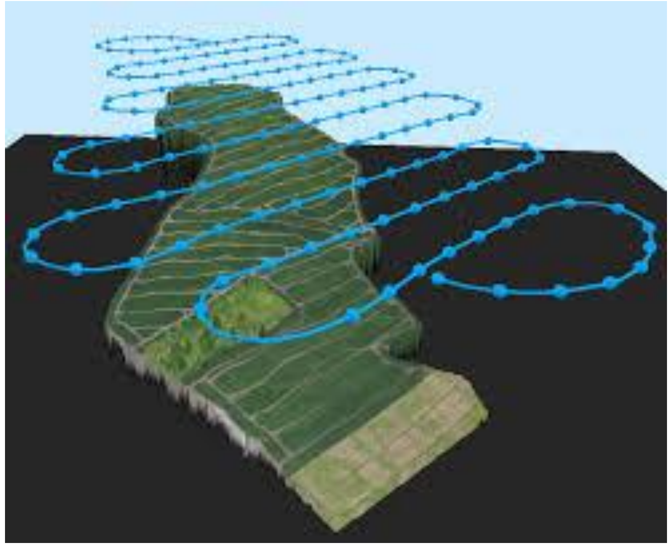




- The professional use of drones is continuously growing.
- Most applications involve monitoring and **measurements**.

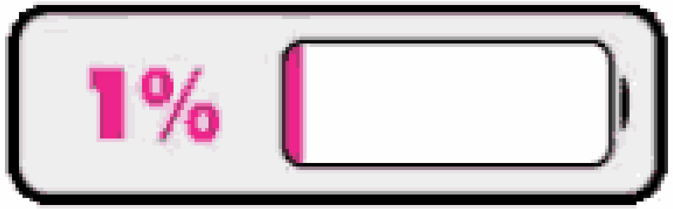
DRONE FOR MEASUREMENTS: PROS

- Low weight;
- Small size;
- Low cost;
- Easy handling;
- Drone is a platform able to survey wide areas and reach human-hostile environments;
- Flexible platform, several kinds of sensors can be embedded on them.



DRONES FOR MEASUREMENTS: CONS (1/2)

- Due to the payload and the power consumption limits, the drone cannot be equipped with heavy instruments;



- Usually, the data processing is not performed on board (limited payload and battery);

DRONES FOR MEASUREMENTS: CONS (2/2)

- The flight mission and the environmental parameters can affect the measurement results;

- More and more uncertainty sources should be considered compared with a “terrestrial” measurement system.

DRONE AS AN INSTRUMENT

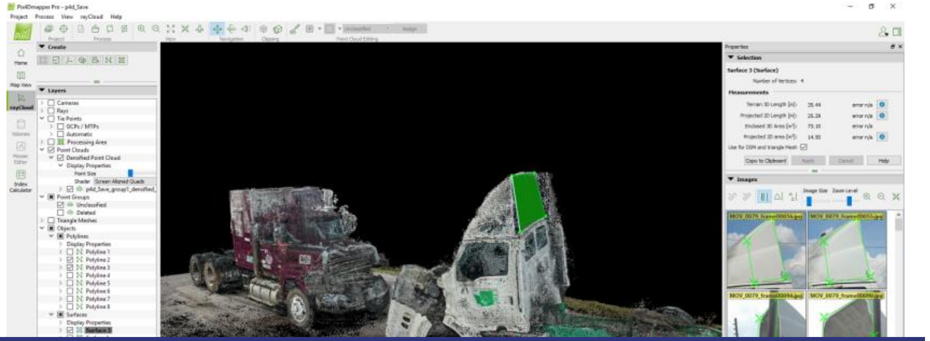
- As a measurement instrument, the drone must guarantee the metrological traceability and its measurements must comply with international standards;

- It is very hard to evaluate the measurement uncertainty of a drone because several quantities affect the measurement result.

DRONE AS AN INSTRUMENT: EXAMPLE

Drones have been recently proposed for the documentation of car accidents:

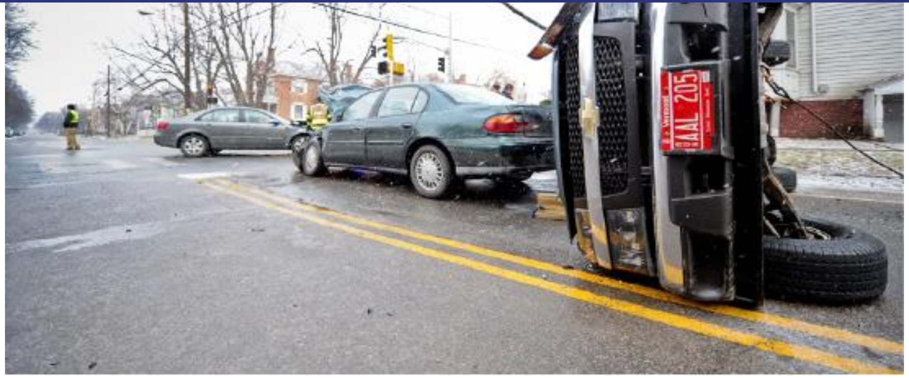
- -80% of occupation time of the road;



How is the measurement uncertainty assessed in case of drone?

How is metrological traceability guaranteed?

measurements, with **unofficial and approximate accuracy** of 2-5 cm.



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MEASUREMENT UNCERTAINTY OF DRONES (1/4)

In several applications, the traceability and the measurement uncertainty assessment are not considered, or specific solutions are adopted that refer the measurement uncertainty with drones to the measurement uncertainty obtained with terrestrial reference systems.

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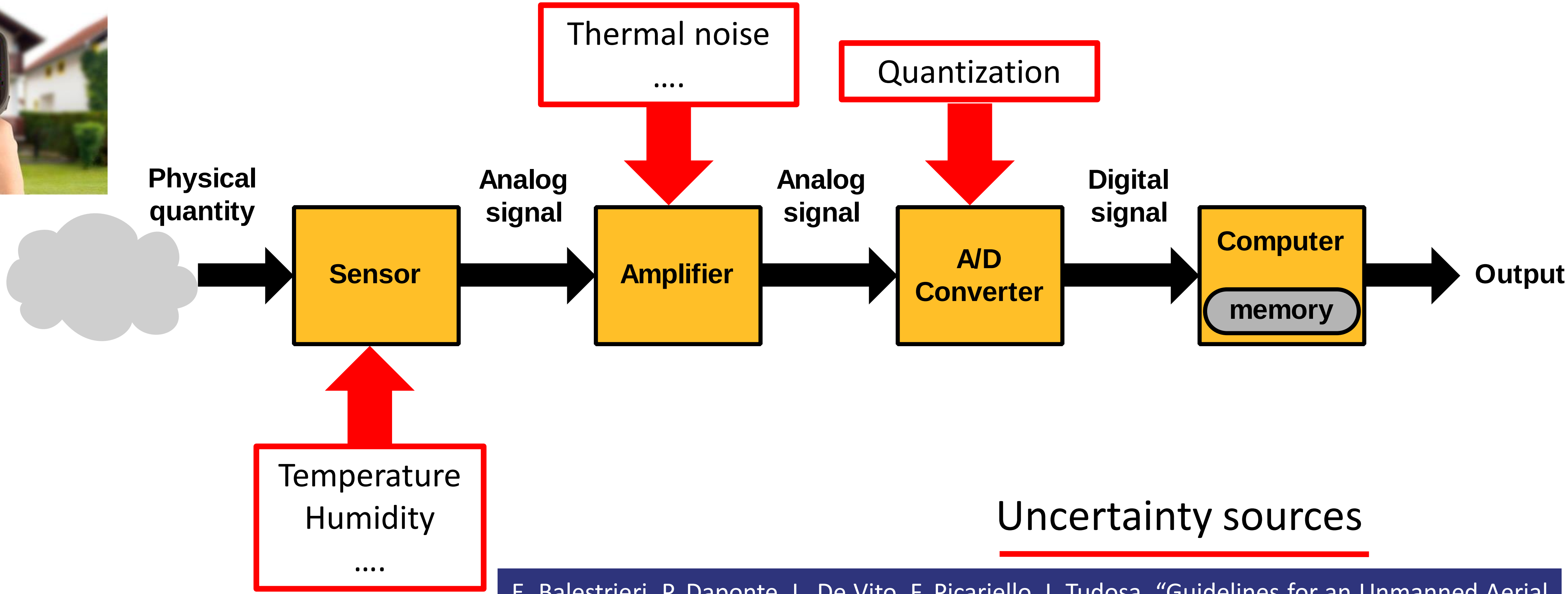
MEASUREMENT UNCERTAINTY OF DRONES (2/4)

A drone-based measurement instrument is a complex system:

- Several sub-systems (propulsion, flight control, power supply, etc.) contribute to define the overall system behavior;
- The final measurement result is generally obtained by complex indirect methods operating on data from several sensors.

MEASUREMENT UNCERTAINTY OF DRONES (3/4)

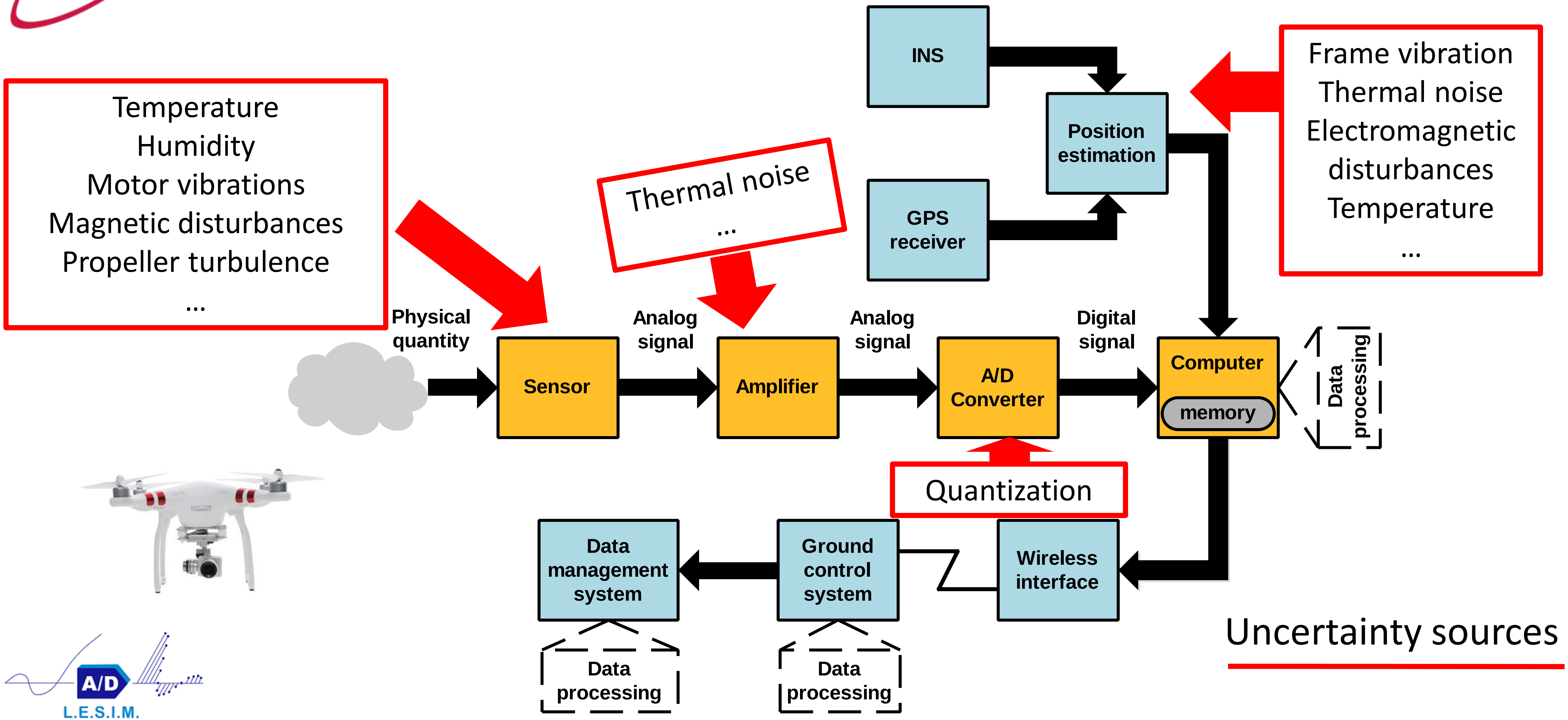
Conventional instrument



Uncertainty sources

E. Balestrieri, P. Daponte, L. De Vito, F. Picariello, I. Tudosa, “Guidelines for an Unmanned Aerial Vehicle-based measurement instrument design”, accepted to be published on the Instrumentation & Measurement Magazine, 2020.

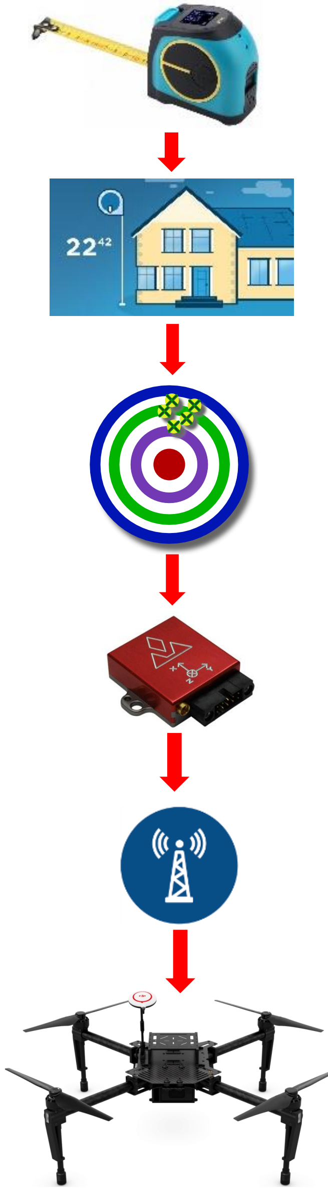
MEASUREMENT UNCERTAINTY OF DRONES (4/4)



DRONE-BASED MEASUREMENT INSTRUMENT: THE DESIGN STEPS

The steps for designing a drone-based measurement instrument are:

1. Definition of the measurand (mission measurement);
2. Definition of the target uncertainty and measurement range;
3. Uncertainty budget analysis;
4. Definition of the requirements related to the sensors for navigation and for mission;
5. Definition of the communication link;
6. Definition of the drone platform according to the weight and power consumption budgets.



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DRONE: FUTURE TRENDS

- Drones are still an emerging technology however, there is little doubt they can and will completely disrupt existing business models.
- Most companies are only beginning to understand how to use this powerful combination to function more efficiently and effectively.
- The superb data gathering capabilities of drones will affect our lives in ways we cannot yet imagine.

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CONCLUSIONS

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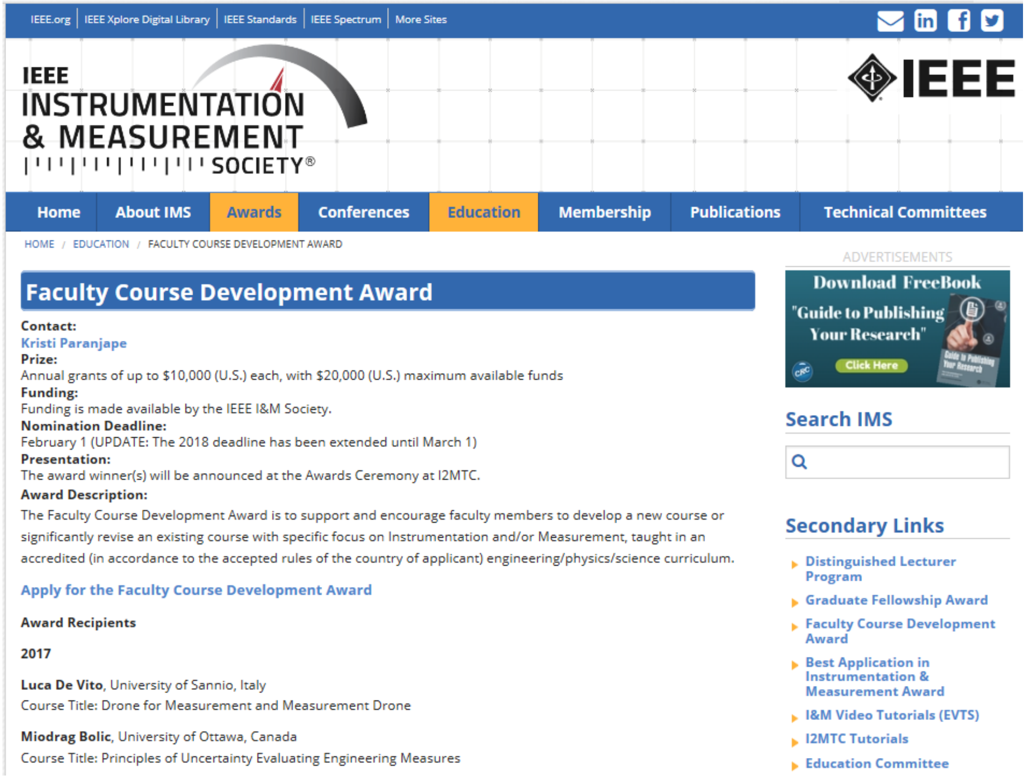
A Ph.D. course supported by the IEEE Instrumentation & Measurement Society is available at the University of Sannio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Course Title: Drone for Measurement and Measurement Drone

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Course Title: Principles of Uncertainty Evaluating Engineering Measures

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Contents:

- ✓ Introduction to drones;
- ✓ The drone architecture;
- ✓ The sensors for flight control including inertial and navigation sensors;
- ✓ Data fusion algorithms for navigation;
- ✓ The sensors used as payload, including LIDARs, visual cameras and thermal cameras.
- ✓ Drone programming;
- ✓ 3D reconstruction by aerial photogrammetry.
- ✓ Practical experiences with drones.

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THANK YOU FOR YOUR ATTENTION !
ANY QUESTIONS?

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