This activity is supported by: The NATO Science for Peace and Security Programme

ADVANCED TRAINING COURSE

Modern technologies enabling safe and secure UAV operation in urban airspace

L.E.S.I.M.

Laboratory of Signal Processing and Measurement Information, (LESIM)
Department of Engineering, University of Sannio, Benevento, Italy

Part I: Aerial photogrammetry for critical infrastructure assessment

Pasquale Daponte

Part II: Design and characterization of a drone for photogrammetric Surveys

Luca De Vito

Contents

L.E.S.I.M. activities;

Researches upon developments for mobile measurement platforms;

Drones;

Measurements for drone and drone for measurements:

- Sensors for navigation;
- Drones as mobile measurement platforms;
- Applications;

Design of a drone-based measurement instrument:

- Drones and uncertainty
- General concepts about uncertainty and measurement
- General architecture of a drone-based measurement instrument
- Design parameters
- Measurement uncertainty budget
- Case study: 3D mapping of archaeological sites

Methods and instruments for drone characterization

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- Measurement uncertainty budget
- Case study: 3D mapping of archaeological sites

Methods and instruments for drone characterization

Where is Benevento?

Who's who ?

L.E.S.I.M.

Laboratory of Signal Processing and Measurement Information

Prof. Pasquale Daponte

Prof. Sergio Rapuano

Prof. Luca De Vito

Prof. Francesco Lamonaca

Prof. Eulalia Balestrieri

Dr. Ioan Tudosa (Researcher)

Dr. Francesco Picariello (Researcher)

Eng. Gianluca Mazzilli (Researcher)

Eng. Liliana Viglione (Researcher)

Eng. Grazia Iadarola (Researcher)

Eng. Enrico Picariello (Researcher)

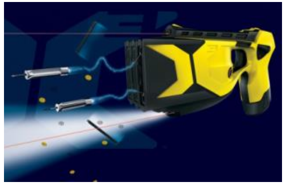
LESIM activities

Laboratory of Signal Processing and Measurement Information

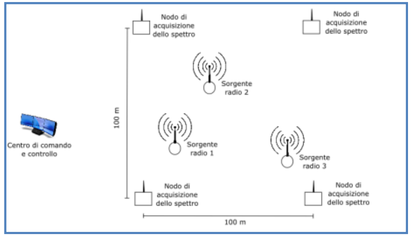
- ✓ **LESIM is involved in**
  - ✓ Definition of new measurement methods
  - ✓ Processing of measurement information
  - ✓ Development of new electronic measurement instruments
- ✓ **Application field**
  - ✓ Characterization of electronic components - ADC and DAC Testing
  - ✓ Telecommunication - Monitoring 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

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ologies enabling safe and secure UAV
eration in urban airspace

Italian Government Grant
€ 900.000,00

UNIVERSITY OF SANNIO

Educational for Drone
eDrone

Prof. Pasquale Daponte

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

L.E.S.I.M.

Università degli Studi del Sannio

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.

6 European Partners

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11 Partners

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Civil Aviation Agency of Georgia.

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DPM Elettronica
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Business and technology consulting

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Modern technologies enabling safe and secure UAV operation in urban airspace

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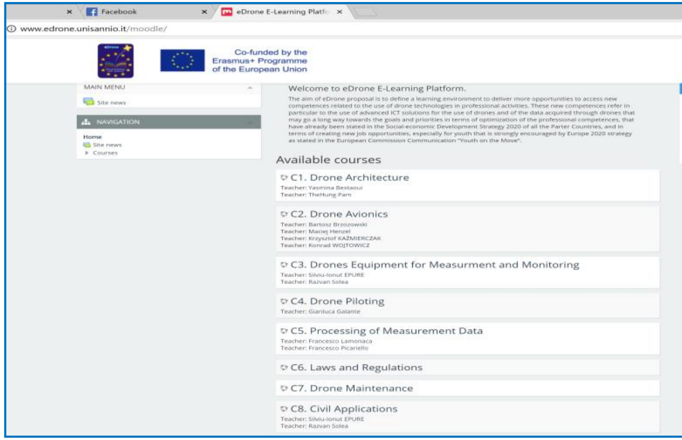
Outputs

ERASMUS+ Project *eDrone*

www.edrone.unisannio.it

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

Content management system



Course for Training the Teachers (CTT)

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

Aprobat
Senatul USM
din „19" 12. 2017"
procesul verbal Nr. 4

Coordonat
Ministerul Educației, Culturii și Cercetării al Republicii Moldova

PROGRAMUL

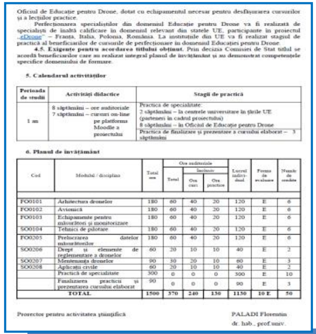
de recalificare profesională „Educație pentru drone"

în cadrul proiectului Erasmus+ „Educație pentru Drone – eDrone"

574090-EPP-1-2016-1-IT-EPPKA2-CBHE-JP

Domeniul general de studiu (codul și denumirea) – **071 Inginerie și activități inginerești**
Domeniul de formare profesională – **0710 Inginerie și management**
Specialitatea – **0710.1 Inginerie și management pe ramuri**
Numărul total de credite de studiu – **50**
Calificarea profesională – **inginer licențiat**
Baza admiterii: **studii superioare**
Forma de organizare a învățământului – **cu frecvență redusă**

CHIȘINĂU 2018



Oficial de Educație pentru Drone, dotat cu echipamentul necesar pentru desfășurarea cursurilor și a lecțiilor practice.

Perfecționarea specialiștilor din domeniul Educație pentru Drone va fi realizată de specialiști de înaltă calificare în domeniul relevant din statele UE, participante în proiectul „eDrone" – Franța, Italia, Polonia, România. La instituțiile din UE va fi realizat stagiul de practică al beneficiarilor de cursurile de perfecționare în domeniul Educației pentru Drone.

4.5. Exigențe pentru acordarea titlului obținut. Prin decizia Comisiei de Stat titlul se acordă beneficiarilor care au realizat integral planul de învățământ și au demonstrat competențele specifice domeniului de formare.

5. Calendarul activităților

Perioada de studii	Activități didactice	Stagii de practică
1 an	8 săptămâni – ore auditoriale 7 săptămâni – cursuri on-line pe platforma Moodle a proiectului	Practica de specialitate: 2 săptămâni – la centrele universitare în țările UE (parteneri în cadrul proiectului) 8 săptămâni – în Oficiul de Educație pentru Drone
		Practica de finalizare și prezentare a cursului elaborat – 3 săptămâni

6. Planul de învățământ

Cod	Modulul / disciplina	Total ore	Ore auditoriale: Total	Inclusiv: Ore curs	Inclusiv: Ore practice	Lucrul individual	Forma de evaluare	Număr de credite
FO0101	Arhitectura dronelor	180	60	40	20	120	E	6
FO0102	Avionică	180	60	40	20	120	E	6
FO0103	Echipamente pentru măsurători și monitorizare	180	60	40	20	120	E	6
SO0104	Tehnici de pilotare	180	60	40	20	120	E	6
FO0205	Prelucrarea datelor măsurătorilor	180	60	40	20	120	E	6
SO0206	Drept și elemente de reglementare a dronelor	60	20	10	10	40	E	2
SO0207	Mentenanța dronelor	90	30	20	10	60	E	3
SO0208	Aplicații civile	60	20	10	10	40	E	2
	Practică de specialitate	300	0	0	0	300	E	10
	Finalizarea practicii și prezentarea cursului elaborat	90	0	0	0	90	E	3
TOTAL		1500	370	240	130	1130	10 E	50

Prorector pentru activitatea științifică — PALADI Florentin, dr. hab., prof.univ.

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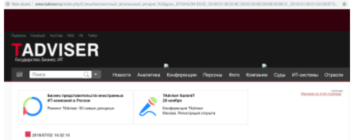
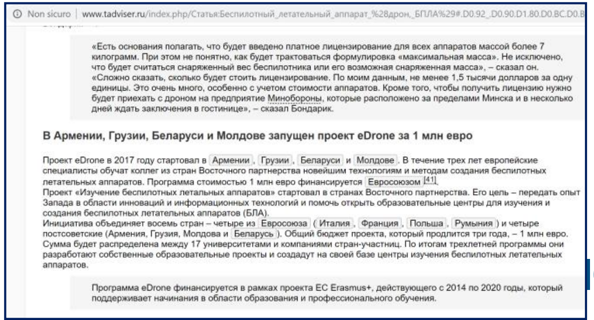
Disseminations





Non sicuro | www.tadviser.ru/index.php/Статья:Беспилотный_летательный_аппарат_%28дрон,_БПЛА%29#.D0.92_.D0.90.D1.80.D0.BC.D0.B

«Есть основания полагать, что будет введено платное лицензирование для всех аппаратов массой более 7 килограмм. При этом не понятно, как будет трактоваться формулировка «максимальная масса». Не исключено, что будет считаться снаряженный вес беспилотника или его возможная снаряженная масса», – сказал он. «Сложно сказать, сколько будет стоить лицензирование. По моим данным, не менее 1,5 тысячи долларов за одну единицы. Это очень много, особенно с учетом стоимости аппаратов. Кроме того, чтобы получить лицензию нужно будет приехать с дроном на предприятие Минобороны, которые расположено за пределами Минска и в несколько дней ждать заключения в гостинице», – сказал Бондарик.

В Армении, Грузии, Беларуси и Молдове запущен проект eDrone за 1 млн евро

Проект eDrone в 2017 году стартовал в Армении, Грузии, Беларуси и Молдове. В течение трех лет европейские специалисты обучат коллег из стран Восточного партнерства новейшим технологиям и методам создания беспилотных летательных аппаратов. Программа стоимостью 1 млн евро финансируется Евросоюзом [41].
Проект «Изучение беспилотных летальных аппаратов» стартовал в странах Восточного партнерства. Его цель – передать опыт Запада в области инноваций и информационных технологий и помочь открыть образовательные центры для изучения и создания беспилотных летательных аппаратов (БЛА).
Инициатива объединяет восемь стран – четыре из Евросоюза (Италия, Франция, Польша, Румыния) и четыре постсоветские (Армения, Грузия, Молдова и Беларусь). Общий бюджет проекта, который продлится три года, – 1 млн евро. Сумма будет распределена между 17 университетами и компаниями стран-участниц. По итогам трехлетней программы они разработают собственные образовательные проекты и создадут на своей базе центры изучения беспилотных летательных аппаратов.

Программа eDrone финансируется в рамках проекта ЕС Erasmus+, действующего с 2014 по 2020 годы, который поддерживает начинания в области образования и профессионального обучения.

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UNIVERSITY OF SANNIO

Italian Air Force @ MetroAeroSpace 2014

2014 IEEE International Workshop on Metrology for AeroSpace

Benevento, Italy - May 29-30, 2014

Predator B

32° Stormo Italian Air Force

Amedola (Foggia), Italy

Italian Air Force @ MetroAeroSpace 2015

2015 IEEE International Workshop on Metrology for AeroSpace

Benevento, Italy - June 4-5, 2015

STRIX-C

16° Stormo Italian Air Force

Martina Franca, Italy

Italian Air Force @ MetroAeroSpace 2016

2016 IEEE International Workshop on Metrology for AeroSpace

Florence, Italy - June 22-23, 2016

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Military Metrology for AeroSpace

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Italian Air Force @ Military Metrology for AeroSpace 2019

Military Metrology for AeroSpace

Torino, Italy - June 19, 2019

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AFCEA NAPLES CHAPTER

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ALTEC

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Modern technologies enabling safe and secure UAV operation in urban airspace

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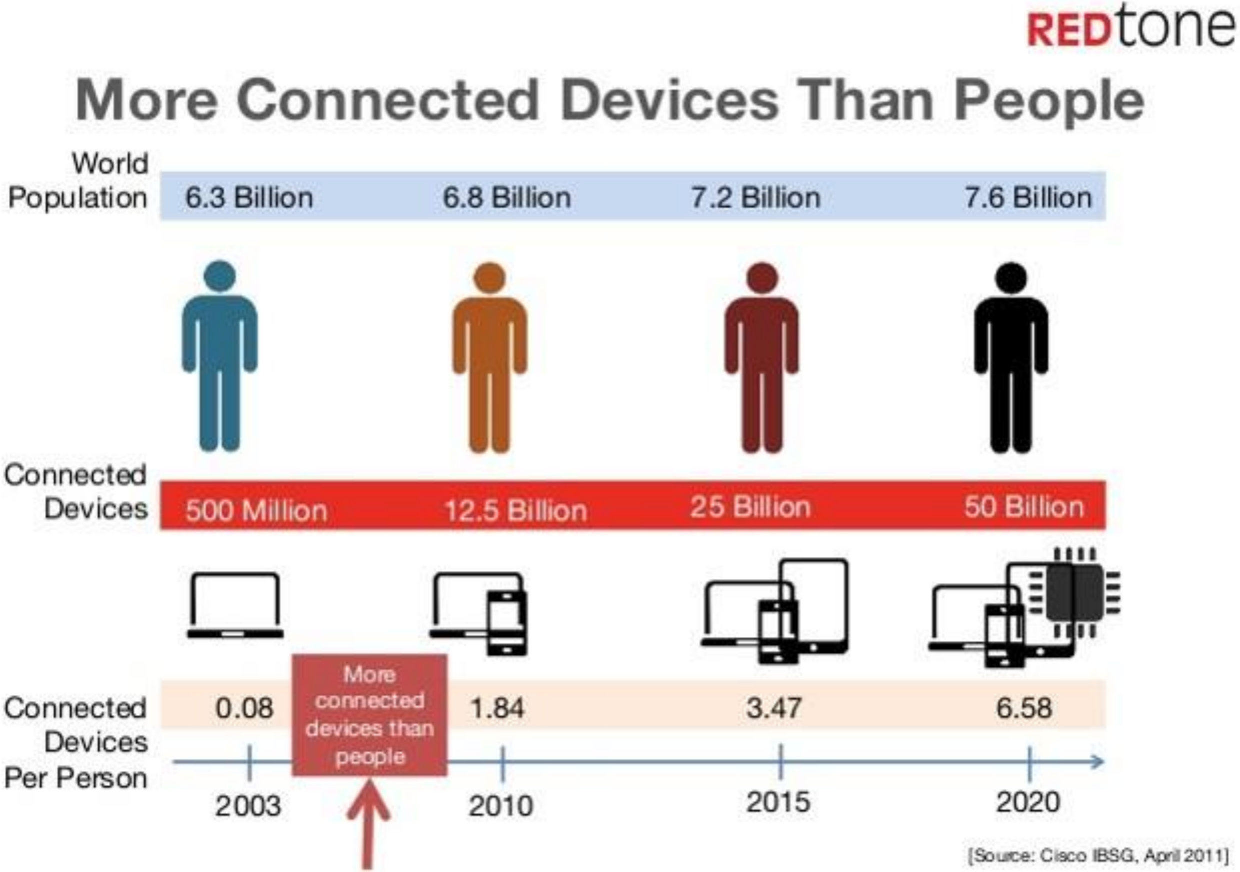
Contents

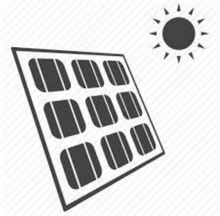
Researches upon developments for mobile measurement platforms



Examples of growing technologies

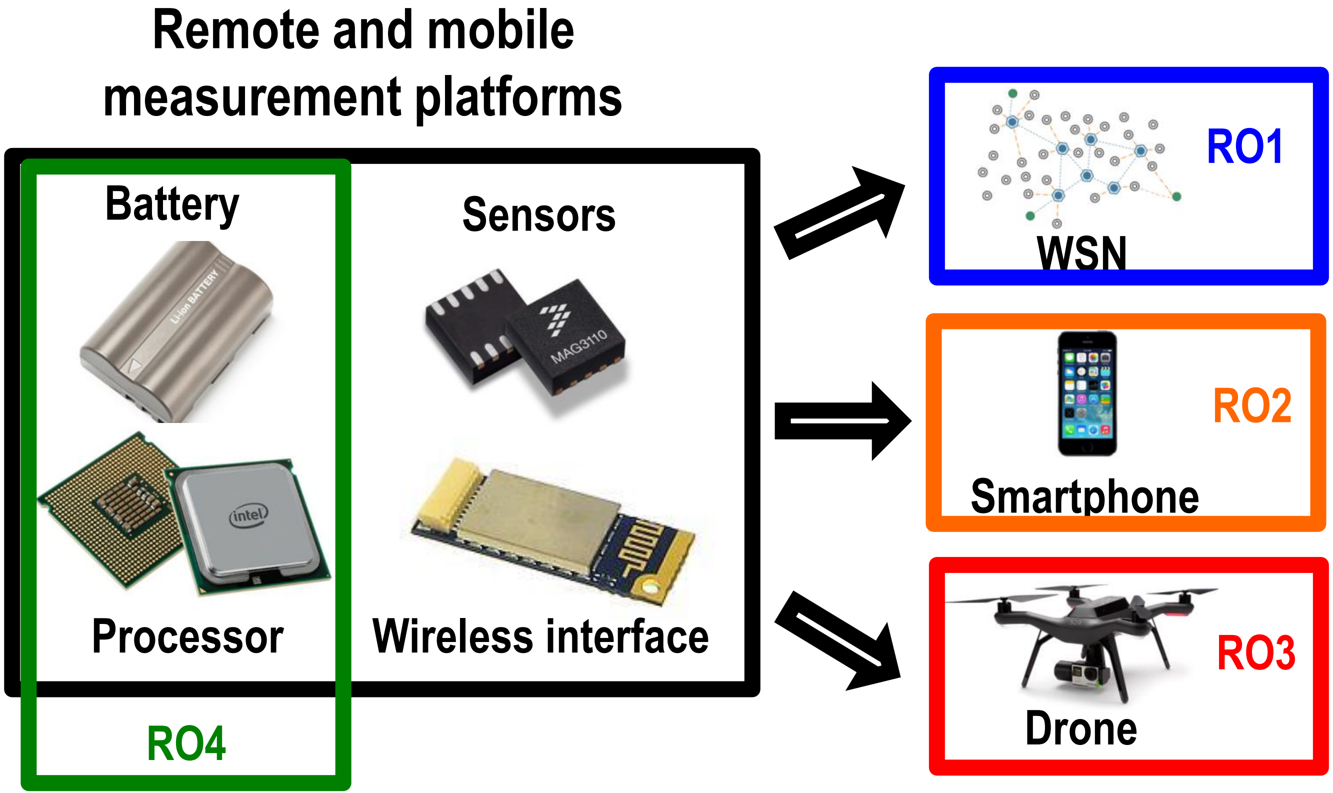
- **Advanced CPUs** are available with low power requirements and in a small size.

- **Research in materials science** has resulted in novel sensing materials for many chemical, biological, and physical sensing tasks.

- **Transceivers for wireless devices** are becoming smaller, less expensive, and less power hungry.
- **Power source** improvements in batteries, as well as passive power sources such as solar or vibration energy, are expanding application options.

LESIM Research objectives



Wireless Sensor Network

Measurement 57 (2014) 1–14

Contents lists available at ScienceDirect

Measurement

journal homepage: www.elsevier.com/locate/measurement

ELSEVIER

Prototype design and experimental evaluation of wireless measurement nodes for road safety

CrossMark

Pasquale Daponte, Luca De Vito, Francesco Picariello, Sergio Rapuano, Ioan Tudosa *

Department of Engineering, Laboratory of Signal and Measurement Information Processing, University of Sannio, Piazza Roma 82100, Benevento, Italy

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Keywords:
Speed measurement
Distance measurement
Traffic information system
Embedded systems
Wireless sensor networks

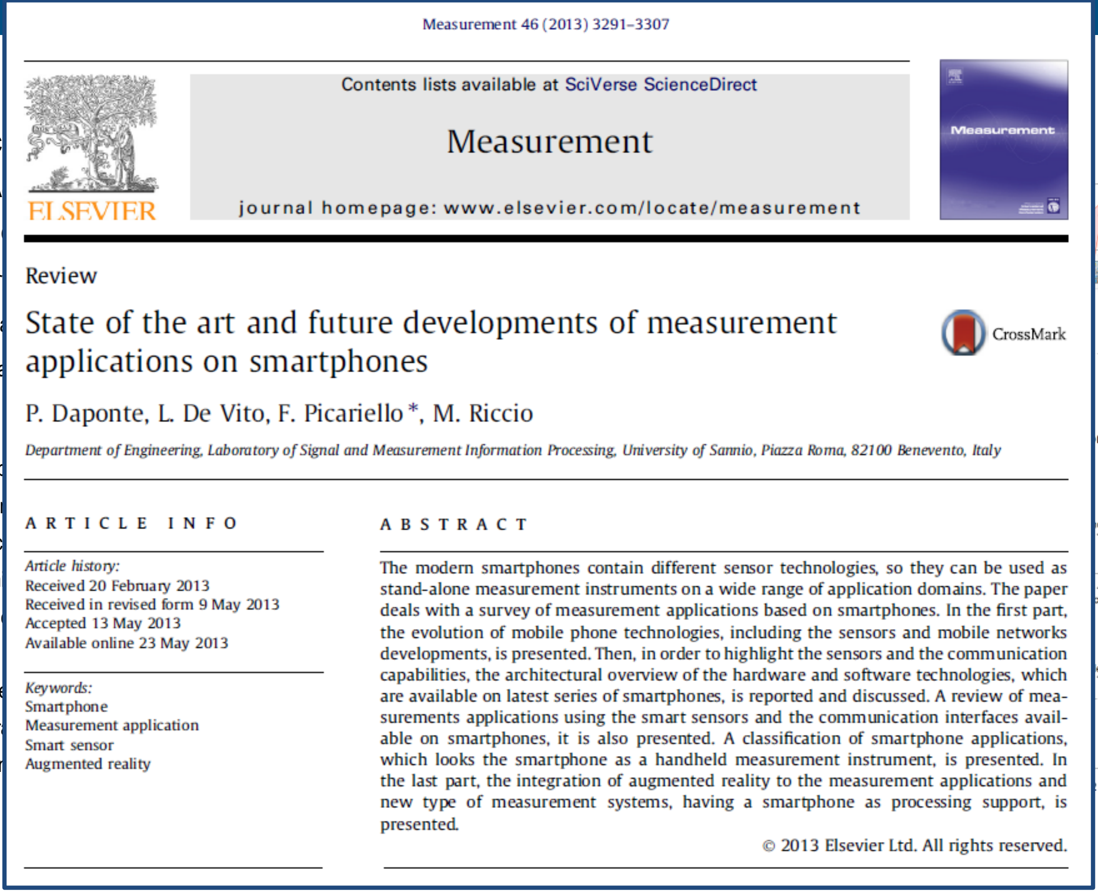
ABSTRACT

The paper presents the design and the experimental evaluation of prototypes of measurement nodes that are part of the Wireless Active Guardrail System (WAGS). The WAGS is an innovative infrastructure, allowing increasing traffic safety on roads, by monitoring vehicle speed, proximity between vehicle and guardrail, impact of a vehicle with the guardrail, and several environmental parameters. In particular, in this paper, the designs and prototypes of the nodes dealing with speed and proximity measurements are presented. Then, all the phases of their experimental evaluation are reported and discussed.

Smartphone teardown

- Octa-C
- GPU A
- RAM 4
- Memor
- Camera
- Front fa

- Fingerp
- Acceler
- Gyrosc
- Proxim
- Digital
- GPS
- Barome
- Heart r
- Oxygen



Measurement 46 (2013) 3291–3307

Contents lists available at SciVerse ScienceDirect

Measurement

journal homepage: www.elsevier.com/locate/measurement

Review

State of the art and future developments of measurement applications on smartphones

P. Daponte, L. De Vito, F. Picariello *, M. Riccio

Department of Engineering, Laboratory of Signal and Measurement Information Processing, University of Sannio, Piazza Roma, 82100 Benevento, Italy

ARTICLE INFO

Article history:
Received 20 February 2013
Received in revised form 9 May 2013
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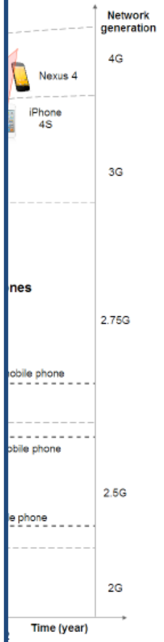
Keywords:
Smartphone
Measurement application
Smart sensor
Augmented reality

ABSTRACT

The modern smartphones contain different sensor technologies, so they can be used as stand-alone measurement instruments on a wide range of application domains. The paper deals with a survey of measurement applications based on smartphones. In the first part, the evolution of mobile phone technologies, including the sensors and mobile networks developments, is presented. Then, in order to highlight the sensors and the communication capabilities, the architectural overview of the hardware and software technologies, which are available on latest series of smartphones, is reported and discussed. A review of measurements applications using the smart sensors and the communication interfaces available on smartphones, it is also presented. A classification of smartphone applications, which looks the smartphone as a handheld measurement instrument, is presented. In the last part, the integration of augmented reality to the measurement applications and new type of measurement systems, having a smartphone as processing support, is presented.



Drones

Measurement 98 (2017) 192–198

Contents lists available at ScienceDirect

Measurement

journal homepage: www.elsevier.com/locate/measurement

ELSEVIER

A height measurement uncertainty model for archaeological surveys by aerial photogrammetry

CrossMark

Pasquale Daponte, Luca De Vito, Gianluca Mazzilli, Francesco Picariello*, Sergio Rapuano

Department of Engineering, Laboratory of Digital Signal Processing and Measurement Information, University of Sannio, Piazza Roma, 82100 Benevento, Italy

A R T I C L E   I N F O

Article history:
Received 30 September 2016
Received in revised form 14 November 2016
Accepted 19 November 2016
Available online 21 November 2016

Keywords:
Aerial photogrammetry
UAV
Stereoscopic measurement
Measurement uncertainty

A B S T R A C T

In this paper, an uncertainty estimation model for object height measurement by aerial photogrammetry using Unmanned Aerial Vehicles (UAVs) is proposed. In particular, a procedure to evaluate the height measurement uncertainty and its sources has been designed. In order to evaluate the uncertainty values related to height measurements, experimental tests to obtain repeated measurements have been conducted. Furthermore, an uncertainty propagation model has been developed considering the uncertainty sources affecting the measurement process. An evaluation of each uncertainty source contribution has been obtained by comparing the results of the experimental investigation and the estimation provided by the proposed propagation model. The 3D maps, which provide object height measurements, are generated by a commercial aerial photogrammetry application, the Pix4Dmapper Pro, and a 3D reconstruction application developed ad hoc. The obtained results and a discussion related to each uncertainty source contribution are presented.

DronesBench: An Innovative Bench to Test Drones

Pasquale Daponte, Luca De Vito, Francesco Lamonaca, Francesco Picariello, Maria Riccio, Sergio Rapuano, Luca Pompetti, and Mauro Pompetti

As forecasted by the United States Air Force Aerospace Management Systems Division, it is expected that in 2028, the number of drones for civilian use will be greater than that used for defense [1], and in 2035, the number of commercial drones populating the US sky will be 175,000, i.e., ten times the actual number of defense-related (public) drones (Fig. 1).

This trend is justified by the growing use of drones for professional activities. In particular, the use of light Vertical Take Off and Landing (VTOL) Remotely Piloted Aircraft Systems (RPASs) is continually growing in several application fields such as agriculture, environment, energy, geology, archaeology [2], photogrammetry, and so on [3], [4].

For civilian applications, an important issue is to ensure an acceptable level of safety during drone operations [5]. For this reason, national regulations aim to define rules for drone design and use. Today, many measurement systems are devoted to verifying that the drone components comply with the design specifications [6], but the reliability of the drone as a whole system must be assessed at each mission to assess the effects of aging and wear. In the literature, the systems used for testing drones are mainly used for measuring parameters related to each component of the drone itself (such as 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.

To overcome this lack, an innovative test bench called DronesBench [7] has been proposed. The DronesBench is currently at the pre-series stage, with academic, educational and commercial collaborations in progress. In this paper, the first outcomes of the collaboration between the Laboratory for the Signal Processing and Measurement Information (LESIM) research group and the company DPM Elettronica S.r.l. (Foggia, Italy) are reported. This collaboration aims to: (i) design and implement the DronesBench platform; (ii) develop a

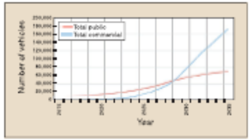


Fig. 1. Total drone forecast 2015-2035 [1].

mathematical model describing the system from the measurement point of view; (iii) evaluate the measurement uncertainty for each measured quantity; (iv) define and automate a measurement procedure for evaluating a figure of merit (FoM), which provides information about the drone performance versus time; (v) improve the DronesBench platform in terms of measurement accuracy; and (vi) develop a fault detection method for the drones under test.

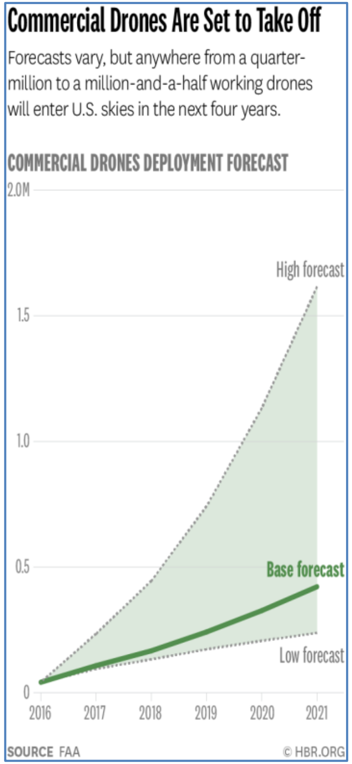
The DronesBench platform is described, and a first model referring to thrust force measurements is presented. Furthermore, an automatic procedure for evaluating the FoM is proposed. The first results obtained from the characterization of a commercial drone using DronesBench are also reported.

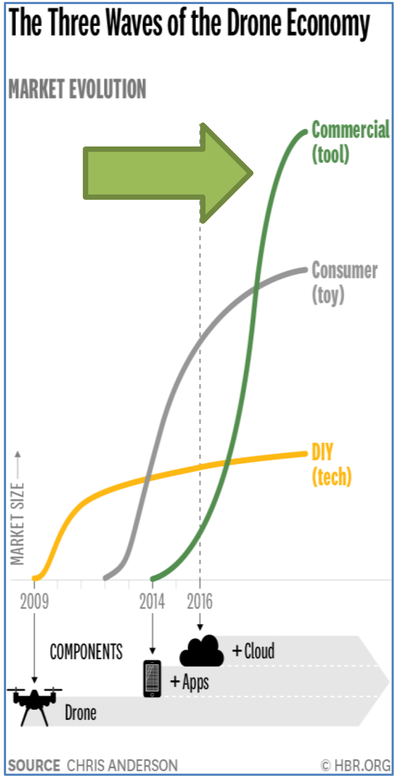
General Architecture of a Light VTOL-RPAS

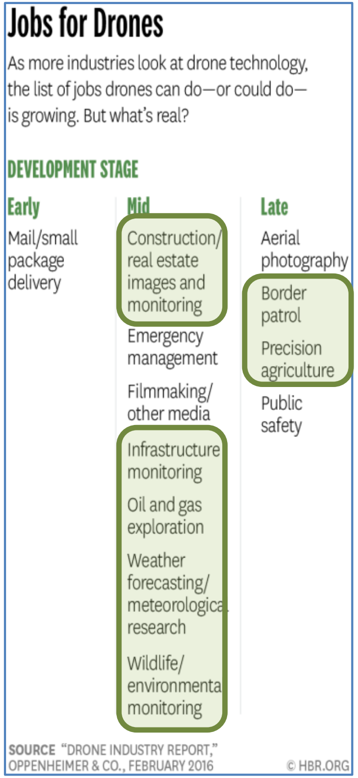
Light RPASs are Unmanned Aerial Vehicles (UAVs) having a mean take-off weight (MTOW) that is less than 150 kg [8]. Fig. 2 shows a light VTOL-RPAS architecture. It is composed of: (i) frame, (ii) battery, (iii) brush less direct current (BLDC) motors, (iv) electronic speed control (ESC) modules, (v) control board, (vi) inertial navigation system (INS), and (vii) transmitter and receiver modules [4], [8]. A quad-rotor RPAS has four

The research discussed in this paper was initially presented at the Industry Session of the 2017 IEEE International Instrumentation and Measurement Technology Conference (I2MTC).

Jobs for Drones







Drones under study at LESIM

Specifications:

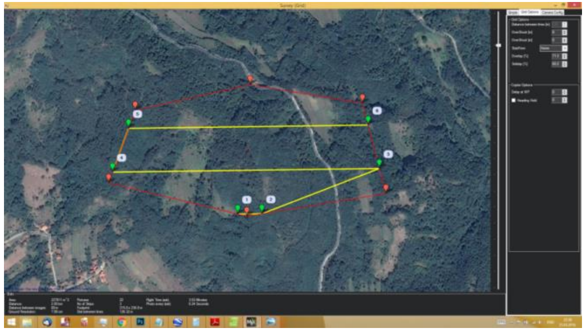
MTOW < 13.5 kg;

Vertical Take-Off Landing (VTOL);

Very low altitude (VLA), 500 ft;

Operations in line-of-sight (*LOS*) and beyond-line-of-sight (*BLOS*)

Remotely operated (semi-autonomous): the drone can perform high-level commands (waypoints, objects tracking, etc.), and its performance is monitored by a trained operator.



Drone equipment at LESIM

Self-made quadcopter

LESIM has facilities to design and build drones.

We are glad to share these opportunities with other National or International research groups

Drone equipment at LESIM

Exacopter with stereo camera housing

- 670 mm wheelbase length
- 6 Pulso U22 M motors
- DJI Naza-M V2 flight controller
- 4S 5000 mAh battery

Drone equipment at LESIM

DJI Phantom 4 Pro

- Weight: 1388 g
- Diagonal size: 350 mm
- Max flight time: ~ 30 min
- Hover Accuracy Range (vert.): ± 0.1 m
- Hover Accuracy Range (horiz.): ± 0.3 m
- 3-axis Gimbal with stabilization within 0.02°
- 20 Mpixel camera

Parrot Bebop 2 FPV

- Max flight time: ~ 30 min
- 14 Mpixel camera with digital stabilization

Drone equipment at LESIM

Intel Aero RTF development platform

- Intel Aero compute board with Intel Atom x7 processor
- Linux operating system (Yocto or Ubuntu distro)
- Intel Aero flight controller running PX4

2 Ublox C94-M8P GNSS/RTK development boards

- Station and rover configuration
- 2 cm positioning accuracy

RP-LIDAR 360 Degree Laser Range Scanner

- 4000 samples/s 10Hz
- Range: 6m
- Rotation speed: 600 RPM
- Resolution: 0.9°

Contents

What are drones? for others…

Drone is for making pictures;

Drone is for military missions;

Drone is a toy.

What are drones? literature…

"An Unmanned Aircraft System (UAS) comprises individual system elements consisting of 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."

European Aviation Safety Agency (2009)

Number	Mean take-off weight (MTOW)	Name
0	Less than 1 kg	Micro
1	Up to 1 kg	Mini
2	Up to 13.5 kg	Small
3	Up to 242 kg	Light/ultra light
4	Up to 4332 kg	Normal
5	Over to 4332 kg	Large

Source: Dalamagkidis et al. (2012)

MTOW is proportional to the expected kinetic energy imparted at impact.

What are drones? for us…

"Sensors and sensing strategies enable an unmanned aircraft to sense, see, hear and understand the world around it"

Valavanis et al.

Drones are mobile measurement platforms making measurements during flight

Contents

Measurements for drone and drone for measurements

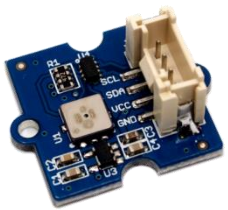
Drones require measurements for flying

The drone as mobile measurement instrument

Measurements for drone

During flight the drone must:

1. monitor the attitude of the drone during the flight mission;
2. localize the drone during the mission;
3. detect objects along the mission path;
4. measure the drone altitude respect to the ground.

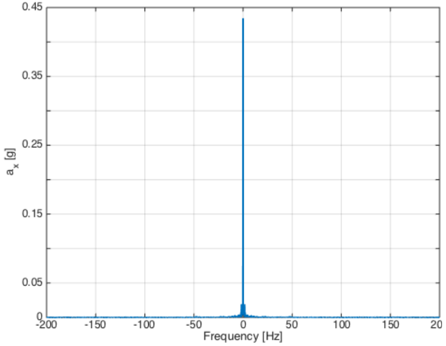


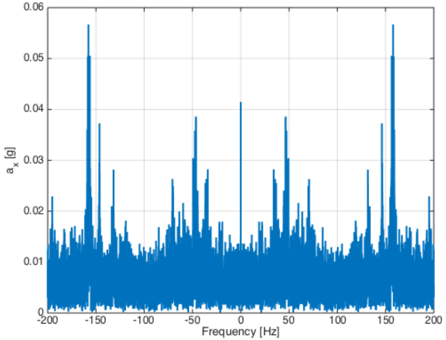
According to that, the sensors embedded on drone are:

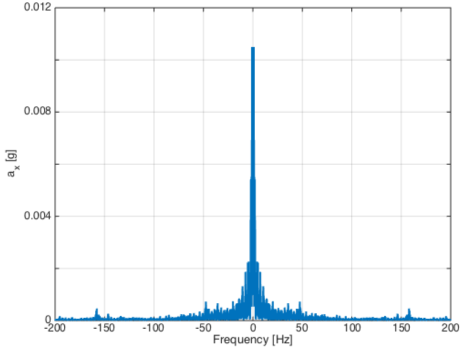
1. Inertial Measurement Unit (IMU);
    a) Gyroscope
    b) Accelerometer
2. Global Positioning System (GPS) or Differential GPS;
3. Light Detection and Ranging (LiDAR);
4. Ultrasonic sensor;
5. Barometer

Accelerometer embedded on drone

Accelerometer measurements

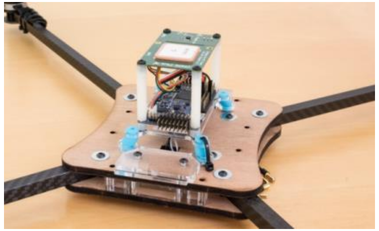




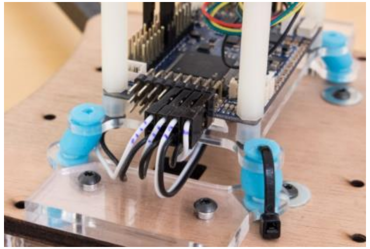


Measurements on ground in static conditions

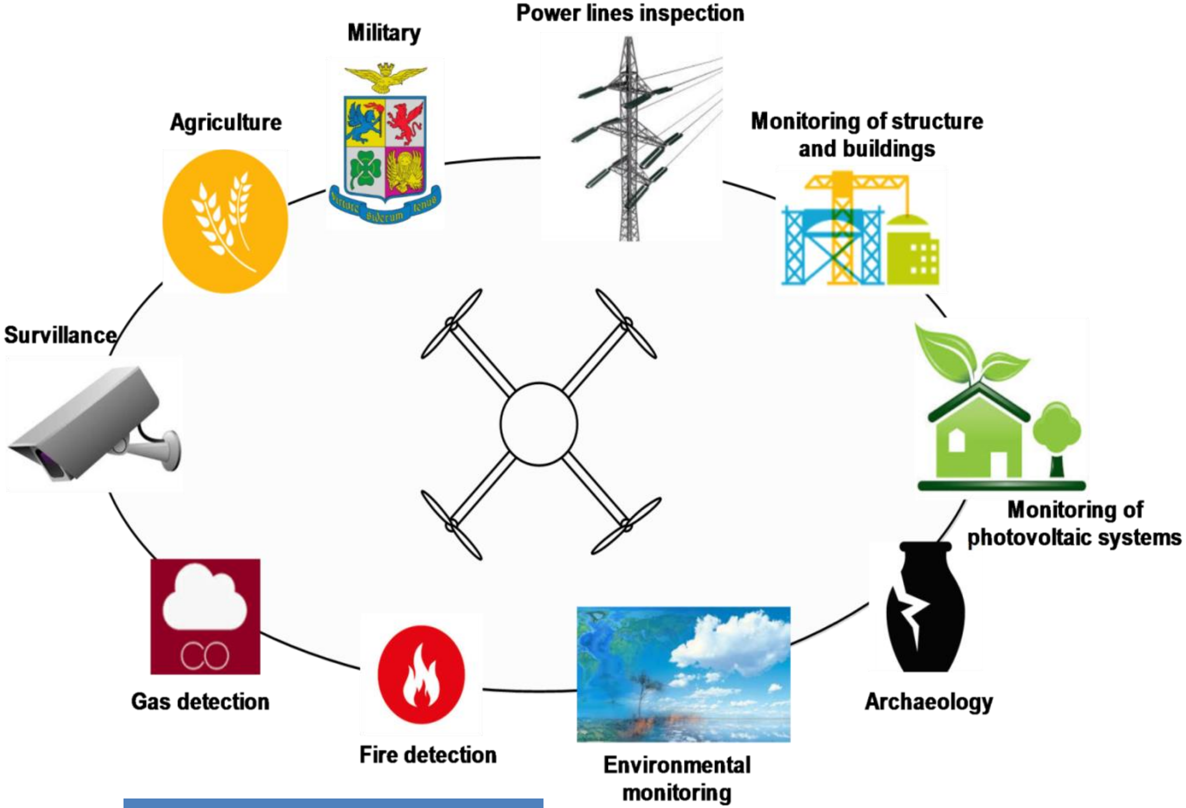
Static conditions measurements with propellers running



Static conditions measurements with damping platform



Drones for measurements



Drones and Measurements

- Industries have long sought data from above, generally through satellites or planes, but drones are better “**sensors in the sky**” than both.
- They gather higher-resolution and more-frequent data than satellites (whose view is obscured by clouds over two-thirds of the planet at any time), and they’re cheaper, easier, and safer than planes.
- Drones can provide “anytime, anywhere” access to overhead views with an **accuracy** that rivals laser scanning.

“Drones go to work” (1)

SYSMAP SenseFly

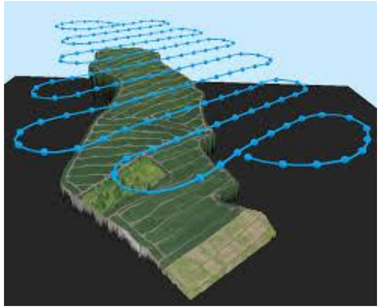
Pros of drone as measuring platform

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.

Cons of drone as measuring platform

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 (payload and battery);

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.

I&M applications of drones (1)

Monitoring of photovoltaic systems

The drone is equipped with:

- Video camera, for detecting cracks, yellowing, snail trails and brunt cells;
- Thermal camera, for detecting high temperature regions on a photovoltaic module surface (hot-spot);
- GPS receiver for measuring the position related to an identified failure.

I&M applications of drones (2)

Structural health monitoring

The drone is equipped with:

- Video camera;
- GPS receiver.

Drone can be used for automatic monitoring and localization of damages.

I&M applications of drones (3)

Power line inspection

The drone is equipped with:

- Video camera, for detecting broken strand;
- Infrared camera, for preventing breakage of the strands;
- Ultra-violet camera, for detecting corona effects;
- GPS receiver for measuring the position related to an identified failure.

I&M applications of drones (4)

Environmental monitoring

The drone is equipped with:

- GPS receiver;
- A sensor board, which depends on the environment to monitor;

Example - The drone for water pollution monitoring:
Video camera and multi-spectral camera (sediment pollution, oil spill, red tide, and thermal pollution).

https://www.dronegenuity.com/drones-helping-marine-biologists/

Documentation of archaeological sites

Survey of archaeological site aims to obtain accurate measurements for producing maps and 3D models.

An important task is to choose the appropriate technique for the specific survey.

A case study will be presented later.

Contents

L.E.S.I.M. activities;

Researches upon developments for mobile measurement platforms;

Drones;

Measurements for drone and drone for measurements:

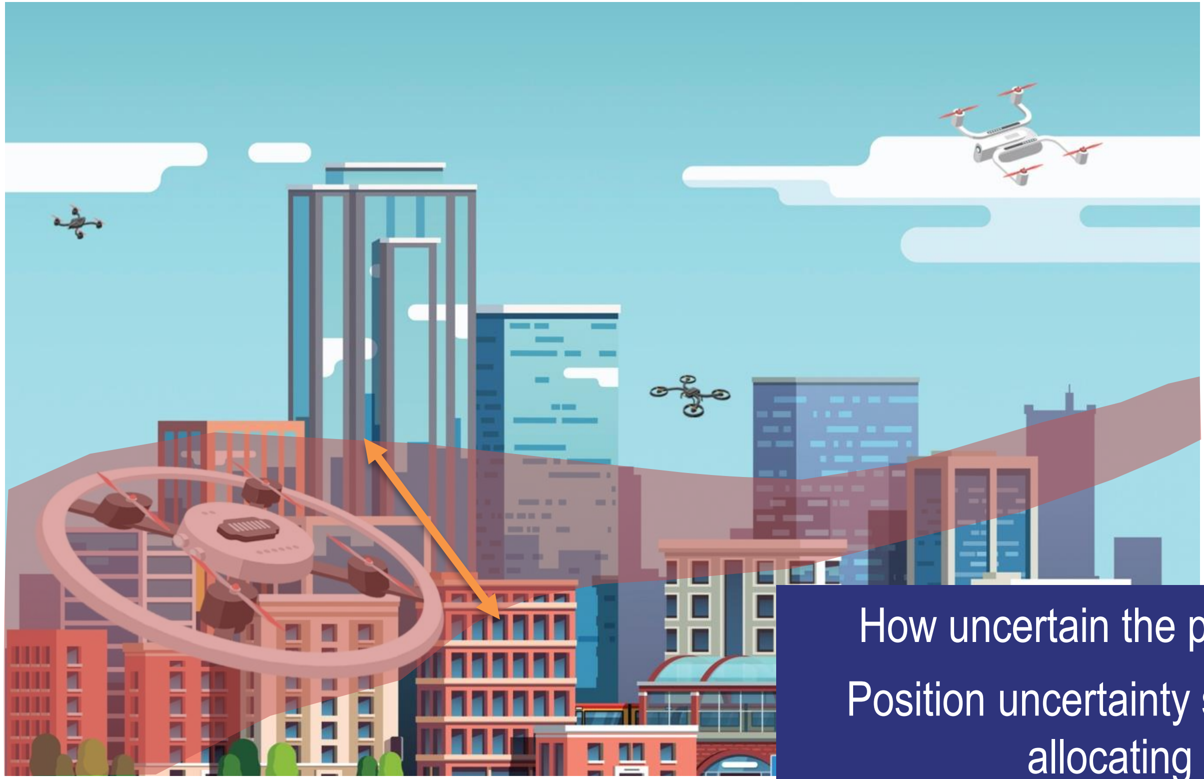
- Sensors for navigation;
- Drones as mobile measurement platforms;
- Applications;

Design of a drone-based measurement instrument:

- **Drones and uncertainty**
- **General concepts about uncertainty and measurement**
- **General architecture of a drone-based measurement instrument**
- **Design parameters**
- **Measurement uncertainty budget**
- **Case study: 3D mapping of archaeological sites**

Methods and instruments for drone characterization

Uncertainty and Operation in Urban Environment



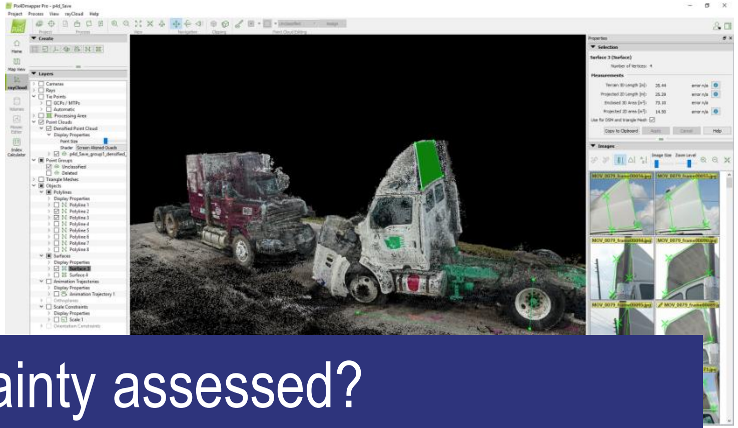
How uncertain the position of the drone is?

Position uncertainty should be considered in allocating drone routes.

Measurement with drones: Uncertainty and Traceability

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

- -80% of occupation time of the road;
- -67% of measurement time



How is the measurement uncertainty assessed?

How is metrological traceability guaranteed?

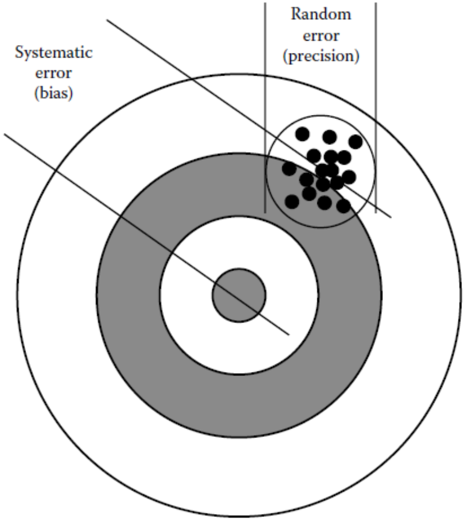
In all cases when economic transactions or legal issues are involved, it is fundamental to provide the uncertainty of the measurement result through structured and traceable procedures.

“4 Reasons Drones will revolutionize accident scene response” (2)

Drone calibration

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.

Accuracy and errors

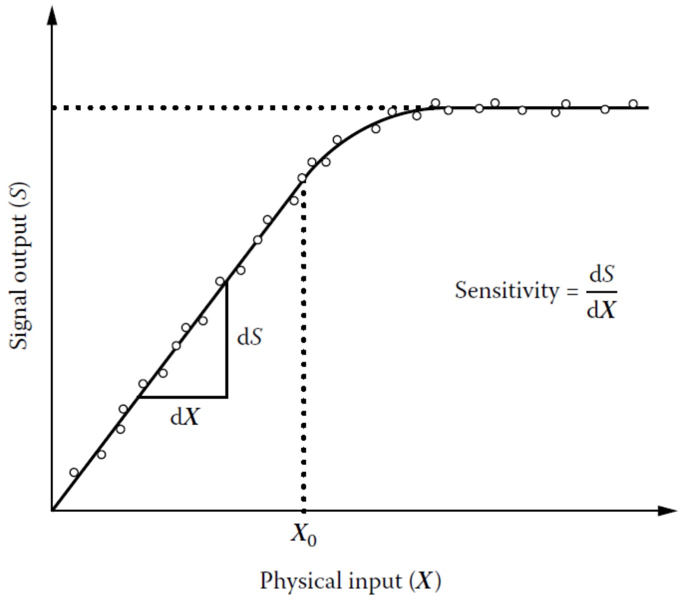


The **accuracy** of an instrument is defined as the difference between the true value of the measurand and the measured value indicated by the instrument. Typically, the true value is defined in reference to some absolute or agreed upon standard.

For any particular measurement, there will be some error due to **systematic** (bias) and **random** (noise) error sources.

There are a variety of factors that can result in systematic measurement errors. One class of cause factors are those that change the input–output response of a sensor resulting in miscalibration.

Calibration



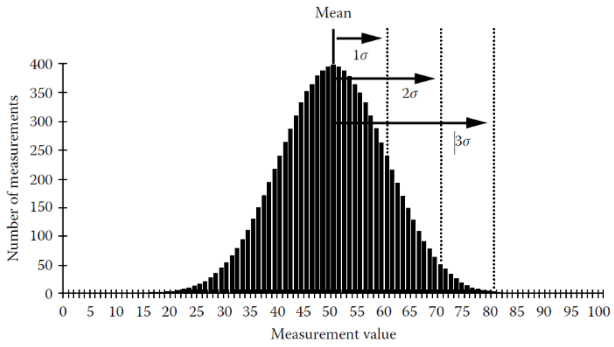
The relationship between the physical measurement variable input and the signal variable (output) for a specific instrument is known as the calibration of the instrument.

Precision and Random error sources

In many cases, if the systematic error source is known, it can be corrected for by the use of **compensation methods**.

Random error is sometimes referred to as noise, which is defined as a signal that carries no useful information.

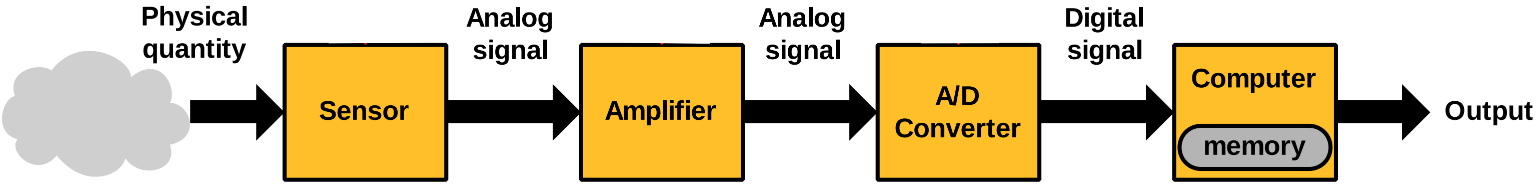
Precision indicates the closeness of agreement between measured quantity values obtained by replicate measurements



In case of random error **Gaussian distributed**, the precision of the measurement is normally quantified by the standard deviation (σ).

Such value is then called **standard uncertainty.**

General architecture of a digital measurement instrument



The design of an instrument involves the evaluation of the **uncertainty budget**, by assessing the different components of the measurement uncertainty and their combination.

Indirect measurements

Many physical quantities are indirectly measured, by exploiting functional relations (**a model**) that connect them to other directly measured quantities.

$$Y = F(X_1, X_2, \dots, X_n)$$

In this case the uncertainty of the measurement result is obtained from the combination of the uncertainties of the directly measured quantities (if the measured quantities are all independent):

$$u_Y = \sqrt{\left(\frac{\partial F}{\partial X_1}\right)^2 u_{X_1}^2 + \left(\frac{\partial F}{\partial X_2}\right)^2 u_{X_2}^2 + \cdots + \left(\frac{\partial F}{\partial X_n}\right)^2 u_{X_n}^2}$$

The assessment of the measurement uncertainty

To assess the measurement uncertainty, it is necessary to:

- Identify the uncertainty sources;
- Define a model of the measurement procedure;
- To evaluate the measurement uncertainty of the input model quantities;
- To apply the law of propagation of uncertainty according to the model.

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.

Design parameters

The main parameters to be considered for designing a drone-based measurement instrument are:

1. Weight;
2. Power consumption;
3. Communication link;
4. Measurement uncertainty.

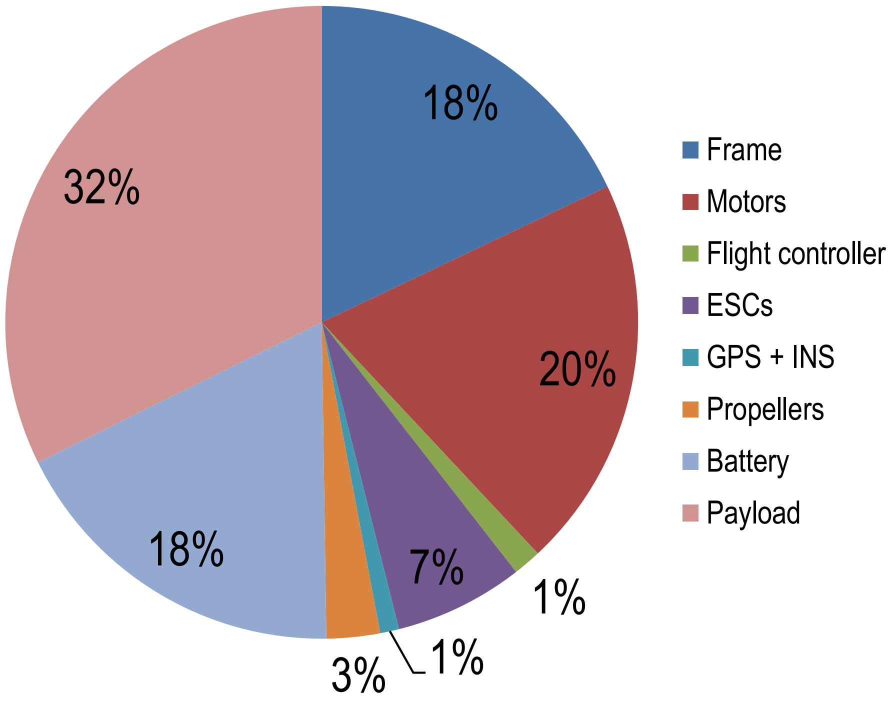
Those parameters strictly depend on the mechanical and electrical parts of the drone.

Weight budget

The weight is the main parameter for sizing the motors, the propellers, and the frame of the drone.

The main contributors to the drone weight are:

1. The payload that depends on the application (usually it contains at least a gimbal and a camera);
2. The frame. Its contribution on the total weight can be reduced using carbon fiber frames;
3. The brushless motors;
4. The battery.



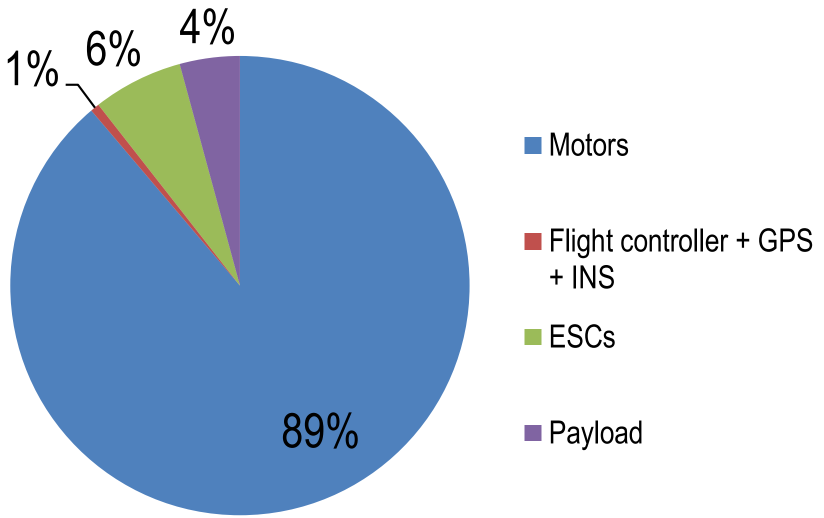
Power consumption budget

The battery of the drone is sized according to its power consumption and the required flight time for a mission.

The power consumption shares have been estimated considering the maximum power consumption values exhibited by each drone sub-system.

For the payload, a gimbal with a camera and the transmitter have been considered.

Usually, the main contributors to the drone power consumption are the motors.



The capacity of the battery is estimated as:

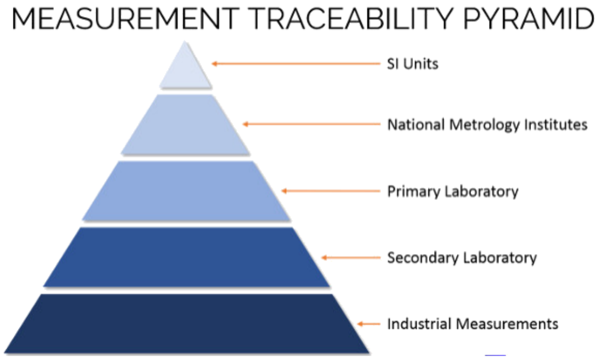
$$C = 16.67 \cdot \frac{P}{V_b} \cdot t_f \qquad \text{[mAh]}$$

Communication link budget

	FHSS		S-FHSS		Wi-Fi IEEE 802.11			AM/FM (First-Person View FPV)		COFDM (FPV)	
	2.4 GHz		2.4 GHz		2.4/5 GHz			900 MHz/1.2 GHz/2.4 GHz/5.8 GHz		900 MHz/1.2 GHz/2.4 GHz/5.8 GHz	
	Bit rate [Mbit/s]	Distance [m]	Bit rate [kbit/s]	Distance [m]		Bit rate [Mbit/s]	Distance [m]	Bandwidth [MHz]	Distance [m]	Bit rate [Mbit/s]	Distance [m]
	3	1500	128	5000	b	11	140	16 (FM)	5000	5	10000
					g	54	140				
					n	300	250				
Remote control	X		X		X					X	
Telemetry	X		X		X					X	
Payload					X			X (camera)		X (camera)	

Measurement uncertainty budget (1)

- The on-board sensors must be chosen such that the measurement result complies with the target uncertainty.

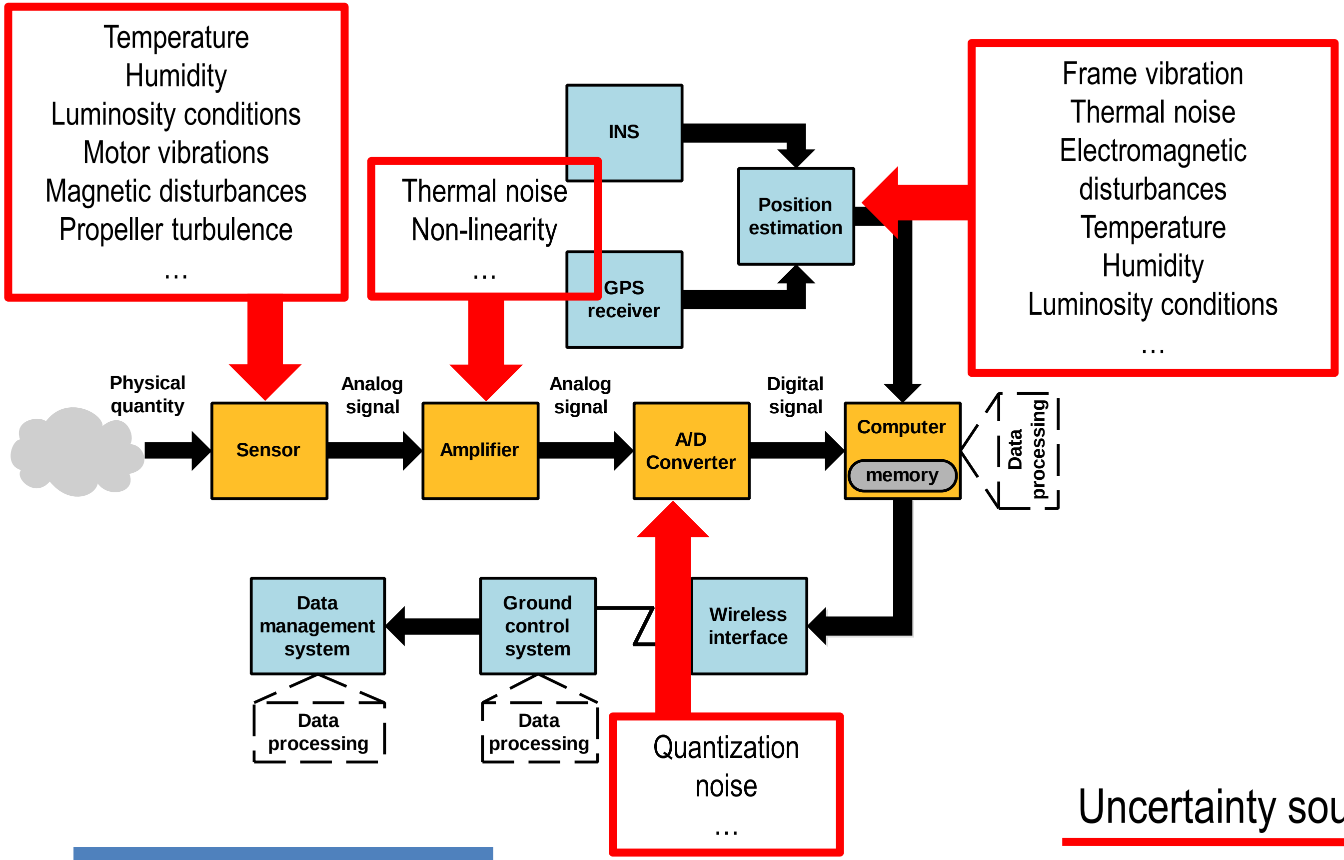


http://www.isobudgets.com/

- Specific calibration methods must be defined, applied and documented in order to guarantee the measurement traceability.

https://bblsa.com/

Measurement uncertainty budget (2)



Uncertainty sources

Measurement uncertainty budget (3)

To define the measurement uncertainty budget, the following steps are needed:

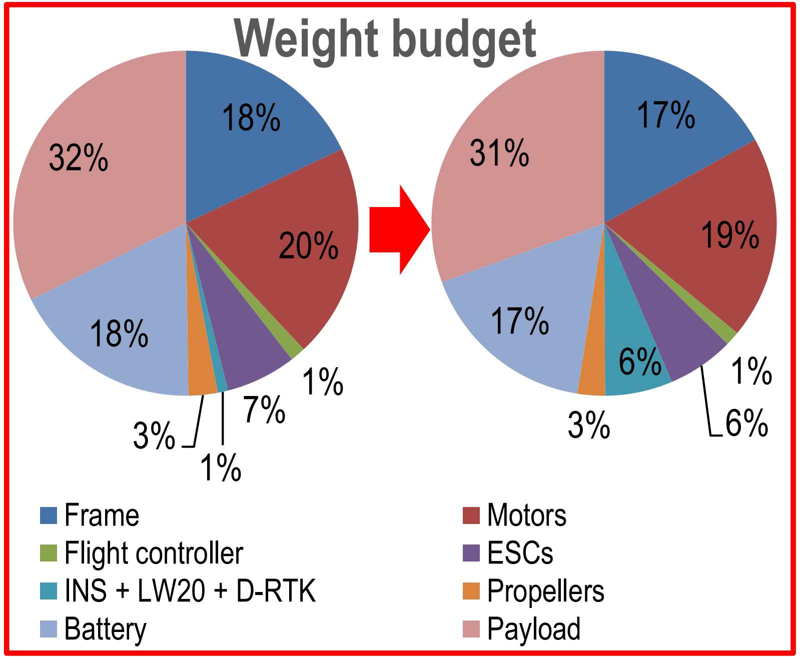
1. Identification of the uncertainty sources affecting mission measurements;
2. Evaluation of an uncertainty model according to the identified uncertainty sources;
3. Uncertainty sensitivity analysis.

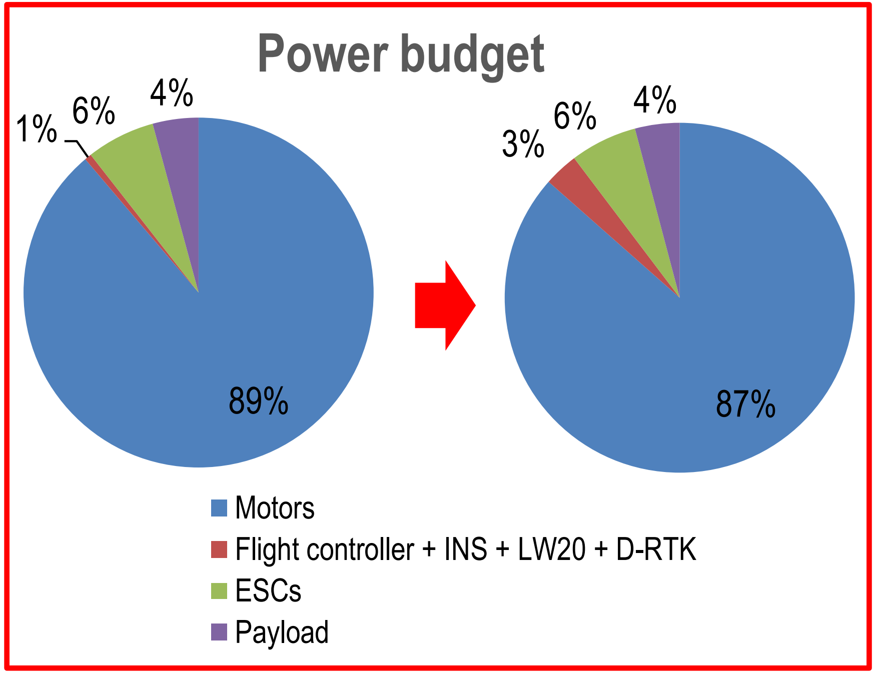
The outputs of the uncertainty budget analysis are:

- The feasibility of the system according to the target uncertainty;
- The definition of the sensor specifications in terms of uncertainty for both the pose and the mission measurements.

Balance among budgets (1)

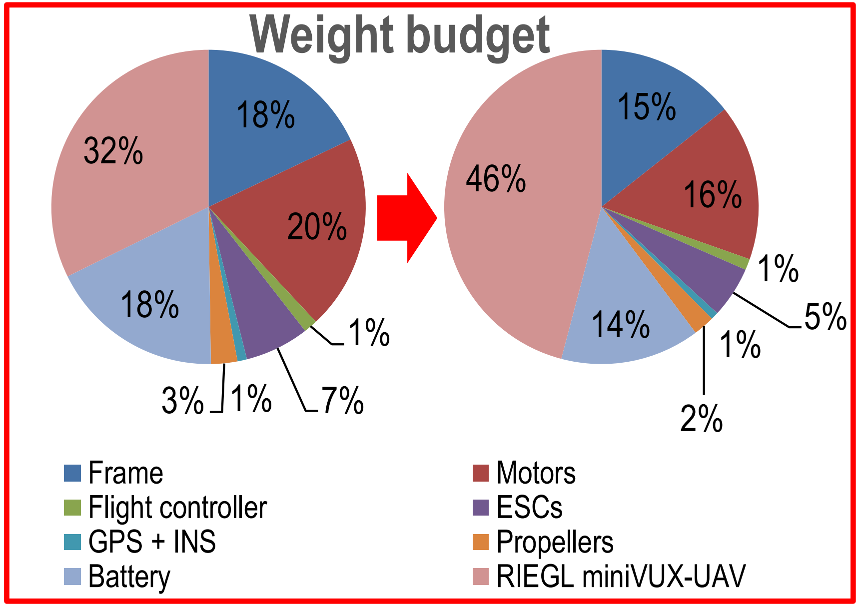
What?	How?	Effect
Reduction of the drone pose measurement uncertainty	Integration of a LIDAR altimeter (LW20) and GNSS (D-RTK)	Change of frame and motors

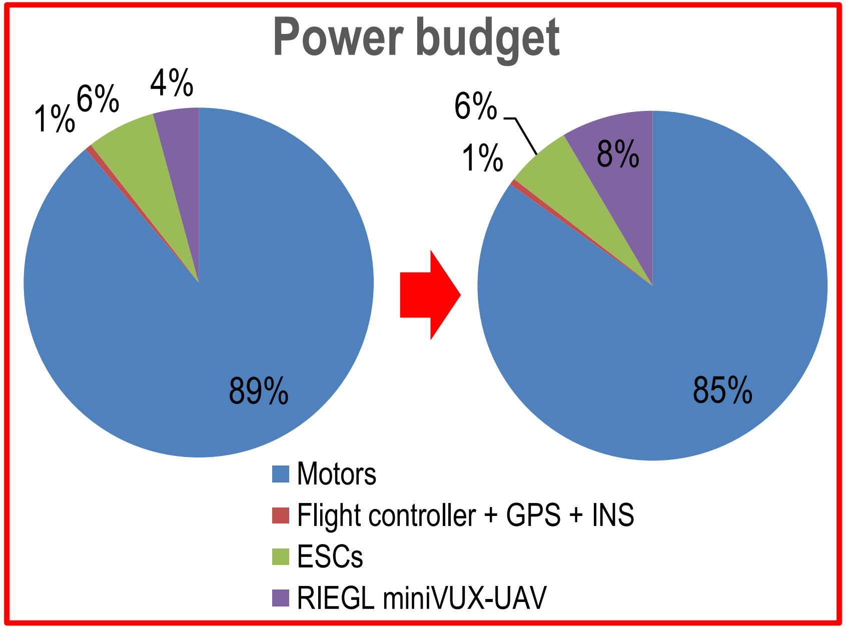




Balance among budgets (2)

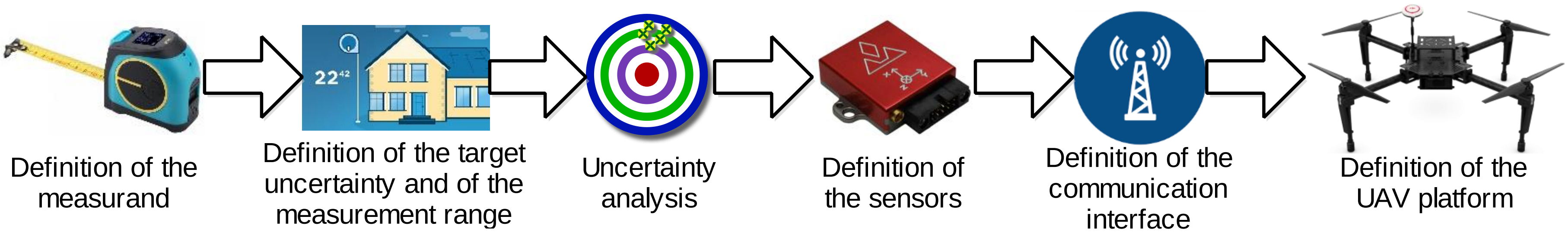
What?	How?	Effect
Reduction of the uncertainty related to mission measurement	Using of a LIDAR for 3D mapping (RIEGL miniVUX-UAV) against RGB camera	Change of frame and motors





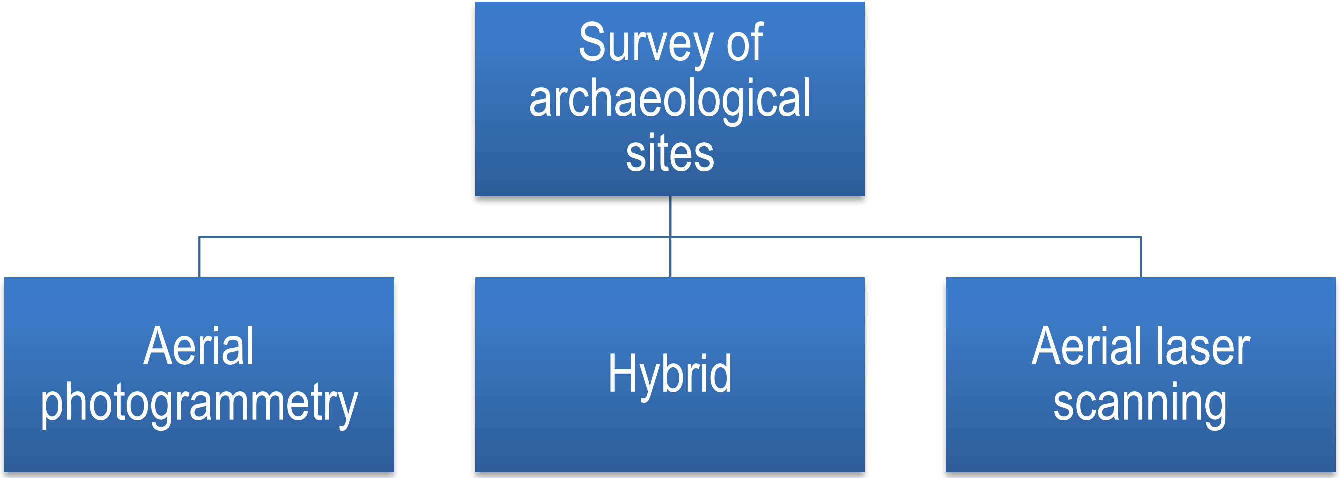
Drone-based measurement instrument design steps

According to the presented budgets, it is possible to define the steps for designing a drone-based measurement instrument:



Case study: 3D mapping of archaeological sites

The aim is to provide a 3D map containing geometrical measurements related to wide archaeological sites or archaeological sites with difficult access.

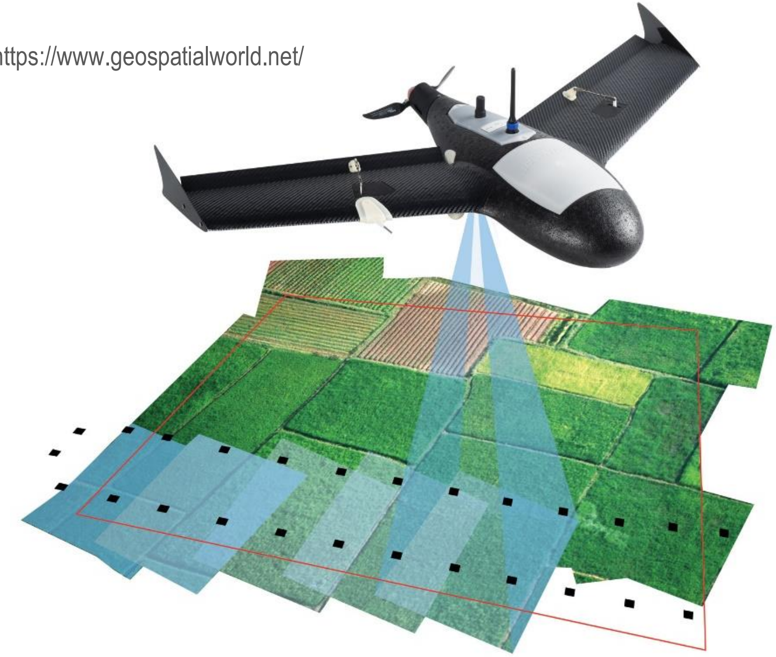


P. Daponte, L. De Vito, F. Picariello, S. Rapuano, M. Riccio, "An uncertainty model for height measurement based on aerial photogrammetry", Proc. of 1st International Conference on Metrology for Archaeology, Benevento, Italy, October 22-23, 2015 (5)

Aerial photogrammetry

In aerial photogrammetry, the 3D reconstruction is implemented by means of structure from motion.

https://www.geospatialworld.net/



The structure from motion consists of observing objects from different positions.

In aerial photogrammetry, the structure from motion is implemented acquiring two consecutive images during the flight mission.

Aerial laser scanning

An aerial laser scanning (ALS) system consists of a drone with embedded a LIDAR system.

Phoenix aerial systems

Hybrid

- This technique combines aerial, terrestrial photogrammetry and terrestrial laser scanning.
- In order to define the reference coordinates, several targets for each acquisition method are placed in the archaeological site and localized through a total station.
- The acquisition and processing steps are: (i) localization of the targets by means of total station, (ii) acquisition of the images with aerial photogrammetry, (iii) acquisition of the images with terrestrial photogrammetry, (iv) generation of the 3D models, and (v) 3D models integration.

3D models integration

Comparison

In this table, it is reported a qualitative analysis of the three techniques.

	Accuracy	Sensing time	Processing time	Cost
Aerial Photogrammetry	Low	Low	Medium	Low
~~Hybrid technique~~	~~High~~	~~High~~	~~High~~	~~High~~
Aerial laser scanning	High	Medium	Low	Medium

1. Definition of the measurand - 2. Definition of the target uncertainty, and measurement range

The **measurands** are the geometrical dimensions (height, width, and length) of each object in the surveyed area.

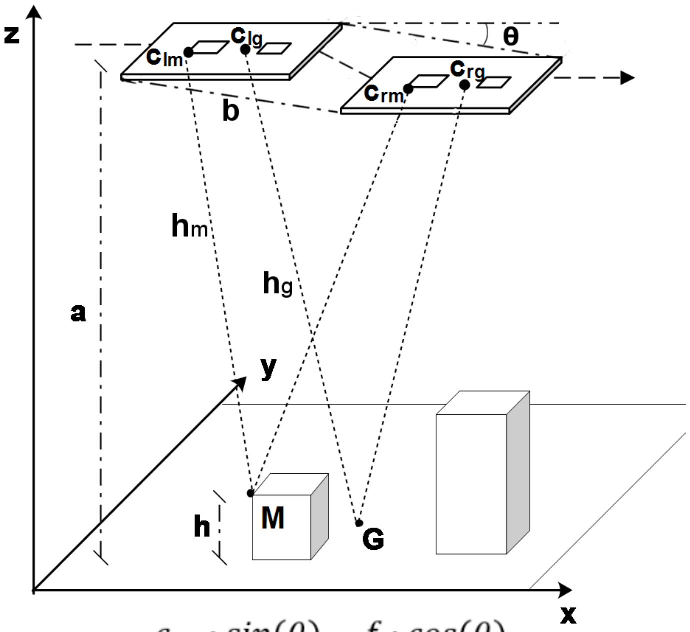
Two values of **target uncertainty** will be considered: about 20cm and about 5cm.

The **measurement range** depends on the maximum height of the object in the surveyed area (e.g. 3 m).

Another important parameter for this specific application is the time required for the survey (**sensing time**).

3.a Uncertainty budget analysis (aerial photogrammetry)

In case of aerial photogrammetry height has a higher uncertainty than the other dimensions.



$$h_m = \frac{c_{rm} \cdot sin(\theta) - f \cdot cos(\theta)}{f \cdot (c_{rm} - c_{lm})} \cdot \left(f \cdot cos(\theta) - c_{lm} \cdot sin(\theta)\right) \cdot b$$

- h_m is the distance between the camera in the first waypoint and the point M;
- C_{lm} and C_{rm} are the pixel projections of the point M on the camera sensor array in both left and right positions;
- C_{lg} and C_{rg} are the pixel projections of the ground level point G on the camera sensor array;
- θ is the drone elevation angle of drone in the second waypoint referred to the first;
- b is the distance between the positions related to image acquisitions;
- f is the camera focal length.

$$h = h_g - h_m = \frac{c_{rg} \cdot sin(\theta) - f \cdot cos(\theta)}{f \cdot (c_{rg} - c_{lg})} \cdot \left(f \cdot cos(\theta) - c_{lg} \cdot sin(\theta)\right) \cdot b - \frac{c_{rm} \cdot sin(\theta) - f \cdot cos(\theta)}{f \cdot (c_{rm} - c_{lm})} \cdot \left(f \cdot cos(\theta) - c_{lm} \cdot sin(\theta)\right) \cdot b$$

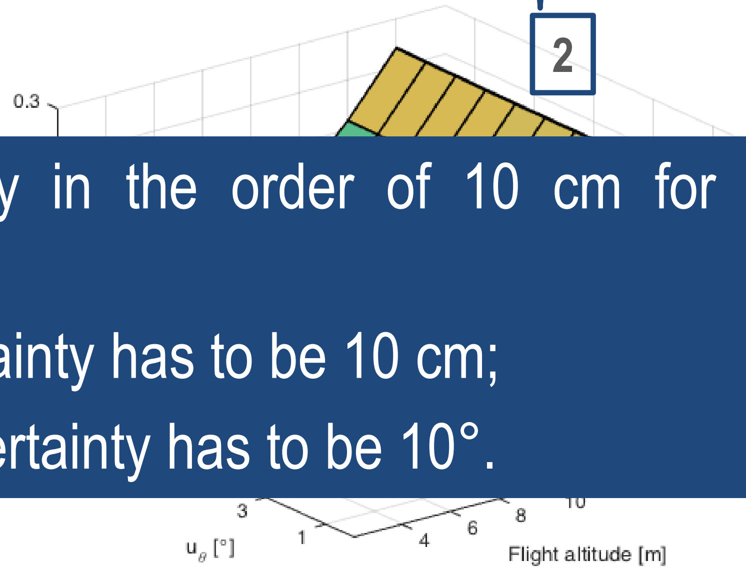
3.b Uncertainty budget analysis (aerial photogrammetry)

$$u_h^2 = \underbrace{\left(\frac{dh}{dc_{rm}}\right)^2 \cdot u_{c_{rm}}^2 + \left(\frac{dh}{dc_{lm}}\right)^2 \cdot u_{c_{lm}}^2 + \left(\frac{dh}{dc_{rg}}\right)^2 \cdot u_{c_{rg}}^2 + \left(\frac{dh}{dc_{lg}}\right)^2 \cdot u_{c_{lg}}^2}_{1} + \underbrace{\left(\frac{dh}{d\theta}\right)^2 \cdot u_{\theta}^2 + \left(\frac{dh}{db}\right)^2 \cdot u_b^2 + \left(\frac{dh}{df}\right)^2 \cdot u_f^2}_{2}$$

This

1.

2.



For achieving a target uncertainty in the order of 10 cm for a maximum flight altitude of 14 m:

- The maximum baseline, b, uncertainty has to be 10 cm;
- The maximum orientation, ϑ, uncertainty has to be 10°.

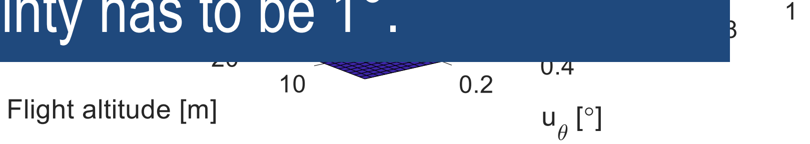
Uncertainty [m] vs. flight altitude [4, 16] m and pitch angle uncertainty **[1°, 10°]**, for different baseline uncertainties **[1.5, 10] cm**

3. Uncertainty budget analysis (aerial laser scanning)

In case of aerial laser scanning, the LIDAR provides the distance of each point respect to its z-axis. This measurement has to be aligned to the drone coordinate reference

For achieving a target uncertainty in the order of 10 cm for a maximum flight altitude of 25 m:

- The maximum uncertainty related to the distance measurements has to be 10 mm;
- The maximum orientation, ϑ, uncertainty has to be 1°.



The uncertainty sources affecting measurements are:

- The uncertainty related to the distance measurements provided by laser;
- The uncertainties related to the measurements of the pitch and roll angles.

4. Definition of the requirements related to the sensors for navigation and for mission (aerial photogrammetry)

For the measurements of the baseline b, distance between two waypoints, and the angle ϑ, elevation angle of the drone in the second waypoint referred to the first, mainly two techniques can be considered:

- The payload includes a RGB camera with a gimbal;
- The sensors for navigation are GPS and INS.

GNSS-based technique (e.g. D-RTK)

F

- The baseline uncertainty is 1 cm (max. target 10 cm);
- The orientation uncertainty is 0.2° (max. target 10°).

Image-based pose estimation technique

- Luminosity conditions;
- Wind conditions;
- Gimbal stability;
- Background texture conditions.

4. Definition of the requirements related to the sensors for navigation and for mission (aerial laser scanning)

In case of aerial laser scanning, the system provide in real-time at each waypoint the point cloud acquired by the LIDAR system.

	RIEGL miniVUX-UAV
[illegible]	[illegible]
Measurement distance uncertainty	[illegible]
Scan rate	100 scans/s
Points per second	100 kpt/s

- The payload includes a LIDAR;
- The sensors for navigation are GPS and INS.

https://www.lidarusa.com/

RIEGL mini VUX - UAV

5. Definition of the communication link

	FHSS		S-FHSS		Wi-Fi IEEE 802.11			AM/FM (First-Person View FPV)		COFDM (FPV)	
	2.4 GHz		2.4 GHz		2.4/5 GHz			900 MHz/1.2 GHz/2.4 GHz/5.8 GHz		900 MHz/1.2 GHz/2.4 GHz/5.8 GHz	
	Bit rate [Mbit/s]	Distance [m]	Bit rate [kbit/s]	Distance [m]	Bit rate [Mbit/s]		Distance [m]	Bandwidth [MHz]	Distance [m]	Bit rate [Mbit/s]	Distance [m]
	3	1500	128	5000	b	11	140	16 (FM)	5000	5	10000
					g	54	140				
					n	300	250				
Remote control data	X		X		X					X	
Telemetry data	X		X		X					X	
Payload data					X			X (camera)		X	

6.a Definition of the drone platform according to the weight and power consumption budgets.

Aerial photogrammetry
Weight budget

Gimbal + camera (Zenmuse X4S)	253 g
Quadrotor Frame (F330)	156 g
Flight controller + GPS + IMU (N3 DJI)	132 g
4 ESCs (DJI - E305)	108 g
4 Propellers (Z-BLADE 9450)	52 g
4 Motors (DJI – 2312E)	224 g
Tot.	925 g

Takeoff weight 400 g/rotor with 4S LiPo
Max. total weight = 1600g.

Aerial laser scanning
Weight budget

LIDAR (RIEGL miniVUX-UAV)	1500 g
Hexarotor Frame (F550)	478 g
Flight controller + GPS + IMU (N3 DJI)	132 g
6 ESCs (DJI – E800)	258 g
6 Propellers (Z-BLADE – E800)	114 g
6 Motors (DJI – E800)	636 g
Tot.	3118 g

Takeoff weight 800 g/rotor with 4S LiPo
Max. total weight = 4800g.

6.b Definition of the drone platform according to the weight and power consumption budgets.

Aerial photogrammetry
Power consumption budget

Gimbal + camera (Zenmuse X4S)	5 W
Flight controller + GPS + IMU (N3 DJI)	5 W
4 ESCs (DJI - E305)	200 W
4 Motors (DJI – 2312E)	
Tot.	210 W

By considering a flight time of 20 min, the capacity of the battery has to be about 4600mAh (4S-LiPo).

Aerial laser scanning
Power consumption budget

LIDAR (RIEGL miniVUX-UAV)	16 W
Flight controller + GPS + IMU (N3 DJI)	5 W
6 ESCs (DJI – E800)	400 W
6 Motors (DJI – E800)	
Tot.	421 W

By considering a flight time of 20 min, the capacity of the battery has to be about 9200mAh (4S-LiPo): 2 x 4600mAh (4S-LiPo).

6.c Definition of the drone platform according to the weight and power consumption budgets.

Aerial photogrammetry

Gimbal + camera (Zenmuse X4S)	253 g	5 W
Quadrotor frame (F330)	156 g	
Flight controller + GPS + IMU (N3 DJI)	132 g	5 W
4 ESCs (DJI - E305)	108 g	200 W
4 Motors (DJI - E305)	224 g	
4 Propellers (Z-BLADE 9450)	52 g	
Battery 4500 mAh 4S LiPo	375 g	
Tot.	1300 g	210 W

Cost: $ 1,500 – $ 2,000
Estimated uncertainty: 0.16 m

Aerial laser scanning

LIDAR (RIEGL miniVUX-UAV)	1500 g	16 W
Hexarotor frame (F550)	478 g	
Flight controller + GPS + IMU (N3 DJI)	132 g	5 W
6 ESCs (DJI – E800)	258 g	400 W
6 Motors (DJI – E800)	636 g	
6 Propellers (Z-BLADE – E800)	114 g	
2 Batteries 4500 mAh 4S LiPo	750 g	
Tot.	3868 g	421 W

Cost: $ 15,000 – $ 20,000
Estimated uncertainty: 0.05 m

Contents

L.E.S.I.M. activities;

Researches upon developments for mobile measurement platforms;

Drones;

Measurements for drone and drone for measurements:

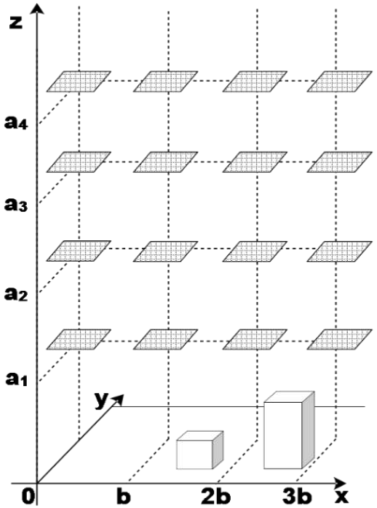
- Sensors for navigation;
- Drones as mobile measurement platforms;
- Applications;

Design of a drone-based measurement instrument:

- Drones and uncertainty
- General concepts about uncertainty and measurement
- General architecture of a drone-based measurement instrument
- Design parameters
- Measurement uncertainty budget
- Case study: 3D mapping of archaeological sites

Methods and instruments for drone characterization

Characterization performed during flight: aerial photogrammetry



Camera parameters	Value
Number of effective pixels	12.4 megapixels
Field Of View	94° at 20 mm
Image Max Size	4000 x 3000 pixels
Sensor wide	6.16 mm
Sensor high	4.62 mm
Focal length	4 mm
Diagonal pixel sensor size	21.8 μm
ISO 5800:1987 range	100-1600

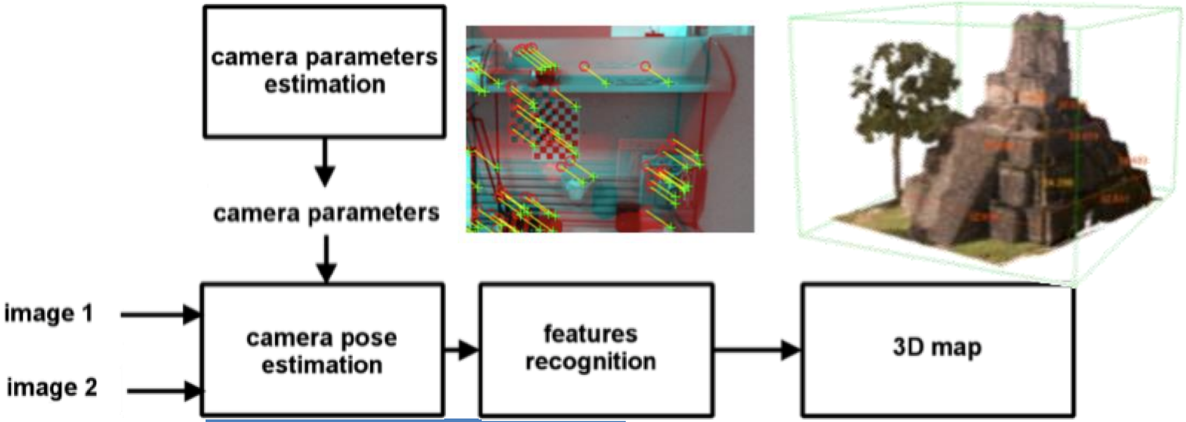
- For each position, 20 images have been acquired to evaluate the uncertainty related to each measurement.
- As target, a box has been used and its height of 0.418 m has been measured with the Leica Disto D3a infrared distance meter.
- Two averages of 6 distances camera-topside box (h_m) and 6 distances camera-ground level point (h_g) have been considered.
- The difference between these averaged values provides the object height measurement.
- An image scaling operation is performed in order to compensate systematic effects.

3D reconstruction applications

Pix4Dmapper Pro:

- Initial Processing, Pix4Dmapper Pro computes key points on the acquired images and provides a preliminary 3D map of the scene;
- Point Cloud and Mesh step increases the density of 3D points on the 3D map realized in Initial Processing step;
- Digital Surface Model (DSM) and Orthomosaic step provides a digital surface model and orthomosaic of the 3D map points. The 3D map can be scaled according to a reference size.

The developed 3D reconstruction application (MATLAB):



Results

Flight altitude [m]	MATLAB-based 3D application [m]	Proposed model [m]	Uncertainty of stereovision geometry parameters [m]	Pix4D [m]	Proposed model [m]	Uncertainty of stereovision geometry parameters [m]
3	0.20	0.20	0.20	0.25	0.24	0.24
7	0.12	0.11	0.10	0.45	0.44	0.44
9	0.17	0.16	0.13	0.43	0.43	0.42
11	0.23	0.22	0.18	0.30	0.29	0.26

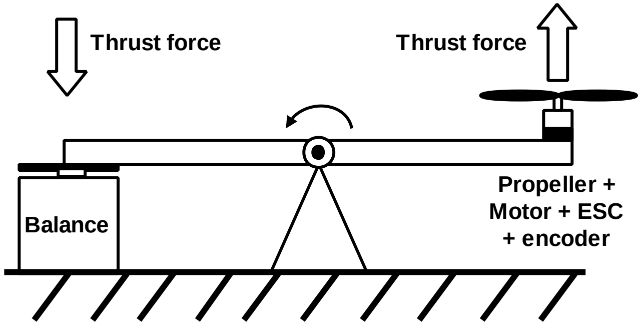
- The main uncertainty sources for both the 3D reconstruction applications are due to the estimation of the stereovision geometry parameters;
- The uncertainties related to the estimation of these stereovision parameters are higher for low flight altitudes than for the high ones. This is due to the fact that for low flight altitudes more details of the background are in the acquired images;
- The camera pose estimation algorithm is confused by the presence of more similar details on the background texture.

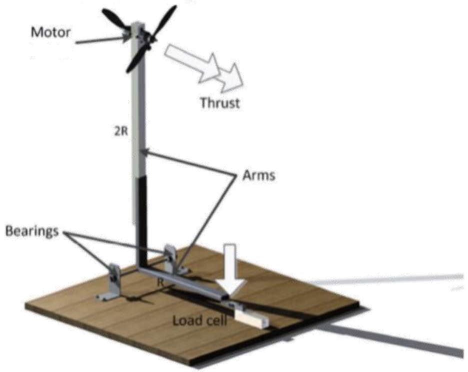
Bench characterization of drone elements

The most important parameters to be measured are: (i) the thrust forces in relation to the motor speeds, (ii) the motor speed response time, and (iii) the power efficiency in terms of Newton per Watt, [N/W].

A common test bench used for measuring the static thrust force is implemented using an electronic weight balance.

A characteristic speed versus thrust force can be obtained and it can be used for optimizing the mechanical and the electrical drone design and the control method.





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 and Measurement Magazine, vol. 20, Dec. 2017 (7)

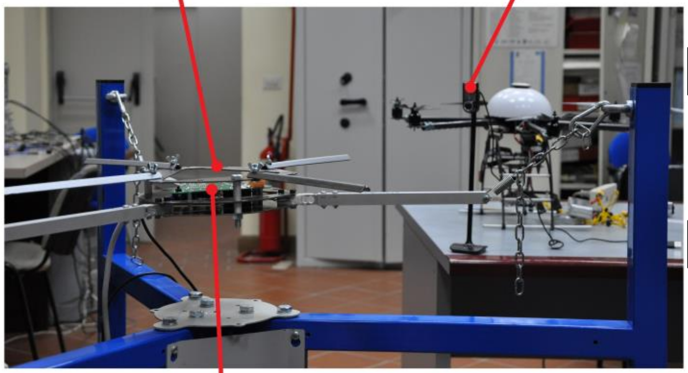
Open issue

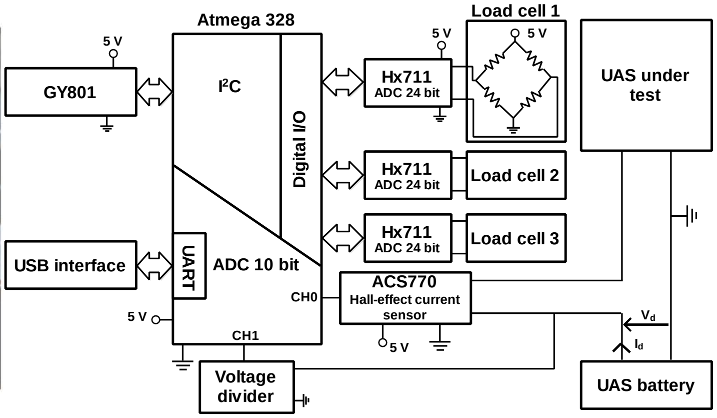
In literature, the systems used for testing drones are mainly used for measuring parameters related to each component of the drone itself (such us control board, propeller, motor, and so on).

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.

B. Brzozowski, P. Daponte, L. De Vito, F. Lamonaca, F. Picariello, M. Pompetti, I. Tudosa, K. Wojtowicz, "A remote controlled platform for UASs testing", accepted to be published into IEEE Aerospace and Electronic Systems Magazine. (8)

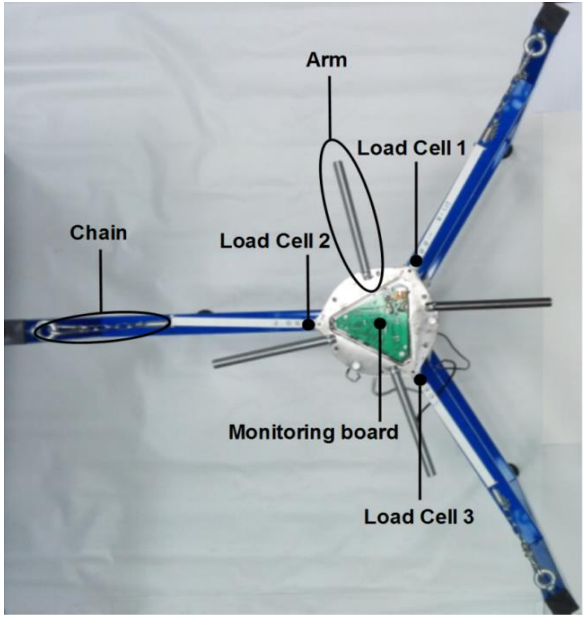
DronesBench (1)





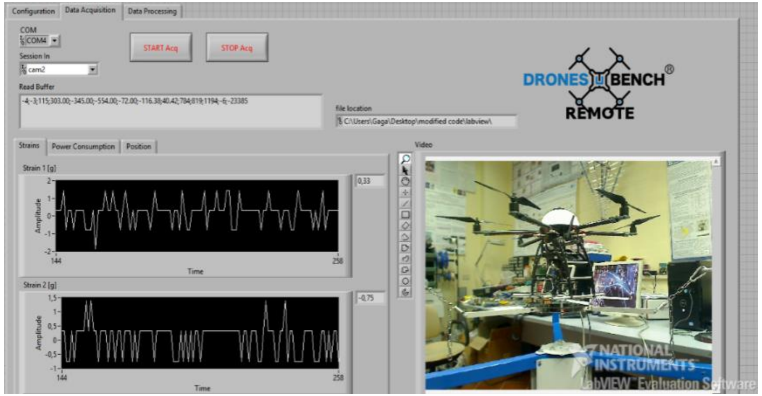
The system consists of: (i) the accommodation plane, where the drone is inserted, (ii) the monitoring board, which is used for acquiring the data of the sensors, and (iii) the video camera for online visualization and recording of the testing scenario.

DronesBench (2)



- The sensing tips of the three load cells are attached to the accommodation plane, while the other fixture tips are connected through the chains to the test bench frame.
- 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 (3)



By acquiring the data provided by each load cell and by considering the z-axis of the three load cells aligned, at each sampling instant the thrust force exerted by drone along the z-axis is evaluated as follows:

$$F = F_{z,1} + F_{z,2} + F_{z,3}$$

The thrust force values, acquired at each sampling instant, are stored in the vector:

$$\boldsymbol{F} = [F(0), \dots, F(N)]$$

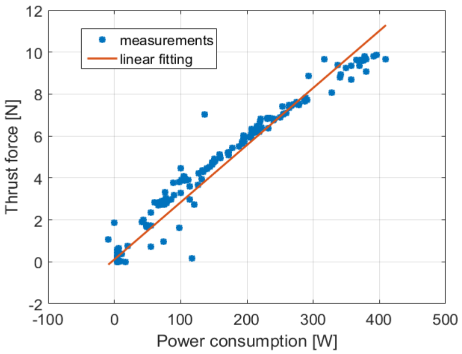
The power consumption values, acquired at each sampling instant, are stored in the vector:

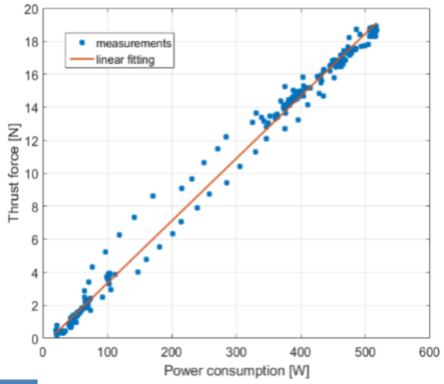
$$\boldsymbol{P} = [P(0), \dots, P(N)]$$

A linear regression, based on least square fitting between vectors ***F*** and ***P***, is performed, and the obtained slope (*FoM*) is associated to the drone efficiency in terms of Newton per Watt, [N/W].

Preliminary results (1)

Quadrotor
FoM = 0.027 N/W



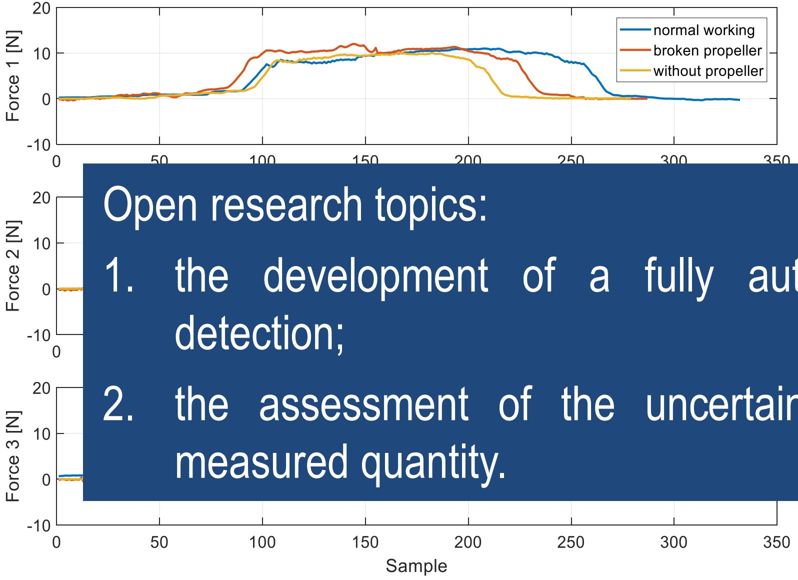


Hexarotor
FoM = 0.038 N/W

	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

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.

Preliminary results (2)



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

Test 2: the hexarotor was tested with one ... m of ... oken ... ut a ... orce ... and identifying faults or damages of drones.

Open research topics:

1. the development of a fully automated system for faults detection;
2. the assessment of the uncertainties associated with each measured quantity.

B. Brzozowski, P. Daponte, L. De Vito, F. Lamonaca, F. Picariello, M. Pompetti, I. Tudosa, K. Wojtowicz, "A remote controlled platform for UASs testing", accepted to be published into IEEE Aerospace and Electronic Systems Magazine. (8)

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10) P. Daponte, L. De Vito, L. Glielmo, L. Iannelli, D. Liuzza, F. Picariello, G. Silano, "A review on the use of drones for precision agriculture", IOP Conference Series: Earth and Environmental Science, Volume 275, No. 1, 2019.

Thank you for your attention !
Any questions?

{devito, daponte}@unisannio.it

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