CZU: 681.586:623.746-519

SENSORS AND MEASUREMENTS FOR UAV SAFETY

Luca DE VITO
University of Sannio, Benevento, Italy
ORCID: 0000-0003-1896-2614,
email: devito@unisannio.it

Abstract: This paper presents an overview of sensor and measurement technologies for enhancing the safety of Unmanned Aerial Vehicles (UAVs). In particular, the paper discusses the sensors and measurement technologies to improve the perception of the environment in UAVs as well as the platforms for ground verification of UAVs. The paper finally presents the prototype of a UAV test platform for small UAVs, developed as result of a collaboration between the University of Sannio and a company, allowing to measure the thrust force in several directions, the orientation of the UAV and the power consumption. The platform was recently enhanced with a machine learning-based fault detection method which was proven to identify propeller defects.

Keywords: Unmanned Aerial Vehicle, Testing, Safety.

Introduction

The rapid advancement of unmanned aerial vehicles (UAVs) has revolutionized various sectors, including agriculture, logistics, surveillance, and disaster management. These versatile devices offer unprecedented capabilities, from high-resolution aerial photography to precise delivery services. However, as UAVs become increasingly integrated into our daily lives and critical infrastructures, ensuring their safe operation has become crucial.

The UAS (Unmanned Aerial System) safety risk portfolio and analysis [1], published in 2016 by the European Union Aviation Safety Agency (EASA) has documented all safety occurrences in the period between 2010 and 2016. According to the EASA definition, a safety occurrence is any safety-related event which endangers or which, if not corrected or addressed, could endanger an aircraft, its occupants or any other person.

Fig. 1 reports the trend of reported occurrences from 2010 to 2016. It is worth noting that [1] only reports partial data for 2016 until the end of May; therefore, it was expected to have at the end of the year a value at least twice what is reported in the figure. It can be observed that the occurrences increased every year, thus confirming the growing interest in UAV safety.

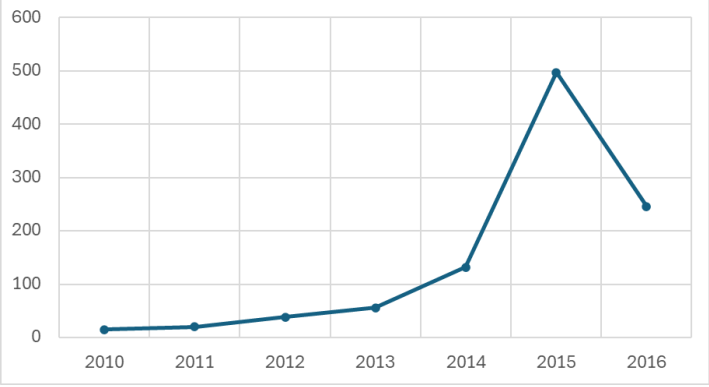


Fig. 1. UAS occurrences per year (source: [1])

In [1], key risk areas have been identified. Two significant areas among them are the collision of he UAV with people or objects and the failure of any UAV subsystems.

This paper presents sensor and measurement technologies to enhance UAV safety by reducing these risk areas. In the next section, the sensor and measurement requirements to enhance UAV awareness of the surrounding environment are presented regarding the former risk area. Then, the platforms for ground verification of the UAV subsystems will be described, which aim to reduce the risk associated with the latter area. Finally, a test platform designed as a result of a collaboration between the Laboratory of Measurement and Signal Processing of the University of Sannio and a company will be discussed.

Sensors and measurements for collision avoidance

As mentioned above, one of the most significant risks for a UAV is the collision with people or objects. To reduce this risk, the UAV must be equipped with proper devices and algorithms able to sense the presence of objects and people in the neighborhood and to react by both predicting the risk of collision and eventually moving away from the point of a collision or changing the flight trajectory to avoid it. According to [2], collision avoidance can be divided into two phases (Fig. 2): perception and action. In the perception phase, the contribution of measurement and instrumentation is crucial as the UAV must become aware of the possible risk of collision. For this, different sensor technologies are used, which can be classified into passive and active sensors. In active sensors, the working principle is based on the transmission of light or the emission of a wave and the reflected back-scatter reading. LIDARs, sonars and radars belong to this category. Passive sensors use instead a different source, such as the reflected object sunlight, to read the obstacle discharged energy. Cameras or passive infrared sensors are part of this category. Since different sensor types can have advantages and disadvantages, advanced collision avoidance systems often use a combination of sensor technologies whose data are fused by specific algorithms.

Regarding the action phase, actions can be classified into four types: geometric, force-field, optimized, and sense-and-avoid. Geometric actions use the UAV's position data to steer clear of obstacles. Force-field actions navigate around obstacles by applying attractive and repulsive forces. Optimized actions utilize predefined parameters for obstacle avoidance. Sense-and-avoid actions depend on real-time sensor data to make immediate decisions for avoiding obstacles.

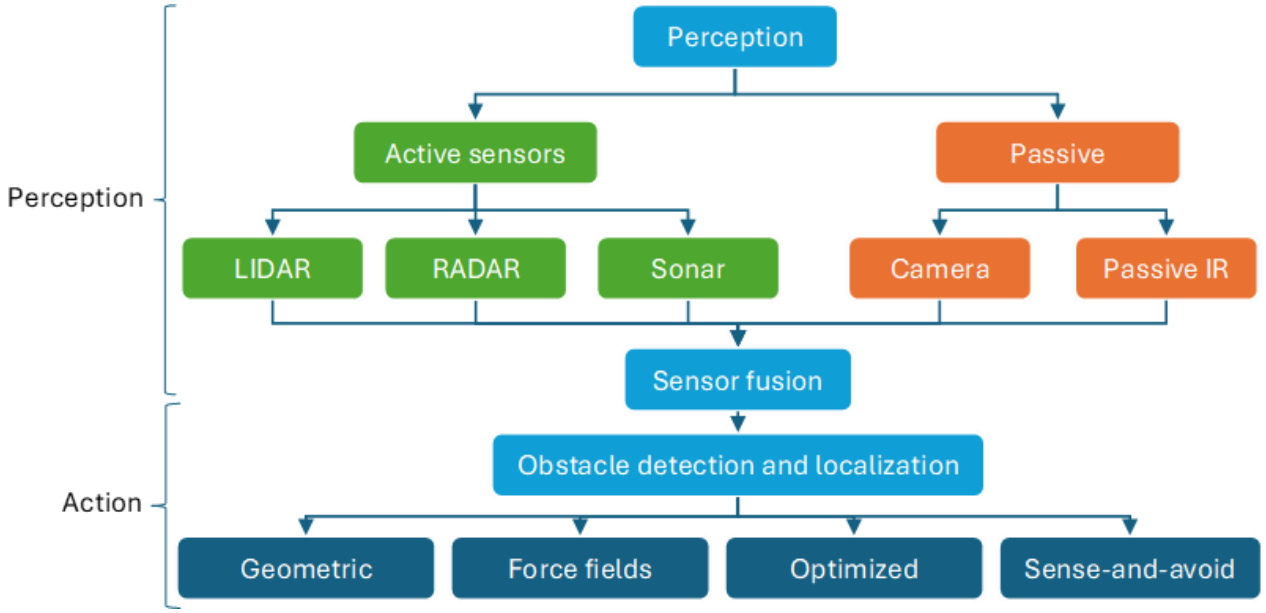


Fig. 2. Stages of collision avoidance

Platforms for ground UAV verification

To reduce the risk of failure in any UAV subsystems, it is crucial to perform accurate verifications of the UAV, which could have a good coverage of a broad range of malfunctions. In the literature, many platforms have been proposed to evaluate the performance of UAV subsystems, such as the battery reliability or the performance of the propulsion system.

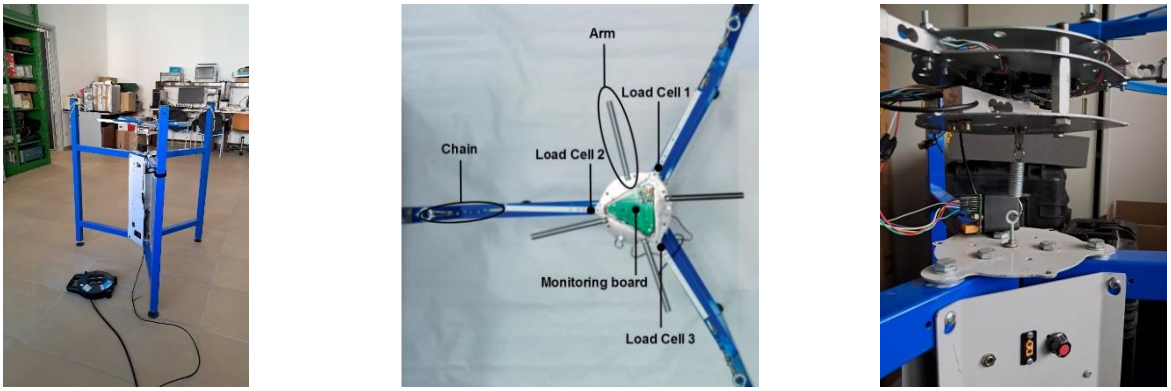
In [3], the authors proposed a test bench equipped with: (i) a load cell to measure the thrust force of the pair motor-propeller, (ii) an infrared speed sensor TCRT5000, to measure the propeller angular speed, and (iii) voltage and current sensors, to measure the power transferred by the battery. With such a platform, they evaluated the efficiency (i.e. the produced thrust force per unit of power), the propeller angular rate and the consumed power for different values of the imposed throttle. Similar approaches were used in [4] and [5].

These test benches, however, were mainly intended to evaluate different combinations of motor and propeller at the design stage rather than for UAV verification before the flight. Moreover, they are only able to verify the propulsion system and do not provide an automatic identification of possible faults or the early detection of small damages.

In [6], the authors proposed an approach based on the installation of accelerometer sensors on each arm of the UAV frame (a quadrotor UAV was considered). They prove that the sensed acceleration signals are sensitive to defects in any of the motor-propeller couples and they also provided a machine learning-based method for the identification and the localization of the faults. While providing fault detection and localization, this method involves the installation of specific sensors on the UAV, and the fault detection results could depend on the UAV shape and size, as well as on the location of the sensors. Therefore, it does not adapt well to the verification of a general UAV before the flight.

The Dronesbench platform

To overcome the limitations mentioned above, a UAV test platform called Dronesbench has been designed, as a result of the collaboration between the Laboratory of Signal Processing and Measurement Information of the University of Sannio and the DPM Elettronica company [7-8]. It consists of a base with three feet (Fig. 3a) supporting a measurement head (Fig. 3b). The measurement head consists of a star-shaped structure with three arms, with a 120° angle each other. The measurement head is equipped with four load cells to measure the thrust produced by the UAV in different directions. Three load cells are located at the end of each arm, where the measurement head is suspended from the base. A fourth load cell (Fig. 3b) is located below the head to measure the thrust in the vertical direction.



(a) (b) (c)

Fig. 3. Pictures of the Dronesbench test platform

An electronic board is also installed on the measurement head, whose block scheme is depicted in Fig. 4. It consists of: (i) an Arduino Nano board equipped with an Atmel ATMega328 microcontroller, which is in charge of managing all other circuits and collecting the measurements; (ii) a 1/3 voltage divider and a 0.2 Ω shunt, which serves capture the voltage and current signals transferred from the battery to the UAV, (iii) four HX711 2-channel 24-bit Analog-to-Digital Converters (ADCs), allowing to digitize both the signals from the load cells and those of the current and voltage; and (iv) an Inertial Measurement Unit, which is in charge of measuring the orientation of the measurement head.

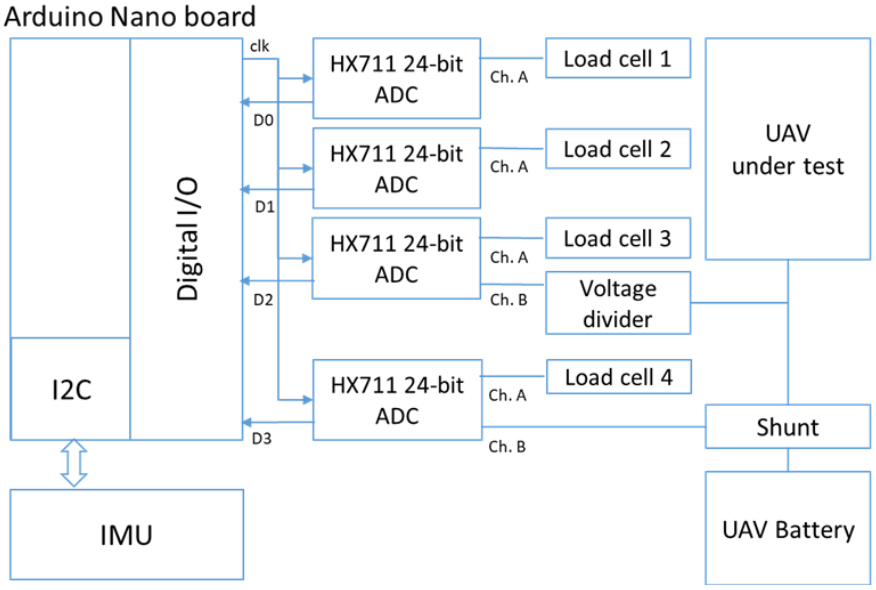


Fig. 4. Block scheme of the Dronesbench electronic board

During the test, the UAV is tied to the measurement head, and its battery is connected to the platform to extract the voltage and current signals. The platform can provide measurements of the thrust obtained by the four load cells, the orientation of the head and the power transferred by the battery.

As described in [8], the Dronesbench has been complemented by a machine learning-based fault detection method. The method was used to identify and locate faults in the propellers. Two types of faults were considered, i.e. a propeller having a cut on a single tip or both tips.

With the considered faults, a signal dataset was created consisting of: (i) 60 records in case of all propellers intact (ii) 100 records in case of one propeller with a cut on a single tip, 25 for each of the 4 considered propeller positions, and (iii) 100 records in case of one propeller with cuts on both tips, 25 for each of the 4 considered propeller positions. Two fault detection problems were defined aiming to: (i) identify the presence and type of the defect, i.e. one-tip or two-tip cut, and (ii) identify the location of the damage, i.e. on the left side or the right side of the UAV, respectively. For each record and each measured quantity (i.e., 4 thrust force measurements, triaxial accelerations and angular rates, current, and voltage measurements), time and frequency domain features were extracted from each trial consisting of approximately 300 samples. The extracted features in the time domain were peak value, mean, root mean square (RMS), standard deviation (std), total harmonic distortion (THD), and signal-to-noise and distortion (SINAD) ratio. The features in the frequency domains were the band power, the frequency of the first harmonic peak and its magnitude. The features were ranked using one-way Analysis of Variance and the first 15 for each detection problem were selected.

A dataset with the feature values was therefore created and used for the training and classification. In particular, 80% of the dataset was used in the training and validation phases, while the remaining 20% was used for testing. Different classification algorithms were evaluated, including Quadratic Discriminant, Neural Network, K-Nearest Neighbors, Ensemble Tree, Subspace Discriminant Ensemble, and Support-Vector Machines. The classifiers obtaining the best results were the Quadratic Discriminant, and the Subspace Discriminant Ensemble, for the defect identification and localization problems, respectively. Fig. 5 reports the confusion matrices obtained by these classifiers, where it can be observed that a True Positive Rate or 90% or above was obtained in both cases, confirming the capability of the platform to accurately identify both the type and the location of the defect.

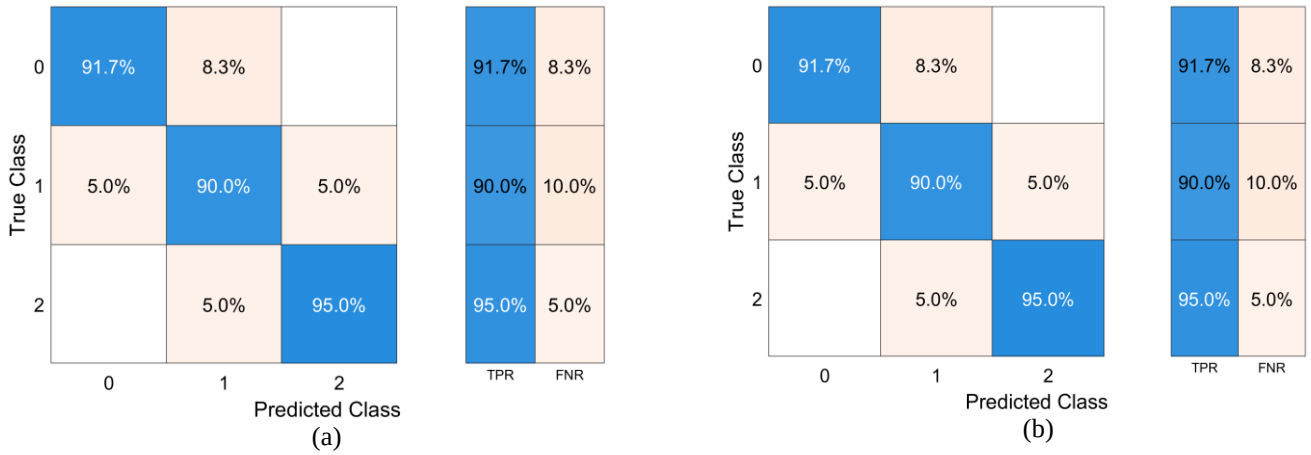


Fig. 5. Confusion matrices for the classification of the type (a) and the location (b) of the defect

Conclusions

In this paper, instrumentation and measurement technology for UAV safety was discussed. According to EASA two major risk areas for UAVs are the risk of collisions with people or objects and the failure of some UAV subsystems. Therefore, instrumentation and measurement technologies to enhance safety in these two areas were discussed. In particular, to test UAV subsystems, test platforms are used to evaluate the UAV capabilities before the flight. A test platform designed as a result of the collaboration between the Laboratory of Measurement and Signal Processing of the University of Sannio and a company was presented. It is able to measure the thrust in different directions, the orientation of the UAV and the power transferred from the battery to the UAV. Moreover, it was complemented with a machine learning-based fault detection method that was able to identify and locate small defects in the propellers. Although several instrumentation and measurement technologies have been proposed for improving UAV safety, there are still open research gaps. Advanced mapping systems and fast and accurate reaction algorithms are still required for collision avoidance. Moreover, sensors and measurement methods for in-flight self-diagnosis are still to be improved. Finally, integrated platforms capable of testing several subsystems and detecting early faults are needed.

References:

1. EASA, UAS Safety Risk Portfolio and Analysis, 2016, https://www.easa.europa.eu/en/document-library/general-publications/uas-safety-risk-portfolio-and-analysis.

2. WANNER, D., HASHIM, H.A., SRIVASTAVA, S., STEINHAUER, A. UAV avionics safety, certification, accidents, redundancy, integrity, and reliability: a comprehensive review and future trends. Drone Systems and Applications, Vol. 12, 2024, pp.1-23, doi: 10.1139/dsa-2023-0091.

3. HERNÁNDEZ, J.D., NANDAR, J.E., CHANGOLUISA, I.D., CRUZ, P.J., VALENCIA, E. Test-bench development for the efficiency analysis of UAV motor-propeller sets. In: Proc. of 2021 IEEE Fifth Ecuador Technical Chapters Meeting (ETCM), 2021, pp. 1-6, doi: 10.1109/ETCM53643.2021.9590717.
4. FAUNDES, D.N., WUNSCH, V., HOHNSTEIN, S., GLASS, B., VETTER, M. Research paper on the topic of different UAV drive train qualification and parameter sets. In: Proc. of the 32nd Digital Avionics Systems Conference (DASC), East Syracuse, NY, Oct., pp. 6-10, 2013, doi: 10.1109/DASC.2013.6712629.
5. CZYBA, R., SZAFRAŃSKI, G., JANIK, M., PAMPUCH K., HECEL, M. Development of Co-Axial Y6-Rotor UAV − Design, Mathematical Modeling, Rapid Prototyping and Experimental Validation. In: Proc. of 2015 International Conference on Unmanned Aircraft Systems (ICUAS), 2015.
6. BONDYRA, A., GĄSIOR, P., GARDECKI, S., KASIŃSKI, A. Development of the sensory network for the vibration-based fault detection and isolation in the multirotor UAV propulsion system. In: Proc. of the 15th International Conference on Informatics in Control, Automation and Robotics – Volume 2: ICINCO, INSTICC. SciTePress, 2018, pp. 102–109, doi: 10.5220/0006846801020109.
7. DAPONTE, P., DE VITO, L., LAMONACA, F., PICARIELLO, F., RICCIO, M., RAPUANO, S., POMPETTI, L., POMPETTI, M. DronesBench: an innovative bench to test drones. In: IEEE Instrumentation & Measurement Magazine, vol. 20, No. 6, pp. 8-15, December 2017, doi: 10.1109/MIM.2017.8121945.
8. DAPONTE, P., DE VITO, L., PICARIELLO, F., TUDOSA, I. UAV test-bench platform for propeller diagnostics using Machine Learning. In: Proc. of 2024 Int. Workshop on Technology for Defense, Naples, Nov. 2024.

The work has been supported by the following project: "Advanced Technologies for Physical ResIlience Of cRitical Infrastructures (APRIORI)", code: SPS G6140, funded by the NATO, Science for Peace and Security (SPS) Call for Proposals 2023-1.