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Qualitative and quantitative validation of drone detection systems

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Abstract—As drones are more and more entering our world, so comes the need to regulate the access to airspace for these systems. A necessary tool in order to do this is a means of detecting these drones. Numerous commercial and non-commercial parties have started the development of such drone detection systems. A big problem with these systems is that the evaluation of the performance of drone detection systems is a difficult operation, which requires the careful consideration of all technical and non-technical aspects of the system under test. Indeed, weather conditions and small variations in the appearance of the targets can have a huge difference on the performance of the systems. In order to provide a fair evaluation and an honest comparison between systems, it is therefore paramount that a stringent validation procedure is followed. Moreover, the validation methodology needs to find a compromise between the often contrasting requirements of end users (who want tests to be performed in operational conditions) and platform developers (who want tests to be performed that are statistically relevant). Therefore, we propose in this paper a qualitative and quantitative validation methodology for drone detection systems. The proposed validation methodology seeks to find this compromise between operationally relevant benchmarking (by providing qualitative benchmarking under varying environmental conditions) and statistically relevant evaluation (by providing quantitative score sheets under strictly described conditions).

Index Terms—Unmanned Aerial Vehicles, Drones, Detection systems, Drone detection, Test and evaluation methods.

1 Introduction

1.1 Problem statement

CONSUMER drones are more and more becoming commodity items in our modern world. This is a positive evolution, as these tools have many positive use cases and the affordability of the current systems means that all new business opportunities pop up. However, we cannot be blind as well to the negative aspects these novel tools may induce into our society. Indeed, next to the many airspace infringements, where uneducated hobbyists enter potentially dangerous airspace (e.g. near airports, close to manned aviation, ...) inadvertedly, we also see an increasing use of drone technology by criminals [1], [2]. In most countries, rules for access to airspace by unmanned aerial vehicles / drones / Remotely Piloted Aircraft Systems (RPAS) have been created. The challenge is now to enforce these rules, as the police services lack the means to automatically detect airspace infringements. Indeed, something like a car traffic speed camera for the air does not really exist yet, but it is deerly needed.

1.2 Previous work on drone detection

Numerous commercial and non-commercial parties have noted this gap in the market and have started the development of drone detection systems.

There are in general two main difficulties related to the detection of drones. First, the cross section / detection baseline for these systems is in general very limited, whatever sensing technology is used. Indeed, drones have a small RADAR cross section, a small acoustic signature (from a relevant distance), a small visual / infrared signature, they use common radio signal frequencies, etc. Of course, it would be possible to make the detection methodologies extremely sensitive, but this then leads to the second difficulty: how to avoid false positives? Indeed, the signature of many drones is quite close to the one of birds, so it is really difficult to filter out these false positives [3].

Sensing modalities that can be used to solve the drone detection problem are typically RADAR [4], acoustics [5], visual [6], IR [7] (thermal and short-wave), sensing of the radio spectrum [8], LIDAR [9], etc. However, as the problem is so difficult to solve in realistic operating conditions, most of the existing solutions rely on a mix of different sensing methodologies in order to solve the drone detection problem [2] and use a mix of traditional detection and tracking methodologies [10], [11] originating from computer vision to achieve multi-sensor tracking.

1.3 Previous work on quantitative operational validation

The problem with the evaluation of drone detection systems is twofold:

1) Drone detection systems most often rely on complex data fusion & processing of sensor data, which means that it is required to carefully control the test conditions in order to single out the limits of the system under test.
2) Drone detection systems need to be operational 24/7 and under all weather conditions, meaning that it is required to assess their performance within a wide range of conditions.

Clearly, both of these constraints are somewhat in contradiction with one another and it is not evident to seek a

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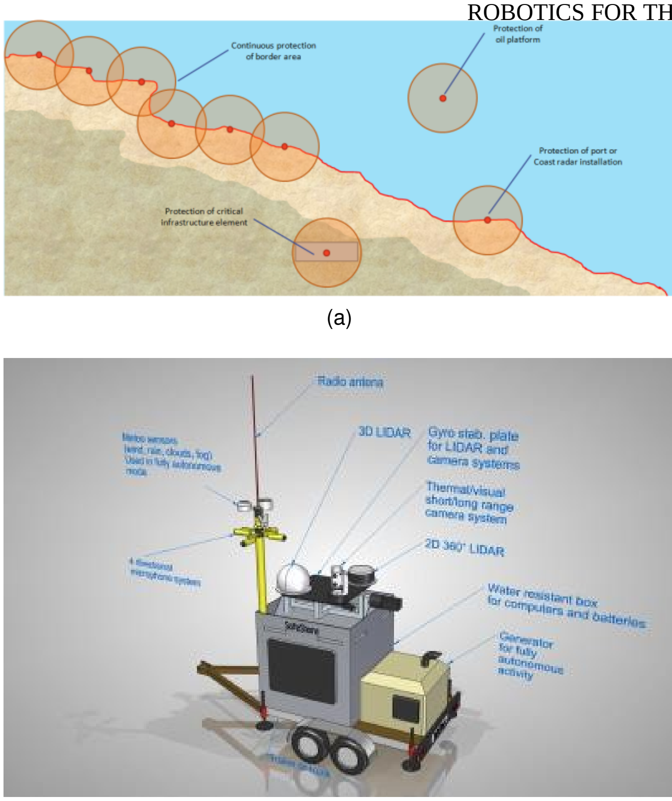

(a)

(b)

Fig. 1. SafeShore concept sketch.

compromise between these two types of requirements. The objective is therefore is to find a validation methodology that satisfies both the request of the end-users towards a qualitative operational validation of the system and the platform developers of a quantitative statistically relevant validation.

Such qualitative and quantitative validation methodologies have been proposed before, e.g. by the U.S. National Institute of Standards and Technology (NIST) in the field of robotics [12]. In [13], a qualitative and quantitative validation methodology was proposed, based on the work performed at NIST and this technique was validated in [14]. In this research work, we will elaborate on this methodology and port it from the realm of search and rescue robotics to the field of drone detection.

1.4 Introduction to the SafeShore project

The use case that was chosen in the scope of this research work was the validation of a drone detection system, developed within the scope of the EU-H2020-SafeShore project [15].

The main objective of the SafeShore project is to cover existing gaps in coastal border surveillance, increasing internal security by preventing cross-border crime such trafficking in human beings and the smuggling of drugs. It is designed to be integrated with existing systems and create a continuous detection line along the border.

The SafeShore solution for detecting small targets that are flying in low attitude is to use a 3D LIDAR that scans the sky and creates above the protected area a virtual dome shield. In order to improve the detection, SafeShore integrated the 3D LIDAR with passive acoustic sensors, passive radio detection and video analytics. All those technologies can be considered as low cost and green technologies (compared to the traditional RADAR systems). It is expected that a combination of orthogonal technologies such as LIDAR, passive radio and acoustic and video analytics will become mandatory for future border control systems in environmentally sensitive areas.

The SafeShore objective is to demonstrate the detection capabilities in the missing detection gaps of other existing systems such as coastal radars, thereby demonstrating the capability to detect mini-RPAS along the shore and the sea or departing from civilian boats.

Another important SafeShore goal is to ensure fusion of information and increasing the situational awareness and better implementation of the European Maritime Security Strategy based on the information exchange frameworks while ensuring the privacy of the data and conformity to internationally recognized ethical issues concerning the safety of the information and the equipment subject of the project.

2 Proposed Methodology

2.1 Requirements gathering methodology

A first step in the development of the validation framework was the requirements analysis, which followed a step-wise approch:

- The end user community was approached via market studies and targeted interviews
- An early draft methodology proposal was compiled
- This draft document was extensively discussed with both end users (in this specific case: maritime border management agencies) at relevant events and with platform developers in order to come to target performance levels which are both operationally realistic from and end-user point of view and also realistic from a platform developer point of view in terms of required effort, resources and state-of-the-art and physical constraints.
- As SafeShore focuses on drone detection for the protection of maritime borders, a number of operational validation scenarios were proposed in order to address major issues the maritime border security community is facing today.
- For each of the validation scenarios, target performance levels were proposed in discussion with end users and platform developers.

2.2 Concept overview

Two crucial aspects of obtaining realistic results from validation scenarios are that the scenarios should be as close as possible to operational reality and that the validation tests should be repeated enough to ensure statistical relevance. These two considerations are often in conflict with one another, as operational testing requires uncontrolled environments, whereas statistical relevance of results can only be obtained in controlled settings.

Within SafeShore, we have aimed to strike a balance between both aspects, by providing a qualitative and quantitative assessment of the SafeShore system capabilities and by having multiple repeated experiments in realistic environments, following scenarios which are described by end users, based upon their needs and their practical maritime border security problems of today.

The different components of the SafeShore validation concept are:

- A traceability matrix which indicates clearly what are for each validation scenario the relevant user requirements which are tested, allowing to identify how (by which validation scenario) each system requirement will be validated. This important in order to keep track of the different user requirements and to make sure that for each of the requirements, there is a validation scenario in place that makes sure that the attainment of the requirement can be verified.
- A number of detailed scenarios, each related to maritime border security and safety. In total, SafeShore considers 14 validation scenarios: 5 to be executed in Belgium, 3 in Israel and 6 in Romania. In this paper, we will focus on those executed in Belgium. Each of these scenarios contains:
  - A capability score sheet, allowing for a qualitative assessment of the validation of the target performance levels. These capability score sheets allow to make a binary assessment (YES / NO) whether one of the user or system requirements has been attained by the system or not.
  - Template forms to be filled in during the validation tests, providing standardised information on the threat agents and the detection results. These template form contain valuable environmental information, such as weather conditions, sea state, etc. They also provide crucial information on the drones used as test agents: their visual / infrared / radio-frequency / acoustic / LIDAR signature, including ground truth timestamped GPS tracks, which allows for a full quantitative evaluation of the precision of the detection results. These evaluation forms also provide a means to evaluate the human-machine interface, as they gather information on the sample sizes for human verification, the detection resolution and video framerates, etc.
  - A score sheet for the different metrics (Key Performance Indicators or KPI's), allowing for a quantitative assessment of the validation of the target performance levels.
  - Detailed target performance levels for each of the measured metrics. For each of the KPI's, 3 different levels of scoring were assessed in collaboration with the end users:
    * Minimum Acceptance level: Performance below this level is not acceptable by the end users in operational conditions. Anything above is considered workable.
    * Goal level: This is the performance level hoped for by the end-users.
    * Breakthrough level: This is a performance level beyond initial expectations that end users would like one day to have.

3 Validation of the Methodology

3.1 Trial concept & execution

As discussed above, five different trial scenarios related to maritime border security and safety were validated during the SafeShore trial in Belgium, which was the first in a series of 3 trial events of the project where this validation methodology was applied.

For this operational field test, 11 different drone platforms (rotary wing, fixed wing, systems made of different materials, very fast drones and slow ones, etc) were deployed during a 2-week measurement campaign, in order to grasp different kinds of system capabilities and meteorological and operational conditions.

Figure 2 shows the SafeShore prototype as it as installed on the beach in Belgium for a period of 2 weeks, while detecting numerous types of drones.

3.2 Trial results

As this was the first out of a series of 3 successive test campaigns, it was to be expected that the system was going to have some quirks and child diseases. The perforamnce validation methodology was therefore essential in order to identify these issues and to give indications on the causes for these problems.

Thanks to the proposed validation, at the end of each validation day it was possible to provide an overview of the performance of the system, both from a qualitative as from a quantitative point of view. As a result of this, daily debriefings between SafeShore developers and SafeShore end users could be held in order to discuss the possibilities and deficiencies of the system. As such, an action plan could be set up on a daily basis in order to improve the performance of the system. Due to this iterative review of the system, the performance of the SafeShore system improved on a daily basis.

At the end of the trial, the proposed validation methodology enabled to provide a full overview of the performance of the system for all 5 scenarios, both from a qualitative as from a quantitative point of view. However, as this was the very first trial, it was not possible to sort out all problems with the system by the end of the trial period. Based upon the result of the validation method, a new action plan was therefore elaborated between end-users and developers in order to improve the performance of the system during the next trials in Israel and Romania.

4 Conclusions

In this paper, a validation methodology was proposed for evaluating complex systems that aims to strike a balance between the rigourous, scientifically correct and statistically relevant evaluation methodologies requested by platform developers in the iterative design stage on one hand and the requirements of the end users on the other hand, who require field tests in operational conditions in order to evaluate the real-life performance of the system. The proposed methodology reaches this objective by incorporating

Fig. 2. SafeShore system as installed on the beach in Belgium. ©Daniel Orban.

and integrating qualitative and quantitative aspects in the validation process. The proposed methodology was tested on a drone detection system in the context of the EU-H2020 SafeShore project and allowed the project participants (a heterogeneous mix of end users and platform developers) to improve the performance of the system on a daily basis during operational field tests of the system, thereby proving the value of the proposed methodology.

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