SAND2020-5704C

Proceedings of the INMM 61st Annual Meeting
July 12-16, 2020, Baltimore, MD, USA

Development Of Metrics And Requirements To Enable Down-selection And Evaluation Of Commercial Counter-unmanned Aircraft Systems Products

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Abstract:

Recent security events involving unmanned aircraft systems (UAS) or Remotely Piloted Aircraft Systems (RPAS) have left many Nuclear Sites wondering if they should implement counter-UAS technologies. Many sites are, therefore, beginning to assess the security risks and potential impact of UAS threats on security operations to determine whether implementing counter-UAS (CUAS) technology or products is warranted. If assessments indicate unacceptable levels of risk, operators have a challenging task of determining what kind of CUAS capabilities to select and implement and how to conduct performance testing to evaluate the product specifications and claims made by manufacturers. For operators or regulators seeking to incorporate CUAS capabilities into their security systems, a critical next step is to generate requirements based on risk, policy, threat, and performance trade-offs. This activity is independent of and must be completed prior to searching for or deploying a CUAS technology. Doing so enables more effective technical exchanges, requests for information, development of test plans and procedures, and provides a solid basis for justifying procurements actions. This is best done through multiple discussions involving all security stakeholders on topics such as: what is the anticipated budget for acquisition, deployment, annual training, operation, maintenance and sustainment, performance testing, and system updates; what UAS characteristics (type, navigation methods, size, speed, altitude, payloads, behaviors, etc.) should be used to determine unacceptable levels of security risk from UAS threats; what forms of sensing and tracking are preferred given local environment conditions; what kinds of mitigations are acceptable, legal, and effective given local conditions and regulations; etc. The results of these discussions are the foundation upon which requirements and metrics to evaluate the performance of a CUAS system are employed, regardless of the type of technology being considered. In this presentation, multiple performance metrics that can be applied to CUAS at various sites are reviewed. The metrics presented are based on an established methodology that has been applied to detection and neutralization of threats to high-security applications for over 40 years.

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1. INTRODUCTION

The potential for using an unmanned aerial system (UAS) as a delivery platform or for facility surveillance for malicious intent is a security concern. As a result, the commercial sector has started to market detection, assessment, and neutralization systems to counter UAS incursion. This work focuses on characterizing metrics of integrated counter UAS (CUAS) technologies and their components. An integrated system consists of detection, assessment, tracking, and neutralization to mitigate a UAS threat.

2. CUAS PERFORMANCE METRICS

Technical evaluations of physical security systems or its elements are necessary to determine whether the system or element meets a minimal set of performance requirements. As CUAS are a relatively new physical security technology, performance requirements were not yet finalized. To address this, a preliminary set of CUAS performance metrics were developed by utilizing the Systems Engineering Framework for the Design, Evaluation and Deployment of Physical Security Systems (Figure 1). Performance metric development was performed by subject matter experts (SMEs) in sensors, imagers, UAS platforms, and physical security system analysis. As CUAS technologies mature and the sophistication of the UAS threats evolve, the proposed requirements should be re-examined.

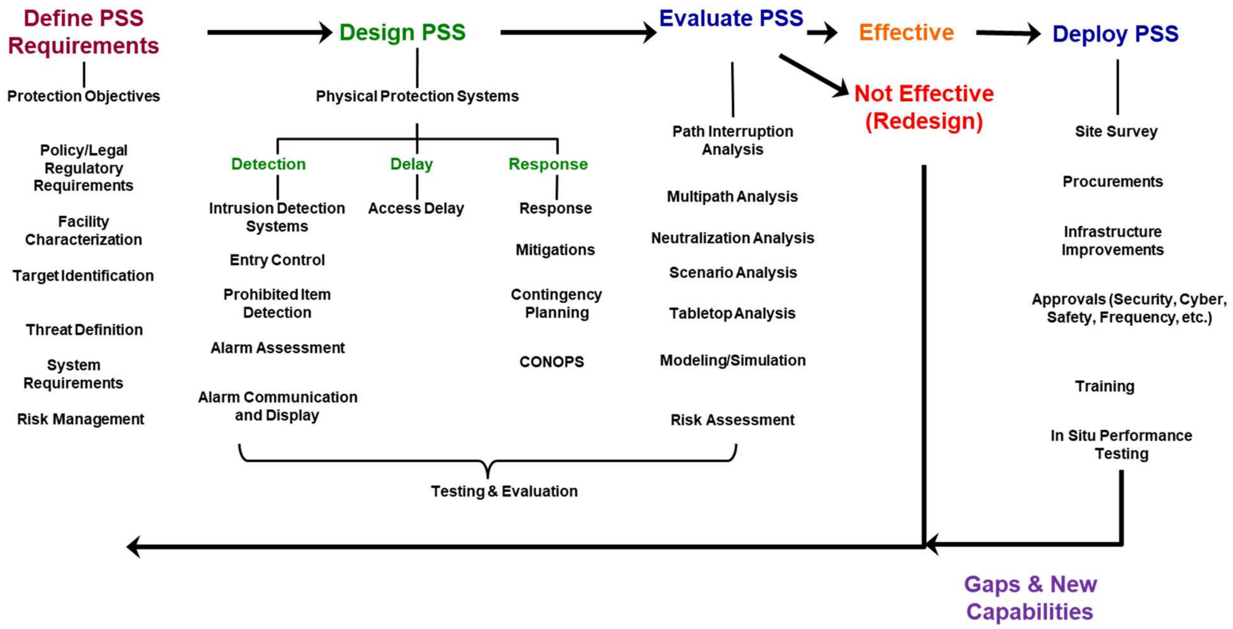

Figure 1. ***Systems Engineering Framework for the Design, Evaluation and Deployment of Physical Security Systems***

Performance Metrics and Definitions

In general, performance metrics are measures of system effectiveness. The performance metrics for any physical protection system include those associated with the probability of detecting an intruder and the likelihood the intruder can be neutralized before completing their mission.

The most common and most misunderstood performance metric used to quantify a physical intrusion detection system is detection. Probability of detection (P_D) is the product of P_S and P_A. Figure 2 shows a notional example of a CUAS scenario and test metrics and Figure 3 shows CUAS performance metric volumes:

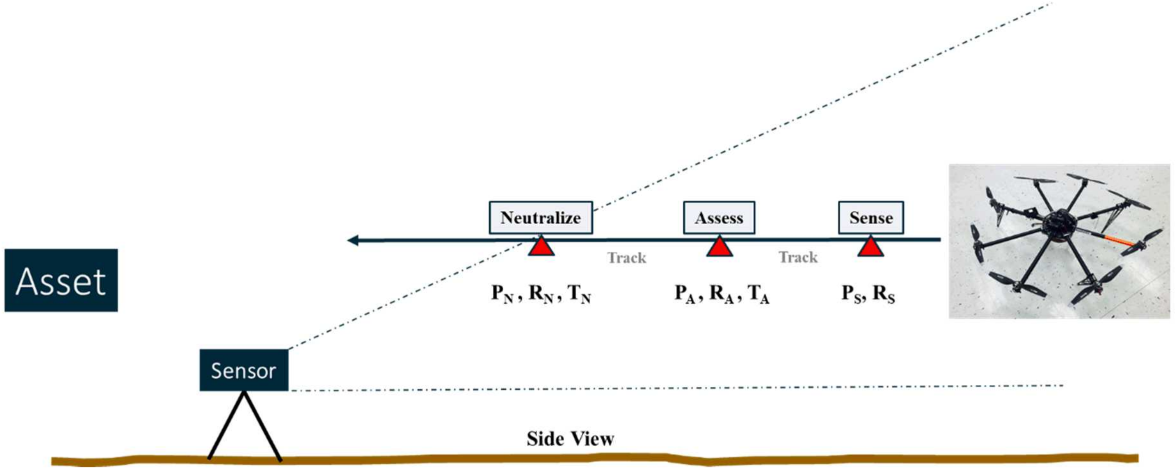

Figure 2. ***Notional Example of a CUAS Scenario and Test Metrics***

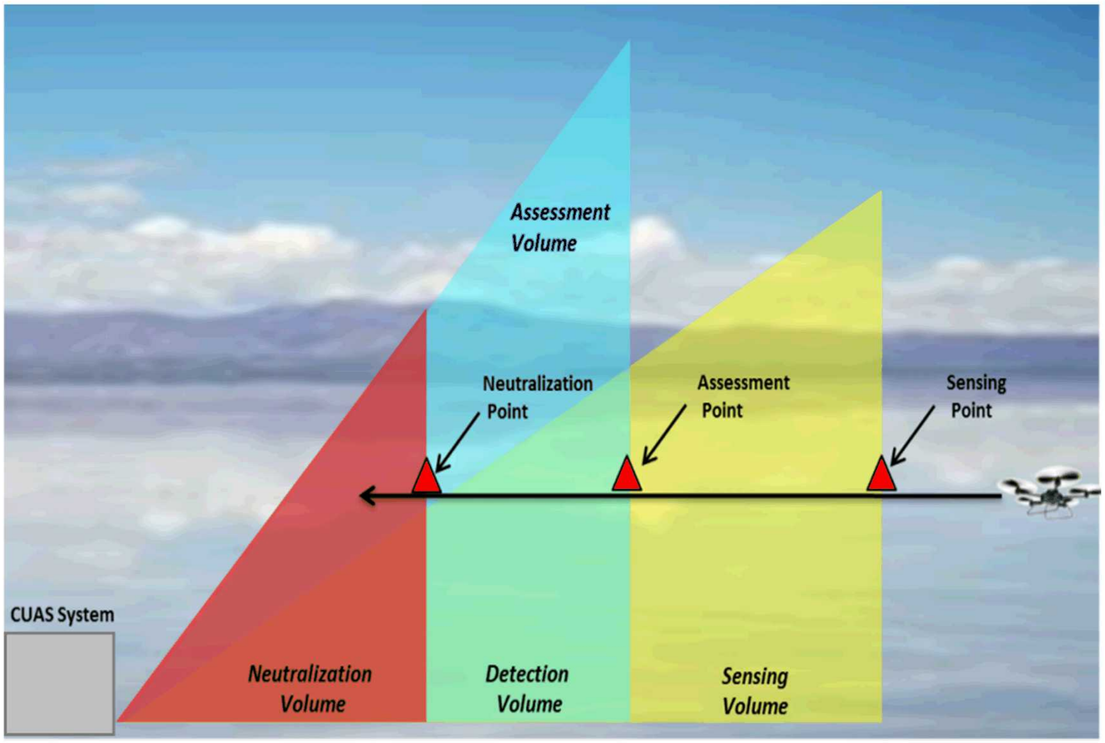

Figure 3. ***Illustration showing CUAS performance metrics volumes.***

$$P_D = P_S*P_A$$

P_S and P_A are the probability of sense and probability of assessment, respectively. Detection is dependent on the capability of the sensor's performance to declare an alarm during an adversary intrusion and the capability to accurately assess the cause of the alarm. The proposed detection metrics for CUAS are:

- **Probability of Detection (P_D):** P_D is the probability of the CUAS to sense and assess the presence of a UAS. Establishing a P_D value for a CUAS is costly due to the cost to obtain P_S and P_A.
- **Detection Point (DP):** DP is the location at which the UAS is detected by the CUAS. The DP is characterized by coordinates referenced from the CUAS location. In most cases, the DP is the same as the assessment point (AP) due to the assumed unit probability of communication.
- **Detection Time (DT):** DT is the time the UAS was detected by the CUAS. The DT is estimated from the sensing time (ST) to the time an accurate assessment is made. In most cases, the DT and the assessment time (AT) are the same due to the assumed unit probability of communication.
- **Detection Volume (DV):** DV is a 3D plot of the sensing point (SP) coordinates from the test set that creates a volume at which the sensor can be expected to initiate an alarm caused by the presence of the UAS stimulus.

UAS neutralization is defined as the capability to direct the UAS away from a security interest or to stop its forward progress toward a security interest. The neutralization performance of a CUAS is evaluated using metrics based on probability, location, and time.

- **Probability of Neutralization (P_N):** P_N is the probability associated with the capability of the CUAS system to direct the UAS away from a security interest or to stop its forward progress toward a security interest. Establishing a P_N value for a CUAS is costly due to the number of tests required.
- **Neutralization Point (NP):** NP is the location where the UAS is effectively neutralized, meaning the UAS is no longer under the control of the original pilot. Ideally at this point, the UAS is now flown/controlled by the CUAS to a specific location where the site security force can appropriately address the threat. If the CUAS technology does not have the capability to fly the UAS to a specific set of coordinates, the NP is where the UAS's forward progress is halted by the CUAS, and the UAS is forced to land or return home. The NP is characterized by coordinates referenced from the sensor location.
- **Neutralization Time (NT):** NT is the time required to neutralize the UAS. The NT is measured from the time that the neutralization begins to the time the CUAS system either directs the UAS away from a security interest or stops its forward progress toward a security interest.
- **Neutralization Coordinates (NC):** NC is the specified coordinates where the UAS is effectively neutralized.
- **Neutralization Volume (NV):** NV is a 3D plot of the NP coordinates from the test set that creates a volume at which the neutralization of the UAS initially occurs.

If an adversary chooses to use a UAS to perform remote surveillance over a protected area, the security operations may want to prevent video information or other data from being transmitted back to a collection point. The capability to inhibit the RF data stream can be considered a form of neutralization. The same metrics cited in this section could also apply to neutralization of data transmissions or command and control (C2) transmissions.

Sensing characterizes the capability of a sensor to react to a UAS stimulus and initiate an alarm. The following sensing metrics are used to evaluate each component of the CUAS technology.

- **Probability of Sense (P_S):** P_S is the probability associated with the capability of the sensor to detect the presence of a UAS. Establishing a P_S value for a CUAS is costly due to the number of tests required.
- **Sensing Point (SP):** SP is the location at which the UAS is sensed by the CUAS. The SP is characterized by coordinates referenced from the CUAS location.
- **Sensing Volume (SV):** SV is a three-dimensional (3D) plot of the SP coordinates from the test set that creates a volume during which the sensor can be expected to initiate an alarm caused by the presence of the UAS stimulus.

Tracking is defined as the displaying or recording of successive positions of the moving UAS. Tracking position information includes the current location, speed, and heading of the UAS in real time. Many CUAS sensor technologies are dependent on directionality for proper assessment and neutralization given this dependency; therefore, tracking may directly affect the capability of the CUAS to assess and neutralize a UAS. The performance metrics that are used to quantify the effectiveness of a CUAS's tracking capability include calculating the quantity of tracking drops during sensing, assessment, and neutralization paths.

- **Tracking Drops during Sensing (TDS):** TDS is the number of times that the CUAS fails to maintain consecutive positional information after the SP has been declared and before the AP is established.
- **Tracking Drops during Assessment (TDA):** TDA is the number of times that the CUAS fails to maintain consecutive positional information after the AP has been declared and before the NP is established.
- **Tracking Drops during Neutralization (TDN):** TDN is the number of times that the CUAS fails to maintain consecutive positional information after neutralization has been initiated until the UAS has no longer been determined to be a threat, e.g., landed, returned to home, or remained away from the site being protected.
- **Tracking Accuracy (TA):** TA is the measured distance between the CUAS tracking points and the actual UAS position. This value is determined by subtracting the coordinates supplied by the CUAS and the coordinates from the UAS GPS tracker.

Assessment characterizes the CUAS capability to determine the cause of an alarm, specifically whether the alarm was caused by a UAS. Depending on the CUAS technology, assessment may or may not require the presence of a human operator. For example, assessment may require an operator to study an image provided by a camera to determine if an alarm is caused by a bird or a

UAS. If an alarm is associated with detection of a specific communications protocol, then assessment may not require human interaction. The performance metrics used to quantify the effectiveness of a CUAS's assessment ability are as follows.

- **Probability of Assessment (P_A):** P_A is the probability associated with the CUAS's capability to determine whether the alarm was caused by a UAS or some other stimulus such as weather or wildlife. Establishing a P_A value for a CUAS is costly due to the number of tests required.
- **Assessment Point (AP):** AP is the location at which accurate assessment occurs. The AP is characterized by coordinates referenced from the sensor location.
- **Assessment Time (AT):** AT is the time required to make an accurate assessment of the cause of the alarm. The AT is measured from the ST to the time an accurate assessment is made.
- **Assessment Volume (AV):** AV is a 3D plot of the AP coordinates from the test set that creates a volume at which accurate assessment of the cause of the alarm can be expected.
- **NAR/FAR:** There are two other performance metrics that must be considered when evaluating a CUAS: nuisance alarm rates (NAR) and false alarm rates (FAR). A nuisance alarm is an alarm reported by the sensor that was assessed to be caused by some stimulus other than a threat (e.g., birds or inclement weather). The NAR represents the number of nuisance alarms created per day. Unfortunately, the NAR tends to be a sensor characteristic that is overlooked or underestimated by inexperienced designers. A high NAR overwhelms the ability of the alarm monitoring staff to assess the cause of every alarm. Even if the alarm monitoring staff can assess a high rate of incoming nuisance alarms, the recognized tendency is for the staff to begin to assume that all alarms are nuisance alarms, thereby becoming complacent in a relatively short period of time [4]. This complacency can also result in the misclassification of NAR, losing the opportunity to address trends in system issues, especially when they relate to maintenance. In this condition, an actual intrusion has a very low probability of being detected, and thus, the intrusion detection system may no longer be effective.

  A false alarm is an alarm reported by the sensor for which the system was unable to determine a cause. FAR represents the number of false alarms created per day. False alarms are recorded whenever UAS are not being flown. A FAR is then established by dividing the total number of alarms recorded during the collection period by the duration in days of the collection period.

3. EVAULUATION OF PERFORMANCE METRICS

This section describes the methods used to evaluate the key performance metrics (KPMs) that would be collected during CUAS testing and evaluation. Each metric, obtained through testing, plays a large role in the ability of a CUAS to successfully mitigate a threat from a UAS. Figure 4 shows a star chart with the KPM's from above and other KPM's which provide a simple way to compare tested CUAS. The grey represents hypothetical performance requirements for the CUAS under test. The blue and yellow represent average performance values over optimal and degraded conditions respectively. The optimal and degraded conditions are a measure of performance variance and risk being accepted by deploying this hypothetical system.

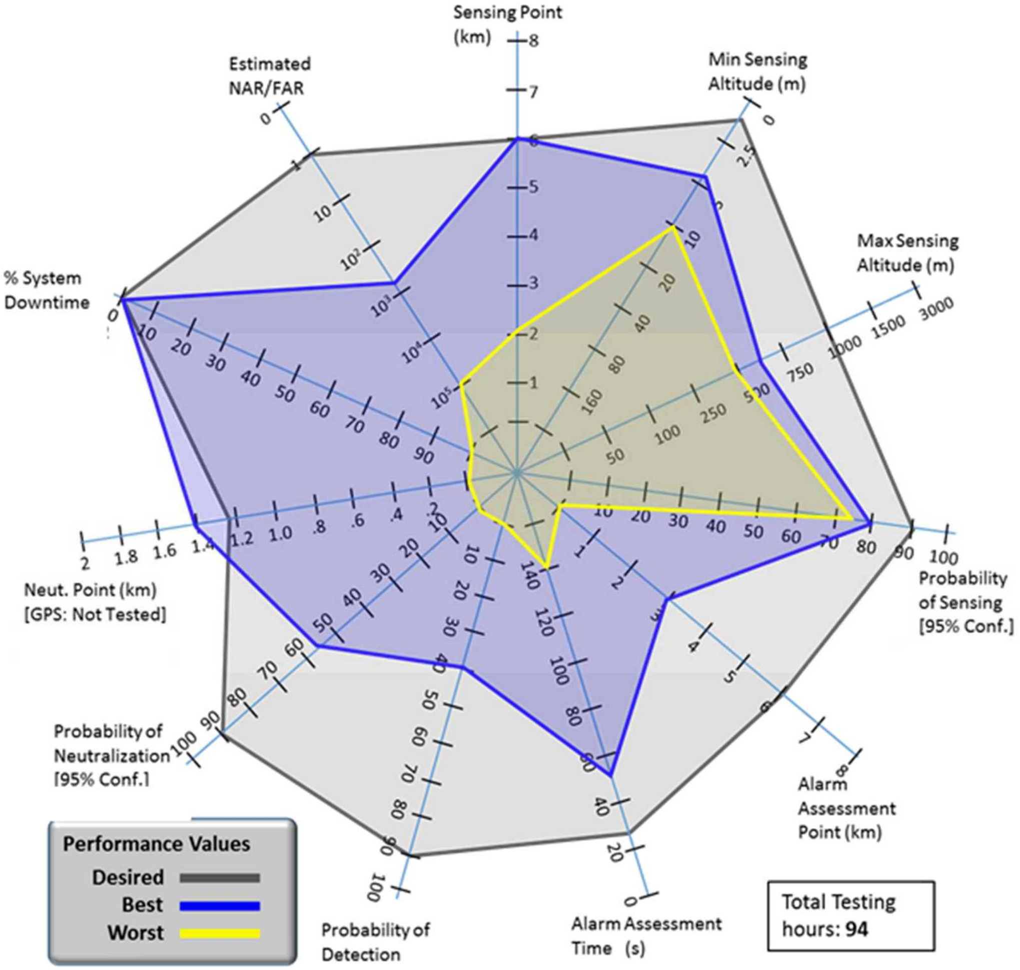

Figure 4. ***KPM Star Chart***

Degradation Factors

Degradation factors are conditions that could exist at a site that would render the performance of the sensor to be less than the P_D, P_A, and P_N to which it was originally tested. These factors can be related to installation (e.g., uneven terrain, presence of structures, RF background sources), the environment (e.g., fog, wind, illumination level, wildlife), or other factors.

As discussed during NAR/FAR testing, the testers should retain notes on installation, maintenance, testing, and environmental factors that affect the performance of the sensor system. These factors represent the beginning of the degradation factor list. Additionally, testers should brainstorm other factors that could affect performance but that have not yet been observed during NAR/FAR testing. If needed, testing of the proposed degradation factors can be performed to determine how significant the factor is or how sensitive a particular CUAS system is to the degradation factor. This testing can be performed during the later stages of NAR/FAR testing or after NAR/FAR testing is completed.

Requirements and Performance Metrics

To verify that the requirements and performance metrics of a CUAS adequately address the UAS threat, which is shown in Figure 1, it is important to repeat the scenario from the point of neutralization backward. In this manner, the interdependencies between the requirements definition and the performance metrics can be more clearly confirmed. For example, assume the CUAS is expected to prevent a Group 2 UAS from delivering explosives to a location where people are present. There are three important elements to consider for this scenario; the maximum speed of a Group 2 UAS (290 mph), the maximum payload of the UAS (55 lbs.), and the standoff distance needed between the explosive and the location where people are present (1850 feet) [7]. .

Working backwards, the standoff distance is the point where the UAS neutralization range (R_N) must occur, as shown in Figure 2. Based on the maximum velocity of a Group 2 UAS and the time it takes to sense, assess, and neutralize the UAS, the point at which the CUAS must sense the Group 2 UAS can be calculated. Once this is determined, the relevant CUAS performance metrics will confirm capabilities to ensure that the CUAS meets the requirements to successfully neutralize the defined UAS threat. .

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