MCMA+CRET: A Mixed Criticality Management Architecture for Maximizing Mission Efficacy and Tool for Expediting Certification of UAVs

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ABSTRACT

In recent times the number and capabilities of Unmanned Air Vehicles (UAVs) – a mission-critical Cyber Physical System (CPS) – has transcended beyond the basic Intelligence, Surveillance and Reconnaissance (ISR) developed in years past e.g. hunter-killer MQ-1 Predator. The challenge is the composite verification and certification of the systems and software for high-confidence survivable UAVs. To this effect, this paper develops MCMA – a Mixed Criticality Management Architecture to model and evaluate UAV behavior under uncertainties. A Crisis Response Evaluation Tool (CRET) based on MMA is being developed using AADL. The tool can allow certification of the UAV behavior under uncertainties. This is achieved by enabling automated evaluation of UAVs' behavior such that the risk of losing the UAVs is minimized (increasing their survivability).

Categories and Subject Descriptors

K.7.3 [**Computing profession**]: Testing, Certification, and Licensing.

General Terms

Management, Performance, Design, Reliability, Human Factors, Standardization, Languages, Theory, Verification.

Keywords

Keywords are your own designated keywords.

1. INTRODUCTION

This paper deals with the complex high-risk mission management of UAVs – an example of mission-critical Cyber-Physical Systems (CPS). Proper certification of UAVs for the complex critical mission management is necessary to develop high-confidence UAVs for risky military missions. This goes beyond the evaluation of traditional waypoint based plan generation in modern UAVs. Mission planning has to take into account the cost (e.g. resource consumption such as fuel and armament), risk (e.g being engaged by the enemy), and the reward (e.g. martial advantage after the success of the operation) associated with different alternative set of actions to be performed during the mission. There exists a *window-of-opportunity* to respond to such critical situations before there is a disaster (i.e. UAV gets lost). Within this event-dependent window-of-opportunity certain mitigative interdependent actions need to be performed to avoid disaster. The efficacy of these actions depends on such diverse parameters such as the availability of resources and the expertise (and mental state) of humans who perform these actions.

Proper evaluation and verification of the UAV actions and behavior in high-risk complex missions is essential for certification of future UAVs. To this effect, Mixed Criticality Management Architecture (MCMA) is presented in this paper to provide modeling and evaluation framework for CPS. It is further applied to the complex mission management using UAVs. MCMA designs the UAVs' actions' *qualifiedness* towards the mission objectives. MCMA uses a state-based stochastic model to describe the behavior of UAVs under uncertainties. Further, using MCMA, a Crisis Response Evaluation Tool (CRET) is developed, which can allow certification of the UAVs through proper evaluation of UAVs' behavior under uncertainties.

2. MIXED CRITICATITY MANAGEMENT ARCHITECTURE (MCMA)

The concept of *Criticality* is used to characterize crises in Cyber-Physical Systems (CPS) [1-3]. The changes in the system's environment which lead the system into a crisis/disaster are called *critical events*. The *resulting effects* of the critical events on the smart-spaces are defined as criticalities. Two verifiable properties of criticality management – *Responsiveness* to criticalities, and *Correctness* of criticality response – are identified and analyzed. A *controllability condition* is established based on the real-time requirements of the criticalities. This condition encompasses the level of responsiveness to give an upper bound on the time taken for detecting and responding to the critical events. *Manageability* metric characterizes how *effectively* the crisis management can respond maximizing inhabitants' safety. This is measured in terms of the *Q-value* or the *Qualifiedness* of the response actions. The Q-value depends on the controllability condition and the uncertainties involved in performing the response actions due to possible human involvement. A *state-based stochastic model* is established in this regard where critical states are considered when the system is under one or more criticalities. Using the stochastic model, MCMA is designed as a generic modeling framework i) to evaluate the effectiveness of the crises management in CPSs; and ii) to select appropriate crises response actions accordingly [2].

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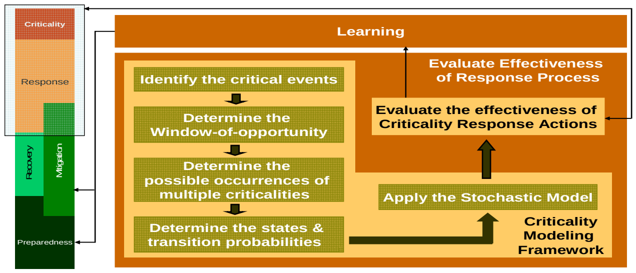

Figure 1: MCMA – a criticality evaluation framework.

3. CRITICALITY RESPONSE EVALUATION TOOL (CRET)

The tool uses description languages such as XML, AADL to specify MCMA. The specification has four basic components:

Criticality Specification: This includes the names, descriptions, identification numbers, and windows-of-opportunity of the possible criticalities in the system. Users can input different values depending on the situation they want to evaluate.

Critical State Specification: Each state is specified by an identification number, the total number of concurrent criticalities, and the identification number of all the concurrent criticalities.

Transition Specification: This specification includes the time taken for the transitions, the probability of the transitions (i.e. the probability of occurrence of the corresponding criticality or the success probability of the corresponding response actions).

Policy Specification: The response action selection criteria at any state are specified as: i) per-state, ii) state-independent, and iii) a combination of these. Per-state specification allows the flexibility to specify different action selection criteria at different states.

Based on these specifications, the tool calculates the manageability of the criticality response processes in terms of the actions' *Q-value* (Section 2).

3.1 CRET to certify UAVs

MCMA can be used to characterize the response during a kill chain e.g. *F2T2EA*: Find Fix Target Track Engage Assess. Each criticality is associated with a time-constraint, called the window-of-opportunity, which determines the delay between the occurrence of the event causing the criticality and the resulting losses of UAVs. Events that cause criticality are called the critical events. An example critical event could be the detection by a UAV that it is being targeted by the enemy. Window-of-opportunity in such a case would be the average estimated time for the UAV to be engaged by the enemy. This could be a function of the type of threat, its mobility, and its distance to the UAV. Under one or more criticalities, the system is said to be in a critical state. From a given critical state, if there are two or more potential actions (e.g. retreat from the mission or continue with the mission) that the UAV can take, the choice of the action depends upon factors such as:

- the risk of losing the UAV in performing the action;
- the reward associated with the action;
- the probability of successfully completing the action;
- the meeting of the temporal requirements;
- the resource cost of completing the action.

At every level, cost is the expenditure of finite resources. Risk is the chance of mission failure e.g. the loss of the UAV before the mission goal is completed. All these factors can be combined to measure the actions' *appropriateness* to the mission objective. For this purpose, the *Q-value* metric can be augmented with the cost-benefit trade-off of the actions. Ideally, any mission planning should maximize the actions' *appropriateness* in any situation.

3.2 Example Usage

Consider a simple scenario. There is one UAV to find-and-destroy a set of enemy targets inside the high risk enemy territory. For this purpose the UAV has to enter the enemy territory with the risk of being involved in the kill-chain by the enemy missiles. We assume there are only two enemy Surface-to-Air Missile (SAM) launching stations. We map the phases of the kill chain from one SAM and one UAV as the possible critical states. Fig. 2 shows the critical states. There are two branches in the state transition to represent threats due to two SAMs. With increase in SAMs and/or UAVs the state transition branches can be dynamically added.

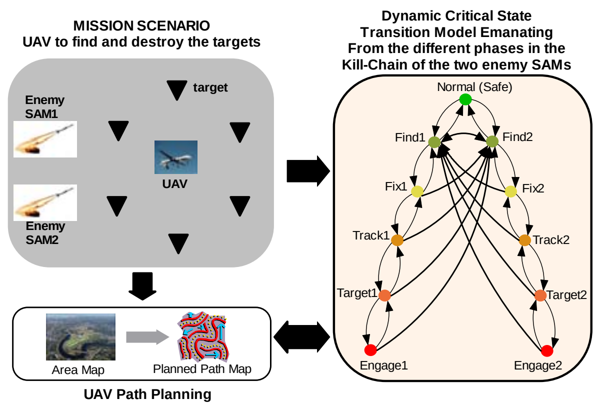

Figure 2: Criticality-Aware UAV Mission Planning

The window-of-opportunity to respond to the first criticality (i.e. when in "Find" state of any branch) depends on the average time to get destroyed in the kill-chain after getting fixed by the enemy. Avoiding the "Engage" state (in any branch) is analogous to getting the UAV out of the kill-chain. When in "Engage" state, the window-of-opportunity depends on the maximum speed of the UAV and the missile launched by an enemy SAM.

4. CONCLUSIONS

MCMA is proposed as a modeling and evaluation framework for critical event management in CPS. It is further applied to complex mission management using UAVs. For this purpose, CRET is developed as a certification tool to evaluate the confidence of the mission-critical UAVs. Both MCMA and CRET enable modeling and specification of UAV behavior, respectively, such that the probability of meeting goals with minimal cost is maximized.

5. REFERENCES

[1] T. Mukherjee, S. K. S. Gupta. A Modeling Framework for Evaluating Effectiveness of Smart-Infrastructure Crisis Management Systems. IEEE HST 2008.

[2] T. Mukherjee, K. Venkatasubramanian, S. K. S. Gupta, Performance Modeling of Critical Event Management for Ubiquitous Computing Applications. ACM MSWiM, 2006.

[3] S. K. S. Gupta, T. Mukherjee, K. Venkatasubramanian, Criticality Aware Access Control Model for Pervasive Applications. IEEE PERCOM, 2006.