U-Test: Evolving, Modelling and Testing Realistic Uncertain Behaviours of Cyber-Physical Systems

Shaukat Ali
Simula Research Laboratory
P.O. Box 134, 1325, Lysaker, Norway
shaukat@simula.no

Tao Yue
Simula Research Laboratory and University of Oslo
P.O. Box 134, 1325, Lysaker, Norway
tao@simula.no

I. Problem Defintion and Its Importance

Uncertainty is intrinsic in Cyber-Physical Systems (CPSs) due to novel interactions of embedded systems, networking equipment, cloud infrastructures and humans. Our daily life has been increasing dependent on CPS applications in safety/mission critical domains such as healthcare, aerospace, oil/gas and maritime [1-3]. For example, the National Institute of Standards and Technology (NIST) reported that direct CPS applications account for more than $32.3 trillions and expect to grow $82 trillions by 2025 [4]. Expecting enormous dependence of our lives on CPSs in the future, dealing with uncertainty is critical to avoid posing unwarranted threats to their end users and environment. To ensure correct functioning of CPSs despite the presence of uncertainty, CPSs must be dependable, i.e., reliable, robust, trustworthy, safe, and efficient. One way to improve the dependability of CPSs is via cost-effective automated verification/validation techniques and one such systematic and automated technique is Model-Based Testing (MBT): automated derivation of test cases from a behavioral model of a system [5, 6]. MBT supports rigorous, systematic, and automated testing, which eventually reduces the number of faults in the delivered systems and thus improves their quality.

The goal of the U-Test project (a recently funded project under the EU Horizon2020 program (http://ec.europa.eu/programmes/horizon2020/) is to improve the *dependability* of CPSs, via *cost-effective*, *model-based* and *search-based* testing of CPSs under *unknown risky uncertainty*. *Unknown uncertainty* is the state of a CPS that can only be determined at the runtime as opposed to *known uncertainty* that is known at the design time and outcome from risky uncertainty is undesirable. To achieve our goal, we will advance the current state-of-art of testing CPSs by developing a novel solution based on sound theoretical foundation for uncertainty testing in the following steps: 1) Developing a *light-weight* modelling solution with *rich formalism* to support *minimal* modelling of known uncertainty with risk information; 2) Intelligently *evolving* known uncertainty models towards *realistic and risky* unknown uncertainty models (evolved models) using search algorithms (e.g., genetic algorithms mimicking natural selection); and 3) Automatically generating test cases from the evolved models to test a CPS under unknown uncertainty to ensure that the CPS continues to operate properly and possibly at a reduced quality of operation, rather than failing completely.

II. Potential Solution

A. CPS and Uncertainty Definitions

We define CPS (Fig. 1) as a set of heterogeneous physical units (e.g., sensors, control modules, actuators) communicating via heterogeneous networks (via various networking equipment) and interacting with applications deployed on cloud infrastructures and/or humans to achieve a common goal.

Uncertainty is a state of a CPS that is unpredictable, a future outcome from the state may not be determined, or there is a possibility of more than one outcome from the state (non-determinism). *Risk* is an uncertainty state from where the outcome has undesired effect, which may result in unfortunate and negative impact on various concerns such as safety. An *Uncertain Behaviour* is the behaviour of a CPS resulting from an uncertainty state that can potentially lead to an undesired effect. *Known Uncertain Behaviour* is fully or partially *known* at the design time of a CPS, such as 1) *Faulty* behaviour (a result of known potential faults at the design time resulting in faulty states (uncertain states) in the CPS) and 2) *Sporadic* behaviour (nominal behaviour of the CPS with low occurrence frequency and having no occurrence pattern to introduce uncertainty). *Unknown Uncertain Behaviour* is not known at the design time, such as 1) *Emergent* behaviour that is unpredicted and only known at runtime and 2) *Runtime* faulty behaviour due to an unknown failure at runtime.

Uncertain behaviour can occur at three levels (Fig. 1): 1) Due to the stimulus (events including data) coming from the user space, e.g., humans interacting with a physical unit (*Application Level Uncertainties*); 2) Due to interactions and dependencies among physical units such as sensors, actuators, and networks or cloud services deployed on the cloud infrastructure (*Infrastructure Level Uncertainties*); and

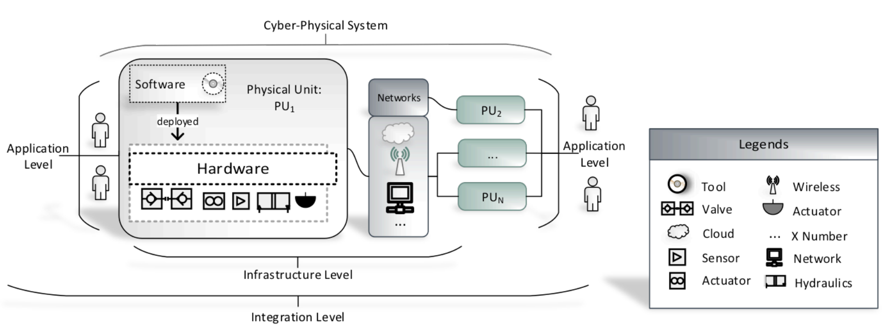

Fig. 1 Illustration of Cyber-Physical Systems

3) Due to interactions between applications and the infrastructure (*Integration Level Uncertainties*).

B. *Proposed Solution and Initial Results*

Our proposed solution (Fig. 2) will be implemented in five steps combining MBT and search-based testing techniques: 1) Devising a uncertainty taxonomy for CPSs; 2) Developing a *Uncertainty Modeling Framework* to support minimal modelling of known uncertainties of a CPS based on existing modelling solutions such as UML and its relevant extensions (e.g., MARTE [7] and SysML [8]); 3) Devising a novel approach (e.g., based on search algorithms) to evolve known uncertainty models towards realistic and risky unknown uncertainty models; 4) Devising a cost-effective *Uncertainty Testing Framework* to generate test cases from known and evolved models; and 5) Devising a systematic way to analyse results of executing generated test cases aiming to further enrich the evolved models for test case generation, along with additional information on the realism and level of risk.

Initially, as part of one of our existing projects on model-based robustness testing of Cisco's Videoconferencing Systems (VCSs), we have developed a search-based approach to automatically generate test data from the constraints specified in the Object Constraints Language [9]. Such data is aimed at simulating faults into the environment of VCSs to test their robustness against uncertainty caused by faults in their environment.

III. Open Research Questions

Table 1 shows various identified issues and potential solutions that we aim to address based on three industrial case studies: ULMA Handling systems (http://www.ulmahandling.com/en/) from the Logistics domain, Geosports of Future Position X (http://fpx.se/geo-sports/) from the Healtchare domain, and VCSs of Cisco Systems (http://www.cisco.com) from the Communciation domain.

Table 1 Open Issues and Potential Solutions

Issue	Potential Solution(s)
Lack of Testing Techniques for Uncertainty Specific to Particular Domains	Domain Independent, Configurable, and Extensible
Lack of Systematic Approaches for Modelling and Testing Uncertainty	Guidelines, methodologies, standards, optimization
Lack of Standardized Classification of Uncertainty	Uncertainty taxonomy at the application, infrastructure, and integration levels from literature and industry
Lack of Standardized Uncertainty Modelling Solutions	Using, extending, and contributing to the standards
Lack of Holistic Modelling Methods for Uncertainty	Modelling and testing at the three levels
Lack of Unified Tool Support for Testing Uncertainty	A complete tool support for testing uncertainty at the three levels
Lack of Advanced Techniques to Test CPSs under Unknown Uncertainty	Search algorithms

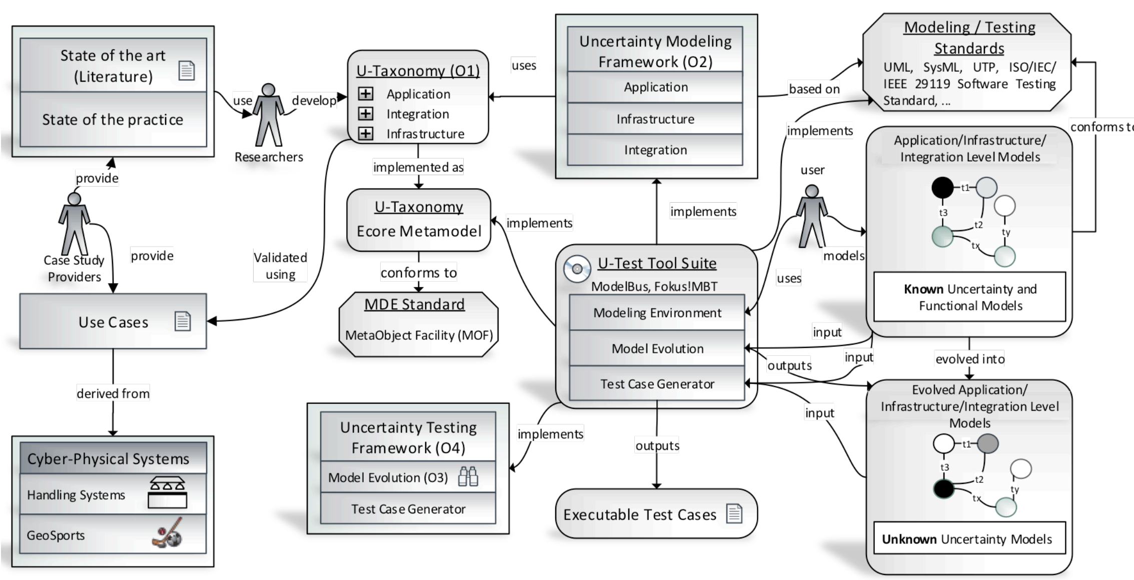

Fig. 2 U-Test Solution

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