Verifiable Autonomy Architecture

Written proposals are limited to 2 pages of technical content and up to 3 pages of appendix material that includes labor rates and hours, a current CV, and a summary of related projects. Selection of approximately 18 - 20 proposals will be based upon participant experience, proposed approach, and time available.

Research Objectives

1. **Examine correctness of service implementations and tie to assume/guarantee framework**
2. **Analysis of systems consisting of mixed continuous and discrete dynamics (hybrid systems) by using reachability, falsification, or other verification approaches**
3. **Construct a probabilistic model of subsystems and perform analysis using probabilistic model checking to determine robustness of components**
4. **Analyze system framework for security vulnerabilities**

Project Description

Introduction

We propose to explore falsification techniques for the analysis of hybrid systems. Using our previous work and developed tools, we propose to address both safety and security analysis of software controlled hybrid dynamical systems. We expect the research to yield techniques which can be used to analyze relevant subsystems of UxAS and other generic cyber-physical systems.

Reachability analysis of hybrid systems is a undecidable for all but the simplest kind [1]. Existing analysis can be parititoned into verification [2, 3, 4, 5, 6] or falsification techniques [7, 8, 9]. The verification procedures use over-approximations to verify a given property whereas current falsification techniques are comparable to testing methodologies and search for a concrete violations of the property.

Furthermore, testing methodologies for software controlled plants are lacking. Current indsutry practices perform separate tests on the software and the plant. Although useful, these strategies do not address the combined functional behavior. We proposed a symbolic-numeric falsification approach in [10], augmenting the more rigorous, but less scalable verification approaches [11].

Specefically, we are interested in designing automatic falsification methods which can analyze black box models of physical sub-systems (dynamical systems) against controller code.

To improve the scalability (and time-horizon) of the approach, we propose to use PWA moodels. PWA models can be automatically computed Piece-Wise Affine (PWA) models for the plant, which can be composed with control code and model checked using mature model checkers [12]. The accuracy of the PWA models can be controlled by several parameters including the discretization step Δ_t, quantization function Q and number of samples.

Background And Challenges

We are primarily interested analysing hybrid systems which result due to the pairing of software controllers with continuous dynamical systems. For analysis, we use the model of sampled data control systems.

The challeneges are as follows **Safety**

- Is there a behavior of the system which violates a given safety specification.
- Discovered violations must be reproducible. This entails a combined analysis of the software and physical model, as separate analysis will result in false positives.
- Ability to explore software artifacts which can lead to functional ‘bugs’.
- Symbolic approach is white box in nature and rigorous, whereas the numerical approach for hybrid dynamical sysems is scalable.

Proposed Research

We propose to address the safety and security analysis for control system implementations. We now describe our model and assumptions.

Sampled Data Control System (SDCS) consists of two components, as illustrated in Figure 1. (a) A discrete time plant model P , and (b) a controller implementation C described by a program whose semantics are formally defined. Finally, the closed-loop parallel composition assumes that the continuous plant has been discretized with the controller's sampling period Δ_t.

The SDCS model allows for modeling of measurement noise at the controller and plant disturbances using exogenous input ω_c and ω_p. Additionally, the attack model is described as an additive input $\mathbf{a}$ to the plant's output $\mathbf{y}$.

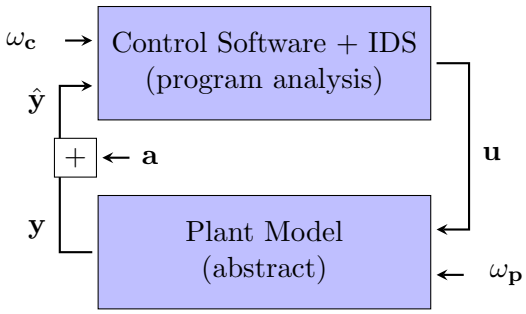

Figure 1: Closed loop symbolic execution.

Discrete time abstractions

Safety Analysis of Sampled Data Control Systems
We have explored the symbolic-numeric analysis approach towards falsification of safety properties in [].

Falsifications and reachability of software controlled physical sytems.

- Needs accurate models - Black box falsification can work - Reachability

We are exploring relational PWA models of plants, specifiaclly built for the purpose of reachability analysis. Relational abstractions [13] and our previous research [14]

These models can either be model checked directly using off-the-shelf SMT solvers or combined with software controllers and model checked. [15].

Furthermore, we would like to explore models based on machine learning due to the recent progress [16, 17, 18] and [19].

Security Analysis of Sampled Data Control Systems [[falsification for security]]

We also propose to extend the falsification framework to find attack signals. We focus on the most general model where the sensor can be compromised. The model also includes an intrusion detection system, which further constraints on the attack signal, thereby focusing the search for non-trivial attacks. Using the same framework for search for exogenous disturbance, we propose to find attack signals.

Prior Work

In our prior research, we have explored the problem of falsification in hybrid systems from both the perspective of white box and black box testing. In [20], we explored the use of multiple shooting for re-formulating the reachability decision problem into the feasibility problem and solved using

off-the-shelf optimization engines. We then extended this approach to black box testing [21] by combining multiple shooting with a counter-example guided abstraction refinement (CEGAR) procedure. Finally, we combined symbolic analysis of programs with the analysis of hybrid dynamical system and proposed a falsification approach for sampled data control systems in [10]. All the above approaches were prototyped as tools and benchmarked on several case studies.

[[security]]

References Cited

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[10] A. Zutshi, S. Sankaranarayanan, J. V. Deshmukh, and X. Jin, "Symbolic-numeric reachability analysis of closed-loop control software," in *Proceedings of the 19th International Conference on Hybrid Systems: Computation and Control*. ACM, 2016, pp. 135–144.

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CV

(updated: 9th March, 2017)

EDUCATION

University of Colorado, Boulder *May 2011 - July 2016*
Ph.D in Electrical and Electronics Engineering
Dissertation: Reachability Analysis of Cyber-Physical Systems using Symbolic-Numeric Techniques.
Adviser: Prof. Sriram Sankaranarayanan (Dept. of Computer Science)

University of Colorado, Boulder *Aug 2009 - May 2011*
M.S. in Electrical and Electronics Engineering
GPA: 3.80/4

Manipal University, Manipal, India *Aug 2003 - May 2007*
Bachelor of Engineering in Electronics & Communications
GPA: 8.43/10

PUBLICATIONS

Symbolic-Numeric reachability analysis of closed-loop control software. [Best Student Paper Award]
Aditya Zutshi, Sriram Sankaranarayanan, Jyotirmoy V. Deshmukh and Xiaoqing Jin
In Proceedings of the 19th International Conference on Hybrid Systems: Computation and Control (HSCC) (pp. 135-144). ACM, 2016.

Multiple shooting, CEGAR-based falsification for hybrid systems. [Best Paper Award]
Aditya Zutshi, Sriram Sankaranarayanan, Jyotirmoy V. Deshmukh, and James Kapinski.
In Proceedings of the 14th International Conference on Embedded Software (EMSOFT), p. 5. ACM, 2014.

A trajectory splicing approach to concretizing counterexamples for hybrid systems.
Aditya Zutshi, Sriram Sankaranarayanan, Jyotirmoy V. Deshmukh, and James Kapinski.
In 52nd IEEE Conference on Decision and Control (CDC), pp. 3918-3925. IEEE, 2013.

Timed relational abstractions for sampled data control systems.
Aditya Zutshi, Sriram Sankaranarayanan, and Ashish Tiwari
In Computer Aided Verification (CAV) (pp. 343-361). Springer Berlin Heidelberg

AWARDS & HONORS

Selected for French-American Doctoral Exchange (FADEx 2016: Cyber-physical Systems)
Best Paper Awards (EMSOFT 2014, HSCC 2016)
Manipal Inst. of Tech Scholarship (2003-04, 2004-05)

PROJECTS

Current

· **PWA-Modeling for Falsification:** We are working on improving the search for unsafe behaviors in black box dynamical systems by using symbolic methods. Using regression on numerical simulations, we build Piece-Wise Affine models. SMT solvers and linear programming is used to model check the PWA models. The generated counterexamples guide the falsification of safety properties.

Completed

· **S3CAM-X:** A tool to find unsafe behaviors in closed loop control software. We augmented S3CAM with symbolic software analysis to automatically generate test cases and find unsafe behaviors in grey-box closed loop control software (white-box control software + black-box hybrid dynamical systems). The usefulness of the approach was demonstrated by finding 'bugs' in several benchmarks.

· **S3CAM:** A tool to find violations of safety properties in black box descriptions of continuous hybrid dynamical systems. We proposed trajectory splicing to automatically search for error trajectories using only numerical simulations. A combination of multiple shooting and Counter-Example Guided Abstraction Refinement (CEGAR) was used.

· **Falsification using Trajectory Optimization:** We developed automatic falsification techniques based on multiple shooting and trajectory optimization. The aim was to find violations of safety properties in hybrid automata. The prototype used off-the-shelf optimization engines.

· **Timed Relational Abstractions:** We devised timed relational abstractions for sampled-data control systems: a combination of continuous hybrid dynamical systems and discrete controllers. We used interval arithmetic to compute verified (bounded matrix exponential) solutions to linear differential equations in conjunction with SMT solvers to model check their properties.

The implementations of the above projects can be found at: `https://github.com/zutshi`

TALKS

Reachability Analysis of Cyber-Physical Systems, French-American Doctoral Exchange Seminar (FADEx), July 2016

Symbolic-Numeric Reachability Analysis of Closed-Loop Control Software, April 2016.

- Robert Bosch GmbH, Renningen, Stuttgart, Germany
- Centre d'intgration (CEA), Palaiseau, France
- HSCC 2016, Vienna, Austria

Beyond single shooting: Iterative approaches to falsification, ACC 2015, Chicago, USA, July 2015.

Multiple Shooting, CEGAR-based Falsification for Hybrid Systems, EMSOFT 2014, New Delhi, India, Oct. 2014.

Falsification of safety properties for Hybrid Systems using trajectory splicing, Charles University, Prague, Czech Republic, Dec. 2013.

A Trajectory Splicing Approach to Concretizing Counterexamples for Hybrid Systems, CDC 2013, Florence, Italy, Dec. 2013.

Timed Relational Abstractions For Sampled Data Control Systems, MVD 2012, The University of Kansas, Lawrence, Kansas, USA, Sept. 2012

RESEARCH EXPIRIENCE

Duke University ***(Postdoctoral Researcher)*** Feburary 2017 - Present
Adviser: Prof.Miroslav Pajic *Durham, NC*
Security of cyber physical systems.

Toyota Technical Center ***(Internship)*** August 2014 - December 2014
Mentors: Dr.Jyotirmoy Deshmukh and Dr.James Kapinski *Gardena, CA*
Work published in HSCC 2016.

Toyota Technical Center ***(Internship)*** January 2013 - April 2013
Mentors: Dr.Jyotirmoy Deshmukh and Dr.James Kapinski *Gardena, CA*
Work published in CDC 2013 and EMSOFT 2014.

INRIA ***(Internship)*** July 2012 - August 2012
Mentor: Dr.Bertrand Jeannet *Grenoble, Rhone-Alpes, France*
Worked on abstract acceleration of loops describing discrete dynamical systems.
Used linear algebra techniques to soundly summarize loops.

SRI International ***(Internship)*** May 2011 - August 2011
Mentor: Dr.Ashish Tiwari *Menlo Park, CA*
Work published in CAV 2012.

PROFESSIONAL DEVELOPER EXPERIENCE

Toshiba August 2007 - July 2009
Associate Software Engineer *Bangalore, Karnataka, India*

· *Toshiba Media Framework* (based on OpenMax IL): Worked on implementation and test suite design. Developed GTK+ based GUI to demo the framework usage.
· *Full Segment ISDB-T(Integrated Services Digital Broadcasting - Terrestrial)*: Worked on design and implementation of OpenMAX IL components.

Roles Undertaken: designing, prototyping, implementing, testing, debugging and documenting.

TECHNICAL SKILLS

Computer Languages	Python, C, C++, OCaml (basic), Verilog (basic)
Technical Tools	MATLAB, Simulink, VIS, SAL/HSAL, SpaceEx, Apron, PPL, PySMT, Z3, Yices, KLEE, Pathcrawler, S-TaLiRo, GLPK
Tools	Git, Subversion, LaTeX

d. Labor rate(s) and hours for proposed participants. $91,500 hotel: 150/day, apts: 1k/mo max car: 600/mo, may-aug: 2631

Budget Justification

A. Senior Personnel

A1. Includes PI at 10% CY.

E. Travel

1) NC - OH
2) S5 Conference