Caltech/Colorado SEC Quarterly Status Report

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SEC Quarterly Status Report

Outline

10:00   Introductions, [Overview of SEC program]
10:30   Review of action items from last time
11:00   Current status of tasks
    ▪   II-1. Optimization-based control for single/multiple vehicle systems
    ▪   II-2. Software environments for embedded control systems design
    ▪   II-3. Experimental implementation and demonstration using OCP
12:30   Lunch
1:30    Planning
    ▪   OCP implementation on testbed
    ▪   MICA program coordination
2:45    Action item review
3:00    Adjourn
Project Schedule

Task 1
- Theory for Multi-vehicle MPC
- Algorithms for multi-vehicle MPC

Task 2
- Initial domain descriptions for sample problems
- Multi-vehicle, dynamic distributed specifications
- Stability and other issues, driven by implementation
- Integration of MPC with LPE (single veh, no traps)
- Vehicle management layer, with executable specs
- Prototype environment for design methodology

Task 3
- MPC demonstration on ducted fan
- MPC demonstration on multi-vehicle

- OCP implementation of MPC on Caltech ducted fan
- Single vehicle, MPC control, generated by LPE
- Multi-vehicle rejoin demonstration (adversarial environment)
February Action Item Status

Action items from last time:

1. Post ducted fan library (with documentation) on web page [Franz, 4/1/01]
2. Decide what to write for SEC book (e-mail conversation; RMM to kickoff) [RMM, 2/28/01]
3. Get copies of completed/pending papers from Jadbabaie [Jadbabaie, 2/23/01]
4. Get copy of October SEC presentation from John Hauser [JEH, 2/24/01]
5. Identify concrete project for Troy that will revolutionize the world of multi-vehicle controls (or, if not possible, go in his thesis) [RMM, 3/1/01]
6. Plan trip for Ryan to Caltech to work with Bill, Mark: get NTG, dfan libraries, working together [JEH to coordinate with Ryan; 2/26/01]
7. Check with NGC at next PI meeting [RMM, 6/15/01]
8. Send e-mail to Paunicka to get access to Boeing site for Bill and Jason [JYH, 3/15/01]
9. Send e-mail to Betty Sue and track status of UColo dSPACE purchase [RMM, 2/24/01]

Status (10/11/01): (open)

1. Library posted at Colorado. Ryan to send URL to RMM [4/27/01]
2. Done
3. Done
4. Done
5. Dropped
6. Done
7. Done
8. Done
9. Done
April Action Item Status

Action items from last time:
1. Purchase dSPACE plugboard for ACE Kit to allow testing of Colorado controllers [Henrik, 5/4/01]
2. Post dfan library + documentation on SEC web page [Ryan, 4/27/01]
3. Get access to OCP web site and download current library + documentation before PI meeting [Hauser, 5/4/01]
4. Publicly domainable version of NTG + docs: meet to decide on who is going to write what [Murray, 5/31/01]
5. Get access to alpha machine for Mark [RMM, 4/27/01]
6. Make new quad chart for updated project [Murray, 5/7/01]
7. Set up “talks/” subdirectory in SEC web for use by project team [Murray, 5/4/01]
8. Movie and data of hover to hover NTG operations [Franz, 4/27/01]
9. Movie and data for simple trajectory following [Dunbar, 5/6/01]
10. Slides on MPC theory (status + future => 3 slides) [Jadbabaie, 5/6/01]

Status (10/11/01):
1. Done
2. RMM to post on Caltech web page
3. Done
4. Original meeting cancelled. Need to reschedule. When??
5. Not needed anymore.
6. Done.
7. Done. On “internal/”
8. Done
9. Done
10. Done
Task II-1. Optimization-based control
Subtask: (a) Theory
Team: Hauser (lead), Dunbar, Franz, Flores

OBC Theory

Status
- SCL paper under revision (on terminal cost)
- Ali Jadbabaie has taken postdoc position at Yale; no progress on trajectory following
- IFAC 02 (JEH): Projection operator approach to trajectory optimization
- Implementation of receding horizon control on ducted fan (dmfm01:ifac)
- ACC02: receding horizon w/ finite computational time – ideas + implementation

Open Questions
- Finding better CLFs: formation stabilization, constraints, tracking, robustness, …
- Robustness analysis/synthesis
  - One way to approach active state models
  - Also important for multi-vehicle, approximate approach (“rest of the world” models)
- Computation/delay effects – combining continuous and discrete.
  - Useful for computation costs but also possibly for (network) communication delays
  - Tie to “anytime algorithms”: doesn’t seem to be a good match with these problems
  - Idea: pipelined MPC – run multiple, overlapping MPC runs

Next steps
- Melvin: literature survey in robust MPC (incl. “model on demand”, multi-model [Morse])
- Bill: (1) alternative MPC using contractive constraints + variable horizon
- Ryan: continue work on computation/delay effects; first stabilization then extend to tracking. Also trajectory generation and tracking more generally
- John: work on trajectory tracking MPC
Multi-Vehicle MPC

Status

- Multi-vehicle theory (WBD): extension of stability proof to stability to sets
- New simulation results on multi-vehicle with more realistic dynamics (testbed)
- ROS: distance functions on graphs for structural stabilization, tracking, etc
- New SEC postdoc: Eric Klavins (from U. Mich, CS)
- New MICA student (human centered control): Dave van Gogh
- New MICA postdoc (cooperative control): Feng-Li Lian (starts 11/1)

Open Questions

- Problem formulation: given a task, what is the optimization problem, how do we distribute cost between vehicles, what are the fundamental limits, etc
- Changing from one formation to another
  - Base on domain of attraction analysis?
  - Look for topological limitations? (reachability analysis)
  - Use intermediate formations?
- Tie in to networked control systems and information flow (MURI, AFOSR)

Next steps

- Bill/Eric: language for representing controllers (MPC as primitive, eventually); hope to reason about it using formal methods
- Reza: join/rejoin maneuvers

Task II-1. Optimization-based control
Subtask: (a) Formation transition control
Team: Dunbar (lead), Olfati-Saber, Klavins, (van Gogh), Hauser, Murray
NTG Development

Status

• Main NTG development is done; being used extensively on project
• State flow implementation of NTG: handles multiple processors, multiple NTGs, timing decisions, etc
• Rick Hindman has taken position at Raytheon (Tucson)

Open Questions

• Error bounds based on discretization, order of fit, … (order of convergence results, etc)

Next steps (SEC)

• Documentation of NTG for use by others and archival documentation
  ▫ Part from Mark’s thesis (architecture, algorithms, etc)
  ▫ Set up meeting at Caltech to coordinate remaining documentation
• Mark: release next NTG version using finer grid for quadrature evaluation
• Nicolas Petit to continue NTG development from France
• Melvin: start looking at OCP implementation on multi-vehicle platform
• Ryan: continue focus on ducted fan, NTG, MPC, state-flow, …
• Post a retrievable version of NTG on SEC web page (OK to keep off of main site)
Formal Synthesis

Status
- Continuing LPE reading group to build shared understanding of controls, computer science
- New postdoc: Eric Klavins (U. Mich)
- General compilation platform for robust development in a formal environment
  - Transformation to FIR (functional intermediate representation)
  - In principle, can express logics and specifications for control problems and algorithms
  - Missing: specific languages for control

Open Questions
- Verification in presence of physics
- Specification and implementation languages for control problems
- Real-time implementations
- Automation: effective correct by construction techniques

Next Steps
- MetaPRL: need to improve reasoning to higher levels needed for control
- Extension to distributed computing environment (Cristian)
- Need to define a control language
  - Concepts, syntax, logic
  - Use prototype manoeuvres (join/rejoin, RoboFlag drill, etc)
- Proof of concept on multi-vehicle simulator and (eventually) physical testbed
Ducted Fan Implementation

Status

- dSPACE implementation up and running
  - Real-time trajectory generation on dSPACE alpha processors
  - State flow for implementation of decision logic
- Continued work on system identification (high speed, etc)
- Multiple papers submitted to IFAC02, ACC02 with experimental results

Next steps

- Continue to verify theoretical assertions
- Test out different terminal costs (CLFs), optimization formulations, weights, etc

Task II-2. Experimental Implementation

Subtask: (a) Implementation of RHC on ducted fan hardware
Team: Franz (lead), Milam, Dunbar, Hauser, Murray
Status

- Ryan Franz attended OCP API meeting; recommended focusing OCP on multi-vehicle platform instead of ducted fan
  - Concerned about effects of CORBA in our scenario (JH, EK)
- RMM visited Stanford (Tomlin) to discuss PC-104 implementation
- DURIP project status: closed loop control working, 2-3 vehicles built
- No progress on OCP implementation (but we now all know what the initials stand for)
- New student: Melvin Flores, to work on OCP implementation

Next steps

- Melvin: implement and test OCP on windows machine, then multi-vehicle computer (linux)
- Melvin, Lars, Bill: implement current single-vehicle controller on top of OCP
Publications and Submissions
(see web page for titles, etc)

Appeared in last six months
• Conference: ACC -- JPH01, JH01, HO01; NOLCOS -- PMM01 (inversion based control)
• IEEE TAC [Jadbabaie, Yu, Hauser]

Accepted for publication
• Journals: Automatica [Yu, Jadbabaie, Primbs, Huang]
• CDC 2001: Jadbabaie/Hauser (general terminal cost)

Submitted for publication
• Jadbabaie/Hauser (SCL) – general terminal cost [in revision]
• IFAC02: 4 publications based on SEC work
  • Projection Operator Approach to Optimization of Trajectory Functionals. Hauser
  • Distributed Cooperative Control of Multiple Vehicle Formations Using Structural Potential Functions. Olfati-Saber and Murray
  • Real-Time Constrained Trajectory Generation Applied to a Flight Control Experiment. Milam, Franz, Murray
  • Model Predictive Control of a Thrust-Vectored Flight Control Experiment, Dunbar, Milam, Franz and Murray
• ACC02: Applied Receding Horizon Control of the Caltech Ducted Fan, Franz, Milam and Hauser
• ICRA02: Automatic synthesis of controllers for distributed assembly and formation forming, Klavins
• IJRNC: aggressive maneuver of a thrust vector flying wing: RHC approach, Jadbabaie, Hauser

Planned submissions
• Journals: real-time trajectory generation + RHC on ducted fan (Milam et al)
• SEC book chapter
SEC PI Meeting Presentation: Outline

1. Overview of the project [5 min, Title/outline + 2 charts]
   • Coordination (distinction) of SEC, MURI, AFOSR, MICA projects
2. Progress since last meeting [15 min, 4 charts + 1 movie]
   • New receding horizon + TG results (and good movies)
     • Timing models/results
   • Improved multi-vehicle simulations
   • Split/rejoin, tracking ideas (Reza)
3. High Confidence SEC [10 min, 5 charts: JASON HICKEY]
4. Summary and conclusions [5 min, 1-2 charts]
New Action Items (October 2001)

1. Post dfan library + documentation on SEC web page [RMM; ASAP]
2. Meeting to discuss NTG documentation and dissemination [RMM; Nov/Dec 01]
3. Melvin to grab OCP and test on some platform [Flores; Nov 01]
4. Implement MVWT controller on top of OCP [Cremean, Flores; Jan 02]
5. Post public domain version of NTG on SEC web page [Milam, Murray; Dec 01]