A DRC post mortem by Teams ViGIR and HECTOR

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Christopher Newport University, Newport News, United States
Personal Intro

- Stefan Kohlbrecher
  - PostDoc at TU Darmstadt, SIM group (Prof. Oskar von Stryk)
  - Team Lead Team Hector (2011-)
  - Onboard S/W Lead DRC Team ViGIR (2012-2015)
  - Onboard S/W Lead Team ARGONAUTS (2014-)

- Research Interests
  - (Supervised) Autonomy for USAR systems
  - SLAM
  - Manipulation

- kohlbrecher@sim.tu-darmstadt.de
Outline

- Intro
  - The DRC
  - Teams
- (ROS based) Infrastructure
- VRC
- System Overview
- DRC Finals
- Lessons Learned
...close study of the disaster's first 24 hours, before the cascade of failures carried reactor 1 beyond any hope of salvation, reveals clear inflection points where minor differences would have prevented events from spiraling out of control.

*IEEE Spectrum*, November 2011 pg. 36. ([online version](#))
DRC - Tasks and Rules

IEEE Spectrum
The “C” in DRC

- Uneven terrain, stairs and ladders
- Motions with multiple contacts (e.g. getting out of a vehicle)

Versatile and robust (Loco-)Motion
The “C” in DRC

Versatile and robust Perception

- Perceive Environment for locomotion
- Perceive objects for manipulation
- Ability to acquire new objects and their potential purposes on the fly
- Robustness to different lightning conditions

Versatile and robust (Loco-)Motion
The “C” in DRC

- Versatile and robust Perception
- Versatile and robust (Loco-)Motion
- Versatile and robust Manipulation

- Many different tools, only few exactly known in advance
- Acquiring new manipulation modes
- Ability to coordinate manipulation, locomotion & active perception
The “C” in DRC

Versatile and robust
Perception

Versatile and robust
Manipulation

Versatile and robust
(Loco-)Motion

Efficient interaction with
Human Supervisor

Limited
Wireless Communication
bandwidth, delays, losses
DRC - The Meta-Challenges

- Highly compressed timeline
- Multiple competition events
  - VRC (June 2013)
  - Trials (Dec 2013)
  - Finals (June 2015)
- Systems integration
- High reliability
  - Only few attempts at tasks
Team ViGIR

International collaboration, Track B Atlas team. Vi\text{r}ginia \text{G}ermany Interdisciplinary \text{R}obotics

- TORC Robotics (Blacksburg, VA)
- TU Darmstadt (Darmstadt, Germany)
- Virginia Tech (Blacksburg, VA)
- Cornell University (Ithaca, NY)
- Leibnitz Universität Hannover (Hannover, Germany)
- Oregon State University (Corvallis, OR)
Team ViGIR

- Track B team, DRC participation from day one
  - Virtual Robotics Challenge (VRC)
  - DRC Trials
  - DRC Finals

- Software available: [github.com/team-vigir](https://github.com/team-vigir)
  - Exceptions:
    - Robot controller
    - Comms bridge

- Other teams using ViGIR software at DRC Finals
  - HECTOR (SIM, TU Darmstadt)
  - VALOR (TREC, Virginia Tech)
Team Hector Darmstadt

- **Heterogeneous Coacting Team of Robots**
- Focus on autonomous systems for monitoring/exploration in disaster scenarios
  - Example/validation scenario RoboCup Rescue
- Robots
  - Unmanned ground vehicles (UGVs)
  - Unmanned aerial vehicles (UAVs)
  - Humanoids
- Successful participation in international competitions
- Major parts of developed software available to the research community

http://www.sim.informatik.tu-darmstadt.de/teamhector/
https://www.facebook.com/TeamHectorDarmstadt/
Team Hector DRC

- Late Entry (January 2015)
- Leverage and demonstrate platform independence of existing ViGIR software
- Robotis THOR-MANG robot
  - THOR-MANG number 5 → Name “Johnny 05”
  - ~50kg
  - ~1.50m
  - Electrically actuated
Open Source Efforts by other DRC competitors

- **MIT:**
  - Pronto State Estimator ([pronto-distro github](https://pronto-distro.github.io))
  - Drake Planning and Control ([drake github](https://github.com/robotics-drake))
  - Director UI ([director github](https://github.com/director-project))

- **IHMC:**
  - IHMC Controller
  - SCS Simulator ([ihmc_ros bitbucket](https://bitbucket.org/ihmc-robotics/ihmc_ros))

- **JSK:**
  - Extensive ROS-based Software ([jsk-ros-pkgs github](https://github.com/jsk rospy))
Hardware

- **Boston Dynamics (BDI) Atlas robot**
  - Hydraulically actuated
- **Our Atlas nicknamed “Florian” (after patron saint of firefighters)**
- **API provided by BDI**
  - Walking/Stepping
  - Balancing
- **Upper body planning decoupled from low level balance control**
Hardware - Atlas Versions

  - Tethered
  - 6DOF arms
Hardware - Atlas Versions

  - Tethered
  - 6DOF arms
  - Untethered
  - Onboard Computing
  - 6DOF arms
Hardware - Atlas Versions

  - Tethered
  - 6DOF arms
  - Untethered
  - Onboard Computing
  - 6DOF arms
  - As V4, but 7DOF arms (lower 3 joints electric)
Infrastructure

- Use of ROS from the beginning
  - Prior experience
  - Great community
  - A lot of useful software
  - Integration with DRCsim
- Private git(lab) repos
  - Now moved to github
- Project management via Redmine
  - Every task in issue tracker
  - Hundreds of Wiki-pages
Timeline with a Focus on Infrastructure

Oct 12 | Jan 13 | Jan 14 | Jan 15 | Jan 16
--- | --- | --- | --- | ---
VRC | DRC Trials | DRC Finals

Atlas V3
Atlas V4
Atlas V5

Ubuntu
12.04
14.04

ROS
Fuerte
Groovy
Hydro
Indigo

rosbuild
catkin
Infrastructure - Managing Robot Variability

- Many variants:
  - 3+ Atlas versions
  - 4 Hand types
- Could use args/params
  - Unwieldy to forward through launch files
- Use environments variables
- Generate robot model (and onboard software setup) at launch-time

```bash
filename="$(find atlas_description)/urdf/$(optenv VIGIR_ATLAS_ROBOT_TYPE atlas_v5) simple_shapes.urdf" /
filename="$(find atlas_description)/urdf/$(optenv VIGIR_ATLAS_ROBOT_TYPE atlas_v5) $(optenv VIGIR_SIM_TYPE
filename="$(find atlas_description)/urdf/$(optenv VIGIR_ATLAS_ROBOT_TYPE atlas_v5).transmission" /
filename="$(find atlas_description)/robots/multisense/$(optenv VIGIR_ATLAS_MULTISENSE_TYPE sim)_multisense
filename="$(find atlas_description)/robots/hands/$(optenv VIGIR_ATLAS_LEFT_HAND_TYPE l_stump).urdf=xacro"
filename="$(find atlas_description)/robots/hands/$(optenv VIGIR_ATLAS_RIGHT_HAND_TYPE r_stump).urdf=xacro"
github.com/team-vigir/vigir_atlas_common/blob/master/atlas_description/robots/vigir_atlas.urdf.xacro
```
Infrastructure – Deployment to multiple machines

- Complex system
  - 3 Onboard Computers
  - 1 Field Computer
  - 4 OCS Computers

- Fast development cycles
  - Build and deploy quickly and consistently

- Remotelaunch scripts
  - Build using catkin (install)
  - Deploy using rsync
  - Start using ssh/screen

[github.com/team-vigir/remotelaunch]
Infrastructure - Deployment to multiple machines

Launch scripts for each machine

```
# theoden
roslaunch vigir_atlasbringup common_parameters.launch
roslaunch vigir_atlas_controller atlas_robot.launch
roslaunch pgr_camera sa_cameras.launch
```

Common environment setup executed on each machine

```
#!/bin/bash

# This code will be run in every screen on the remote machine. It is typically
# used to source ros and setup any other environment variables you need.

cmdline="$@

if [ $# == 0 ]; then
    cmdline=($SHELL -i)
fi

export VIGIR_ROOT_DIR=/home/user/vigir_repo
echo "sourcing catkin_ws................."
source "/home/user/vigir_repo/catkin_ws/install/setup.bash"
echo "sourcing scripts setup.bash................."
source "/home/user/vigir_repo/scripts/setup/setup.bash"
shopt -s expand_aliases
exec "${cmdline[@]}"
```
## Infrastructure - Simulation Options

- No single solution that can do everything currently available (as open source)
  - IHMC controller/Atlas with Gazebo integration to be released?

<table>
<thead>
<tr>
<th>Simulator/Robot</th>
<th>Locomotion</th>
<th>Manipulation</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Atlas/BDI/DRCsim</td>
<td>(Yes)</td>
<td>No</td>
<td>Only with BDI lib</td>
</tr>
<tr>
<td>Atlas/IHMC/SCS</td>
<td>Yes</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>Atlas/IHMC/DRCsim</td>
<td>(Yes)</td>
<td>(Yes)</td>
<td>Coming soon?</td>
</tr>
<tr>
<td>Valkyrie/IHMC/DRCsim</td>
<td>(Yes)</td>
<td>(Yes)</td>
<td>Coming soon?</td>
</tr>
<tr>
<td>Thor-Mang/Gazebo4</td>
<td>No</td>
<td>Yes</td>
<td></td>
</tr>
</tbody>
</table>
Coming soon :)

![Robot Simulation Screen](image)
## DRC - Communication constraints

<table>
<thead>
<tr>
<th></th>
<th>Uplink (to OCS)</th>
<th>Downlink (to robot)</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>VRC</strong></td>
<td>Total ~115 kB for 30 minutes. 500 ms latency</td>
<td>Total, ~7 MB for 30 minutes. 500 ms latency</td>
<td>Worst case (20% of scenarios)</td>
</tr>
<tr>
<td><strong>Trials</strong></td>
<td>1 MB/s, 50ms latency</td>
<td>1 MB/s, 50 ms latency</td>
<td>Good comms</td>
</tr>
<tr>
<td></td>
<td>100 kB/s, 500 ms latency</td>
<td>100 kB/s, 500 ms latency</td>
<td>Bad comms</td>
</tr>
<tr>
<td><strong>Finals</strong></td>
<td>1.2 kB/s</td>
<td>1.2 kB/s</td>
<td></td>
</tr>
<tr>
<td></td>
<td>300 Mbit/s</td>
<td></td>
<td>Outages of 1-30 seconds after robot traverses door</td>
</tr>
</tbody>
</table>

**VRC Rules** (pdf)
**Trials Rules** (pdf)
**Finals Rules** (pdf)
VRC

- 15 runs
- 30 mins each
- Variability in scenarios
- 7 MB/30 minutes from robot worst case
## VRC

<table>
<thead>
<tr>
<th>Task 1</th>
<th>Run 1</th>
<th>Run 2</th>
<th>Run 3</th>
<th>Run 4</th>
<th>Run 5</th>
<th>Total (Max. 20)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>Task 2</td>
<td>4</td>
<td>2</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>18</td>
</tr>
<tr>
<td>Task 3</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>6</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Team</th>
<th>Task 1</th>
<th>Task 2</th>
<th>Task 3</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>IHMC</td>
<td>12</td>
<td>20</td>
<td>20</td>
<td>52</td>
</tr>
<tr>
<td>WPI</td>
<td>15</td>
<td>20</td>
<td>4</td>
<td>39</td>
</tr>
<tr>
<td>MIT</td>
<td>5</td>
<td>20</td>
<td>9</td>
<td>34</td>
</tr>
<tr>
<td>TRACLabs</td>
<td>4</td>
<td>20</td>
<td>6</td>
<td>30</td>
</tr>
<tr>
<td>JPL</td>
<td>5</td>
<td>20</td>
<td>4</td>
<td>29</td>
</tr>
<tr>
<td>ViGIR</td>
<td>3</td>
<td>18</td>
<td>6</td>
<td>27</td>
</tr>
</tbody>
</table>
Components - Controls

Hardware

Robot Controller  LIDAR(s)  Camera(s)  IMU
**Controls**

- **Use of BDI supplied library**
  - Walk (dynamic stability)
  - Step (static stability)
  - Manipulate (balance while standing)

- **Provided as binary**
  - Black box, no source (also for DRC teams)
  - Not available to general public :(

- **Effort to integrate IHMC Whole Body controller**
  - Use in competition prevented by time constraints/delays
Components - State Estimation

Hardware

- Robot Controller
- LIDAR(s)
- Camera(s)
- IMU
Components - State Estimation

Hardware
- Robot Controller
- LIDAR(s)
- Camera(s)
- IMU

State Estimation
- State Estimator
State Estimation

- Provide state (pose) estimate for robot
- Fuse
  - Leg Kinematics
  - IMU
- Continuous but drifting estimate
  - Low drift with good sensors
- Use MIT's pronto
  - Tuned for Atlas system
  - pod build system
  - LCM communications
- LIDAR use dangerous in non-static environment
  pronto-distro (ViGIR fork)
Components – Perception

Hardware
- Robot Controller
- LIDAR(s)
- Camera(s)
- IMU

State Estimation
- State Estimator
Components - Perception

Hardware
- Robot Controller
- LIDAR(s)
- Camera(s)
- IMU

World model server

LIDAR

Perception

State Estimation
- State Estimator

LIDAR Filter
Perception

- Provide situational awareness for operator(s)
- Provide world state estimate for robot
  - Footstep planning
  - Manipulation
Perception - LidarOctomapUpdater

- Environment octomap updated in real-time
- Provide collision model for planner
- Also provide filtered LIDAR data for overall system
  - Annotate with transform information as tf prohibitive over constrained comms

github.com/team-vigir/vigir_manipulation_planning/tree/master/vigir_lidar_octomap_updater
Perception - Compressing LIDAR Data

- Standard scan too big for 1500 Byte UDP limit

github.com/team-vigir/vigir_perception/tree/master/vigir_filtered_localized_scan_utils
Perception – Compressing LIDAR Data

- Standard scan too big for 1500 Byte UDP limit

- Compress:
  - Split (3 separate scans)
  - Distances to uint_16
  - Intensities to uint_8
  - Self filter bit

- Add start/end global transform info

- Can reconstruct on OCS side
  - Every compressed scan usable standalone

[GitHub Link](https://github.com/team-vigir/vigir_perception/tree/master/vigir_filtered_localized_scan_utils)
Perception - World Model Server

- Collect LIDAR data
- Provide services
  - Pointcloud ROIs
  - Octomap ROIs
  - Gridmap slice ROIs
  - Distance queries
- Two instances
  - Onboard
  - OCS
- Sync via compressed scans

github.com/team-vigir/vigir_perception/tree/master/vigir_worldmodel_server
Situational Awareness using Fisheye Cameras

- Fisheye cameras provide high FOV
- Hard to interpret for humans
- Calibrate Fisheye cam using the ocamlib toolbox
- Virtual pinhole camera that follows tf frames

[GitHub link: github.com/team-vigir/vigir_wide_angle_image_proc]
Mesh Visualization

- Latest image data texture mapped onto mesh
  - Depth image-based: Fast update rate, low range
  - LIDAR-based: Low update rate, high range

![Diagram of mesh visualization process](image)
Mesh Visualization

Rviz Mesh DisplayPlugin

shape_mgs/Mesh

DepthImg to Mesh Node

[Links]
github.com/team-vigir/vigir_perception/tree/master/vigir_point_cloud_proc
github.com/team-vigir/vigir_ocs_common/tree/master/vigir_ocs_rviz_plugins/vigir_ocs_rviz_plugin_mesh_display_custom
Components - Footstep Planner

Perception
- World model server
- LIDAR Filter

State Estimation
- State Estimator

Hardware
- Robot Controller
- LIDAR(s)
- Camera(s)
- IMU
Components - Footstep Planner

Perception
- World model server
- LIDAR Filter

Planning
- Footstep Planner

State Estimation
- State Estimator

Hardware
- Robot Controller
- LIDAR(s)
- Camera(s)
- IMU
Footstep Planner

- Based on work by Hornung et. al. [1]
  - A*-search-based planning approach

$\mathbf{s}' = (x', y', \theta')$

$a = (\Delta x, \Delta y, \Delta \theta)$

Discrete Foot Placements

Successor Set

Footstep Planner

- Complex Locomotion:
  - 3D perception and modeling
  - Safe sequences of foot placements
  - 6DOF foot placements
  - Obstacle avoidance
  - Balance control

- Divide and conquer
  - Terrain Model Generator
  - 3D Footstep Planning
  - Robot Controller

github.com/team-vigir/vigir_footstep_planning_core
Terrain Model Generator

- Only point clouds required
  - Octree as back-end
  - Incremental updates
  - Stand-alone ROS package
    - Usable in other domains

github.com/team-vigir/vigir_terrain_classifier
**Terrain Model Generator**

- **Online Generation**
  - Surface Normals (left)
  - Height Map (right)
Footstep Planner: 3D Planning

- Extension to 3D

- States: Become full 6 DOF
- Actions: Remain the same
- Roll, pitch and step height are constrained by underlying terrain
- Search space does not enlarge
- No expensive branching tree!
Footstep Planner: 3D Planning

- **Ground contact estimation**
  - Sampling of foot surface
  - Estimate contact situation of each sample using height map
  - More flexible collision checking model
  - Allows overhanging steps
Footstep Planner: Plugins

- Plugins used for customization of all relevant system aspects
- Setups for 3 robots already available:
  - Atlas
  - Thor-Mang
  - ESCHER
Footstep Planner: Example
Footstep Planner: Interactivity
Components - Footstep Planner

Hardware
- Robot Controller
- LIDAR(s)
- Camera(s)
- IMU

Perception
- World model server
- LIDAR Filter

Planning
- Footstep Planner

State Estimation
- State Estimator

Components include:
- LIDAR(s)
- Camera(s)
- Robot Controller
- IMU
Components - Manipulation

Perception
- World model server
- LIDAR Filter

Planning
- Footstep Planner
- Manipulation Planner

Template Manipulation
- OT Server
- Manipulation Controller

State Estimation
- State Estimator

Hardware
- Robot Controller
- LIDAR(s)
- Camera(s)
- IMU
Motion Planning - Requirements

- Manipulation
  - Collision free planning
  - Cartesian Paths
  - Manipulation in contact with environment
  - Maintain stability

- Sliding Autonomy:
  - Operator/OCS-based (Teleop)
  - Operator/Object template based (Task level)
  - Behavior Executive (Autonomous)

➔ Use MoveIt! as back-end
Motion Planning - Robot Setup

- Different robot variants
- Different hand variants
- Combinatory explosion of configs
  - Do not want to run setup assistant for every (possible) combination

Solution:
- Use of xacro macros to change configs

[GitHub link: github.com/team-vigir/vigir_atlas_planning/tree/master/vigir_atlas_moveit_config]
Motion Planning - Overview

- scan
  - Lidar Octomap Updater
  - vigir_move_group
    - manipulation_action_capability
  - vigir_move_group
    - octomap_access_capability
  - vigir_move_group
    - robot_state_retrieval_capability
  - Standard move_group plugins
- JointTrajectoryAction
- move_group
- filtered_scan
- vigir_move_group
  - action
- octomap
- robot_state
- OCS Teleop
- Manipulation Controller
- FlexBE Behaviors
- Topic
- Service
- Action
### Planning - Capabilities

- **Additional move_group capability**
  - Different types of motion requests
    - Joint goal
    - Cartesian goal
    - Cartesian Path (waypoints)
    - Circular motion
  - Specify planning reference pose relative to endeffector
  - Constrain joint limits selectively at run-time

---

**github.com/team-vigir/vigir_manipulation_planning/tree/master/vigir_move_group**
Planning - Object Templates

- On top of vigir_move_group
- Operator places objects
- Planning relative to instantiated object templates
- Object template library
  - Geometry
  - Mass/Inertia
  - Grasps
  - Stand poses

github.com/team-vigir/vigir_object_template_manager
Planning - “Ghost” robot

- Pre-plan motions with virtual “Ghost Robot”
- Additional capabilities compared to start/goal state visualization in MoveIt! Rviz plugin
  - Snap endeffectors to objects
  - Move to stand poses relative to object templates
  - Constrain IK joint limits
  - Send low-bandwidth planning request directly from OCS

github.com/team-vigir/vigir_manipulation_planning/tree/master/vigir_ocs_robot_model
Manipulation Pipeline Example
Manipulation Pipeline Example
Manipulation Pipeline Example
Manipulation Pipeline Example
Manipulation example
Manipulation - Drake Integration

- Switch between MoveIt! and MIT's Drake planning framework on a per plan request basis
  - Whole Body Motions
  - Using github.com/tu-darmstadt-ros-pkg/rosmatlab
Manipulation - Reaching motion using Drake Integration
Components - FlexBE Behavior

Executive

Perception
- World model server
- LIDAR Filter

Planning
- Footstep Planner
- Manipulation Planner

Template Manipulation
- OT Server
- Manipulation Controller

State Estimation
- State Estimator

Hardware
- Robot Controller
- LIDAR(s)
- Camera(s)
- IMU
Components - FlexBE Behavior Executive

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Behavior Executive
- FlexBE

State Estimation
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Hardware
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- Camera(s)
- IMU
Behavior Executive - High-Level Approach

- Communication constraints
- Limited time
- Complex robot system

Flexible Robot-Operator Collaboration

- Unstructured environment
- Complex tasks
- Robustness important

Motivates high degree of **robot autonomy**

Motivates high degree of **operator support**
Behavior Executive - High-Level Approach

- SMACH, XABSL, etc.
  - Focused on pure autonomy
  - Pre-defined robot behavior

- Required features:
  - Allow multiple degrees of autonomy
  - Support and restrict robot when in low autonomy
  - Adapt behavior to unforeseen situations
  - Abstraction of complex behavior design
  - Robust against runtime failure
 Behavior Executive - FlexBE

- “Flexible Behavior Engine”
  - Based on SMACH → Hierarchical state machines
  - Adds robot-operator collaboration
  - Available on GitHub: github.com/team-vigir/flexbe_behavior_engine
FlexBE - States

- Interface basic robot capabilities / actions
- Executed periodically
- Event-based lifecycle (simplified):

- on_enter
- execute
- on_exit

Send command(s), eg.
- publish message
- actionlib call

Check conditions and evaluate results
→ Determine outcome

Clean up
**FlexBE - Autonomy Level**

- Behavior runs with explicit *Autonomy Level*
  - Can be changed any time during execution
- State outcomes define required autonomy
  - High enough $\rightarrow$ Autonomous execution
  - Too low $\rightarrow$ Operator confirms or rejects
- Operator can force outcomes any time

```
Close Fingers
```

```
Lift Object
```

```
Try Alternative
```

**Autonomy**

- Off
- $\rightarrow$ Low $\leftarrow$
- High
- Full

*success*
*missed*
**FlexBE - Data Input**

- Behavior can request required data from operator
- Integrated into operator control station
FlexBE - Runtime Changes

- Behavior is locked in a specific state
- Modifications are sent to the onboard executive
- New version is generated and imported
- Active state is transferred
  - Extracted from old, running version
  - Integrated into new version
- Old version is stopped
- New version is executed

→ Arbitrary adaptation
FlexBE - User Interface

- Facilitates behavior development
- Automated code generation
- Integrated operator interaction

→ Is prerequisite for operator-robot collaboration
  - Behavior re-definition during runtime feasible
  - Transparent robot decision-making
  - Send context-dependent high-level commands
FlexBE - Editor

- Drag&Drop state composition
- Configuration of state properties
- Detailed documentation of states
- Dataflow graph and verification
Human-Robot Collaborative High-Level Control with Application to Rescue Robotics

Philipp Schillinger, Stefan Kohlbrecher, Oskar von Stryk

IEEE International Conference on Robotics and Automation (IEEE ICRA) 2016
Components - Comms Bridge

Perception
- World model server
- LIDAR Filter

Planning
- Footstep Planner
- Manipulation Planner

Template Manipulation
- OT Server
- Manipulation Controller

Behavior Executive
- FlexBE

State Estimation
- State Estimator

Hardware
- Robot Controller
- LIDAR(s)
- Camera(s)
- IMU
Components - Comms Bridge

Perception
- World model server
- LIDAR Filter

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Comms Bridge
- OCS Master
- Onboard Master
- Comms Bridge
Comms Bridge

- Single ROS Master infeasible
  - Unreliable connection between operator and robot
- Dual Master approach
  - OCS
  - Onboard
- Prioritization
- Special treatment of high rate state data
  - Compress using domain knowledge
- Other data compressed using `blob_tools`
  - Bz2 compression per default
Components - OCS

- Perception
  - World model server
  - LIDAR Filter

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- Comms Bridge
  - Comms Bridge
  - OCS Master
  - Onboard Master
  - Comms Bridge
  - Comms Bridge
  - OCS Master
3D visualization based on librviz

- Map View (Top Down)
  - Rectangle selection (query sensor data ROI)
- Main View
- CameraView
  - Camera data visualization

Multiple Qt widgets for general controls

- “Ghost Control”
- Pre-canned joint configurations
Components - Install

- Install instructions for complete setups: github.com/team-vigir/vigir_install/wiki
  - Waiting for Atlas IHMC/Gazebo integration for full capability (walk/manipulate) Atlas example
Components - Tutorial video

Manipulation Control Approach for Remote Humanoid Robots under Human Supervision

Open Source Tutorial

Team ViGIR’s software using Team Hector’s robot "Johnny" in Gazebo Simulator
Work in Progress - Behavior Synthesis

ROSCon 2015 Example

State machine

Open this Statemachine  Display synthesis

Synthesis
Initial Conditions:
stand_prep
Goal:
pickup_object

Synthesize
This will delete the current content!

Outcomes
finished: Inherit
failed: Inherit
Work in Progress - Behavior Synthesis

- Compile formal Linear Temporal Logic (LTL) specification from:
  - High-level task (goals and initial conditions)
  - Abstract description of the robot-plus-software system, defined a priori (think config files)

- The formalism treats the outcomes of actions as an adversarial environment
Automatically synthesize a finite-state automaton that is **guaranteed** to satisfy the formal LTL **specification** no matter what the environment does.
Work in Progress

- Mapping from abstract symbols to low-level system components (here, FlexBE states)
- Instantiation of symbolic automaton as an executable state machine in FlexBE
Behavior Synthesis - Example
DRC Finals

- Decision not to do egress
  - Significant development effort
  - Risk of (catastrophic) damage to robot
- Limited testing under degraded comms conditions
DRC Finals - Day 1

Video Day 1 Pt.1
Video Day 1 Pt.2
DRC Finals - Day 1
DRC Finals - Day 1

- Flawless Driving
- Comms bridge setup issue
  - Behavior control
  - Footstep planning
- Switch to teleop mode
- Slow but reliable
DRC Finals - Day 2
DRC Finals - Day 2
DRC Finals - Day 2
DRC Finals - Day 2
DRC Finals - Day 2
DRC Finals - Day 2

- Start delay due to arm hardware failure
- (Too) fast driving
- Reset after touching barrier
- Successful driving
- Door opened
- Pump shutdown
  - Possibly due to overheating
- Reset
- Fall while walking through door
DRC Finals Results

- 3 Points (Day 1)
- Scored lower than would have been achievable and expected
  - Achievable: 7 points (No egress)
- Missed chance at Day 1 due to comms issues
- Unknown cause for pump shutdown at Day 2

- Driving approach worked well on both robots that used it
  - ViGIR Florian (Atlas)
  - HECTOR Johnny (Thor-Mang)
Lessons Learned - ROS

- Workspace setup using wstool works well
  - Few convenience scripts helpful
- Keeping pace can be painful
  - From rosbuild to catkin
  - From hydro to indigo (switching ROS distro and Ubuntu version simultaneously)
- Using plain “catkin_make” in large projects bad idea
  - Use catkin_tools
- Limited constrained comms capability
- Supporting different configurations feels more involved than it should
  - Environment variables?
Lessons Learned - Big Picture

- Having a transatlantic, nine time zone team works
  - Right mindset and people
  - Tools
- DRC showed what is possible
  - Brilliant display of state of the art capabilities
  - Still a long way to go till robots can be useful for real DRC-like tasks
- Continuous Integration
  - Simulation-in-the-loop testing desirable
- Everybody wins
  - Leap across wide range of capabilities
  - Open source developments (Gazebo, code releases..)
  - Incredible sportsmanship and cooperation across DRC teams
- Low level control access advantageous
  - Top three scoring Atlas teams all used their own whole-body controllers
Conclusions

- DRC overview
- ROS infrastructure discussion
  - Useful tools
- Intro to open source components
  - Let us know what you're interested in
- DRC results discussion
- Lessons learned

Questions?
References


- YouTube playlist with manipulation examples
Open Source Driving Controller Concept for Humanoid Robots: Teams Hector and ViGIR at DARPA Robotics Challenge 2015

Alberto Romay, Achim Stein, Martin Oehler, Alexander Stumpf, Stefan Kohlbrecher and Oskar von Stryk
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David C. Conner
TORC Robotics
ARGOS FlexBE
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Current and Future Work

- Integration with IHMC open source controller/simulator
- Automated Object Recognition/Localization
- Adaptability to higher uncertainty
  - Whole body control/planning
  - Online adjustable object templates
  - Improved state estimation
- Capture point based walking control for Thor-Mang robot
- Behavior Synthesis
  - Generate behavior state machines automatically