Shared Autonomy for Robotics
Closing the Loop

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www.edinburgh-robotics.org
One of the world's top 20 Universities
Our research landscape
Valkyrie Humanoid

Flagship Robotarium Platform:
UoE-NASA Valkyrie Humanoid
UK Hub for Humanoids Research
Space Robotics Challenge
NASA Space Robotics Challenge

Credits: IEEE Spectrum
Advanced Whole Body Motion Planning
Robots That Interact

Full-autonomy challenges due to:
1. Close interaction with multiple objects
2. Noisy sensing with ambiguity
3. Hard to model dynamics
4. Guarantees for safe operations
5. Highly constrained environment
6. Un-modelled user intentions
1: Understanding and Representing the world around you

(Tracking and Localisation)

Toyota’s Human Support Robot (HSR)
1: Understanding and Representing the world around you

State Estimation: **unified percept** of the world

Fallon et al., Dense Mapping for Locomotion on uneven terrain, Best Paper Award, Humanoids 2015
1: Understanding and Representing the world around you
(Closed Loop Sensing and Manipulation)
2: Understanding and Representing the world around you

Bridging Representations

- Interaction with dynamic, articulated and flexible bodies
- Departure from purely metric spaces -- focus on relational metrics between active robot parts and objects/environment
- Enables use of simple motion priors to express complex motion

Ivan V, Zarubin D, Toussaint M, Komura T, Vijayakumar S. Topology-based Representations for Motion Planning and Generalisation in Dynamic Environments with Interactions. IJRR, 2013
Robots for Confined Spaces

Courtesy: OC Robotics Ltd.
3: Dealing with Uncertainty

- through Compliant Actuation

HASy (DLR); BLUE and miniBLUE compliant bipeds @ University of Edinburgh

Variable Stiffness Actuation

EMG (left) → Motor (right) + Stiffness

EMG (right) → Motor (left) + Damping

Impedance
Compliant Actuators

- VARIABLE JOINT STIFFNESS

\[ \tau = \tau(q, u) \]

\[ K = K(q, u) \]

MACCEPA: Van Ham et al., 2007

DLR Hand Arm System: Grebenstein et al., 2011

Torque/Stiffness Opt.

- Model of the system dynamics:

\[ \dot{x} = f(x, u), \quad u \in \Omega \]

- Control objective:

\[ J = -d + w \frac{1}{2} \int_{0}^{T} \|F\|^2 dt \rightarrow \min \]

- Optimal control solution:

\[ u(t, x) = u^*(t) + L^*(t)(x - x^*(t)) \]

iLQG: Li & Todorov 2007

DDP: Jacobson & Mayne 1970

Highly dynamic tasks, explosive movements

Optimising and Planning with Redundancy: Stiffness and Movement Parameters Scale to High Dimensional Problems

Multi-phase Movement Optimization

- Task encoding of movement with multi-phases

\[ J = \phi(x(T_f)) + \sum_{j=1}^{K} \psi^j(x(T^-_j)) + \int_{T_0}^{T_f} h(x, u) dt \]

- Terminal cost \( (3) \)
- Via-point cost \( (2) \)
- Running cost \( (1) \)

- cf. individual cost \( J_i \) for each phase \( T_{j-1} \leq t < T_j \)
- total cost by sequential optimization could be suboptimal

Optimization problem

1. optimal feedback control law \( u = u(x, t) \) to minimize \( J \)
2. switching instances \( T_1, \ldots, T_k \)
3. final time (total movement duration) \( T_f \)
Optimized Brachiating Maneuver

Swing-up and locomotion

Additionally optimize for Movement Time
4: Learning to Predict and Adapt

- Predicting Consequences
- Predicting Task Goals and Intentions

Learning the Internal Dynamics       Learning the Task Dynamics


http://www.ipab.inf.ed.ac.uk/slmc/software/lwpr
On-the-fly adaptation at Any Scale

- Fast dynamics online learning for adaptation
- Fast (re) planning methods that incorporate dynamics adaptation
- Efficient Any Scale (embedded, cloud, tethered) implementation

Putting it all together: Adaptive, Human-in-the Loop Behaviour

This capability is crucial for safe, yet precise human robot interactions as well as applications as diverse as wearable exoskeletons.
Teleoperation

Autonomy

Shared Autonomy
Shared Autonomy

“Full autonomy is a 20th century rhetoric”

“The real frontier is collaboration, which includes autonomy but different levels of autonomy at different moments under the control of a human operator.”

“Such systems should have the ability to turn on autonomy when it can be helpful. Autonomy can reduce human workload and fatigue, but humans should still be present in the loop.”

- IEEE Spectrum, David Mindell (MIT)
Shared Autonomy: An Example
EPSRC CDT-RAS
The EPSRC Center for Doctoral Training in Robotics & Autonomous Systems

• Multidisciplinary ecosystem – 65 PhD graduates over 8.5 years, 50 PIs across Engineering and Informatics disciplines
  Control, actuation, Machine learning, AI, neural computation, photonics, decision making, language cognition, human-robot interaction, image processing, manufacture research, ocean systems …

• Technical focus – ‘Interaction’ in Robotic Systems
  Environment: Multi-Robot: People: Self: Enablers

• ‘Innovation Ready’ postgraduates
  Populate the innovation pipeline. Create new businesses and models.

• Cross sector exploitation
  Offshore energy, search & rescue, medical, rehabilitation, ageing, manufacturing, space, nuclear, defence, aerospace, environment monitoring, transport, education, entertainment ..

• Total Award Value (> £14M ): CDT £7M, Robotarium £7.1M
  38 company sponsors, £2M cash, £6.5M in-kind (so far ..)
  Schlumberger, Baker Hughes, Renishaw, Honda, Network Rail, Selex, Thales, BAe, BP, Pelamis, Aquamarine Power, SciSys, Shadow Robot, SeeByte, Touch Bionics, Marza, OC Robotics, KUKA, Dyson, Agilent …

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ROBOTARIUM
A National UK Facility for Research into the Interactions amongst Robots, Environments, People and Autonomous Systems
Translation and Impact

Example: for Prof. Vijayakumar (2013)

- Translation through Industrial & Scientific Collaborations and Skilled People

Immediate Impact Domains

- Healthcare & Assisted Living
  - Smagt (TUM): Biosignal Interfaces
  - KINOVA: Assistive manipulators
  - Venkadesan (NCBS): Gait
  - Touch Bionics: Upper Limb Prosthetics

- Marine (Field)
  - Lane (HWU): Marine
  - BP, Schlumberger, SubSea7, BlueFin: UUVs, Oil and Gas, Marine Environment
  - OC Robotics: Confined Space, Nuclear
  - Cheng (TUM): Smart Tactile Sensors

- Industrial & Manufacturing
  - Chli (UoE): Real Time Sensing

- Humanoid (Field)
  - LAAS (Toulouse): Humanoid Motion Planning
  - HAL-Tsukuba: Exoskeletons
  - DRC

- Renewables
  - Komura (UoE): Close Contact Animation
  - Fallon (UoE): DRC Sensing
  - Ramamoorthy (UoE): High-level Decision Making

- Service Robotics
  - PELAMIS: WEC
  - AQUAMARINE: WEC
  - MICROSOFT: Multicharacter Gaming and Interfaces
  - HONDA: Full Body Multi-Contact Manipulation
  - DYSON: Compliant Home Appliance
  - KUKA: Compliant Manipulation

- Industrial Partners (italics: CDT/EDU – RAS linked)
  - Directly Collaborating Academic Partner
“we tend to overestimate technology in the short term and underestimate technology in the long term”

Arthur C. Clarke
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