Beyond Intention Inference in Human-Machine Collaboration

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Centre for Autonomous Systems, UTS

- Two Autonomous Grit-Blasting Robots in service at the Sydney Harbour Bridge (SHB) for maintenance since 2013
- UTS Spin-off company: SABRE, 2013
- One bio-inspired autonomous climbing robot in use for inspection of confined space at the SHB since 2016 • Smart Hoist extensively evaluated at an aged care facility
- in Wollongong, NSW, 2014-2015
- Step climbing wheelchair technology transformed in 2016 • Research outcomes on robot teams implemented in the world's first fully automated container terminals



Intention Inference in Science & Engineering

Learn to discriminate one class from another

- Anomaly detection •
- **Behaviour classification** lacksquare
- Surveillance
- Self-diagnosis





Engine self-diagnosis





Human-Readable Intention Inference

Finding a classifier that separates one group from another

can we explain the system's behaviour/intent?

How to express binary classification in terms of intuitive physical/temporal relationships?



- From a given time series (trajectory, sensor observations, etc.),
- How do we **reason** about classification result in our own language?



Formal Methods in Robotics



$\Phi_3 = \mathcal{P}_{max}^{0:h} [\neg house \ \mathcal{U} \ photo]^{\pi}$

"Reach the goal while complying with the altitude regulations:

- Fly above safety altitude in the middle regions,
- Fly below certain altitude when approaching the goal, and
- Not to fly over household regions shown in black blocks"

no re

C. Yoo, R. Fitch and S. Sukkarieh, "Probabilistic Temporal Logic for Motion Planning with Resource Threshold Constraints", In Proc. of RSS. 2012 **C. Yoo, R. Fitch** and S. Sukkarieh, "Online Task Planning and Control for Aerial Robots with Fuel Constraints in Winds", In Proc. of WAFR. 2014





Intention Inference with Temporal Logic



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* C. Yoo and C. Belta, "Rich Time Series Classification Using Temporal Logic", Proc. of RSS, 2017





 $\phi^* = \mathcal{G}_{[0,60]} \neg c \land (\mathcal{F}_{[27,39]} a \lor \mathcal{F}_{[59,60]} a \lor \mathcal{F}_{[16,21]} b)$

"A vessel successfully enters Boston Harbour when it avoids **region c**, and visit **region a** within 27 and 39 time steps, or visit **region a** within 59 and 60 time steps, or visit **region b** within 16 and 21 time steps." (the misclassification rate is 0.029)







What is beyond inference?

- ullethuman and machine
- each other's intention in precise manner





Beyond Inference: Monitoring a Team of Robots



0110110...







A: "I am going to ..." B: "I am going to ..." C: "I am going to ..."





Beyond Inference: Intention-based Surveillance



"I think he is going to ..."



"I think he is going to ..."





Beyond Inference: Decentralised Human-Robot Collaboration





"I am going to ..."









Robot Decision-Making





Paths-to-STL Translator											
$\frac{\mathbf{F}}{f_1}$ f_2 f_3 f_4 f_5 f_6 f_7 f_8 f_9	$\begin{array}{c} t = 0 \\ a \\ a \\ b \\ a \\ b \\ b \\ \vdots \\ \end{array}$	$\frac{t=1}{a}$	$\frac{f_i}{a_0 \cdot \emptyset_1\\ \emptyset_0 \cdot a_1\\ a_0 \cdot a_1\\ b_0 \cdot b_1\\ a_0 \cdot b_1\\ b_0 \cdot a_1\\ b_0 \cdot \theta_1\\ \emptyset_0 \cdot \theta_1\\ \emptyset_0 \cdot \theta_1$	$\frac{g(f_i)}{176}$ 120 82 39 11 6 13 81 $\wedge F_{[}$	b(f _i) 13 8 0 22 0 2 59 90 272 10,30	r 0.371 0.422 0.452 0.517 0.523 0.530 0.587 0.611 0.725				Communicate intention packet	





Human Decision-Making







Impact

Long term:

- Robots behave optimally with respect to human behaviour
- Human can optimise own behaviour given intentions of team
- Core capability for information gathering tasks such as surveillance (air, ground, water)

Short term:

- Rigorous mathematical methods for intention estimation and coordination - Lay foundation for experiments with real robots/humans



