Robots in human spaces

A pressing question facing researchers and developers in robotics is how to create robots that can safely share space with humans in domestic, public, or industry settings. The concept of safety needs to extend beyond the physical domain, encompassing economic and psychological safety - how do we ensure robots support rather than replace human labour, and increase rather than decrease social connectivity?

Cooperative robots (or cobots) are usually conceived of as humanoid [1] and futuristic, but shared-space robots designed to enhance or extend human abilities have a vast array of morphologies [2] and are already deployed in multiple arenas [3]. That said, advances in capability, social responsiveness, and accessibility are still required before these types of robots are ready for wide dissemination across domains. My research focuses on developing the technologies to create the next generation of robot coworkers, particularly the following key areas:

1. enhanced perceptual awareness in unstructured environments
2. using targeted morphological design, soft technologies, and compliant actuation to create safe, predictable, and communicative motion.
3. finding the most effective methods of robotic deployment and integration via structured needs-based development.

Enhanced perception in unstructured environments

Modern sensors and communication protocols, while not quite reaching the flexibility, size optimization, or adaptability seen in nature, are increasingly capable, allowing high-speed transmission of massive quantities of data. To be effective, robots must make sense of this ever-increasing information load, filtering, rejecting, parsing or storing it as appropriate. Biology serves as an important source of inspiration for behavioural algorithms based on minimal or limited information that result in complex emergent responses. Drawing on a background of research in bio-inspired algorithms - especially how small-brained animals such as insects encode or filter large amounts of information [4] - I plan to explore methods in multi-sensor data fusion to build augmented environmental maps, using novel memory-efficient data storage and retrieval methods such as sketch algorithms and voxel compression.

In past research, I have worked on enhanced perception in several different forms. My post-PhD research created novel vision sensors that can improve scene understanding and provide robust navigational information for autonomous vehicles [5], [6] (Figure 1.1A). Combining parallel streams from a polarized vision system, we developed a visual sky compass and attitude detector and demonstrated its utility on a small autonomous quadcopter (Fig 1.1B). This method used bio-inspired principles to enable real-time attitude control and navigation in the absence of GPS or IMU information, and can be used alone, as a failsafe system, or to compensate for IMU drift. More recently, I have been adapting RGB-D hardware for small-scale applications, improving resolution and enabling sub-millimeter depth mapping of visually homogeneous environments (Figure 1.1C, D). This hardware has already been tested and deployed in challenging field conditions such as the Namibian desert[7]. All these sensors are small, portable, robust, and operate in real time at moderate to high speeds with high data throughput.

I intend to enhance the utility, robustness and application domains of RGB-D technology by optimizing it for constrained, unstructured, and visually ambiguous spaces, such as the inside of a termite mound, or navigating a collapsed building. New advances in sensor technology mean we can create ever-smaller hardware envelopes with more precise scene resolution, and with appropriate implementation these will enable micro-scale reconstruction of difficult environments, allowing us to e.g. explore obstructions in subterranean networks, investigate animal habitats, and map complex geological structures.

Nevertheless, there are many operating scenarios where vision-based sensing is either impractical or inefficient. Drawing on an extensive background in tactile sensor evaluation and implementation on humanoid robots [8], I am presently researching non-visual exploration techniques using soft, robust, bio-inspired tactile sensors. My immediate research plans include further developing these novel sensors and encoding methods to create haptic maps for navigating close and cluttered environments, which can augment or fuse with vision data to provide enhanced material and structural information.

An additional challenge in creating intelligent autonomous systems is imparting contextual awareness, which will further advance the ability of shared space robots to adapt to human presence and needs. This might

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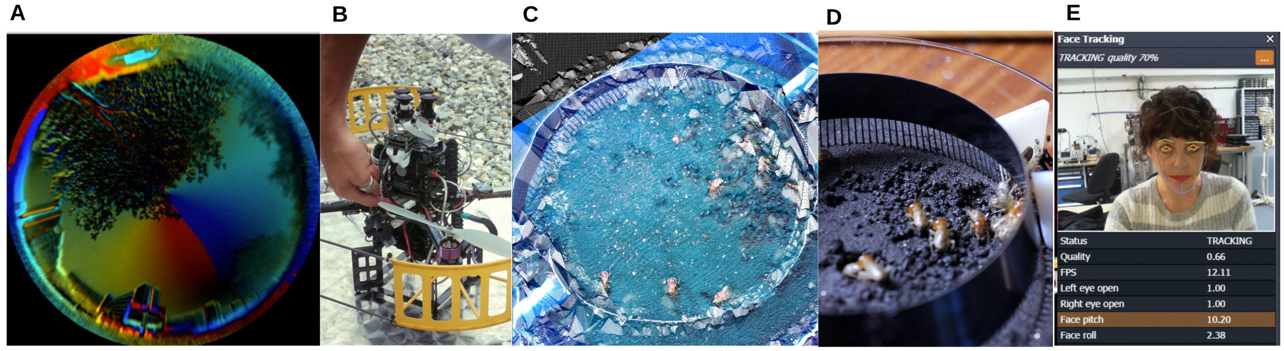

Figure 1.1: A: Video output from a UAV navigating with the aid of polarization vision sensors, University of Bielefeld 2012. B: System A in use on a quadcopter. C, D: Sub-millimeter RGB-D reconstruction of termite digging activity, Namibia 2017. E: Facial movement recognition as part of an enhanced social perception environment for robots, Engineered Arts 2014

encompass structures such as fast-access contextual databases which can help differentiate between overlapping physical scenarios, or multi-dimensional learning algorithms to tune and optimize response behaviours. In 2012 my team at Engineered Arts received a 170k grant to develop the next generation of informational robots for public spaces, which by tracking movement, micro-expressions, conversational meta-data and employing salient information filtering and retrieval, enabled real-time responsiveness in complex social environments (Figure 1.1E). Leveraging this commercial robotics experience with new discoveries in data transmission and compression will enable the development of context-aware robots with augmented perception capabilities.

Long term I aim to bring these research strands together. Using bio-inspired active sensing techniques (e.g. termite-inspired vibration analysis of material and structural qualities) in combination with situational awareness allows us to create augmented environmental maps that can perceive more than a human operator, can be stored and accessed quickly and efficiently, and have the contextual awareness to communicate human-relevant data in appropriate and intuitive ways.

Morphological design for safe operation and communication

A major constraint on shared-space or cooperative robots is human safety. Physical risks can be averted or mitigated by using ‘soft’ joints, which incorporate springs or other compliant elements. However this can result in sub-optimal accuracy or strength [9]. The use of impedance control methods - i.e. tunable compliance that actively responds to outside forces - can in principle maintain accurate positioning, but may still present a danger if a human makes contact in a non-predicted way. It also locks hardware to a rigid state during failure modes, which may itself cause injury.

Combining passive and active compliance with high-accuracy distributed perceptual systems and active vibration damping can close the loop on this hardware, delivering both accuracy and safety. Force-sensitivity also increases the communication modalities available between human and robot, and opens the way to learning-by-demonstration. Another harm-mitigation technique is the use of bio-mimetic motion, which maps more easily to motion-responsive visual pathways in the human brain, making robot behaviour more intuitive and predictable. In 2013 my team at Engineered Arts Ltd. won a grant to develop a prototype of a parallel active/passive dynamic biped (Byrun, [10], Figure 1.2A). Related projects included integrating novel compliant actuation methods within a human-sized envelope to create force-responsive, predictable movement in constrained and shared environments (eg Figure 1.2B). This research has gone on to produce the lifelike Mesmer robots and the interactive parallel-actuated humanoid RT4, while the Byrun prototype is currently on display at the London Science Museum https://creatorsvancouver.com/robots/.

The overall thrust of this research was to create robots capable of developing social bonds with humans, by incorporating subliminal and indirect communication modalities with anthropomorphic characteristics. This results in robots which require less active work on the part of the users in order to integrate into shared environments. Continuing this research and combining it with the enhanced perception described in the previous section will result in

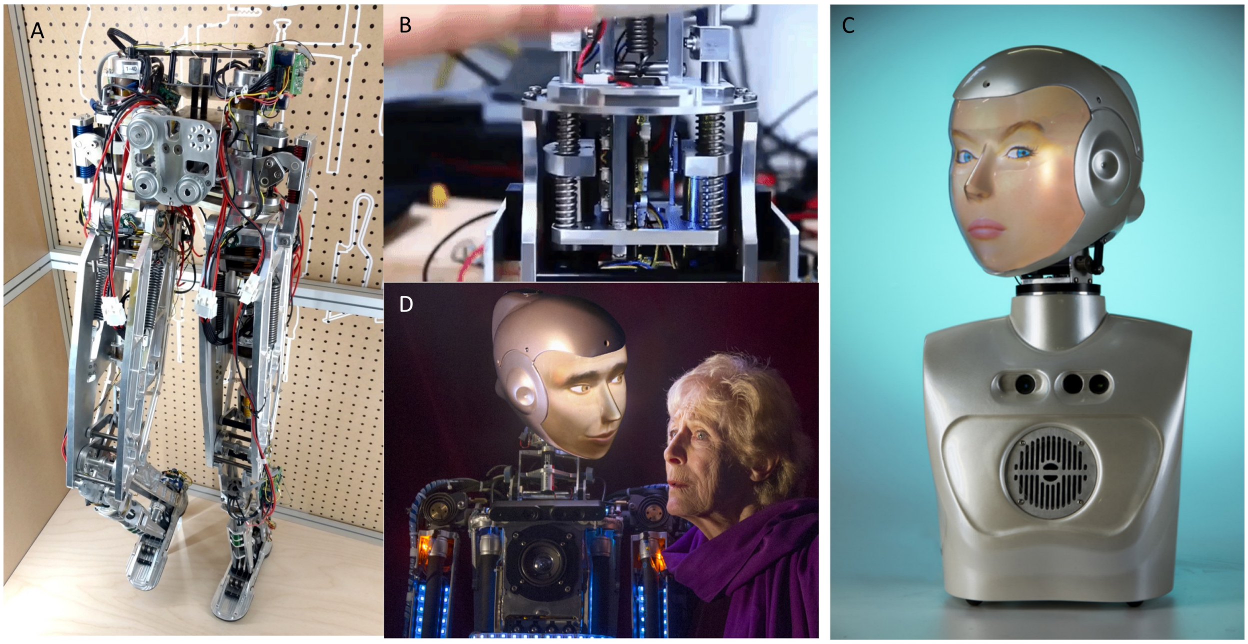

Figure 1.2: Commercial robots and systems I have worked on, clockwise from top left. A: Third generation Byrun prototype, Engineered Arts 2014, at London Science Museum. B: Force-sensitive compliant neck design for a humanoid robot. C: Socibot Mini 2.0, Engineered Arts 2014. D: "Raybot", Pipeline Theatre 2015.

distributed sensing systems that enable high-affordance, fast manipulation, and through active-passive compliance can act as useful human assistants while occupying the same physical space as an operator or coworker.

Structured needs-based development with stakeholders and end-users

The tremendous societal impact of new robotics and automation technologies is undeniable, however while many of these effects are positive (eg. minimizing waste, maximizing efficiency, injury reduction), we also see the potential for very real harms to arise (eg. violations of rights or privacy, loss of accountability, negative impacts on local workers and economies).

These harms can be mitigated or even avoided by approaching robotics as an integrated component of complex social structures and systems (rather than a series of disconnected bespoke solutions for individual problems) [11], [12]. For researchers, this means robotic solutions for real-world problems should be defined by and responsive to the needs of all stakeholders. Contextual aspects, such as access and distribution, cost scaling, harm avoidance, and needs-based design must be considered. By incorporating concepts such as universal and inclusive design, sustainability and long-term environmental effects, inequity reduction, and quality-of-life benefits as early as possible in the design process, we can maximize effectiveness and improve social and economic outcomes of innovation. In aid of this, academia can act as a nexus between e.g. corporations, manufacturers, NGOs, government departments, local communities, and other groups, and can hence understand, communicate, and accommodate the needs and concerns of these groups when conducting application-driven research.

In my research, I use a systems-based approach to understand the requirements and impact of robots across social and ecological networks [13], thus developing effective robotic solutions that are best placed to produce a net positive effect on communities. This requires an embedded design approach, discussion of needs, solutions, and likely impacts with disparate stakeholders and organizations, often including marginalized populations who may require sensitive and responsive intervention.

When developing technology to enhance multimodal communication for inclusive social robots, I worked with disability support and exhibition group Dialogue in the Dark to develop requirements and use cases (http://www.dialogue-in-the-dark.com/). I also collaborated with care home facilities and community groups, Plymouth Hospital, and researchers in human-robot interaction to define useful and appropriate capabilities which could be securely and ethically implemented on the Engineered Arts social robot platform, which is now a successful commercial product: (Socibot Mini [14], Figure 1.2C). In 2015, we created a bespoke robot with stage-control software integration for the production "Spillikin" (performed at Edinburgh Festival and on tour in the UK [15], Figure 1.2D). Behaviours and script were developed in conjunction with Alzheimer's groups and researchers in aged care and human-robot interaction. The production was the recipient of a UK Arts Council Grant and shortlisted for Best of the Edinburgh Festival.

Most recently I've been a invited speaker and organizer on multiple panels and round-tables on robot ethics (NIH Trust Conference on Social Robotics, Berkmam Center Roundtable on law, regulation, and ethics of emerging robotics technologies, IRSPM 'Disruptive Technologies' Panel) and engaging in outreach to promote cross-sector communication around ethical issues relating to robotics [16], [17]. I am also a principal investigator on the multi-instituational ANZSOG grant "Robots and the delivery of care services: Governance implications of robotic technology in the care sector" (HC171025). This project examines current and potential future uses of robots as care and support services, seeking to predict potential ethical and legal issues and devise suitable governance strategies for new socially-focused technology.

Drawing on these experiences, I intend to continue to develop application-driven robotic projects suitable for training the next generation of engineers, and work with industry, government, and community groups to ensure the problems we tackle are both amenable and suitable to robotics-driven solutions. I will also continue to incorporate larger ethical concerns and regulatory issues into the design process, to ensure the development of sustainable, equitable technologies. As an advisor on a forthcoming application to create a Disability Technology Hub (submitted under the Australian Industrial Transformation Research Hubs Scheme), I am working to establish connections encouraging the development of innovative and disruptive technologies that meet the needs of individuals with disabilities, applied ethically and equitably. This project involves working with the UNSW Disability Innovation Institute and alongside US-based researchers and organizations to establish a truly global connected network of stakeholders and experts.

Funding

My background in both research and industry demonstrates a strong track record in managing disparate multi-institutional groups, and acting as project manager and communication nexus for robotics projects linking academia, industry, and arts/educational organizations. Since 2012 I have established over $USD600,000 in R&D and commercialization grants, and both individually and as a member of a research team have brought multiple robotics and hardware projects from conceptualization to either prototype, demonstration, pre-market or commercial level.

Enhancing the capabilities of robots for shared spaces fits squarely within the purview of NIH Robotics Initiative 2.0, and I intend to seek funding from this area. Cross-sector collaborative grants and industry-based funding also offer opportunities and sources I intend to explore in depth. To advance prior exploratory work in governance of care technology, I am writing an ARC grant application with my current ANZSOG grant partners, which will provide travel and funding for qualitative research. The outcomes of this grant will give legislators and innovators the tools and guidelines to develop social robots for therapy/support roles, which ensure beneficial outcomes without reducing social inclusion. My aim is to eventually extend this work to a US context, and to support this I will be seeking funding from the NSF Science, Technology and Society grant pool.

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