Robots that can cope with danger and uncertainty

Dr Jing Xiao develops artificially intelligent and responsive algorithms for compliant and deformable robotic structures that can manipulate and assemble objects even in confined, chaotic spaces.

Why did you become interested in robotics?

Like many people, I am intrigued by artificial intelligence and robotics. I jumped at the opportunity to conduct research into robotics during my PhD studies and have been working in the field ever since, even when robotics went through a low point in the 1990s. Robotics has become a hot field again in the last few years.

Can you describe continuum manipulators?

Continuum manipulators are inspired by invertebrate structures found in animals, such as octopus tentacles or elephant trunks. Unlike articulated manipulators inspired by human arms, continuum manipulators do not have skeletons and can smoothly bend anywhere along their structure to comply with the environment with which they interact. This makes a continuum manipulator more flexible and robust for safe operation in congested environments and for whole arm manipulation of objects under imprecise and uncertain conditions.

What are the difficulties in developing robotic technologies for applications where contact may be required in an uncertain environment, such as with humans?

Safety and robustness of operation are two main difficulties. When a robotic manipulator hands a person a glass of water, for example, it cannot hit the person due to imprecise information about the person’s pose, and it cannot drop the glass before it is securely held by the person.

Safety and robustness of operation are not only important to the people and objects a robot interacts with, but also to the robot itself. When a robot conducts a precision assembly operation, it must cope with uncertainty in part locations. It must avoid jamming or damaging a part, or damaging itself on unintended contact. To overcome such difficulties, my research has been focused on planning robot motion, compliant with contact during assembly, and regulating contact force/torque.

Can you introduce the contribution that you have made in real-time adaptive motion planning (RAMP)?

My group developed the unique RAMP approach to enable a high degree-of-freedom (DOF) robot, such as a mobile manipulator, to operate in a dynamic environment full of obstacles with unknown motions. Clearly, one cannot plan the robot’s motion offline and beforehand, as dynamic environments change in unknown ways over time. RAMP enables simultaneous sensing, planning and execution of motion through an anytime and parallel planning algorithm. This algorithm maintains and updates a diverse set of alternatives to adapt the robot’s trajectory to changes in the environment. RAMP is a completely distributed approach to motion planning of multiple high DOF robots working in the same environment without colliding into one another.

How would you describe your role as Site Director of an Industry/University Cooperative Research Center (I/UCRC) dedicated to Robots and Sensors for Human Well-being (ROSE-HUB)?

I/UCRCs are US National Science Foundation (NSF)-funded consortiums of universities, companies, non-profit organisations and government agencies working together on industry-relevant research in an emerging field. A company or organisation – which can be US-based, multinational or from outside of the US – joins a site as an industrial member by paying a small annual membership fee, which is used solely for funding research projects of their interest.

ROSE-HUB is the only NSF I/UCRC focused on robotic and sensing technology for human safety and security. It consists of five sites: University of Minnesota (lead); the Universities of Denver, North Carolina at Charlotte (UNC Charlotte) and Pennsylvania; and Purdue University. As the Site Director for UNC Charlotte, my goal is to recruit industrial members and create a healthy ecosystem of member companies to best leverage our site’s faculty research expertise to solve real-world problems and provide training to graduate students to maximise benefit to each member as a value multiplier.

In which areas do you see your research having potential applications?

Research conducted in ROSE-HUB, including my own, benefits applications where robotic and sensing technology can spare human workers from operating in hazardous environments or undertaking dangerous or non-ergonomic tasks. These environments exist in healthcare, energy, transportation, manufacturing, materials handling, agriculture, space, entertainment and homeland security, emergency preparedness and response – there are just too many exciting possibilities to enumerate, from space to underwater to everyday life!

Advances in robotics and sensing technologies will mean a robot can work both autonomously and together with human workers in spite of environmental uncertainty and unpredictability. I am glad to be part of this fascinating field.
WITH A FEW exceptions – like HAL 9000 in Stanley Kubrick’s 2001: Adamski's Odyssey – robots imagined in science fiction novels and films often take on a human-like form, with jointed arms for grasping and manipulating objects. Initially, robotics research explored the opportunities possible from arm-like structures; however, with the advent of robotic technology, robots began to assume a much more versatile continuum in the late 20th Century.

Dr Jing Xiao, Professor of Computer Science at the University of North Carolina at Charlotte, is Site Director of a US National Science Foundation (NSF) Industry/University Cooperative Research Centre on Robots and Sensors for Human Well-being (ROSE-HUB). Xiao’s primary interest is robot interactions with people, objects and other robots under real-world, changing conditions.

To date, her work has addressed robot motion planning, haptic interaction, and autonomous robotic manipulation and part assembly. Initially, the approach to the problem of achieving autonomous, whole-arm grasping and manipulation of objects using an elephant’s trunk-shaped manipulator in cluttered, chaotic environments. To begin solving this, she and her team developed real-time algorithms that enabled the manipulator to grasp a target object even where it is surrounded by undefined and unknown obstacles. Using RGB-D camera sensing and visualisation, Xiao extended this capability to achieve automatic detection of objects where there is no clear line of sight in any direction. Her team also developed a machine learning method that enables a robot to evaluate and recognise a cluttered environment from a single view, as well as an optimised visualisation technique for better object manipulation.

Borrowing from nature, the Research Centre on Robots and Sensors for Human Well-being at the University of North Carolina at Charlotte develops artificial intelligence solutions to enable robotics to function more effectively in a broad range of applications.

COMPLIANT MOTION

One area where Xiao and her collaborators are making great strides is robotic manipulation using so-called continuum manipulators, which can be thought of similarly to the tentacle-like arms that H G Wells gifted to the tripod Fighting Machines in his science fiction thriller, The War of the Worlds.

Unlike human arms, continuum manipulators are not constrained in where they can bend. Inspired by the supple movement of elephant trunks, octopus tentacles and snakes' backbones, this style of robotic ‘arm’ is continuous and compliant, and can bend at any point by smoothly moulding itself around the shape of an object, enabling it to grasp and manipulate even very fragile objects. The manipulator we have worked on is called OctArm and was built by Dr Ian Walker’s group at Clemson University. OctArm has three sections, with each section modelled as a bent and extendable cylinder,” she shares.

Excitingly, Xiao’s work on robotic assembly of parts takes into account that there may be inaccuracies in information about the positioning or orientation of each part, its dimensions or shape. She explains that making the motion of the manipulator compliant on contact with the part, however, reduces the dimensionality of its motion and thus uncertainty: “This means that the manipulator can carry out high precision assembly operations in tightly confined spaces”.

To achieve autonomous, compliant motion of a manipulator for its different contact states and in relation to their associated constraints, detailed information about each contact state is required. Building a base of such information manually would be highly tedious and is likely infeasible because of the quantity of data involved for even the simplest assembly tasks. “To circumvent this problem, we build models of possible contact states between two randomly selected polyhedral or curved objects within complex scenarios, including their adjacency relations, to generate contact space information automatically in a graph,” Xiao explains. Her models also generate paths for compliant transition from one contact state to a neighbouring contact state. This enables automatic generation and execution of a compliant motion plan for the manipulator to assemble parts, which is guided by sequential steps through different constraining contact states.

DEALING WITH DISORDER

In the past five years, Xiao has aimed to address the question of how to achieve autonomous, whole-arm grasping and manipulation of objects using an elephant’s trunk-shaped continuum robotic manipulator in cluttered, chaotic environments. To begin solving this, she and her team developed real-time algorithms that enabled the manipulator to grasp a target object even where it is surrounded by undefined and unknown obstacles.
Xiao foresees a world where robots will commonly help with healthcare and care for the elderly, undertake missions too dangerous for people on Earth and in space, and, ultimately, help humankind survive the increasing volatility of the natural environment.

University in Beijing, Xiao is helping to develop a haptic simulation for virtual training of dental students to carry out dental operations. “We have achieved feedback frequencies of up to 1 kilohertz,” she shares.

OPEN FOR BUSINESS
Xiao foresees a world where robots will commonly help with healthcare and care for the elderly, undertake missions too dangerous for people on Earth and in space, and, ultimately, help humankind survive the increasing volatility of the natural environment. “Robots is not just about a monolithic machine called a robot; it is an interdisciplinary, comprehensive field about intelligent systems for physical interactions with people and environments,” she enthuses.

“Progress in real-time robotic manipulation based on sensing is challenging, but necessary for broad applications of robotic technologies in many domains, such as manufacturing, material handling, healthcare, search and rescue, nuclear inspection, agriculture, etc.”

Therefore, Xiao offers the considerable resources and expertise of ROSE-HUB to help companies solve real-world problems, especially those where robotics or simulation can enable completion of a task in a setting difficult or dangerous for humans. “We really want to build strong connections with industry members with the goal of improving society,” she concludes.

While the general problem of robotic manipulation in uncertain environments still requires much more research, Xiao’s Real-time Adaptive Motion Planning (RAMP) approach goes a long way towards solving this complex problem. Funded by NSF, this approach is applicable for high degree-of-freedom (DOF) robots, such as mobile manipulators, when they are required to negotiate dynamic environments full of moving obstacles, such as crowded rooms full of people.

RAMP accommodates different motion goals and optimisation criteria, and allows changes to them ‘on the fly’, according to varying circumstances. Under the RAMP paradigm, Xiao explains: “Robots can be programmed to carry out tasks independently, or in cooperation with other robots, while avoiding collisions with any other robots in the environment even without knowing their movements”.

COMPLEX SIMULATIONS FOR FINE MANIPULATIONS
Another field of robotics that is close to Xiao’s heart is haptics – the study of adding a sense of touch and force feedback to a virtual environment so that a user can experience manipulation of virtual objects via an avatar. Effective haptic interaction is becoming increasingly useful in a wide range of applications, from virtual training of surgeons, to virtual assembly, virtual prototyping and telerobotics. In fact, Xiao has recently co-authored a book – Haptic Rendering for Simulation of Fine Manipulation – to address the key opportunities and issues embedded in this highly impactful field.

Specifically, Xiao’s activities in haptics research focuses on complex, multiregional contact scenarios and the resulting deformations where objects with different characteristics, such as rigid or elastic, interact. For example, in collaboration with researchers at Beihang University in Beijing, Xiao is helping to develop a haptic simulation for virtual training of dental students to carry out dental operations. “We have achieved feedback frequencies of up to 1 kilohertz,” she shares.