UK-RAS
NETWORK
ROBOTICS & AUTONOMOUS SYSTEMS

Robotics in Social Care:
A Connected Care EcoSystem for Independent Living

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UK-RAS NETWORK
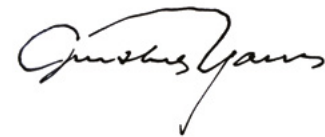ROBOTICS & AUTONOMOUS SYSTEMS

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FOREWORD

Welcome to the UK-RAS White Paper Series on Robotics and Autonomous Systems (RAS). This is one of the core activities of UK-RAS Network, funded by the Engineering and Physical Sciences Research Council (EPSRC). By bringing together academic centres of excellence, industry, government, funding bodies charities, and the public, the network provides academic leadership and expands collaboration with industry while integrating and coordinating activities at EPSRC-funded RAS capital facilities, Centres for Doctoral Training and partner universities. A priority for the UK government is to care for older people and those living with long-term conditions. Over 11 million people living in the UK are aged 65 or older. The latest projections are for this figure to reach 14 million by 2025 and almost 19 million by 2045. The number of individuals disabled by one or more long-term condition is also increasing, driven by overall population growth, improved health care and

sedentary lifestyles. Caring for older people, particularly those with disabilities, places a significant strain on the economy. Innovation, including through advanced robotic and autonomous systems, can have an important role to play. A clear roadmap for a connected care system for independent living is important for providing long-term sustainable social care solutions for the UK. In this whitepaper, we look at the emerging crisis in UK social care and present our vision for creating a connected care ecosystem linking home, residential and hospital care as a continuum. Key research challenges for the future use of RAS in social care are discussed and the report also highlights the opportunities--as well as the associated ethical and societal issues--for researchers, policy-makers and all social care stakeholders to work together.

The UK-RAS white papers are intended to serve as a basis for discussing UK industrial

and social strategies and for engaging the wider community and stakeholders, as well as policy makers. It is our plan to provide annual updates for these white papers so your feedback is essential—whether it be pointing out inadvertent omissions of specific areas of development that need to be covered, or major future trends that deserve further debate and in-depth analysis.

Please direct all your feedback to white-paper@ukras.org. We look forward to hearing from you!

Prof Guang-Zhong Yang, CBE, FREng

Chair, UK-RAS Network

Professor Tony Prescott,
University of Sheffield and
Sheffield Robotics.

Dr Praminda Caleb-Solly,
University of the West of England
Bristol Robotics Laboratory, and Designability.

Contributions:
Jake Beech; Tony Belpaeme, University of Plymouth; Heriberto Cuayahuitl, University of Lincoln; Heidi Christensen, Sheffield Robotics & CATCH; Sebastian Conran, Sebastian Conran Associates; Kerstin Dautenhahn, University of Hertfordshire; Mauro Dragone, Heriot Watt University; Michael Fisher, University of Liverpool; Nigel Harris, Designability; Nick Hawes, University of Birmingham; Ray Jones, University of Plymouth; Oliver Lemon, Heriot Watt University; Paul Newman, University of Oxford; Tony Pipe, Bristol Robotics Lab; Subramanian Ramamoorthy, University of Edinburgh; Amanda Sharkey, University of Sheffield; Noel Sharkey, University of Sheffield; Tom Sorell, University of Warwick; Hilary Sutcliffe, SocietyInside; Sethu Vijakumar, University of Edinburgh

Conflict of Interest Statement: Tony Prescott is a Director and Shareholder of the UK company Consequential Robotics that develops assistive and companion robot technologies.

CONTENTS

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To be effective, rehabilitation requires hundreds of repetitive movements each day. With escalating demands on healthcare resources and increasing requirements in the population, the only way to deliver the rehabilitation people need is to automate routine therapy using robotic devices. This then frees the resources of highly skilled therapists to perform the complex and demanding assessments and treatments for which they are trained.

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Professor Rory J O'Connor MD MEd FHEA FRCP
Charterhouse Professor of Rehabilitation Medicine, Leeds School of Medicine

1. INTRODUCTION

Robotics and autonomous systems are making increasing impact in many sectors. While we are most familiar with industrial robots and factory automation, service robots, which includes systems for use in domestic, personal, and healthcare settings, is the fastest growing sector. For the period 2016-19 the International Federation of Robotics (IFR) projects sales of 31 million new service robots for domestic use representing a global market of US $13.2 billion [1]. The IFR also forecasts sales of 37,500 assistive robots, across the same three-year period, targeted specifically to support the care of people who are older or who have disabilities. This is an emerging market projected to have strong growth over the next 20 years.

Social care throughout the UK is under unprecedented pressure due to our ageing population. This challenge will not be solved through technology alone, nevertheless, as a nation we have a history of responding effectively to such crises through creativity and invention. Innovation, including through advanced robotic and autonomous systems, can have an important role to play. The UK has a growing RAS and artificial intelligence (AI) sector, an increasingly integrated National Health Service, is pioneering in telehealth [2], and is recognised as a global innovator [3]. This white paper discusses the potential for RAS to provide long-term

sustainable social care solutions and for the UK to be world-leading in this field. Our report highlights the challenges, opportunities, ethical and societal issues and provides a roadmap towards the enhancement of UK social care through RAS.

An effective strategy to introduce RAS into social care requires that researchers and technologists partner with people in need of care, their formal and informal carers, healthcare and service providers, clinicians and third sector organisations. There is a requirement for repeated cycles of participatory design involving these different stakeholder groups in order to match the best of UK research and innovation with a clear understanding of societal need. We recognise that people have genuine concerns about the increased use of technology in care. The path ahead needs to be charted carefully and progress made with the participation and consent of all stakeholders. Our hope is that such an approach can identify RAS technologies that will provide real improvements to UK social care, alongside safeguards to protect against threats such as a reduction in the human aspects of care. Our strategy is based on a national demand for more effective technologies to support people in need of care and on the belief that as a community we have a moral obligation to research and develop such technologies [4].

© Three Sisters Care

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There are numerous successful tech innovations happening at the frontline of social care, but the current underutilisation of both medicinal and digital technology means that there is real opportunity to unleash a new wave of innovation that could have a revolutionary impact on how care is delivered, and how patients interact with professionals to manage their own health and care […] We recommend pump priming of technological innovation through match funding for new applications that will improve the delivery of social care."

The Institute for Public Policy Research [6].

2. THE CRISIS IN UK SOCIAL CARE

11.6 million people in the UK are aged 65 or older, this number is projected to grow by around 2.4 million in the next decade reaching a total nearly of 19 million by 2045 [5]. The number of individuals with one or more long-term conditions, such as stroke, arthritis, heart disease or dementia, is also increasing driven by overall population growth, access to improved healthcare and poor lifestyle choices. Across the lifespan the incidence of disability increases with age from around 18% of those of working age to 44% of those over state pension age [6].

Providing care for older adults with ageing-related impairments requires considerable resources and public funding is failing to match demand. Total public spending in England and Wales on social care in 2015/16 was £8.34 billion compared to £8.3 billion a decade earlier (2005/6) [7]. Given inflation, and an increase of almost 2 million in the number of people aged 65+, this represents, in real terms, a per capita reduction of available funds of over one third. In April this year the government announced an additional £2 billion to councils in England, over the next three years, to spend on adult social care services, however, this will only begin to plug the funding gap. Age UK estimate that there are now nearly 1.2 million older people who do not receive the help they need with essential daily living activities, an increase of 48% since 2010. Nearly 1 in 8 older people in the UK now live with some level of unmet care need [7].

The UK also has a shortage of qualified nurses and residential care workers, expected to worsen as the number of jobs in care increases by up to one million by 2025 [7]. In 2015/16 the overall staff vacancy rate across the whole of the care sector was 6.8 per cent, up from 4.5 per cent in 2012/13. Turnover rates have risen from 22.7 per cent to 27.3 per cent per year over the same three-year period [7]. Meanwhile, older people are waiting longer for care with waiting times for residential care placements increasing 40 per cent since 2010 [7]. Delays in being discharged from hospital care have increased by more than 180 per cent in the same period placing an additional and costly strain on the National Health Service [7].

What is Telehealth?
Telehealth, or telecare, is the provision of healthcare remotely via telecommunications technology. Telecare includes remote monitoring of patient health, for instance, using portable, wearable, or implanted devices. The remote system can track patient health over time, detect early signs of deteriorating health, communicate with the user remotely with health advice and reminders, and trigger interventions when needed. Telecare helps people to live independently and can reduce the need for hospital admissions. Telehealth provision can be extended using assistive robots that can provide better monitoring, physical support, and that can take immediate action in case of medical emergencies. Telerobotics is the remote operation of a robot by a healthcare practitioner, this could include operating a telepresence robot in the home, and in the future, could extend to remotely operating a robot that can provide a physical intervention.

A 2013 House of Lords report considered the on-going demographic shift and its impact on our care services and stated the problem plainly: "The UK population is ageing rapidly, but the Government and our society are woefully underprepared" [8]. The challenge is recognised by the UK parliament and social care became a key topic for debate in the UK 2017 General Election; the government has committed to publish a Green Paper this year. Although all of the major political parties have promised to increase spending on social care there is a need for a coherent long-term strategy to address the consequences of our ageing population whose impacts will be felt across at least three generations.

Whilst we will need to invest more in social care in the coming years, both as a society, and as individuals who are living longer, technology could have an important role to play in easing the care burden. Carers UK, a charity which represents 6.5 million unpaid carers in the UK, has called for increased investment in technology to support

caring as part of the UK government's industrial strategy [9]. The independent think tank, the Institute for Public Policy Research, have also called for a new wave of innovation in social care [10], and the Policy Innovation Research Unit, which is sponsored by the Department of Health, has called for new thinking about how we provide affordable healthcare [11]. A large-scale, randomised UK trial showed that use of telehealth services is associated with lower mortality and emergency admission rates [12]. The message of the current report is that there is potential for using advanced service robots and autonomous systems as part of a broader national strategy to meet the healthcare requirements of the UK's ageing population. RAS technologies can enhance telehealth provision both through the use of artificial intelligence and through their capacity to physically act in the world. This should not only provide cost savings but could also deliver user benefits in terms of immediacy of care, perceived control, and protection of dignity.

What are Robots and Autonomous Systems?

Robots and Autonomous Systems differ from standard machines in that they make their own decisions—this is what we mean by "autonomy". To act autonomously these systems must be able to understand the world sufficiently well to plan good courses of action and this requires both appropriate sensors (cameras, microphones, and so on) and smart control software. This often includes the kind of computer programs that are described as having "artificial intelligence" (AI) and that can adapt and improve their behaviour over time using machine learning. Robots are autonomous machines that have a physical presence in the real world--they are able to move and act and may have "actuators" such as wheels, jointed limbs and grippers. Although we often imagine robots as looking like people—what we call "humanoid" robots, they can also look like everyday devices such as tables, vacuum cleaners, and cars as this report will show. Indeed, it is likely that most of the robots that will be used in social care will look more like familiar items that we already find in the home than the robot "butlers" imagined in Science Fiction. At the same

time, however, there may be a role for more human-like or animal-like "companion" robots in providing some forms of social interaction and support in care.

The term "autonomous system" describes a collection of machines and devices that share information and coordinate their actions often through centralised decision-making. In social care an example of an autonomous system could be a "smart home" that senses its occupants and that manages multiple systems within the house such as heating, air-conditioning, lighting and alarms based on knowledge of the occupant's needs and activity. In the future, more and more devices in the home will become part of this autonomous system including smart fridges and cookers, washing machines and driverless vehicles. Future smart homes will also include different kinds of robots, such as ones that clean and tidy, or that prepare food. Hospitals and residential care facilities will also include more of this kind of autonomy, and these different locations in which care is provided will link to with each other via cloud services to provide an integrated care service from home to hospital and back.

The use of assistive robots also has the potential to address the growing shortage of health and social care workers. Suitably configured robots could assist professional carers to be more efficient, allowing them to focus more on the human-to-human aspects of their work, and reducing the physical demands of caring (such as lifting and carrying) and consequent risk of injury. Robots are being developed to provide general assistance around the home, for instance, performing household chores and assuring safety, but they also have the potential to assist directly with physical aspects of care including help with personal mobility, eating and drinking, dressing, and toileting [13, 14]. Robots are also being developed to help people rehabilitate following illness or injury, allowing a more rapid return to health and independent living. We will explore these technologies in this white paper and demonstrate how a network of these systems, connected via digital infrastructure, and integrated with human social care support, could provide a new care ecosystem for the UK.

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Health systems across the world need new thinking. They are increasingly facing escalating demand from an ageing population and the growing incidence of chronic disease. Healthcare is consuming an ever-increasing share of gross domestic product (GDP). The search is on for ways of providing the best quality healthcare as affordably as possible.

The Institute for Public Policy Research [11].

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It is my wish and it's my challenge to you and to others out there to build me a robot. Yes, that's right a robot! It sounds almost insane but as a child and even today I've always wanted and would love to have a robot. The main thing the robot would be doing is picking up the objects I drop such as a pen, knife, fork, and or my phone. This robot would become my hands and legs [...] the challenges I face everyday get bigger and far greater to overcome. I know I can overcome these challenges but I need your help.

(Joanne O'Riordan, Speech to the United Nations, April 2012).

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3. PEOPLE WHO ARE IN NEED OF SUPPORT THROUGH SOCIAL CARE

It is important to understand the needs of people who, in different phases of life, may require support through social care. Such an understanding will allow for the development of appropriate and effective technologies to assist in the provision of care to different user groups.

The largest group of people who are in need of support through social care are those in later life.

As we enter later life, most of us retain intellectual and physical function but face increasing challenges in maintaining our environments—for example, difficulty in completing household chores—through a gradual decline in physical agility, sensing (the senses of sight, hearing, smell, touch), and mental acuity. At some point during ageing many of us also face additional challenges of acute or chronic illness that can lead to increased disability and to difficulties in looking after our physical selves. The challenge of providing direct physical support is most significant amongst the oldest old (85+).

We propose that the development of robots for social care can be focused towards both of these general categories of need—help in maintaining your home and a healthy lifestyle, and help with the physical challenges facing those living with frailty or with long-term illness or disability.

A need for increased support and care can be triggered by negative health events but also by psychological and social factors. For instance, a sudden failing of the body, for example due to a fall, or a loss of social support, such as through bereavement, could lead an older person to lose confidence in their ability to live independently. Assistive technologies, including robotic systems, could provide support through such a transition that could help avert an early move into institutionalised care.

A further important user group for UK social services are people living with long-term disabilities who may be of any age and whose condition may be stable over the long-term. In the UK, nearly seven million adults of working age and around three-quarters of a million children are living with some form of disability [15]. The needs of these groups are varied and can differ significantly from those of people who have become disabled as they are ageing. The technologist and disability campaigner Hugh Herr, who develops prosthetic limbs and walking aids, has argued that we should not accept the limitations of disability but should use technology to overcome them. In 2012, the Irish teenager Joanne O'Riordan, who was born without arms or legs, gave a speech to the United Nations asking for a robot that could help her to replace the function of her missing limbs in order to live a more independent life. The ambitions of these visionaries can be realised through a concerted societal effort. There is the potential to develop technologies that can partially or even fully compensate for some forms of disability helping people to become more independent, fulfil personal ambitions, move into employment, and participate more fully in social and cultural life. Since AI and robotic systems lend themselves to personalisation there is also the potential to develop generic solutions that can be customised through software and machine learning to match individual needs. At the same time, we are also inspired by the social model of disability, and as such recognise that the social, environmental and organisation context also need to be adapted [16]. The onus is not all on the person with the disability to adopt technology—improvements to accessibility in the built environment, to products, and to digital resources, will also enhance quality of life.

> " Humans are not disabled. A person can never be broken. Our built environment, our technologies, are broken and disabled. We the people need not accept our limitations, but can transcend disability through technological innovation. "

Hugh Herr, Technologist at MIT Media Lab and Campaigner for the Rights of People with Disability.

4. THE VISION—A CONNECTED CARE ECOSYSTEM: HOME, RESIDENTIAL CARE, HOSPITAL

We propose a role for robotics in supporting social care that connects together support at home, in residential care, and in hospital. To promote care at home is generally the cheapest and preferred option, but support in residential care and in hospital will also improve quality of life. Better support for independent living can ease the transition from hospital back to the home (or care home) freeing up vital resources in the National Health Service. Each care setting has its own challenges. Good solutions will promote universal design and built-in customisation—useful for everyone and adaptable to changing needs.

As the demography of the population changes, and as healthcare technologies become more portable and easier-to-use, we may also see the boundaries between what constitutes social care and what we consider to be healthcare becoming increasingly blurred [17]. With greater availability of point-of-care diagnostics, and an expansion in the range of medical devices developed for use at home, the role for assistive robotics could extend to include monitoring and emergency treatment of acute conditions in the home environment. Telerobotics could form one element of this approach with specialists providing some healthcare services at home via remote operation of robotic devices.

Rehabilitation following accident or illness often involves dietary and exercise regimes that require long-term supervision and support. Robotic and virtual reality (VR) systems are currently entering the healthcare market that can support rehabilitation programmes both in hospital and at home leading to much improved results in long-term recovery. For instance, in the case of a motor impairment due to stroke, a rehabilitation robot can provide a customised training programme directed at a specific group of muscles or movement types, and tuned to reduce the amount of help given as the ability to perform controlled movement returns.
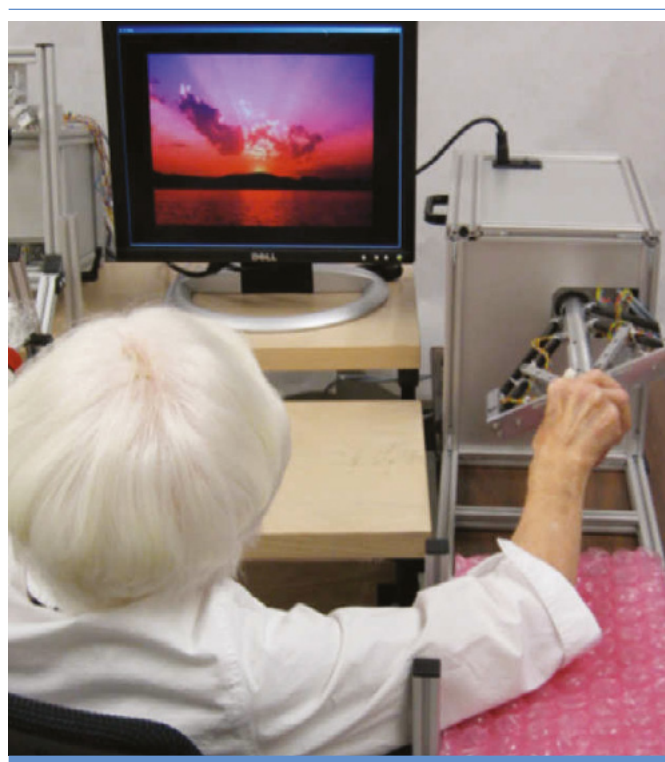
Rehabilitation Robot
Stroke is one of the leading forms of adult disability. Researchers at Imperial College London have examined the needs of people who had suffered stroke and have developed robotic rehabilitation tools to help them to improve their hand function. Clinical trials have shown a significant improvement of the motor function in both hand and arm even though only hand movements were trained.

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Technology to support caring and more flexible working is both a means of supporting the wellbeing and employment prospects of carers and in itself is an area of economic growth that should be fostered and incentivised.

Carers UK [5].

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5. RAS TECHNOLOGIES TO SUPPORT INDEPENDENT LIVING

Successful aging has been defined to include a low probability of disease and disease-related disability, a high level of physical and cognitive functioning, and an active engagement in life [18]. Good health can be promoted as we age through maintenance of physical activity, good diet, regular social interaction, high levels of perceived autonomy, and good quality sleep. Robots developed to assist us as we age should help us to maintain the physical and social activities that we consider important, assist us to eat and drink appropriately, and should promote feelings of control and empowerment. The challenge is to design systems that provide useful forms of support without discouraging people from being active and caring for themselves.

We already have a number of robotic devices that can assist in the home. Many of us have one such device already—the automatic washing machine. This can be viewed as a robot technology since it combines sensing with actuation, and, with modern washers, smart algorithms that determine the most effective washing and drying routines based on clothing type, level of soiling and so on. It is likely that some of the future robots we will have at home will be of this kind, that is, RAS technologies incorporated into everyday devices, that will provide enhanced support for independent living. Robot vacuum cleaners are now becoming increasing popular along with floor cleaners and lawnmowers. Other aspects of daily living are set to be automated such as tidying, ironing, and gardening. As these devices improve their ability to function autonomously, including automatic recharging, scheduling and planning, they will provide better support for people in maintaining their environments as they age.

Robotics devices, alongside digital assistants of other kinds, can also provide people with some forms of social support. For instance, helping to link people to friends and family, suggesting activities, or participating in some shared activities. Older people who live with a companion animal, such as a cat, have reduced experience of loneliness [19] and may have reduced risk of heart disease [20]. For people who are unable to keep animal pets, it is possible that some similar benefits could be obtained from robots designed to emulate the social intelligence of animals. Some evidence in this direction comes from studies using the therapeutic seal robot Paro that have reported positive outcomes including improved mood states and engagement in older adults with dementia [21]. People that live alone may suffer from poor sleep due to worries about safety and the risk of intruders.

Dyson 360 Eye™
The Dyson Robotics Lab at Imperial College is one of the leading research labs in the world on robot vision. It is funded by, and collaborates closely with, the UK company Dyson ltd on the perception, navigation and manipulation capabilities that will enable the next level of smart robotic products. This collaboration has already strongly influenced Dyson's development of their first robotic product, the Dyson 360 Eye robot vacuum cleaner, now on sale around the world.

The presence of a companion robot, acting as a monitoring device and potential interlocutor with support services, could provide some reassurance and thus lead to a better night's sleep.

A key aspect of ensuring the utility of assistive robots will be to develop contextual and social intelligence for robots that will enable them to interact appropriately, safely and reliably in real-time. This will require some understanding of both environmental and human user characteristics, and could be enhanced by integrating RAS technologies with smart home sensors and external healthcare databases. With the support of data analytics a robot could intervene proactively in a range of assistive scenarios, such as medicine adherence, nutrition and rehabilitation support, as well as social engagement.

Robotic systems, currently under development in the UK, that can support independent living include:

- Help with daily living. The Innovate UK project CHIRON is developing a set of interchangeable robotic components that can help people with a range of domestic and self-care tasks independently or with the support from a care assistant. The aim is to develop a solution that offers adaptability to a person's changing needs as they age. The project is led by the assistive technology charity Designability working with Bristol Robotics Laboratory, the Shadow Robot Company, and care provider Three Sisters Care.

MiRO
is a prototype for a pet-like companion robot developed by Consequential Robotics, a spin-out from the University of Sheffield.

GATEway driverless pod
The driverless pods used in Transport for London's Gateway project are controlled by autonomous systems technology developed by Oxbotica a spin-out from the University of Oxford.

- **RAS for smart homes.** Future homes will integrate multiple RAS and Internet of Things technologies with interfaces that allow these to be controlled by users. Plymouth University is developing speech and tablet-based interfaces for assistive robots that are able to operate inside and outside the home. One of their ambitions is to control an outdoor robot on a trip to the local shops. This work is part of a wider EU-funded project, Robot-Era, with commercial and university partners in Italy, Germany, Sweden and Spain. Researchers at Heriot-Watt University are using AI and machine learning methods to autonomously adapt smart home technologies to the changing and evolving situations of their users. The University of Sheffield is developing Automatic Speech Recognition technologies (ASR) for people with conditions that affect their ability to speak clearly.

- **Robot companions.** The MiRO robot is a prototype for a pet-like companion robot that is being developed by Consequential Robotics, a spin-out from the University of Sheffield. Based on twenty years of research on animal-like robots, funded by the EPSRC and EU Framework programmes, MiRo is being evaluated for its potential as a robot companion for the home, and for applications in robot-assisted therapy.

- **Driverless vehicles.** Autonomous transport systems promise to transform mobility for older people and those with disabilities, offering greater independence and freedom of movement. The GATEway project led by Transport for London, uses Selenium, a control system

for driverless vehicles developed by the University of Oxford spin-out company Oxbotica. Selenium has the ability to know where it is, what's around it and what to do next, using data from lasers and cameras placed around the vehicle. The FLOURISH project, sponsored by Innovate UK is using human factors research to investigate older travellers' expectations about driverless vehicles. Working with Bristol Robotics Laboratory and a team of commercial partners, the charity Designability is developing a set of scenarios that explore people's travel needs and analyse barriers and constraints related to accessibility.

- **Building safety and trust in robots.** If people are going to accept RAS into their homes it is essential that they are safe and that people feel able to trust them. Intrinsically safe robots must incorporate safety at all levels—mechanically, in terms of software, and in their interaction with the world. The EPSRC-funded ROBOSAFE project is an academia-industry partnership involving Bristol Robotics Laboratory, together with Hertfordshire and Liverpool universities, that is looking to assess and verify the safety of robotic assistants during interaction with humans. The University of Hertfordshire is part of the Horizon 2020 project SECURE that is training a new generation of researchers to develop safe cognitive robot concepts for human work and living spaces. The team at Hertfordshire are also investigating people's physiological responses to robots in a home environment, where people and robots have to share space, with the goal of designing robots that are able to adapt their behaviours so as to minimise user stress.

6. RAS TECHNOLOGIES TO HELP ADDRESS PHYSICAL AND COGNITIVE CHALLENGES IN CARE

Two groups of people in our society need additional physical or cognitive help through social care: older people who are frail or living with disability and people of any age who are living with a chronic condition or disability. The care needs of people in such circumstances are determined by the extent of their impairments, disease burden, and factors such as depression and withdrawal that may arise as a consequence of perceived loss of control and social isolation.

As people age, the loss of independence in activities of daily living tends to follow a certain sequence [22]. People initially become dependent due to difficulties in performing activities such as dressing and personal hygiene. This is often followed by problems with moving from a bed or chair or in using the toilet independently. Finally some older people may develop difficulties in feeding themselves or could become increasingly bed-bound. These changes are gradual and take place at a varied pace. The Rockwood Clinical Frailty Scale is a useful measure by which to categorise the different levels of physical and cognitive impairments along this trajectory [23]. The goal of assistive robots can be seen as enabling successful ageing by providing help with daily living during the initial decline in abilities whilst promoting activities that will delay the onset of later-stage difficulties. The challenge for a successful RAS solution is to be able to provide support at multiple points along the healthcare continuum and to be able to detect changes in physical and cognitive ability as they happen. Ensuring that the technological solutions that we provide continue to be relevant to a person's needs as they age is not a trivial task.

RAS technologies are being developed to provide physical help with many of these daily living challenges from physical mobility through to self-care tasks such bathing, dressing, toileting, and eating. Devices that support physical mobility can assist with moving from a chair to standing, or from a bed to a chair, support in moving around the home, or outside the home using driverless car technology. Support for physical challenges can include adapting existing devices to include robotic features. For example, intelligent toilets are already available with automatic cleaning and drying features. Nevertheless, many challenges around hygiene and dressing require a level of physical dexterity and safety lacking in present day robots. For help with eating and drinking there are a number of robotic devices that can directly assist with bringing food or drink to the mouth.

Robots with social and companionship capabilities are being developed to support people with cognitive impairments and can be useful alongside human support networks and IT systems to provide monitoring of health and safety and reminders of when to eat or drink or take medicine.

Robotic systems, currently under development in the UK, that can help with physical and cognitive challenges include:

- **Intelligent furniture.** Future homes will integrate robotic technology into many everyday devices and objects; expanding their functionality, ease-of-use, and customisability. An important class of objects will be items of furniture that have embedded intelligence and actuation capabilities. IntelliTable is an overbed table enhanced with robotics capabilities that enables it to come to you, rather than you going it. Developed for people with limited mobility, the table could be useful at home and in hospitals. IntelliTable was developed by the University of Sheffield in collaboration with the UK design company Sebastian Conran Associates and with funding from the EPSRC and Innovate UK. A successful pilot project led to the formation of the spin-out company Consequential Robotics.

IntelliTable
is an example of robotic furniture designed to increase independence in the home for people with limited mobility. Developed by Consequential Robotics a spin-out from the University of Sheffield, and shown here with David Constantine the co-founder of the charity Motivation.

- **Help with dressing.** Dressing and undressing is often one of the first tasks of daily living where people begin to lose their independence. The main objective of the I-Dress project is to develop a system that will provide proactive assistance with dressing to people with disabilities. In the project, which is supported by the EPSRC through the CHIST-ERA initiative, researchers at Bristol Robotics Laboratory are collaborating with partners in Spain and Switzerland.

- **Slowing cognitive decline.** Research demonstrates that keeping the brain active slows cognitive decline in people with dementia. Researchers at the University of Lincoln, supported by Samsung Electronics, are creating a framework for training AI conversational agents to operate in different activity domains and across multiple sensory modalities. This framework has recently been applied to robots playing social games.

- **Exoskeletons and prosthetics.** People with gait disorders can use exoskeleton technologies to improve their motor function and increase their independence. In the future exoskeletons may even replace wheelchairs. The University of Edinburgh in collaboration with the design agency IUVO and the Shadow Robot Company have developed two exoskeletons, one that provides support at the pelvis the other at the ankle. The novel control systems being developed use an optimisation-based framework to modulate and provide the correct magnitude and timing of physical assistance that is appropriate for both the task and the individual user. Edinburgh University is also working with the robotics SME Touch Bionics on sensory feedback and control for iLimb a variable-grip prosthetic hand.

Care Challenges Where Ras Can Provide Assistance

Bathing		Gardening	
Dressing		Taking out the trash	
Toileting		Laundry	
Continence		Public transportation	
Feeding		Taking medication	
Transferring		Mobility	
Using the phone		Connecting to friends and family	
Shopping		Promoting exercise	
Preparing meals			
Housekeeping		Entertainment and education	
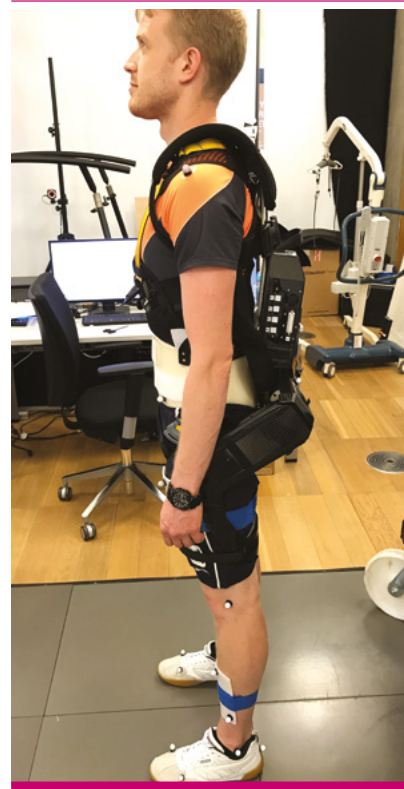
Exoskeleton
This exoskeleton from the University of Edinburgh is being developed to help people who have difficulty walking unaided.

7. KEY RESEARCH CHALLENGES FOR THE FUTURE USE OF RAS IN SOCIAL CARE

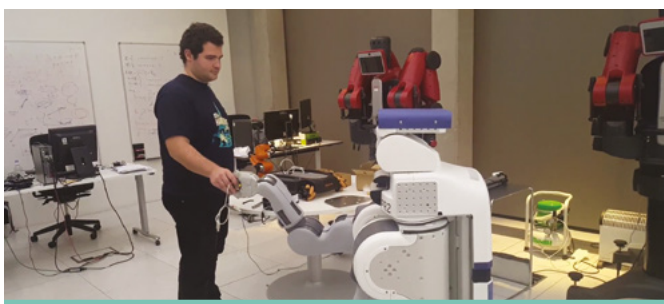To build RAS technologies that can enhance UK social care we will need to improve on the existing state-of-the-art of robotic technologies. Advances are needed in the following areas:

- **Scene awareness.** For robots to operate effectively and flexibly in people's homes requires advances in AI capabilities for mapping and understanding human home environments. GPS does not operate inside buildings, options include integration with smart home localisation systems, tagging rooms with machine-readable beacons, and developing indoor localisation and mapping algorithms, based on vision or active sensing systems (e.g. pulsed laser light). These systems must be able to cope with changing environments including people and objects that move. Advances are also needed in technologies to recognise everyday objects and know what they are used for.

- **Social intelligence.** To be able to help people, robots will first need to understand them better, this will involve being able to recognise who people are, and what their intentions are in a given situation, then to understand their physical and emotional state at that time, in order to make good judgements about how and when to intervene. These systems will need some understanding of how people interact with each other and with objects in their environments in order to operate safely and usefully. In a real world situation, the robot might also have to deal with unpredictable interventions, such as a pet or young child doing something unexpected.

- **Physical intelligence.** Current robots fall well short of the dexterity and safety needed to physically interact with people in tasks that involve close physical contact including many aspects of dressing, feeding, and toileting. The human ability to grasp and manipulate complex objects with our hands is unique in nature, particularly as humans use a range of senses and years of learnt knowledge in order to do this; emulating this with artificial systems will be extremely challenging.

- **Communication.** While technologies for automatic speech recognition (ASR) are improving, there is a need to adapt these system for use in noisy environments and for a wider range of voices, accents and dialects. Some people who are in need of care have impaired speech and are not able to benefit from current ASR technology. Research is also needed to understand verbal intonation and forms of non-verbal communication such as expression and gesture.

- **Dialogue.** The ability to understand the meaning of what people are saying (as opposed to simply recognising the sequence of words in human speech) is still at a relatively primitive level within AI. This means that there can be a disconnect between the ability of existing RAS technologies to talk fluently and their capacity to engage in forms of meaningful dialogue. This can be confusing and disappointing to users, indeed, until dialogue systems improve it might be better for such systems to talk in simpler language more commensurate with their actual level of understanding.

Robots That Learn From Instruction
Researchers at the University of Edinburgh are exploring how to teach a robot to follow instructions, for instance, where an older person wants to train the robot to carry out a daily living task. The robot tracks eye and hand movements, listens to natural language instructions, and uses machine learning to build up an abstract description of the task that can be generalised to other objects or settings. This research is being conducted with PhD students at the Edinburgh Centre for Robotics Centre for Doctoral Training.

Socially Intelligent Conversational robots
Heriot-Watt and Glasgow universities are collaborating to develop spoken dialogue systems fro robots that can interact with humans to understand complex social situations. These conversational systems can act as engaging socially-intelligent "containers" for more task-oriented dialogue interactions such as medication adherence, and can be used to combat social exclusion by proactively suggesting social activities and opportunities for connecting with other people.

- **Learning from data, social interaction and knowledge sharing.** RAS will benefit from learning offline and on the job, based on the latest advances in machine learning and including the ability for users to train robots in specific tasks. Acquired knowledge should be transferable between robot platforms and tasks given appropriate safeguards around data privacy.

- **Memory.** In addition to acquiring skills, RAS technologies will need to have some memory of events and to be able to relate these to people's routines and preferences. Whilst current robots can store everything that happens as raw sensory streams this does not mean that they are able to retrieve useful information when needed or even understand the significance of past events. Data needs to be classified and tagged, and stored in such a way that event memories can be accessed using contextual and user-provided cues. Memory systems need to operate in a transparent way that respects user privacy, in particular, users should be able to choose when the system is storing data, and should be able to selectively delete stored data.

- **Long-term autonomy and safe failure.** To provide effective support in the home RAS technologies will need to be able to operate safely 24/7. This requires improvements in the physical design of robots to make them more robust and strategies for self-monitoring and diagnosis of failure. For critical support systems strategies to manage system down-time during charging or maintenance cycles will need to be considered. When systems fail it is also important that they do so without compromising user safety and are able to recover autonomously where possible.

- **User interfaces.** People will control RAS technologies in multiple ways including via voice command, touchscreen, and gesture. For carers, and for people with disabilities that limit movement, research will develop new ways of operating or interacting with robotic devices including teleoperation through virtual reality and smart clothing, and brain-machine interfaces that allow control of a wearable prosthetic or remote assistive device simply by thinking.
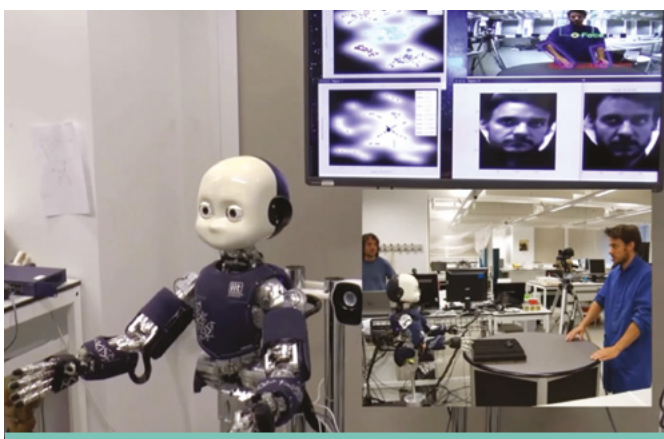
Making Sense of World Through Memory
Sheffield Robotics is developed memory systems for robots that are modelled on human autobiographical memory and our ability to remember appropriate information from the past to better understand the current situation. Here the iCub robot is using computer vision and machine learning to recognise faces and actions performed by people. This research is supported by the European Union Human Brain Project.

Operating 24/7
Researcher at the University of Birmingham are trying to provide robots with the longevity and behavioural robustness necessary to run continuously in dynamic human environments. Their approach is based on understanding 3D space and structure and how it changes over time, from milliseconds to months. Extracted structure includes 3D shapes, objects, people, and models of human activity. The group are also developing control systems that can exploit these 3D models to generate appropriate behaviour in security and care scenarios. This research is part of the STRANDS project funded by the EU Framework Programme.

- **Dynamic autonomy and responsibility.** Human care providers need to be able to override or indirectly control (teleoperate) robotic care systems, this means that such systems should be designed to support varying levels of autonomy. There is a range of stages between full autonomy and direct human control, and the foundations and implementation of variable autonomy across these is only just beginning to be developed.

- **Verification and validation.** We need to be able to verify that RAS technologies will perform as intended, and that their behaviour will match requirements and emerging regulations on service robot safety. RAS technologies will need to be tested rigorously under a range of different conditions to ensure they behave in a predictable manner, suitable benchmarking and testing frameworks will need to be defined for this purpose.

- **Sustainability.** Assistive technologies must be designed to optimise energy efficiency and with a clear strategy for reuse and recycling that will minimise environmental impact. Mobile systems should be able to recharge autonomously and frequently so as to reduce the need to carry heavy and expensive batteries.

- **Integration, networking and security.** To operate as part of the wider care ecosystem we will need to rethink control systems architectures to operate in an environment where communication and interaction with other smart systems is the norm. Given the importance of protecting privacy, good cyber-security is essential. The use of data must be transparent and user-consent must be obtained for any transfer of data outside the home.

- **New robot designs.** Future RAS systems will benefit from advances in materials, sensors, and motors, including the use of lightweight parts and soft robotic components that will increase safety and energy efficiency.

A National Network of Research Laboratories
The EPSRC UK-RAS Network is connecting research institutions around the UK to collectively address many of these research challenges. We have participating research groups in more than a dozen UK Universities, with hubs that include "home lab" test-bed facilities that emulate a home care environment in Bristol, Sheffield, and Edinburgh. This picture shows the Bristol Robotics Assistive Living Studio.

8. THE UK CAN BE WORLD-LEADERS IN SOCIAL CARE

The UK is not alone in having an ageing population. Globally, the proportion of people aged 60 or over was just 8% in 1950 but this is projected to rise to 20% by 2050 [24]. In many European countries, and in Asian economies including Korea, Japan, and China, the proportion of people age 60+ will be approaching 40% by 2050. As a global business and growth opportunity, assistive robots and services present significant possibilities. The worldwide medical robotic systems market size was valued at more than 7 billion dollars in 2014 [25]. This market encompasses assistive robots, which also include home-based rehabilitation robotics. Given the emerging size of this global "silver" market, this represents a significant export opportunity for UK companies that can create advanced technologies for enhancing social care worldwide.

Around the globe the world population is ageing

In 2014 InnovateUK announced a Robotics and Autonomous Systems Strategy [26] to promote the UK's competitiveness in RAS through co-ordinated development of assets and skills across academic, public and private sectors. The strategy recognised that the UK can lead in global innovation in RAS given appropriate co-ordination and support. Robotics in health and social care has been identified as a key area for development and investment by the EPSRC as part of its Healthcare Technologies Grand Challenge [27]. Government programmes are also promoting wellbeing and independence for older people and carers within communities to help people maintain their independence at home. The recent "Long Term Care

Revolution" [28] initiative, established by Innovate UK, is an example of such a scheme looking to encourage innovative solutions that include robotics. Support for research on novel solutions in healthcare and assistive robotics is also provided by the European Horizon 2020 programme which has sponsored a large number of projects that include UK companies and research groups (see, e.g. [29]). With the UK's exit from the European Union it is critical that the UK demonstrates leadership and self-reliance whilst also seeking new opportunities for partnership in Europe and worldwide. Research in the UK is state-of-the-art, however, many of the leading robotic platforms for social care have been developed overseas, for example, in Japan, the USA, and South Korea. Collaboration with international partners could see UK technology, for example homegrown AI, sensing and control systems, working onboard platforms developed elsewhere, however, the greatest impact and benefit to the UK economy will be obtained if we can develop both the hardware and software components of RAS care systems natively. This requires partnerships across multiple fields of engineering alongside involvement of British manufacturing supply chains. Building these systems can create new jobs for skilled workers as part of the emerging "Industry 4.0" economy. The potential benefits of priming growth in this sector through public support has been highlighted in the UK government's industrial Strategy Green Paper [30].

Whilst existing research support is having some impact, investment is low in relation to the scale and importance of the societal challenge. Moreover, there is only limited evidence of research into assistive robotics translating into new products and services, with many assistive robotics research projects not reaching commercialisation. This disparity between the promise of basic research and translation into real-world impact, the so-called the commercial "valley of death", occurs in other domains of innovation and experience shows that it can be bridged through better planning and coordination and through proactive intervention [31]. To achieve commercial breakthrough research needs to be better grounded in an understanding of user need and successful lab-based research must be followed-up by real-world user trials and impact studies. Paths to markets and potential business models should be analysed at an early stage and gaps identified where the investment risk can be reduced through targeted public funding. A key part of the strategy must

be to encourage the emerging SME base for innovation in healthcare robots through UK-based seed funding, and by streamlining opportunities for prototyping and testing within the NHS and within government-funded social care services.

We foresee a strategy that brings together different stakeholders to create a step-change in the capability of robotics and AI systems to support social care. The strategy could be formulated around a 'grand challenge' with realistic targets and milestones based on the growing user demand and the expected advances in RAS technologies (see next section). Successful execution of this strategy will involve working with a worldwide community of developers but with the UK playing a lead role at multiple levels from basic research, through user testing, to understanding societal impacts and addressing ethical concerns.

Stakeholders

UK-RAS
NETWORK
ROBOTICS & AUTONOMOUS SYSTEMS

Government
BEIS, DH, Local authorities

Care Providers
NHS, Public and Private Social Care providers

Regulation
Standards bodies, text & certification, legal services

Hospitals

Care Settings

Residential

Third Sector
Carer organisations, Charities

Telecare

Care at Home

Supply Chain
SME Innovators, system integrators, manufacturers

Research and Innovation
UKRI (InnovateUK, EPSRC), Universities

The Stakeholder Network
Research and innovation in RAS for social care will require collaboration between researchers, end-users, care providers, the manufactuing supply chain, regulators and government. Solutions should be integrated, via telehealth systems, to operate across the different locations where care is provided from the home, through residential care, to the hospital.

9. A ROADMAP TO THE CONNECTED CARE ECOSYSTEM FOR INDEPENDENT LIVING

The table opposite considers how RAS technologies for social care might evolve over the next three years (till 2020), the five years after that (till 2025), and the following decade (till 2035), recognising the expected growth in the number of older people living in the UK during these periods. We consider how RAS will advance in relation to different aspects of care, the business models that will support this, and how this might lead to long-term sustainable solutions. This scenario assumes appropriate investment to research, prototype and test technologies, and to support cooperation between different stakeholder organisations to explore the potential for using RAS technologies in social care.

What might a future care robot look like?
This graphic illustrates the design of a possible future assistive robot. The telescoping arms and body allow the robot to adjust to operate at different heights and to reach hard to access locations. The base of the robot is designed to carry loads, whilst the screen can be used to display information or to operate as a telepresence device. Image created by Sebastian Conran Associates.

Timespan	2018-2020	2021-2025	2026-2035
UK 65+ population	12 million	14 million	17 million
Physical capability of RAS technology for social care	Robotic devices for maintenance of the home and support for some activities of daily living	RAS modifications to home and care environments to provide help with a wider range of physical tasks including dressing, eating and toileting	Robots can provide safe, dextrous close physical interaction for care and support
AI capabilities of RAS technologies	Mapping the home, recognising people and everyday objects, understanding basic tasks, limited learning, some dialogue capability	Understanding user preferences, intentions and emotions, planning more complex tasks, learning from experience and by sharing data, providing more personalised care	Good understanding of the home as a physical and social setting, and of people and their care needs, able to have natural conversations with users based on shared experience and knowledge and give an account of own behaviour
User interfaces	Voice command and touch screen technologies. Wearables for health monitoring and remote operation of devices. Low bandwith brain-machine interfaces	Voice control for people with speech disorders, control by gesture or sign language. Tele-operation of remote RAS devices using wearable controls	High bandwidth wearable and brain-machine interfaces
Integration of RAS technologies	Integration of robot home devices with Internet of Things. Open robotic platforms and standards to facilitate a modular robot ecology and app-based development of robot services	Healthcare and social care better integrated. Robotic technologies integrated into furniture and existing assistive devices for physical support and mobility	New build homes incorporate ecosystem of robotic and digital devices designed to support ageing in place
RAS alongside human care	Consultation with carers, first cycles of participatory design of next generation assistive systems	Carers trained to work alongside assistive RAS technologies in order to make more efficient use of carer time and create a more professional role	Social care provided by human-robot teams with human carers able to prioritise the interpersonal aspects of care
Rehabilitation and robotic augmentation	RAS rehabilitation systems available at home to promote faster and more complete recovery from accident or illness	Significant advances in sensory prostheses. Robotic exoskeletons replace wheelchairs	Advanced physical prostheses and robotic implants such as smart artificial knees or hips
Sustainable development	Development of business models for sustainable development of RAS technologies taking into account re-use, recycling, and energy efficiency	Introduce large-scale pilots in collaboration with local authorities, care organisations, and third sector	Affordable RAS technologies for social care widely available
Ethics and governance	Integrated long-term strategy launched involving stakeholder communities, technology developers, and healthcare providers	International standards estabilished for RAS care systems with a national legal framework for liability and insurance	Legislation to protect the right to some face-to-face human care for people as they age

10. ETHICAL AND SOCIETAL ISSUES

RAS technologies for social care must be affordable, sustainable and add value to people's lives. They must also be developed with appropriate consideration given to a wide range of ethical concerns. As consensus evolves around how such challenges can be addressed, international and national standards and legal statutes will need to be developed and brought into force. Work is already on-going in this area with leadership from the British Standards Institute [32], and, internationally, the Institute of Electrical and Electronic Engineers (IEEE) [33].

Whilst the immediate concern of standards agencies is with product safety and efficiency, the debate around the use of robots in care is necessarily wider and must consider their potential societal impacts. The UK research community has seeded a broad discussion of ethical issues in robotics through the EPSRC Principles of Robotics first published in 2010 [34], however, there is a recognition that further attention to these issues is needed to keep pace with technological developments and with people's evolving expectations and attitudes towards technology [35]. The UK Parliament's Science and Technology Committee (STC) recently concluded a broad review of the ethical and societal impacts of AI and robotics concluding that further investigation was needed, that there may be a role for new governance frameworks (see below), and that "the UK is world-leading when it comes to considering the implications of AI and is well-placed to provide global intellectual leadership on this matter" [36]. Internationally, a growing community of researchers, thinkers, economists, lawyers, and ethicists is considering and debating these issues (see, e.g. [37, 38]).

Whilst it is not possible to review all possible ethical risks here, we highlight some critical challenges that are especially relevant to the use of RAS in social care.

Security and Privacy. One of the key concerns for a connected system is data security. An assistive robot will need access to historic information, as well as information that is current to create a dynamic world view and adapt to the user's changing needs and circumstances. Adapting behaviour and responsiveness requires drawing on information from environmental and activity sensors instrumented into a smart home, as well as information about the user's current physical, cognitive and emotional state through vision, audition, touch, and physiological and biometric sensing. This is sensitive information that shared

inappropriately could compromise an individual's dignity and right to privacy. Maintaining independence needs to be balanced with ensuring a person's autonomy and agency— we must design systems that people find trustworthy, not only from a reliability point of view, but also with respect to assurance of user privacy and security.

Transparency. A related challenge is transparency of function. It should be clear to users, in general terms, what a RAS system does and what it is unable to do, why it is carrying out a task at a particular place or time, what data it is collecting for that purpose and whether this is being shared. The system needs to be able to give an account of itself in everyday terms that users understand and to respond promptly to requests to change behaviour.

Social attachment. Over time, people may form emotional bonds with RAS technologies, as they already do with devices such as mobile phones, tablets and cars. However, there may be a particularly strong tendency to develop ties with animate systems that have a social function such as companion robots. Careful consideration needs to be given to the design of these systems to ensure that the relationships people form with these technologies do not interfere with other aspects of their lives. For instance, for many purposes RAS technologies could resemble existing white goods, or seamlessly integrate with the fabric of the home, rather than having a life-like or humanoid form.

Autonomy of decision-making. As these systems become more complex they will be expected to make more critical decisions about the nature of the care they provide. While many circumstances in which RAS will be used in care are foreseeable, it is likely that future systems will sometimes need to reason about the situation in which they are operating and reach their own conclusions as to the best path of action. The design of systems that can plan effectively, whilst taking into account moral codes, is an active but relatively new area of research. A precautionary approach is required to ensure that machines do not operate outside the window of action for which their behaviour can be verified to match human-specified requirements and that people are involved in over-seeing and checking system decisions.

RAS systems as marketing tools. The operation of these technologies within the home, for instance, in seeking to sell additional services and products to users should be subject to regulation as already applies to existing forms of online

and distance selling. There may be a need for additional forms of control given the growing pervasiveness of AI technologies in people's daily lives.

Respect, dignity, and the right to human care. As people develop increased needs for care there is a risk that they can be treated simply as recipients of support and less as the individual people that they always are. Human subjectivity and experience is changed by some conditions such as dementia but not necessarily diminished. By helping with some of the more intimate and personal aspects of daily life, RAS technologies can assist people to maintain their dignity and autonomy, nevertheless, we consider that it is essential that there is always a human contribution in social care. Indeed, we advocate legislation to protect the right to direct contact with human carers alongside the development of robotic and AI technologies that can support people to live more independent lives.

Impact on carers. Whilst RAS may impact on how social care is delivered in the future, we do not believe that it will replace human jobs in the care sector. First, as technologists who are trying to understand the challenge of care we are very aware of the level of human skill involved in everyday care activities such as helping someone to dress or bathe. RAS can be developed to assist with these activities but they will not match or replace the ability of human carers in the near future. Second, the interpersonal aspects of care such as empathy and understanding are uniquely human. AI personal assistants and social robots may be able to provide a form of synthetic companionship that people may find engaging, but this will never replace human companionship. The UK is faced with a shortage of carers, and care professions are recognised as being poorly paid. The development of RAS for social care should prioritise applications that will relieve the burden on care workers of dull, repetitive and strenuous work, creating a more professional role with a focus on the human-to-human aspects of care. It will be necessary to reassess training needs for some care roles that will in the future require technical knowledge related to customising and deploying RAS technologies. We are likely to see the emergence of a new group of care professionals whose skills include knowledge and understanding of controlling RAS technologies with varying levels of autonomy.

Governance. Nationally and internationally a number of efforts are underway to develop governance frameworks for AI and robotics. Within the UK, an initiative by the Royal Society and the British Academy is considering governance of data [39], and the Parliamentary STC has called for a Commission on the ethical and societal impacts of AI [36]. With regard to RAS there is the potential to build on the EPSRC principles [34] and on the European Parliament's recent effort to develop civil law rules for robotics [40]. Governance and regulation will need to be international if it is to be effective [41] and not simply promote competitive advantages for less regulated countries; useful leadership in this area is being provided by the IEEE [33], the World Economic Forum [42], and the Foundation for Responsible Robotics [43]. We consider that efforts to improve governance of AI and RAS, both in the UK and across the world, are welcome and timely and that the UK can provide global leadership in meeting this challenge.

Research should address the impact on people of long-term interaction with RAS technologies
Robots such as the therapeutic seal-robot Paro can have positive impacts on the people's well-being, for instance, improving mood and engagement [21]. However, more research is needed to better understand the short- and long-term impacts of using robots in care.
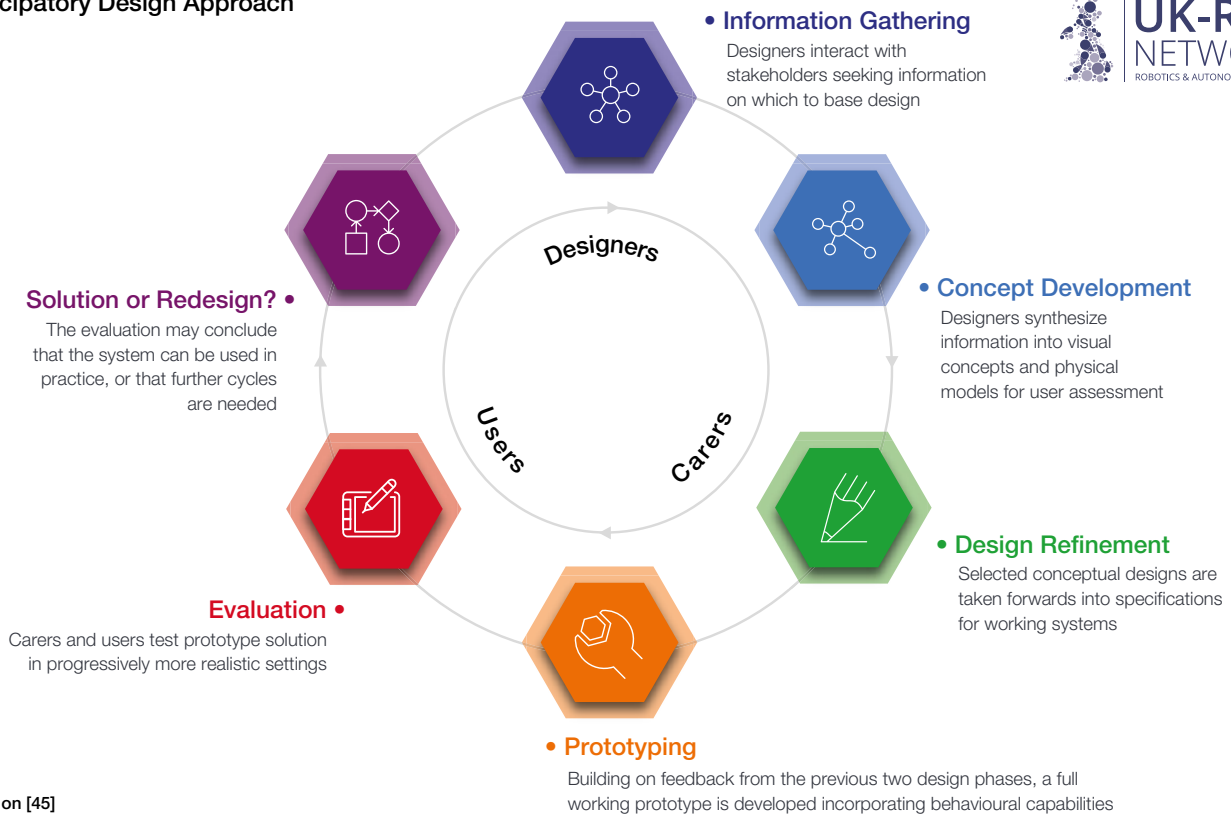
11. A PARTICIPATORY DESIGN APPROACH

To address ethical and societal concerns, and to ensure that new RAS technologies are useful, it is important that they are designed in consultation with the people they are intended to serve. Participatory design is an approach that seeks to involve people who might be the end-users of a new technology in the design process itself, to the extent that this is possible— it is designing "with" people rather than "for" people [44]. In the case of complex technologies such as RAS this is necessarily an iterative process that will involve frequent user trials of prototype systems, with early examples sometimes in the form of storyboards, physical models, or remotely-operated "Wizard of Oz" systems. Moreover, in designing for the longer-term, it is essential to consider the needs and views of people who will use RAS technologies in the future, rather than simply those who have evident needs today.

For example, when designing for older people, those who are older now will have vital experience of ageing, and of the challenges it brings, that can be brought into the design process, however, those who will use these technologies in ten or twenty years may have different attitudes and approaches, for instance to digital culture, that should also be taken into account. Participatory design for social care systems must also consider carers, paid and unpaid, in addition to those who are being supported, and ensure that solutions are developed with sensitivity to their needs and views. Care professionals will be an important conduit of ideas and evaluation for the design process, helping to accelerate innovation by avoiding misconceptions about user needs and preferences.

Participatory Design Approach

• **Information Gathering**
Designers interact with stakeholders seeking information on which to base design

• **Concept Development**
Designers synthesize information into visual concepts and physical models for user assessment

• **Design Refinement**
Selected conceptual designs are taken forwards into specifications for working systems

• **Prototyping**
Building on feedback from the previous two design phases, a full working prototype is developed incorporating behavioural capabilities

Evaluation •
Carers and users test prototype solution in progressively more realistic settings

Solution or Redesign? •
The evaluation may conclude that the system can be used in practice, or that further cycles are needed

Based on [45]

The participatory design approach involves cycles of interaction between designers, users and carers. The repeated iteration will include information gathering, development and refinement of design concepts, and building and user-testing of prototypes. Feedback should be sought as frequently as possible to keep the design process on track to match user need.

12. CONCLUSION

Robots and autonomous systems, combined with artificial intelligence, digital infrastructure and connected data systems have the potential to revolutionise the future provision of social care. Given the rising cost of care, and the need to provide better support to the millions of unpaid and paid carers in the UK, we consider that the development of these technologies should be pursued as a matter of urgency. Introduced in a sensitive way, and with appropriate safeguards, RAS can help people live independent and fulfilling lives supported in their social and physical needs both by human relationships and by appropriately-designed technology. Robotics, in particular, has the unique feature as a technology, of being able to provide responsive physical assistance in a timely and effective way. The UK faces a shortage of qualified carers, RAS operating in support of care professionals could make caring occupations less routine, more focused on the human aspects of care, and therefore more attractive and rewarding.

This report highlights opportunities to introduce RAS into social care over the coming decades and advocates a strategy for developing these systems in a participatory way. We consider that the people of the UK will benefit from the use of RAS in care in terms of improved health, support for active ageing, better choices about how and where to live, and greater opportunity to participate in our national life and to grow old with dignity.

Key findings:

- The ageing population in the UK, and across the globe, will create unprecedented societal challenges.

- Part of the response to this challenge should be to develop RAS technologies that will assist people to live independent and fulfilling lives as they age and to help people, of any age, who are living with disability.

- Assistive systems can be developed to help people maintain active and healthy lifestyles as they grow older.

- RAS can also play important future roles in physical aspects of care, in rehabilitation and in the delivery of medical assistance at home.

- A connected and integrated approach is needed that provides appropriate forms of assistance at home, in residential care, and in hospital.

- Assistive systems that can help people to age 'in place' in their own homes can reduce the societal costs of care and can help people to return home more quickly after a stay in hospital.

- The use of robots in care must be approached with sensitivity and with due consideration to ethical and societal issues. Development of new technologies should take place through close collaboration with people in need of care, their immediate carers, and with public, private and third sector organisations involved in providing care in the UK.

- The innovation culture in the UK combined with a thriving academic base and burgeoning SME sector means that the UK can be a global leader in developing RAS solutions to worldwide challenges in social care.

- There is a need for a national and international effort to promote global governance of technology development in areas including AI and RAS in order to effectively regulate their future societal impacts.

GLOSSARY

Artificial intelligence: Computer software that performs tasks that are normally considered to require intelligence when performed by people, examples are scene and language understanding, planning, and learning.

Assistive robot: A robot designed to provide physical or cognitive assistance to a person.

Autonomy: The ability of a machine to make its own decisions.

Autonomous System: An integrated system of machines and devices that share control programs and sensors and making decisions autonomously.

BEIS: UK Government Department for Business, Energy & Industrial Strategy.

Brain-machine Interface (BMI): An interface that measures activity in the nervous system and uses these signals to control technology. BMIs can be devices that rest against the skin or they can be implants that are directly interfaced to nerve fibres or the brain.

Cloud services: Computer services delivered via the internet including the remote storage of data and off-site computation (for instance for computationally-intensive operations such as speech or face recognition).

Companion robot: A robot designed to communicate with people using spoken language, and/or non-verbal channels of communication such as expression or touch. A companion robot can provide a form of social interaction that could be reassuring and reduce feelings of loneliness, it could also provide advice, confidence building, promote social engagement by acting as an ice-breaker within social groups or as a social 'bridge' to friends and relatives.

DH: UK Government Department of Health.

EPSRC: The UK's Engineering and Physical Sciences Research Council, the UK's principal funding agency for academic research in RAS.

Horizon 2020: The EU's research and innovation programme aimed at securing Europe's global competitiveness.

Innovate UK: The UK's innovation agency.

Internet of Things: The interconnection of computing devices embedded in everyday objects allowing them to send and receive data via the internet.

Machine learning: The ability of a robot or computer to learn from experience or by example. Recent advances in machine learning technologies have allowed computers to reach near-human levels of skill on tasks that involve pattern recognition (e.g. recognising faces or objects).

RAS: Robotics and Autonomous Systems.

Robot: An autonomous machine that has sensors and actuators enabling it to act in the world.

SME: A Small or medium-sized Enterprise. SME's are recognised to be critical to economic growth.

Social care: Provision of care, protection and support services for people in need or at risk, including those with needs arising from illness, disability, old age or poverty.

Service robot: A robot designed for service industries (i.e. not an industrial robot).

Telecare, telehealth: Remote delivery of health and care services via telecommunications technology.

Teleoperation: The remote operation of a device or robot by a person.

Telepresence robot: A mobile robot that allows a user to be remotely present in a location (for instance to be heard and seen in that location in real-time via a remote-control robot with a screen).

UKRI: Prospective governing body for UK Research and Innovation incorporating InnovateUK and Research Councils including EPSRC.

UK-RAS Network: A network of UK Universities involved in research in RAS whose activities are supported by the EPSRC.

Wearables and smart clothing: Electronic devices including sensors and processors that are embedded inside items of clothing including wristbands and shoes.

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We have an obligation, as a nation, to "undertake or promote research and development of, and to promote the availability and use of new technologies, including information and communications technologies, mobility aids, devices and assistive technologies, suitable for persons with disabilities, giving priority to technologies at an affordable cost.

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Article 4 of the United Nations Convention on the Rights of Persons with Disabilities [4].