論 文 内 容 の 要 旨

According to the Japanese National Institute of Population and Social Security Research, the productive age population (between 15 and 64 years old) will continue to decrease. And In 2060, one out of every 2.5 people will be 65 years old or older. The challenge can be summarized as a declining birthrate and an aging population, with two consequences: (i) increase of caring cost and (ii) shortage of young labor. Confronting these challenges, we have conducted two novel studies accordingly: (i) personal care robot named KUT-PCR to help reducing the caring cost of human care givers, and (ii) automatous material transportation robot named Capper, to deal with the time-consuming and laborious on-site handling. Then we introduce how KUT-PCR and Capper contribute to the aging population and declining birthrate respectively.

A. Personal Care Robot, KUT-PCR

A personal care robot was presented to reduce the burden of caring for individuals who are bedridden. The capabilities that allow human care givers to conduct natural caring tasks can be grouped into three categories: sensory, motor, and cognitive. Aiming to achieve the higher lever of cognitive intelligence, the following work has been conducted step by step.

(1) A single-body personal care robot. To confront the long-term daily care challenge caused by the shortage of nursing personnel, we have proposed a novel personal care robot with 23 degrees of freedom. Instead of having a lower body with legs, KUT-PCR relies on an omnidirectional platform for mobility. The combined motion of four omnidirectional wheels allows it to drive in any direction in a planar space and rotate with a zero turning radius, thus enabling it to freely navigate through narrow and uncontrolled environments (such as household environments). A torso lift is also mounted on the platform so that it can reach both objects on the floor and those on a shelf by simply adjusting the lift height. KUT-PCR's humanoid upper body is designed to provide rich perception and manipulation capabilities. The head has three degrees of freedom, namely roll, pitch, and tilt. Each arm has seven degrees of freedom as well as an end effector with one degree of freedom. Finally, the waist has three degrees of freedom. This design allows the robot to perform various kinds of tasks, including object manipulation and HRI. Additionally, the platform is equipped with a range of sensors that allow KUT-PCR to perceive its environment and operate autonomously in unknown and dynamic environments.

(2) Pose estimation of daily containers.

A frequent task during life support is the fetching of daily containers (e.g., milk box, drink bottle), which requires accurate six-dimensional pose estimation. In this work, we develop a pipeline that is capable of providing such estimation. First, transfer learning is used to retrain an object-detection model based on a convolutional neural network to produce accurate rectangular masks. After extracting object clouds based on these masks, the iterative closest point algorithm is used to perform point-cloud registration., resulting finally in poise estimation. Several approaches are introduced to increase the registration accuracy and stability by providing adequate initial alignment, the effectiveness and accuracy of the proposed pipeline were verified considering accuracy requirements.

(3) Context-aware local planning.

Human caregivers can provide high-quality caring services because their behavior considers

where they are and what/who is around them. For a personal care robot to provide caring services similarly, a context-aware local planning method is presented that allows a robot to change between different operating patterns at run time. With a control system that integrates the proposed method, a personal care robot can behave based on the type of room in which it currently stands and whether there are people within its operating range. The proposed method has been tested in an actual household environment and was proved to be effective.

(4) Desire-driven reasoning system.

Caregivers who look after people that are bedridden, due to aging, illness, or an accident, need not only physical strength but also a proper understanding of their patients' physiological needs. Professional caregivers are required to carry out such tasks in nursing homes and hospitals, while visiting caregivers are needed in individuals' homes. However, in order to deal with the nursing shortage and improve care efficiency, a small number of caregivers are unable to focus on specific care recipients but instead must check in on them periodically.

This means that, currently, patients who are bedridden sometimes have no-one to take care of their needs while caregivers are unavailable. If we could develop personal care robots capable of carrying out simple care tasks (such as delivering goods), the burden on caregivers would reduce dramatically. Such robots would hopefully make patients' lives more comfortable by, for example, delivering drinks or adjusting the temperature and lighting while human caregivers are unavailable.

Under this consideration, First, we introduce a method of representing knowledge about everyday objects in terms of their properties and functions. Based on this representation, we then propose a desire-driven reasoning approach that bridges the gap between physiological desires and robot actions. This can also deal with issues caused by uncontrolled domains, including incomplete knowledge and dynamic environments. Finally, we evaluate the proposed method by applying KUT-PCR personal care robot to real household scenarios.

After constructing the basic framework, we argued two more requests regarding long-term care preference (LTCP) and short-term care preference (STCP).

1) LTCP and STCP should both be considered in the reasoning system
   For example, the eating habits should be considered when someone feels hungry However, serving the same food again and again is not reasonable. In other words, although the act of providing something to eat do not change the LTCP; however, the upcoming decisions regarding "hungry" will be influenced, which we suggested to be modeled as an STCP.
2) LTCP should be properly formalized regarding its initialization, optimization, and evaluation
   LTCP varies from person to person and typically evolves slowly over weeks, months, or even years. Good initialization allows qualified services to be provided in shorter period, and suitable evaluation/optimization methods allow preference variation to be handled effectively.

Therefore, we: (i) propose a long short-term care preference model (LSTCPM) for personalized and time-aware care preference modeling; (ii) we apply an optimization approach for LTCP that adopts extended Kalman filters (EKFs); and (iv) we evaluate the proposed approach in a real household environment using KUT-PCR.

B. Automated Material Handling Robot, Capper

Material transport can account for 15%–20% of the total construction work. During the interior renovation process of a construction task, materials and goods unloaded from trucks need to be

transported between working zones on different floors. Human transportation requires a considerable amount of effort. As most construction sites are currently facing the shortage of young labor, Therefore, construction robots can be adopted in some transportation tasks to free up employees for more valuable tasks. As a result, working efficiency is estimated to increase by 20%.

Autonomous transportation robots are devised to transport construction materials and tools in a construction field. But deploying the system faces the following challenges: (i) floors under construction; (ii) complex surroundings; (ii) dynamic environments; (iv) ongoing interior renovation (v) dim and nonuniform illumination.

We first presented an automatic material transportation robot Capper. A newly developed gate-type robot that combines the advantages of other types of robots. A gate-type robot can: (i) move carts of material stably and safely like a forklift-type robot; (ii) has a compact structure, therefore can pass through narrow spaces similar to a unit load AGV; (iii) transport heavy objects easily, because like a trailer-type robot, the weight of the cart is mainly carried by its wheels.

After solving "how" to handle a cart, the other core question is "where" to put it. Either using tape, beacons, or mark-less solutions such as SLAM, the core idea, is self-localization in a global frame. Recently, more effort has been conducted to keep the ideal performance of such types of systems considering unstructured and dynamic environments.

In this work, we argue that, for applications that the goals are not necessarily precise coordinates, a guidance approach could be a more suitable solution. We presented a hallway exploration-inspired guidance approach (HEIGA) which does not require self-localization in a global frame, therefore, the performance of the system can be decoupled from the complexity or the dynamics of the environment.

Extensive experiments have been conducted. (i) an empty supermarket ACOOP was rent, and experiments for new function evaluation are conducted as required in a fully controlled environment; (ii) further experiments were done in the ICI lab of the Maeda Cooperation, which is more close to real construction sites, but still with certain level of controllability. (iii) eventually, material transportation was conducted in real construction sites in Shinagawa, Tokyo, and Nagoya, Aichi respectively. Where the prior is a rather cowed city building, and the latter one is factory-type site with very huge environment.

Our main contributions in this work is summarized as follows. With the goal of contributing to a declining birthrate and an aging population: (i) on one hand, we tried to achieve high-level cognitive intelligence on personal care robot KUT-PCR so that caring tasks can be conducted as required where no care givers are available. As a result, the quality of life of the care recipients can be improved while the caring cost will be decreased; (ii) on the other hand we focus on motion intelligent, that enables autonomous material transportation in construction sites with Capper, so that the effect cased by the lack of young labor in construction sites can be effectively decreased. All the presented approaches have been evaluated in a real household environment and construction sites respectively.