Assistant Robotic Technologies for an Aging Society

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Abstract—Many countries around the world, including Japan, face three major issues associated with their aging societies: declining population caused by low birthrates, an increased proportion of seniors due to changes in the composition of the population, and an increasing number of single-person households because of family structure changes. To explore assistive technologies that can help solve the problems faced by aging societies, we conducted research on a personal mobility robot, which provides safe, secure and barrier-free transportation; a home assistant robot, which improves the ease and productivity of home activities; and a memory support system, which contributes to a more comfortable life for seniors.

Index Terms—Assistive Technology, Personal Mobility Robot, Home Assistant Robot

I. ISSUES OF AN AGING SOCIETY

Issues faced by aging societies are discussed with reference to examples in Japan. The total population of Japan peaked in 2005 at approximately 128 million people and then began to decrease. By 2050, the total population is expected to be 90 million, which represents 30 million fewer people than in 2005. This 25% decrease in Japan's total population will force major changes to the social structure. In terms of the composition of the population, the aging rate, which is defined as the proportion of the population over the age of 65, will approximately double to 40.5% by 2055 from its 20.1% level in 2005. However, the proportion of the population under 14 years of age will be reduced to 8.4% from its current 13.8% level. Japan's society is aging rapidly; thus it is imperative that these important issues are addressed.

However, the trend toward an aging population is a problem not only in Japan but in other developed and emerging countries as well [1]. Many developed countries can already be considered aged societies: the proportion of people over 65 years of age is 20.1% in Japan, 19.7% in Italy, 18.8% in Germany, and 17.2% in Sweden. Aging is occurring even in Asian societies. It has been predicted that seniors will account for more than 20% of the population in Asian countries, including China, Korea, Thailand and Singapore in 2050.

The declining birthrate in Japan has obviously been one cause of population aging. The birthrate was greater than 4.5 children per family after World War II, when Japan experienced a baby boom, and it has declined continuously since then to 1.26 in 2005. Subsequent to 2005, the birthrate increased slightly, although it is currently still below 1.4. A large population discrepancy has developed between the generations as a result of these extreme changes in the birthrate. Thus, Japan has rapidly become an aged society.

With the acceleration of population aging, three effects are anticipated: a declining population, an increased proportion of seniors and changes in family structure. Problems associated with each effect are described below.

Labor shortages because of the declining population

In Japan, because of aging and the declining population, the labor force is expected to decrease to 56 million in 2030 from 67 million today, which is a reduction of 11 million workers over only 25 years (estimate of the Ministry of Health, Labor and Welfare of Japan). To maintain the existing social infrastructure and the international competitiveness of Japanese industries, a labor force of a certain size is necessary. In addition, large and rapid changes in the size of the workforce create an imbalance in the labor supply and demand and lead to a serious risk of labor shortages, especially in the areas of low-wage work and unskilled labor. One possible solution is to temporarily accept workers from abroad. However, Japan is currently not entirely open to this option.

Anxiety about health, loss of motivation, and increased costs of social insurance because of the greater numbers of seniors

Because of the growing proportion of seniors in the population, anxiety about health and/or loss of motivation will become problems for individuals and for families, as will the increasing costs of health care and social insurance. In Japan, if the situation continues, the number of people who require help or nursing care will reach 7 million by 2025, leading to costs of 10.8 trillion yen in 2025, up from 5.7 trillion yen in 2005.

Increased care and/or housework burdens as a result of changes in family structure

In Japan, the number of households where the primary resident is over 65 is predicted to increase to 19 million in 2030.
from 14 million in 2005. In addition, the number of households where only older people live is predicted to increase to 7 million from 4 million. It is anticipated that the number of people who shoulder the burdens of care and/or housework will continue to grow due to increases in one-person households, aged households and people who need care. Furthermore, the number of people in the labor force continues to decline. In an aging society, participation in the labor force by full-time housewives and healthy seniors will be required. However, the increased burdens of housework and care for the elderly may create barriers to this participation.

II. ASSISTIVE TECHNOLOGIES FOR AN AGING SOCIETY

Assistive technologies can be used to address the following areas: labor support to augment the insufficient number of workers because of the decreasing population, healthy lifestyle support to address the growing cost of social insurance caused by the greater proportion of seniors in the population, and household and care support to address the increased housework and care burdens resulting from changes in family structure (Figure 1). An overview of these three areas with specific tasks and supporting technologies is shown in Figure 2.

In the area of labor support, tasks are classified according to industry. Among primary industries, cultivation, mowing and harvesting are candidates in agriculture; timber transportation in uneven terrain and pruning of trees are candidates in forestry; and fish processing and repairing fishing nets are candidates in fisheries. Leveraging assistive technologies can help to reduce labor shortages and excessive workloads, and improvements in work efficiency can be achieved. In secondary industries, unattended heavy machinery, steel-frame work and painting are candidates in mining or construction and cell production, power assistance and skills support for workers are candidates in manufacturing. Supporting technologies can be widely used in fields other than manufacturing industrial products. Among tertiary industries, pickup and delivery in offices, product replenishment in distribution industries, garbage collection and sorting, hospitality support, and non-invasive testing are candidates. Thus, instead of these activities, workers will be able to engage in more creative work.

In the area of healthy lifestyle support, tasks are classified according to the user’s health condition and level of care required. For healthy seniors, continuing social participation through outings and communication and maintenance of health

![Fig. 1. Issues of an aging society](image)

![Fig. 2. Overview of specific tasks and supporting technologies](image)
through the continuous monitoring of biometric data are candidates. These supporting technologies are effective at providing mobility and maintaining health. For seniors with a relatively low degree of disability, help in rising and sitting and assistance recalling past events or acquaintances are candidates. For seniors who need help but can live and go out by themselves, walking assistance, transfer assistance, wheelchair mobility, eating assistance and bathing assistance are candidates. The activity range of seniors can be expanded, and the burden of care can be reduced. For seniors who have difficulty rising, eating or going to the bathroom by themselves, reaching goods, speech aids, and body transport for the prevention of bedsores and bathing assistance are candidates. Thus, it is possible to reduce the inconveniences and burdens of seniors.

In the area of household and care support, tasks are classified according to chore. The candidates are as follows: the kitchen chores of preparing meals, thawing frozen foods, cleaning tables, washing dishes; the laundry chores of operating a washing machine, hanging out the laundry, ironing, folding and storing; the home chores of operating a vacuum cleaner, wiping, sweeping, organizing rooms, dumping weeds, making up beds and removing weeds in the garden; the childcare chores of changing diapers, watching; and the caring tasks of feeding, dressing, transferring, cleaning, bathing and in-bed bathing. Thus, it is possible to significantly reduce the burdens associated with housework and care.

Using assistive technologies to perform these tasks is a way of solving the larger problems caused by the decline in the population: the increased number of seniors and the altered familial structure. However, especially in an aging society, smaller issues clearly come into view that can be great burdens on individuals and families. To promote quality of life for seniors and their families, potential needs were analyzed focusing on the two areas of healthy lifestyle support and household and care support.

Promoting independent living for seniors

To support independent living among seniors, the varying levels of independent living skills of individuals should be considered. The ability to move, which is a basic requirement for independent living, varies widely among seniors. It is expected that providing a sophisticated means of transportation that can be modified according to the mobility of individuals will help seniors live independently.

For seniors who have been driving, their social life becomes greatly constrained when their age prevents them from driving. To maintain the level of socializing that they had previously enjoyed, advanced mobility is crucial. However, no effective services vehicle is critical. This approach to mobility is expected to serve as a new transportation system that directly connects community and home.

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Reducing indirect services from supporters (e.g., caregivers)

The reduction of indirect services from supporters creates a situation in which they can concentrate on direct physical assistance for seniors, and it is expected to facilitate their care. Currently, tasks such as making up beds, doing laundry, sorting laundry, managing storage, clearing tables, tidying rooms, and using cleaners and disinfectants constitute a difficult part of the services provided by nursing staff. Reducing tasks such as making night rounds and watching for changes in the physical condition of seniors reduces the psychological stresses experienced by supporters in charge of care. The use of robotic assistants to perform these indirect services allows supporters with expertise to concentrate on providing attentive care to seniors.

Second, to facilitate care services, it is important to avoid requiring intensive labor from supporters as much as possible to reduce their feeling of being burdened. For example, effective solutions are needed for simultaneously moving multiple seniors in wheelchairs from the living room to the dining room in a nursing facility. Achieving mobility without great effort by seniors and supporters is believed to be of major importance and will significantly reduce the burden of indirect support activities.

Reducing family chores and maintaining social activities

As an aid to families with seniors, it is important to support home assistance and regional care services in terms of equipment and environment to ensure that their levels are comparable to those in nursing care facilities. Furthermore, it is also important to provide a backup so that people who are caring for seniors are able to maintain employment and social activities.

Short-stay and day services can reduce the homecare burden on families with seniors. In collaboration with community care services, mobility that involves automatically riding in a social services vehicle is critical. This approach to mobility is expected to serve as a new transportation system that directly connects community and home.

In tasks such as disinfecting, cleaning, examining physical condition, watching, reaching for objects, helping with recall of daily and past events, and clearing a table, the implementation of assistive technology that provides physical and interactive assistance with information about the target space and objects provides a basic support environment even during the off-hours of professional supporters.

Furthermore, providing support beyond the traditional
information-only assistance leads to expanded freedom for nurses and increased participation in social activities for families.

Based on the above analysis of assistive technologies likely to help to solve the problems of an aging society, we have conducted research on the basic technologies of the personal mobility robot, which provides safe, secure and barrier-free transportation; the home assistant robot, which improves the productivity of home activities; and the memory support system, which makes seniors feel more comfortable.

III. THE PERSONAL MOBILITY ROBOT

The personal mobility robot is intended to provide safe transportation and remove the physical limitations of the user. This means of mobility has to be safe enough to use both indoors and outdoors.

Figure 3 is a photograph of a personal mobility robot. The mechanism is a two-wheeled inverted pendulum with a seat, and it provides the ability to easily move in narrow spaces and on uneven surfaces like the typical spaces a user would encounter on a daily basis. The inverted pendulum mechanism keeps the seat horizontal, which reduces the burden on the driver. Because only two driving wheels are on the ground, the footprint of the robot is small. However, as an inverted type of mobility device, the robot is difficult to re-board after standing up, and the driver requires a mechanism to stand up after boarding as well. To keep the center of gravity over the wheels during the stand-up motion, a leg wheel mechanism and a seat slider mechanism are used.

Design features of the personal mobility robot [2][3]

As requirements for the personal mobility robot, three functions were studied: stability control implemented as an inverted pendulum-type of device, a safety function that recognizes obstacles and pedestrians, and an autonomic navigating function able to change the destination point automatically.

The stability control function prevents falling in a variety of road and floor conditions and keeps the seat in a horizontal position even if one of the wheels runs onto a step or a slope. As key technologies to realize this function, the inverted pendulum control method and the steering interface were studied. The personal mobility robot is equipped with a mechanism that consists of leg wheels and a seat slider. By raising or lowering the leg wheels independently, it is possible to keep the seat in a horizontal position.

To control this mechanism, the wheels, the swing arms and the seat slider were physically modeled three-dimensionally, and a control system for this mechanism was designed using optimal regulator theory. As a result, regardless of the driver, stable stand-up motion, slalom driving, overcoming a 20-mm high step and traveling road with 50-mm high waves were achieved. Figure 4 shows the capacity to overcome a slope height of 50 mm. As an inverted-pendulum type of device, the personal mobility robot is affected by longitudinal swaying caused by acceleration and deceleration. Additionally, as a responsive device, it is affected by centrifugal force caused by changes in direction. To detect the intention of the driver reliably, a steering interface (shown in Figure 5) was developed. The interface uses the pronosupination of the human arm and senses direction by the arm’s rotation while supporting the body of the driver in a longitudinal direction. This interface enables precise steering with minimal muscle load.

![Fig. 3. The personal mobility robot](image)

![Fig. 4. Overcoming a slope of 50mm high](image)

![Fig. 5. Steering interface for the personal mobility robot](image)
The safety function recognizes obstacles and pedestrians as it senses the condition of the road and the surrounding environment. This function helps to avoid accidents by assisting the driver’s navigation. In addition, when combined with autonomous navigation capabilities, the robot will be able to move about freely while avoiding accidents.

Indoors, obstacles are effectively detected by the use of stereo cameras, in which only the legs of chairs or tables are detected by a horizontal laser range finder. The obstacles detected by the stereo camera are integrated onto a map obtained through self-localization, as shown in Figure 6.

Outdoors, obstacles are recognized by three-dimensional reconstruction using a horizontal laser range finder swung vertically by a motor, as shown in Figure 7. Passengers are detected using a laser range finder set at chest height. By using particle filters to represent pedestrians as cylinder models, it is possible to track pedestrians with their direction and speed, as shown in Figure 8.

The autonomous navigating function recognizes the mobility robot’s position and navigates it autonomously to the destination. The component technologies that realize this function include location recognition, mapping technology and routing technology. In location recognition and mapping, the stability of self-position estimation was studied under unstable conditions such as complex road geometry, variable lighting conditions, changing environments with moving obstacles, and shaking or vibrating of the mobility robot. Data were obtained at multiple locations using the laser scanner driven by the motor. The three-dimensional sequences of points obtained by this measurement were integrated by a computer, and a polygon was generated automatically. A high-precision three-dimensional polygon map of the university campus where the tests were conducted was obtained from the data measured at 59 different locations, as shown in Figure 9.

Localization experiments using the map and a laser range finder attached to the mobility robot were executed. It was confirmed that the accuracy was within 10 cm along a given route of about 250 m on the campus, as shown in Figure 10. It was also confirmed that the device recovered soon from a deviation of 30 cm to 50 cm when it lost its location.

Self-localization experiments were executed at different times using panoramic images obtained with an all-direction camera. An inter-frame matching technique using brightness and SIFT (the Scale-Invariant Feature Transform) characteristics was employed, and the current frame position was estimated using particle filters to obtain stable self-recognition results. Compared with the map data recorded in the morning, although the similarity was reduced 23% relative to data obtained during the daytime and 40% relative to evening data, it was confirmed that the similarity tended to be...
For route generation, the road must be smooth enough for a personal mobility robot moving at a speed of 6 km/h to track and efficient enough to reach a given destination. The route generation algorithm for reaching destinations smoothly while avoiding obstacles was studied using the self-localization and obstacle recognition data from the laser range finder installed on the robot. The algorithm was extended to generate a trajectory that passes behind pedestrians by estimating their movement. An avoidance trajectory maintains a distance from pedestrians proportional to the speed of the robot to give them a sense of security.

The personal mobility robot was approximated by a 0.6-m radius circle, and the route was identified by extending the obstacle radius with the circle radius. As a result, it was possible to re-plan the route in less than 200 ms, even when the route was blocked by a moving obstacle, and the robot was able to avoid obstacles without stopping when moving at a speed of 1.8 km/h. In addition, as shown in Figure 12, by combining the safety function and the autonomic navigating function, it was possible to automatically avoid collisions by recognizing the speed and direction of the pedestrians and re-planning the

Fig. 9. High-precision three-dimensional polygon map of the university

Fig. 10. Example of localization experiment using a map and a laser range finder

Fig. 11. Example of self-localization experiment at different times

Fig. 12. Dynamic avoidance of collision and rerouting
IV. THE HOME ASSISTANT ROBOT

The home assistant robot is intended to improve the productivity of home activities and to produce free time. For seniors living alone, families with seniors to care for or for family members who work, the assistant robot handles home chores such as clearing the table, tidying up rooms, sorting laundry and managing storage. Figure 13 shows a photograph of the home assistant robot with dual arms.

Design features of the home assistant robot [4]–[8]

As features required of a home assistant robot, two functions were studied: a holding function that allows the robot to grasp objects firmly without breaking them or altering their recognizable characteristics, and a handling function for tools and equipment such as home electric appliances, built-in house facilities such as door keys and gas valves, trays or wagons to carry dishes, brooms and mops.

The key technologies used to realize the holding function consisted of a grasping strategy for deciding how to grip an object depending on its shape and material and a strategy for handling flexible objects such as clothing and towels.

As a grasping strategy, a descriptive method is used for three-dimensional models that includes weight, visual information such as colors and patterns, gripping points, and distinctive points. This description simultaneously provides information necessary for both visual recognition and grasp planning. With this method, object handling was executed on various levels, including grasping simple objects, carrying a tray, and pouring tea.

The handling strategy for flexible objects enables the assistant robot to handle various deformable objects in the living environment, clothing and string in particular, and to achieve the tasks of storing laundry and packing a suitcase. The issues this strategy needed to address are the detection, recognition and handling of flexible objects. To find clothes, a method that detects wrinkles was proposed, as shown in Figure 14. This method was applied to clothing with a variety of colors and to various kinds of shirts and towels.

By integrating three-dimensional visualization capabilities, a vision system was constructed that can identify the three-dimensional positions of objects and seamlessly connect them to a collection operation. As shown in the experiment in Figure 15, the home assistant robot was effective at finding the clothing on the floor, picking it up and putting it into a washing machine. In other handling operation experiments, a flexible multi-fingered hand successfully picked up clothes from the back of a chair without moving the chair by controlling its finger joints to follow the shape of the object.

The key technologies used to realize the handling of tools and equipment function were a modeling technology reflecting human tool use, an operating technology for tool operation, and a task planning technology for the successive execution of multiple tasks.

In the modeling technology, the three-dimensional geometrical data are supplemented with information on movable structure, grasping points and distinctive points. The effectiveness of the model was confirmed through an experiment with a chest of drawers.
The tool modeling technique makes it possible to simulate operations of the robot in a virtual environment. However, the real world and the simulated world are not necessarily the same. To achieve stable tool operation in the real world, it is necessary to modify the behavior of the home assistant robot to fit real-world situations.

Operation techniques for the equipment included a fitting control method to handle objects with opening and closing mechanisms such as doors or drawers, an end effector force control method to direct the force in any direction, and a method of generating a confined trajectory based on a reinforcement learning algorithm.

As a concrete example, a learning and acquisition experiment involving opening and closing motions was conducted with another robot. For furniture doors and drawers that pose environmental constraints, the robot acquired the trajectory to operate them by trial and error. As shown in Figure 16, the opening and closing motions of the refrigerator door (rotating mechanism) and the drawers (linear mechanism) were acquired and learned successfully. In addition, it was possible to open a cupboard with a complex trajectory of rotation and linear motions.

To efficiently execute a wide variety of everyday tasks with the home assistant robot, planning technology is critical. This technology involves determining the execution order of tasks and generating individual motions of the robot for each task. The planning of individual tasks is described using the example of sweeping a floor with a broom.

Action planning was conducted to generate a trajectory that would successfully clean the floor using the sweeping surface of the tool taking into account the movement capabilities of the carriage and arms of the robot and the interface between the robot and the environment (e.g., tables and chairs). In action planning for the successive execution of multiple tasks, failures were classified into three levels depending on the difficulty of recovery, and different actions were selected depending on the level. The task was rerun in the case of a simple failure, and a new action was called on to recover the failure in the case of a difficult task. As a result, it was possible to continuously perform tasks such as carrying a tray, picking up clothes and cleaning a floor, as shown in Figure 17.

V. THE MEMORY SUPPORT SYSTEM

The memory support system is intended to provide seniors with a more comfortable and active life by recording their daily living activities (or the history of their use of daily commodities) and by presenting appropriate information to support their memory. Thus, we created a memory support system that remembers and presents the stored locations of commodities that seniors use on a daily basis.

Design features of the memory support system

Figure 18 shows the configuration of the memory support system. Triggered by events, image data are collected from cameras mounted on robots or installed on the ceiling. Each image is accompanied by meta information such as when and where the image was acquired. By applying object recognition techniques to the collected image, whether or not a specific commodity is contained in the image is determined. This process, which is related to recognition and determination, is executed online by parallelized computing by a cluster computer. The location where the commodity was last observed is recorded in the database, and the information can be searched through a user interface. The search result is displayed on a screen. Moreover, the home assistant robot points to the storage location, and the indoor personal mobility robot automatically takes the user to the location.

Each ceiling camera is installed at a position where it can observe areas where daily commodities tend to be, for example, on tables or in drawers. The camera has a function that uses motion detection to capture an image during an associated event. Proper use of this function, for example by capturing an image in conjunction with the opening or closing of a drawer, prevents unnecessary image acquisition and reduces the downstream processing.

Each camera acquires images asynchronously and
autonomously and uploads the images to the camera server over a network. The server also accepts images acquired by the robots in the room: the indoor personal mobility robot and the home assistant robot. Each robot captures images at the appropriate time and uploads them to the server with their locations.

To recognize commodities in the images, the scale-invariant feature transform (SIFT), which is a typical local feature of an image, is used. As shown in Figure 19, templates for each commodity (consisting of its image) are prepared. By counting the corresponding SIFT feature points, as shown in Figure 20, it is determined whether the commodity is found in the image. This method is robust in the face of changes in size, orientation and brightness of the object. Furthermore, it is capable of recognizing individual commodities even when many commodities are shown in one image.

The calculation is parallelized by a PC cluster via online processing. It takes about 15 seconds to reflect the movement of a commodity through the concurrent implementation of 5 environmental cameras, 42 image templates and 40 CPU cores. However, with the advancement of computers, the processing time is expected to decline.

Figure 21 shows the search interface. When a commodity is selected on the right-hand screen, the location of the object is immediately displayed in animation on the three-dimensional map on the left-hand screen. At the same time, tasks are sent to the robots, resulting in pointing by the home assistant robot and movement of the personal mobility robot to the target location.

VI. CONCLUSIONS

In the aging societies that many countries around the world, including Japan, are facing, there are three major issues: declining population because of low birthrates, an increasing proportion of seniors because of changes in the composition of the population, and increasing numbers of single-person households because of changes in family structure. These issues will make it necessary to allocate work to smart machines, as in the case of industrial robotics. Therefore, using robotics to realize assistive technologies that help seniors with activities is an urgent need. As examples of assistive
technologies the implementation of which can help solve the problems inherent in an aging society, we conducted research on three basic technologies: the personal mobility robot, which provides safe, secure and barrier-free transportation; the home assistant robot, which improves the ease and productivity of home activities; and the memory support system, which contributes to a more comfortable life for seniors. Continuing research into and development of assistive technologies should provide future innovations for our aging societies.

REFERENCES


