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A Study of New Technologies of Personal Mobility and Robot Suit for the Elderly and Persons with Disabilities

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Abstract

Life innovation is a growth-driving industry that supports the medical, nursing and health-related industries of Japan, the world leader in longevity. Among the technological developments of life innovation, the research, development and commercialization of nursing care robots, personal mobility for the elderly, and life support robots utilizing manufacturing technology, as well as advanced medical technology, and information and communication technology (ICT) are expected.

The aim of the study was to investigate innovative technology for sustainable mobility, particularly scientific technology that could improve mobility for the elderly and disabled. The main issues analyzing the technology for sustainable personal mobility and assistive devices were as follows: 1) Survey exploring the characteristics of the elderly, 2) Survey of existing mobility and robotic technology.

The results indicated little difference in physical activity capacity, standing posture, balance capacity, or walking capacity in the elderly in Japan and other countries. PM aids are easier to maneuver and inflict minimal injury to others in collisions. These systems have thus been suggested to be suitable for the elderly. That said, they cannot be purchased freely under the current scheme. For this reason, PM aids are not as commonly used in Japan as they are in Western countries. The results also showed that a robot suit currently only supports monoaxial joint movement. Robot suit should support movement of multiaxial joints in leg joints for supporting activity of daily livings of the elderly and disabled person in the near future. Research and implementation experiments that combine ICT, Iot, PM, and robot suits are therefore currently poised to take off. Moreover, the versatile environment for the use of PM or robot suit in society should be considered.

Therefore, a new academic field called social medical engineering that fuses social science and medical engineering should be built to develop sustainable assistive devices.

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Contents

1. Introduction

Life innovation is a growth-driving industry that supports the medical, nursing, and health-related industries of Japan, the longevity's world leader. Using life innovation to develop new service and manufacturing industries should enable the construction of a sustainable social security system tailored to Japan's future super-aged society. A new market of approximately 50 trillion yen and the creation of 2.84 million new jobs is expected in these medical, nursing, and health-related services in 2020.[1] Among the technological developments of life innovation, the research, development, and commercialization of nursing care robots, personal mobility for the elderly, and life support robots utilizing manufacturing technology, as well as advanced medical technology, and information and communication technology (ICT) are expected.

Many industrial robots have already been introduced into manufacturing sites. According to a 2008 statistical survey conducted by the International Federation of Robotics, 1,035,674 industrial robots were in use worldwide at the time. The total number of professional service robots is 63,000, and they are primarily used in the military, disaster relief, security, outdoor work, and other areas. Meanwhile, service robots sold to consumers account for 7.2 million units. The proportion of independence-support robots for the elderly and disabled, however, remains small.[2]

Many businesses in Japan are currently researching and developing robots for areas such as life support, entertainment, medical care, nursing care, welfare, disaster relief, and personal mobility. Home appliance and automobile manufacturers are researching and developing robots with the ability to communicate and with transferring support function. Japan's advanced robotics is already expanding overseas in the fields of nursing care, welfare, and rehabilitation. However, robotic medical devices are not currently widely used in the medical and welfare fields.

Moreover, because the sophisticated and expanding information society infrastructure is greatly influencing how everyone works and lives, delving into information technology (IT) will become increasingly important in order to achieve life innovation. Cooperation between IT and information network infrastructure is particularly needed in service robots that will require people to coexist with their living environment.

The automotive industry is an important industry in mobility technology. In one of their surveys, Roland Berger compared the competitiveness of e-mobility in the seven leading manufacturing nations of electric cars (Germany, France, Italy, the United States, Japan, China and South Korea) by using "technology," "industry" and "market" indices.[3] In terms of technology, South Korea was the leader, followed by Germany and Japan. In terms of industry, Japan was in the leading position, followed by the United States. In terms of market, France was the leader, followed by the United States and Japan.

France has developed automatic driving using road marking (white lines) detection technology as a type of mobility innovation, and has successfully restructured street space allocating more room for pedestrians. France also uses IT extensively, with buses and traffic signals connected, thereby achieving signal control through bus operation by drivers. By combining the advantages of Japan's manufacturing technology and France's market technology, innovation that takes advantage of both countries' strengths could be achieved in integrated and sustainable mobility and robotic technology for the elderly and disabled.

The aim of this study was to investigate innovative technology for sustainable mobility, particularly scientific technology that could improve mobility for the elderly and disabled.

2. Methods

Four issues were surveyed to analyze technology for sustainable personal mobility and assistive devices for the elderly and disabled persons.

2.1. Survey exploring the characteristics of the elderly

This study will first examine the mental and physical characteristics of elderly and disabled individuals and then examine the needs of personal mobility and assistive robot technology that elderly and disabled individuals require. The investigative method will involve surveys in the field (facilities for the elderly, hospitals, and homes) and the existing literature. For the field surveys, a medical device developed by Tanaka's lab that tests and trains standing balance ability and a smartphone equipped with a standing balance and gait analysis and an evaluation application capable of acquiring data in care settings will be used to analyze the physical characteristics of elderly individuals in France and compare their similarities and differences with elderly individuals in Japan.[4-6]

2.2. Survey of existing mobility and robotic technology

Current mobility and robotic assistive technology tailored to the characteristics of the elderly and disabled individuals examined in item 1) will be investigated in Japan and the West. The products investigated will include those at the prototype state and those currently used in care settings. Furthermore, differences in the approval systems, patent procedures and other aspects of medical and assistive device production between Japan and the West will be clarified because this is an important matter in deploying these devices in care settings. In particular, the research being conducted by Tanaka's lab into a new medical device for balance and gait evaluation and training to prevent falling in the elderly will be used to compare and analyze the fields of medical engineering in Japan and the West. For example, risk factors in falling will be analyzed on the basis of the results of the physical characteristics survey of frail elderly[4] and disabled individuals obtained in item 1) to clarify personal mobility and robotic technology that provides support tailored to the level of decline in physical function. The differences in physical characteristics of the elderly between Japan and the West will be used to deepen the discussion regarding necessary personal mobility and assistive robot functions.

2.3. Survey of Technology of ICT and IoT (Internet of Things)

This technology is important to mobility and assistive robotic technology, and areas of this technology such as remote data sharing and remote control are expected to rapidly expand in the future. That is why the current status of this technology designed to support the elderly and disabled will be first to undergo survey and analysis. One example of this technology is devices that remotely train (tele-rehabilitation system) the muscles in need of rehabilitation for the disabled. While remote control is possible, no sensory feedback is given to subjects because only muscle strength and joint motion are measured. These devices are thus not widely used in care settings due to the lack of information on the subject (i.e., joint pain, whether the correct joint exercises are being performed, risk management to avoid control of joint movements by the device) from the system (tele-rehabilitation system). Tanaka's lab had been engaged, in joint research with MIT, into tele-rehabilitation systems for the elderly and disabled since 2003 and has been developing this research with the support of the Japanese Ministry of Internal Affairs and Communications since 2012.[7-8] Challenges of ICT and IoT in care settings will need to be clarified in order to use this personal mobility and assistive robotic technology.

2.4. Proposals for new technology

In conducting the three surveys mentioned above, collective proposals for technology that is currently needed, and new technologies that will be needed in the future in personal mobility and assistive robotics for the elderly and disabled will be put forward. Therefore, proposals will be made after summarizing trial interviews with researchers, businesses, and medical and welfare professionals in both Japan and the West regarding technological developments that are advancing both the necessary future new technologies and existing technologies. Once the characteristics of elderly and disabled individuals are fully understood, proposals for new technologies will be widely made with respect to the important challenges associated with this study and required by care settings.

3. Survey of the characteristics of physical activity capacity in the elderly

A survey of the literature and interviews with medical professionals revealed little difference in physical activity capacity, standing posture balance capacity, or walking capacity in adults ≥65 years old in Japan and other countries. In France, the focus is being placed on studies of adult rehabilitation after falling, particularly among women ≥75 years old, and similar trends are being seen in the United States and other developed countries. As an example from the literature, the ratio of unexpected accidental deaths caused by falling increases drastically after 65 years old, reaching 67% for adults ≥85 years old as the top cause of accidental death for that age group[9]. A similar trend is also observed in Japan, where the ratio of unexpected accidental deaths increases after 65 years old, and falling represents the second greatest cause of death for those ≥85 years old after death from suffocation, accounting for 25% of deaths (Ministry of Health, Labor and Welfare's statistics, 2009). However, while it is unclear what accounts for the differences between France and Japan in these rates, one possible factor as an environmental factor for the elderly in France may be a lack of stability on stone-paved streets, level differences between the street and pavement, a lack of ramps and handrails, a lack of elevators in apartment buildings, and a lack of progress in universal design for public facilities, which markedly differs from the situation in Japan. From interviews with therapists regarding medical care for the elderly in France, home care appears more advanced than in Japan. A higher level of one-to-one healthcare services from therapists seems to be available in France, along with a strong tendency for the elderly to request care from people rather than interventions involving machines. This suggests that there may be more resistance to the use of robot suits for the elderly in France than in Japan. One can highlight too that volunteer activities are more extensive in Western countries than in Japan, and finding nursing care help is easier, reducing the need for robotic alternatives. This trend may be the result of differences in religion and culture between Europe and Asian countries, and a social science approach appears warranted. For example, when a robot suit is used for a patient, medical staff and engineers are carefully able to understand the versatile needs and satisfaction of patients and their families thanks to the social science's approach.

4. Regarding the challenge of personal mobility (PM) for the elderly

To characterize PM in Japan, the following definition of the Ministry of Economy, Trade and Industry and Ministry of Land, Infrastructure, Transport and Tourism will be used[10-11].

For an elderly individual requiring light care, PM aids are important devices extending the duration of independence in outdoor transfer and locomotion ability. When envisioning the use of PM aids by the elderly at this stage, one challenge is to determine the best way to ensure that the user can utilize the aid by themselves. For indoor transfer, for example with the RODEM[12], consideration should be given to mechanisms that facilitate transfer to a sitting position. For outdoor vehicles, lower floors and other structural mechanisms should be considered. Various vehicles that do not require a driver's license and move at a speed of maximal 6 km/h are sold in Japan. Examples include the RT.1 and RT.2[13], which adapt to street surface conditions, and three- and four-wheeled motorized scooters[14-15]. However, 6 km/h has been considered too slow and thus those aids may not achieve practical utility. In other countries, motorized wheelchairs can be driven at speeds of ≥15 km/h without a driver's license.

Another point is that the elderly may also have decreased cognitive function, and a number of fatal accidents occur every year in Japan as a result. Some current challenges are making small turns easier as PM aids themselves become smaller, developing intuitive operation interfaces to reduce barriers resulting from cognitive impairment, and, depending on the location where the PM aid is being used, equipping the aid with systems such as collision avoidance to reduce injuries from accidents and the burden of driving. Demand for these features is increasing. In Japan, ultracompact PM aids are registered with an authorization system in which the application is submitted by the municipal authorities, and the devices are registered as light motor vehicles. Smaller and lighter than regular vehicles, PM aids are easier to maneuver and inflict minimal injury to others in the event of collisions. These systems have thus been suggested to be suitable for the elderly. That said, they cannot be purchased freely under the current scheme. For this reason, PM aids are not as commonly used in Japan as they are in Western countries[16-17]. PM technologies do not differ greatly between Japan, Europe, and the United States, and the following challenges exist in all those countries.

1. Issues with traffic infrastructure: The distance for PM aid use is assumed to be within a range of a few kilometers. Accordingly, users must still utilize trains, buses, personal vehicles, and other forms of transportation for medium and long distances. Problems associated with switching modes of transportation must be addressed to facilitate the use of PM aids for social activities. When transferring from home to a given destination using a vehicle, the PM aid must be loaded onto and unloaded from the vehicle and

the user must get on and off the vehicle. Some vehicles already allow boarding in a wheelchair, and similar customization for PM aids is thus needed.

2. Legal issues: When riding outdoors in Japan, the Road Traffic Law must be followed. Currently, motorized wheelchair dimensions must be within a length of 120 cm, a width of 70 cm, and a height of 109 cm, and it must move at a speed of ≤6 km/h (Road Traffic Law Enforcement Regulations, Article 1-4). This is much stricter than in Western countries and represents a substantial obstacle. Conversely, it should be pointed out that traffic laws in Europe are not as strict as those in Japan.
3. Road- and building-related issues: The environment in which PM aids can be used is extremely limited in both Japan and France. Naturally, paved roads wide enough for passage are needed. Spaces are also needed to park the PM aid upon reaching one's the destination, but bicycle and vehicle parking spaces are often either too small or too large, respectively. Another issue is securing power (installation spots) for charging.
4. Issue of understanding by outsiders: The extent of understanding by the wider public regarding use of PM aids is an issue. In Japan, people are still subject to criticism for taking strollers onto trains. This obstacle may be reduced in Europe, but a common understanding and consensus about what others can tolerate is needed concerning the use of PM aids and the occupation of space for those aids.

5. Challenges concerning robot suits, primarily concerning walking assistance for the elderly

As examples in Japan, HAL[18] and ReWalk[19] can be used as walking assistance robots for patients with spinal cord injuries by using the suit with a cane, but a caregiver must always be present. Some patients with intractable diseases are also eligible for reimbursement of medical fees for robot suits. However, numerous challenges remain to be addressed to ensure the use of aids for ambulatory autonomy.

First, one major technological challenge for the robot suit is that it currently only supports monoaxial joint movement, mostly in the knees and hip (flexion-extension of the hip and knee joints), and thus cannot prevent sudden falling. This means that walking assistance is primarily for a flat gait and requires monitoring, so it is only good for rehabilitation programs together with fall-prevention devices[20-23]. Robot models to support movement of multiaxial joints in leg joints are in the research and development stages at university and corporate research institutions. The same trend is seen in Japan, Germany, and other developed countries. Support for joints with the robot suit is also lacking because motor control for controlling smooth movement of the joints in normal human ambulation has not yet been achieved. In addition, quick movements such as postural reflexes and balance reactions that humans possess are required to prevent falling. A current challenge to support walking is therefore to determine how to control smooth multiaxial joint movement, quick movements to prevent falling, and other aspects that are essential for normal human ambulation. Technological challenges are creating more compact, lightweight suits, and motors, and are increasing the power of the motor. In addition, the weight of the battery itself (currently several kilograms) remains problematic.

Robot suits currently work primarily by motor control, but humans have sensory functions that are essential for controlling these types of movements. For example, visual sense, joint position sense to detect the movement of each joint, tactile sense using the sole of the foot, and auditory sense, all of which being crucial sensory elements for human ambulation. Determining how to incorporate sensory functions into robots is an issue. One challenge is determining how to add sensory feedback and feedforward function to aim for normal walking assistance. In addition, detailed analysis of ambulation by elderly and disabled persons to enable control of motor-sensory system by use of the robot suit is important for determining what control method is required, and researchers are now in the process of collecting data with various experimental methods.

In addressing the above issues, a discrepancy can be observed between the needs of the medical site and the needs of the engineer site for producing a robot in both Japan and Western countries. A prerequisite for eliminating this discrepancy and enabling practical use of the devices is the capacity to build team projects to efficiently and effectively pursue joint development in medical engineering based on relations of trust. In Europe, many companies, universities, and hospitals are actively carrying out cross-border industry-academia/industry-government-academia collaborative research.

The following are some other challenges.

1. Sensory modalities that enable the user to manipulate the robot with minimal movement restrictions and minimal cognitive load. Information processing and information presentation technologies that enable prediction of intention.
2. Control technologies that provide the appropriate degree of assistance with correct timing.
3. Wearability, safety, and durability suited to the usage environment.
4. When in use for gait-training purposes in a medical institution or similar facility, the robot can be put on with assistance from a helper and is comfortable to wear. The robot can be used safely and reliably while supervised by a helper. It can withstand continuous use several times a day during the usage period and can be charged and serviced without any problem.
5. When in use for ambulation assistance purposes during day-to-day life at home or elsewhere, the robot is sufficiently light, can be worn and removed easily and is comfortable to wear. If the user has an adequate level of physical and cognitive capabilities, the robot can be used within the range of intended use with minimal risk of injury, such as in case of falling. The robot can be charged and serviced when needed so that it can constantly be operated.
6. Cost issues: Although this applies to all robotic devices, the amount of the cost for initial implementation, maintenance, and operation costs may represent key obstacles to the spreading use of robots. There is a question of who will be able to bear those costs, and how. In the field of assistive devices as well, there is growing criticism about past projects for the government mostly providing aid for the initial costs and leaving the hospitals and businesses take care of the rest. The need for establishing items for maintenance and operation cost is currently being debated. This may be even more important for robotic devices.

6. Current state and challenges of ICT

Regarding PM aids and robot suits using ICT, projects carried out by Singapore-MIT and Panasonic are some examples of motorized wheelchairs. Implementation experiments were launched in Singapore, Haneda Airport, and elsewhere[24] in 2016. BionicLab in the United States developed an exoskeleton robot and a prototype was released that operates the robot with the help of speech recognition technology by Amazon[25-26]. For HAL, implementation studies with biological sensor-added functions, ICT, Iot (Internet of Things), cloud, and so on are scheduled.[27]

Research and implementation experiments that combine ICT, Iot, PM, and robot suits are therefore poised to take off. With advances in AI (Artificial Intelligence), PM control that uses ICT in urban traffic could conceivably gradually be tested: traffic jam avoidance, speed control of PM, route guidance, and so on. Moreover, when used by people, and especially when used by the elderly and disabled persons, ICT is essential as a system for temporally monitoring human biological information and successively providing information to the user and relevant individuals to ensure that no failures occur.

Considering the above, both PM aids and robot suits may be combined with ICT and AI technology, resulting in rapid progress in the development of safe and reliable products that enable transferring and locomotion. In particular, the use of PM aids will then require reorganization of traffic laws and development of urban infrastructure in each country. This will in turn enable even further improvements in activities of daily living and quality of life in the elderly and disabled persons and may be expected to entail reform to community development.

7. Prospects for support of daily life in the elderly and disabled persons with PM aids and robots

Regarding PM aids, according to a March 2017 revision of the Road Traffic Law in Japan, if cognitive impairment is suspected when a person who is ≥75 years old takes a cognitive function test when renewing their driver's license, if that person is diagnosed as having dementia by a doctor, the driver's license will be revoked. The number of elderly individuals subject to restrictions in means of transfer and locomotion, including through the aforementioned revocation of driver's licenses or voluntary return of the driver's license is expected to increase. Many elderly individuals use cars as means of transport to grocery stores that are within walking distance, which entails that PM aids that support the transfer and locomotion of elderly individuals with impaired cognition function are needed. Devices that utilize an individual's remaining physical abilities, have an interface and construction that enable easy riding and operation, and are sufficiently simple to charge and service seem likely to be developed for elderly persons and disabled individuals with impairments in daily living. Products may also be developed for elderly and disabled individuals with impaired cognition function who do not require advanced operation, have operation assistance functions that reduce the risk of injury from accidents and the burden of operation, and may even have autonomous driving functions to reach the destination. For these types of PM aids, depending on the frequency of use and economic circumstances, some aids may be accepted as items that are operated according to usage and owned by the local community, rather than owned by one individual. In addition, with the adoption of ICT, AI, and autonomous driving technology in PM aids, such aids may be launched in environments such as airports and large facilities, where transfer to a destination is easily monitored, similar to the eligibility of self-driving technology for vehicles on highways, and operational issues then need to be resolved. As examples of operational issues, situations may arise that were not predicted during the design phase, and questions remain regarding how to update information when the roads, layout, and other aspects of the environment evolve, what ought to be done when a user wants to change a destination en route after having indicated their destination, how to determine priority when several PM aids or PM aids of other companies that are not cross-compatible cross paths, and so on. During the process of resolving these issues, PM aids and other such devices may not be individually owned, but rather become another form of public transport similar to trains, buses, and taxis, although infrastructural development would be a prerequisite.

Regarding the use of robot suits by the elderly, for home use, there is potential for easily worn wearable robot suits and non-wearable robots that do not require wearing that can support operations users find particularly difficult in day-to-day life, such as rising to a standing position and going up/downstairs. For aids to assist in going outdoors, there is potential for suits that provide assistance as required during the use of existing human capacities, primarily for walking, enable locomotion and transfer within the same activity range as before the appearance of marked deterioration in physical and balance abilities. These suits have an autonomy of about 2-4 h of continuous use, and can be put on easily at the front door or upon exiting an automobile.

In the field of robot suits for disabled persons, when being used for gait training purposes as a medical device in a medical institution, during the phases from sub-acute to maintenance when quantitative training is needed, there is potential for wheeled cart-type (walker-type) robots that help the user to walk on flat surfaces according to their own will and that make it physically impossible to fall, thereby reducing the caregiver's burden of monitoring. There may also be potential for robot suits with comprehensive systems that can be used after hospital discharge in the outpatient phase to monitor daily activities, enable use of that data for more accurate diagnosis during outpatient visits, and encourage self-training by the user in daily activities according to individual circumstances. In addition, as the robot suit would be used by disabled persons as an assistive device, resolving the aforementioned issues would be required first.

8. Conclusion

Fig. 1 shows one ideal system for supporting locomotion and transferring by elderly and disabled persons. In this figure, detailed analysis of the needs of those individuals, including physical capabilities and the surrounding environment, are performed to determine how to support locomotion and transfer and with what technology base. To achieve this, the following is an approach to addressing the diversity of elderly and disabled individuals, using walking assistance as an example. For an elderly person diagnosed as requiring light care and capable of independence, the choice would be a robot suit. For an elderly person with moderately to highly impaired activities of daily living (ADL), the choice for walking, locomotion and transfer assistance would be a PM aid with locomotion and transferring assistance functions. For a disabled person with severe impairment, the choice would be a robotic walking assistance device with a function that assists the user in rising to a standing position. In this manner, individual robot modules could be combined to enable selecting the most appropriate assistance method for that impairment. The best approach for future projects may therefore be the development and commercialization of custom-made devices that can improve ADL and quality of life (QOL) with the use of devices that are PM aids that can be used for a diverse range of ADL impairments (from mild to severe) and that are robot suits. Rather than fabrication of units for each individual as is currently performed for prostheses, all-purpose modularized devices could be more efficient and all-encompassing. This can be said to be similar to the concept of dynamic capabilities that are capabilities enabling companies to constantly predict and adapt to changes, and use the technologies and resources of the company in combination to aim for sustainable advantages[28-29].

In Europe, after mistakes in technology-driven product development and problem solving, the importance of a user-oriented approach have been advocated, and manufacturing based on that approach has been carried out. However, a problem with this approach is that it is compatible with devices that users themselves can recognize, but difficult to resolve issues for devices that users have no experience with or are insufficiently aware of, or cases where they are not aware of the nature of the new products, technologies, or properties. In recent years, a Design-Driven Innovation approach has gradually come into more frequent use[30-31]. Design-Driven Innovation is a method for achieving innovation by pursuing the meaning of products while prioritizing user understanding through observation. Rather than providing products and services that users want to use, innovations in meaning are established in those products and services alongside technological innovations. The design-driven approach is applied to questions such as “why does the user need this?” and “what does it mean to me?” to provide new interpretations and value, and reform is achieved in not only products and services, but society as well. In the robotics field, for example, there are currently not enough examples of robots being purchased or applied by general users out of necessity. What exactly users want from robots or how they will determine their value remains unclear, and developers are not providing sufficient usage methods or clinical implication conditions. For PM aids and robot suits as well, a design-driven innovation approach is aimed at developing assistive devices with novelty (i.e., with innovation) that incorporate an assessment of the user’s needs and recognize the user’s impairment, utilize the individual’s remaining capabilities, and raise the individual’s QOL so that they may be used as devices to assist that individual within the construct of rehabilitation. To achieve this, assessing the current technology base in the field of healthcare and needs in the field of engineering (matching user wishes and the construct of rehabilitation, raising the individual’s QOL). Experts in both medicine and engineering are needed, and a consensus about the products to develop is essential. Moreover, by using a dynamic capabilities framework in the technological side of product development, one approach to the development of products that has a wide application range to meet the needs of each individual is commercialization of an all-encompassing robotic device similar to Fig. 1 and 2 that is suitable as a walker and for standing, locomotion, transfer, and walking for individual use. This may enable construction of concepts that lead to the technological development and product-marketing of sustainable PM aids and robot suits. In other words, as shown in the figure, this means thoroughly analyzing the human-related and environmental factors, widely considering the applications of the product being developed, and creating commercial products that thoroughly take into account applicability, based on a prerequisite of fully understanding the needs and technology base.

Furthermore, it will not be possible to achieve sustainable development simply through collaborations in medical engineering to create products for elderly and disabled persons. Rather, products must be created with consideration of how they can be used in society, including a social science approach that includes the environment.

Therefore, a new academic field called social medical engineering that blends social science and medical engineering should be built to develop sustainable versatile assistive device (Fig. 3).

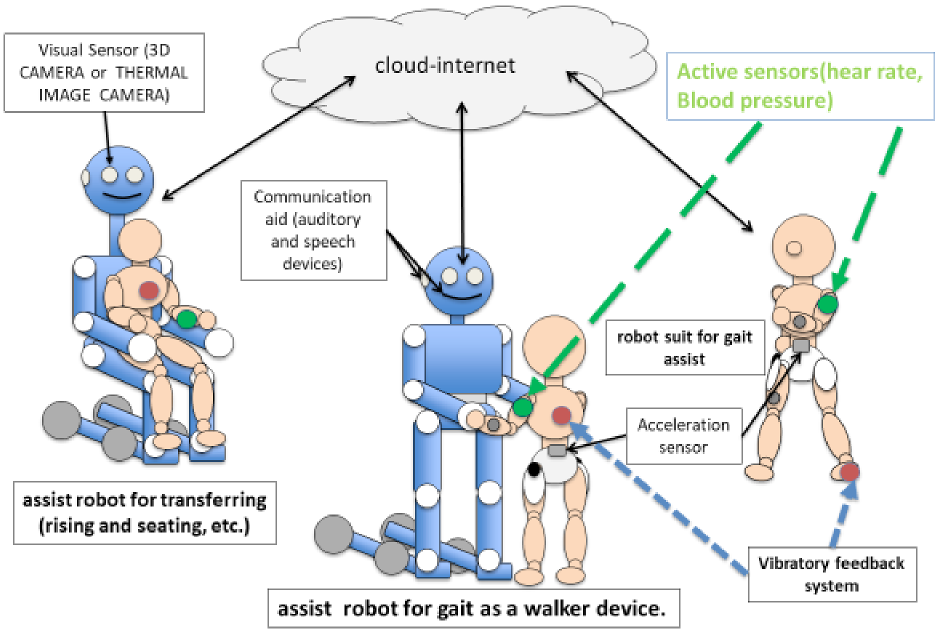

FIG 1. A total ICT assist robot for gait and transferring, and communication.

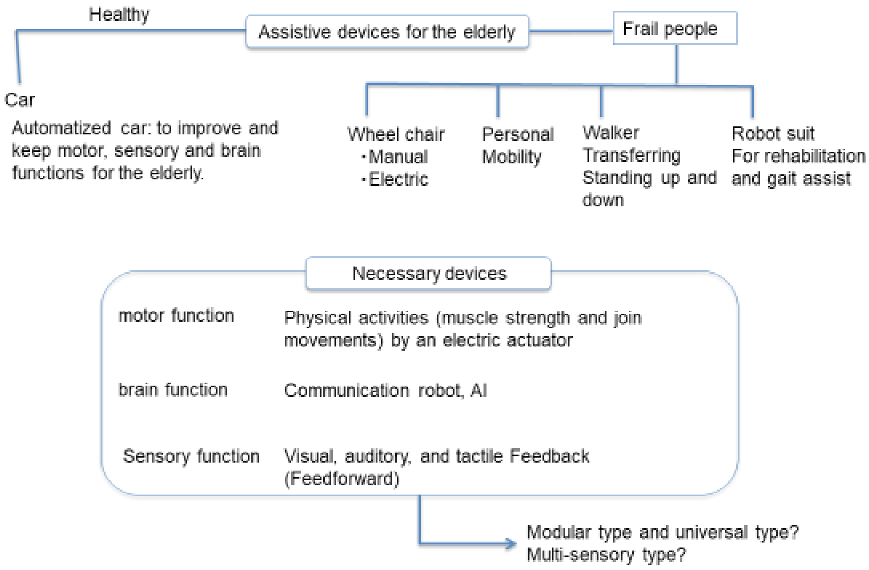

FIG 2. Developmental research of new assistive devices for transferring of the elderly and disabled people.

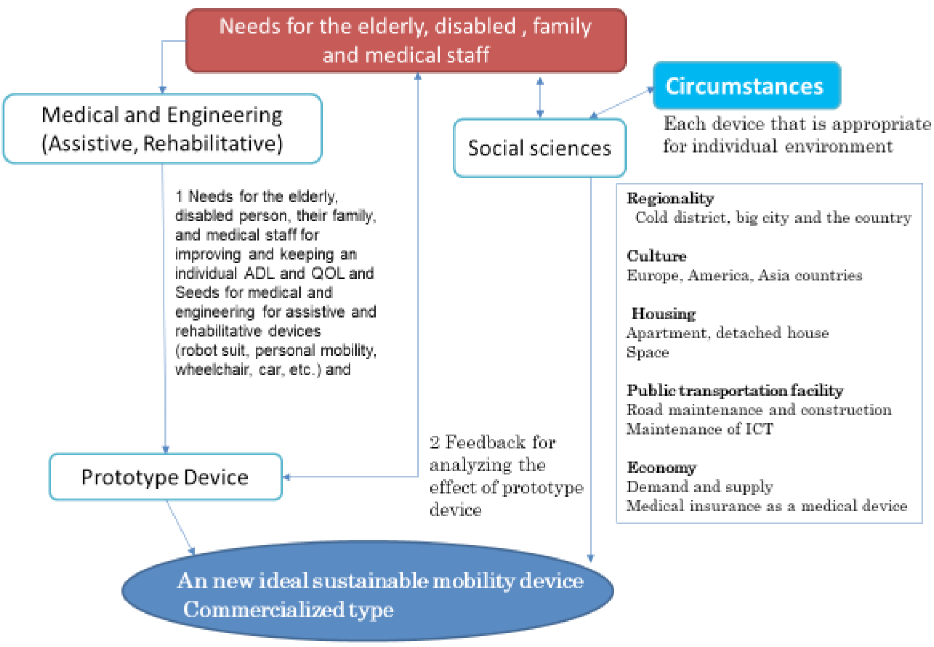

FIG 3. A combined study of social science and rehabilitation engineering for developing assistive devices.

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