Moonshot International Symposium
December 18, 2019

Working Group 1

Expanding human potential toward a society in which everyone can pursue their dreams

Initiative Report

Contents

EXECUTIVE SUMMARY

The progress of our civilization is the progress of tools; be it technology or social framework. Working Group 1 (WG1) concluded that a series of technologies that can be termed “Cybernetic Avatar” will trigger drastic and disruptive transformation of our civilization.

Looking back to the history of mankind, serval turning points often labeled “revolutions” took place and each transformed the industrial and sociological fundamentals of our civilization. Agriculture liberated us from the risk of hunger inherent in hunter-gatherer lifestyle and impacted our community structure. Industrial revolution was brought about by the invention of the steam engine that enabled us to generate and deliver “power” and further resulted in mass production and eventually a drastic change in mobility. Capital intensive industrial structure was an inevitable consequence of technological innovation. Information revolution, or information and communications technology (ICT) revolution, amplified the power of capital and technological superiority. “Data” is the name of the game, and one who owns a large amount of data and is capable of using it can industries and influence our society and lifestyle.

The extrapolation of historical trends considering the acceleration of technologies may result in the vision of “data religion” and *Homo deus* a much superior human model as claimed by Yuval Noah Harari[1] and migration to Mars as envisioned by Elon Musk. While these visions are certainly plausible, individuals who may enjoy benefits of such technological progress may be limited to only a fraction of the whole population. Unless consciously designed and disciplined, “the power of data” may accelerate social divide as eloquently argued by Thomas Piketty[2]. WG1 argues that there is a need to accelerate techno-social transformation that benefits a broad range of individuals with diverse backgrounds and conditions thereby achieving technological progress and happiness of said individuals simultaneously.

Society 5.0, a concept advocated by the Japanese government, is aimed at realizing a sustainable society that enables people with diverse backgrounds and values—such as the elderly, foreigners, and youth—to pursue diverse lifestyles. Its core values are sustainability and diversity. To achieve this, it is necessary to develop technologies that can complement and augment the abilities of different people in their quest for happiness and to develop a sustainable society with diversity and inclusion. Further, the corresponding social system should be changed. By virtue of this, people will be able to achieve their potential and their lives to the fullest.

The daunting reality in Japan is a rapidly aging society with a shrinking labor population. These impacts industries collaborating towards the collapse of rural communities, soaring social security expenditures, and evaporating domestic consumption. Japan is not alone in this situation. Several countries, particularly in East and South-East Asia, will follow the same path.

Although this aging society may appear to present a pessimistic future for Japan, WG1 considers it as an opportunity.

A range of techno-social innovations have to be triggered and implemented globally to achieve the vision of Society 5.0. WG1 proposes research and development on Cybernetic Avatar technology and Avatar Capitalism, as associated techno-sociological transformation, can be one of the major pathways for creating Society 5.0. Cybernetic Avatar technology enabling “capability complementation and augmentation” to meet diverse needs of diverse people should be promoted to realize Society 5.0. “Capability complementation and augmentation” implies that each individual can expand their own abilities by overcoming the limitations of the human “body”, “brain”, and “space and time”. It is important to establish technologies that can enable this. The technology will be a merger of artificial intelligence, cyborg, material science, and biotechnology built on an ultra-high-speed low latency global network.

Cyborg Avatar Capitalism is the associated sociological transformation where Avatars are considered social capital enabling anyone to pursue various lifestyles that is currently not possible thus

liberating existing constraints of physical, cognitive, and perceptional capabilities as well as geographic and economic restraints.

The magnitude of technological breakthrough is gigantic. If all the industrial activities are performed by avatars controlled by handful of individuals the impact on industries would be huge and truly disruptive. Despite such vast industrial impact, actual immediate effect on individual citizens may appear somewhat fragmented and minute as they penetrate into the everyday life gradually. For example, one can work for 30 min at a factory in Brazil and immediately spend next 1 h at a shop in New York, using avatars just before attending an early morning face-to-face meeting in Tokyo. Cybernetic-Avatar with substantial physical capabilities will enable us to participate in activities that requires physical presence rather than those using only audio-visual interactions.

Cybernetic-Avatar designed to augment physical capabilities shall be able to supplement or replace the physical ability of the elderly or persons with disabilities, thereby their limitations can be overcome. Furthermore, if the physical abilities are augmented, the person can perform tasks that they could not do before. A person who has to stay at home to care for someone could use an avatar as their replacement, which works and shares their knowledge and experiences with society. In addition, the augmentation of experience or knowledge expands capabilities and possibilities for any person and lets them participate in various roles in society.

Each of these examples may appear to be personal and fragmented; however, it reflects the reality of the issue when technology is designed to support diversity and inclusion. There is no single solution. Solutions are diverse and may appear to be fragmented because of diverse needs. Therefore, we argue that Cybernetic-Avatar Capitalism needs to be established, where Cybernetic Avatars are developed and deployed as social capital that give power to the people regardless of their backgrounds and conditions.

To realize these individual technological developments are already underway to overcome limitations of our “body” (physical capabilities), “brain” (perception and cognitive capabilities), space and time. However, a cross-cutting, integrated approach can only be implemented with ambitious programs, such as the Moonshot program.

In WG1, “By 2050, realization of a society in which human beings can be free from their limitations of body, brain, space and time with harmonious empowerment” has been proposed as a goal. Hence, we aim to achieve the two action items “Cybernetic Avatar Capitalism for Diversity and Inclusion” and “Cybernetic Avatar Life”.

Ⅰ. VISION AND PHILOSOPHY

1. The Moonshot 「Area」「Vision」 for setting MS 「Goals」 candidate

The visionary council, which consists of experts, proposed the 3 Areas, 13 Visions, and examples of 25 MS Goals that Moonshot Research and Development Program should aim for. The aim is to set ambitious targets and concepts for a social agenda that are difficult to tackle but will have profound impact once resolved. (See Fig.1)

Working Group 1 discusses the following Area and Visions for setting MS Goals candidate.

[Area]

Turning the aging society into the innovative and sustainable society by harnessing diversity through techno-social transformation.

[Vision]

Inclusive Society: anyone can pursue their dreams.

Society without health anxiety: everyone can enjoy life until 100 years old.

[Examples of MS Goal candidate to be used as reference]

1) Create and deploy "Cyborg technology" to augment human capability

2) Fully ubiquitous and inclusive mobility

3) Create and deploy advanced avatars enabling most daily life can be done through avatar

6) Universal medical access at the global scale

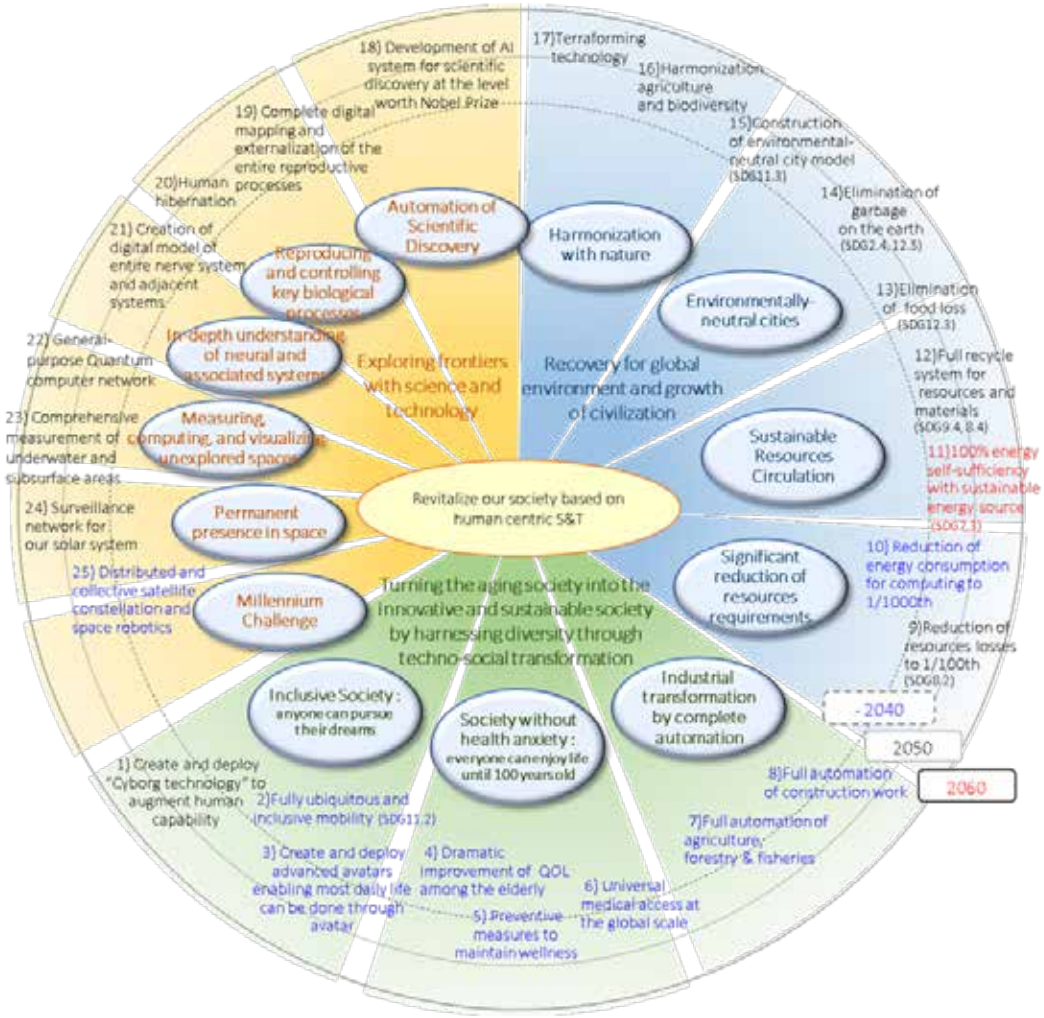

Fig.1. Future visions and 25 MS goal examples

2．Concept of MS Goal candidate

2.1 MS Goal candidate

・By 2050, realization of a society in which human beings can be free from their limitations of body, brain, space, and time with harmonious empowerment.

To realize the society illustrated in the vision, it is necessary for people with diverse backgrounds and values, including the elderly and those needing nursing care and childcare, to participate in society according to their lifestyles. We need to aim for a sustainable society that maximizes their opportunities to pursue dreams.

To realize their social participation, we thought it necessary to realize a society free from the limitations of the body, brain, space and time through harmonious empowerment by technology.

For example, supplementation and replacement of physical abilities of the elderly or persons with disabilities would overcome the limitation of the motion. In addition, building up physical abilities would enable a person to do things that were not possible before. In addition, building up physical abilities would enable a person to do things that were not possible for them before. For those who have to stay home for nursing, an avatar as their alternative, would be able to work and share the person's knowledge and experience with society, which further expands the ability and potential of people of different backgrounds, enabling them to participate in various roles in society.

A series of techniques known as cyborgs and avatars will be discussed in WG1. With these technologies, we believe that we can make use of the aging society and create disruptive socio-technological changes in Japan. We call these "Cybernetic Avatar (C-Avatar)"* Society. We would like to discuss widely on this idea.

---

*Cybernetic Avatar (C-Avatar)

C-Avatar is a concept that includes not only remote avatars using robots and 3D images as proxies but also empowerment of the physical/cognitive abilities of humans using ICT and robotics.

C-Avatar aims to be active not only in the physical world, but also in the cyber-physical world, i.e. Society 5.0.

For that reason, we propose to set two targets of C-Avatar Society to trigger a major socio-technical transformation and to create technological foundations for next-generation industries. The C-Avatar Society is a gentle but vibrant society in which everyone uses multiple shared C- Avatars, regardless of region, gender, or age. To build the society, we propose "C-Avatar Capitalism"** as a business target and "C- Avatar Life"*** as a life target.

The targets proposed by WG1 are presented below:

2.2 Target

We set two targets as proof of concept of C-Avatar Society for achievement of MS Goal

2.2.1 C-Avatar Capitalism for Diversity and Inclusion

- By 2050, develop technologies and infrastructure to carry out large-scale complex tasks using combinations of large numbers of avatars and robots that are teleoperated by multiple persons.

2.2.2 C-Avatar Life

- By 2050, anyone willing shall be able to augment their physical, cognitive, and perceptional capabilities to the level of the best experts of selected domains.

** C-Avatar Capitalism

Avatars will be a form of new capital of the society, where they can be shared or owned by individuals or companies. Avatars remotely deliver value of individual’s capabilities. This property of avatars opens up opportunities for people of diverse backgrounds, conditions, and locations to apply their capabilities anywhere in the world where such capabilities are needed. C-Avatar Capitalism aims to overcome the limitations of human capabilities and uncover the potential of individuals.

The theory of C-Avatar Capitalism shall be investigated and conceptualized. While Thomas Piketty argued that the divide would increase owing to technologies and intrinsic dynamics of the current form of capitalism[2], C-Avatar Capitalism challenges this notion, with technologies to attain inclusiveness and sharing the economy to reduce the social divide. Already, internet services such as Grab and Go-jek are providing effective financial services and job opportunities even for those who do not have bank accounts, in Indonesia and other ASEAN countries[3]. C-Avatar Capitalism extends this idea by providing opportunities for anyone in the world to participate in society, either through business or through charitable contributions.

***C-Avatar Life

The C-Avatar Life aims to research and develop technologies that improve quality of life (QoL) by supporting creative spontaneous activities such as recreational hobbies, travel, volunteering, art and entertainment, as well as everyday life at home.

2.3 Concept

To participate in society, regardless of age, culture, physical ability, time or distance it is important for people to enhance their autonomous and interactive activities, and to be able to supplement and complement balanced abilities, and to adapt to changes in the social environment.

To realize social participation, the constraints to be considered are “body ability”, “brain ability”, “space and time”, and development of “capability supplementation and replenishment” to control the body and actions in a balanced manner in response to changes in age and social environment.

For example, a person who cannot move freely such as an elderly person can overcome this restriction if the physical inability is supplemented or replaced. Furthermore, if a person can augment their physical abilities, things that could not be done before can become achievable.

In addition, if a person can use an avatar instead of their body to perform movements, they can share the senses and actions with the avatar and can remotely perform physical work or share experiences.

This will make travel cost obsolete: one can work for only 30 minutes every day on the other side of the earth.

This will bring about a completely different way of working, and it can be said that avatars will enable the circulation of world-class capabilities.

If a person does not have enough experience or knowledge about a perceptional or motion task, capacity augmentation, such as stabilization and acceleration of athletic ability can be built into an avatar.

In extreme cases, development of reprogramming of the central nervous system will complement the memory and experiences, opening up new possibilities. Such capability augmentation would let any person from any background participate in society with greatly reduced obstacles.

In WG1, the goal is set to eliminate the constraints of “body ability”,” brain ability”, and “space and time” (Fig. 2).

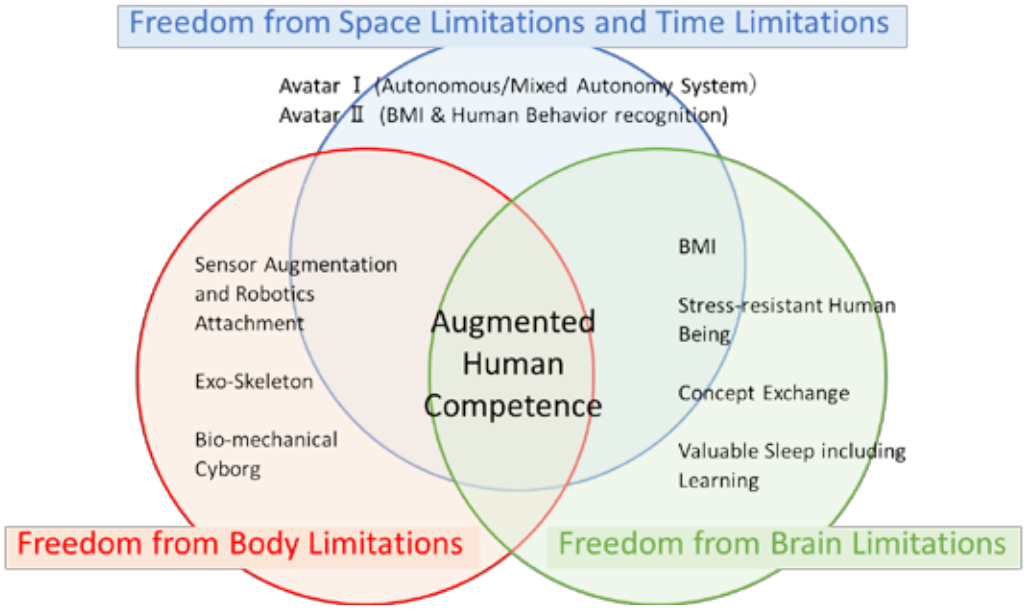

Fig.2. Freedom from body, brain, space, time limitations

We explain C-Avatar Capitalism for Diversity and Inclusion and C-Avatar Life, which are the targets to achieve our goal.

C-Avatar Capitalism for Diversity and Inclusion

The implications of this challenge can be far-reaching. In the practical aspect, this Moonshot target calls for the development of a potential industrial platform where tasks such as farming, construction, fishery, and others, can be performed anywhere on the planet or in space, teleoperated by a single person far distant (e.g. the other side of the planet) from where the tasks are actually being performed. The target assumes avatars to be heterogeneous, to have a certain level of autonomy, and to work in coordination with fully autonomous robots. C-Avatars are controlled not only by the movements of physical body elements like hands, legs, facial expressions or muscles, but also by the brain directly through BMI systems with advanced communication technologies.

The real objective is to overcome social divide and achieve a diverse and inclusive society by creating a new social structure and economy, with avatars being a new social capital. Avatars can be shared or owned by individuals or companies. Avatars deployed ubiquitously in society shall enable everyone to access and contribute to various aspects of society from anywhere at any time. Deployment of ubiquitous and sharable avatars around the world will enable people to communicate and work at any place from anywhere at any time. These avatars will eliminate the time and cost required for a person to travel from one place to another. This implies that one can work at one place for 15 minutes and switch to another workplace within a second, even if the next place is on the other side of the planet. This allows for various work styles and locations and eliminates the various constraints on each individual.

This function of avatars opens up opportunities for people from diverse backgrounds, conditions, and locations to deliver their capabilities anywhere in the world where such capabilities are required. C-Avatar Capitalism aims to overcome the limitations of human capabilities and uncover the potentials of individuals from diverse conditions.

C-Avatar Life

Our abilities do not belong only to our bodies, but also to the relationship with ourselves, others and the environment. Thus, this challenge aims to empower our ability in Society 5.0 with both physical and environmental approach to improve quality of life (QoL).

When we can no longer do what we used to in the past, we feel ourselves weak and lose hope for the future. By creating an environment that properly draws on the capabilities of C- Avatar, we believe that everyone will be able to feel increased capabilities, daily growth, and hope for the future.

The C-Avatar Life aims to research and develop technologies that improve QoL by supporting creative spontaneous activities such as recreational hobbies, travel, volunteering, art, and entertainment, as well as everyday life at home.

Regardless of gender or age, in order for everyone to participate in society and enjoy their life, we need to develop highly sophisticated technologies. C-Avatars are controlled not only by the movement of physical body element like hands, legs, facial expressions or muscles, but also by brain directly through BMI systems with advanced communication technologies.

Such technology can be used in daily life, in a wide range of industries, and to possibly explore new frontiers. The set of technologies developed for this challenge has to be consistent with human physiology in terms of material, structure, control, and aesthetics. It will be drastically different from the robots that we see today, while there may be substantial commonality to cross-fertilize the research and applications. The strengths of robotics, mechatronics, electronics, and material sciences will be further augmented.

By combining both challenges and bringing them to the extreme, we hope to develop technologies as illustrated in Sci-Fi movies such as “Ghost in the Shell”, but applied realistically for the purpose of achieving a society with diversity and inclusion.

MS in the field of medicine, which will be examined and implemented later, aims to research and develop monitoring and intervention technologies to achieve dramatic improvements in QoL and universal medical access, by developing such technologies to complement deteriorating body functions, among other things. Such technologies can address future challenges in the areas of medical and nursing care.

3．Why Now?

There are mainly two reasons why people must set the goal now of realizing a society that enables social participation regardless of age, culture, physical ability, time, and distance, by 2050. One is the social and environmental aspect, and the other is the scientific and technical aspect. These are explained below.

①Social aspect

In Japan, if the proportion of the aging population continues to increase with the declining birthrate, the population is expected decrease to 10.192 million in 2050. The proportion of people over 65 years old will constitute 37.7% of the population, and the number of such people is expected to be around 38.41 million. The working-age population is expected to decrease to 52.75 million [4].

This declining birthrate, aging population, and population decline will inevitably become a common issue in several developed countries and in countries around Asia that follow the same demographics as Japan. Japan, as a top-runner, should solve the problem.

Foreign research has estimated that 50% of the children born in Japan in 2007 will live till the age of 107. Japan already boasts the longest healthy life expectancy in the world [5].

In these 100 years of life, it is necessary to realize a sustainable society (Society 5.0) that enables people of all ages and from diverse backgrounds to pursue diverse lifestyles.

②Science and technology side

At present, science and technology do not allow social participation beyond the constraints of age, culture, physical ability, brain, time, distance, and so on.

For example, when the body becomes incapacitated owing to injury or other issues, there is currently no alternative technology that can completely perform the basic function of a prosthetic leg. With the recent evolution of ICT, it has become possible to move things and sense movements via communication without going to the place. However, it is not possible to convert all human senses and movements precisely, communicate them to the avatar, and operate the avatar.

Furthermore, in the future, in order for all people to actively participate in society by using technology that fuses the human senses and movements with ICT technology, it is important that this technology can be used easily, without any difficult operations, on a common platform such as the current WEB or smartphone.

However, there is no common platform that connects the five human senses. In the following, we will explain from the viewpoint of freedom from "body", "brain" and "space and time" limitations.

(1) Freedom from body limitations

By 2050, elderly people will acquire superior physical abilities by using physical augmentation technologies to complement, replace, or enhance their weakened or lost physical functions.

At present, intelligent prosthetic hands and legs are commercially available, and powered exoskeletons controlled by biological signals are used in medical facilities and nursing homes. However, these devices do not have all the abilities required to cope with various tasks in daily life.

In order to solve the present problem, physical compensation and augmentation technologies are

required, in addition to robot technologies that enable human-like dexterous manipulation, or human-like walking and running.

- New materials for artificial limbs with human-like weight and mass balance are required. Structural materials having sensing functions, and new materials for performing sensing and actuation simultaneously will enable significant weight reduction. For avatars to coexist and with humans, soft materials that can ensure safe physical contact are important. For intelligent prosthesis, biocompatibility is also required.
- Lightweight and highly power-efficient actuators having a wide dynamic range of output—from low power for delicate gripping of flexible and fragile objects, to large power for hammering a nail—are required to address weight restrictions. For intelligent prosthesis, suppressing heat emission is also important.

(2) Freedom from brain limitations

The brain has the restrictions of limited memory, mistakes, and illusions. If a person does not make an effort to learn, they cannot talk freely with people of different languages, and it is difficult for others to clearly understand this person.

By supplementing and strengthening the above constraints with ICT, by 2050, advanced intellectual activities will be possible. For example, the following will be possible:

Everyone can use their specialized knowledge and experience, improve individual productivity, and perform advanced communication to deeply understand people from various countries and cultures. In addition, people will be maximizing their performance, becoming more resistant to stress, and being able to enjoy not only work but also hobbies and leisure.

By 2050, it will be possible to extract human thoughts and brain information and to move distant avatars simply by using one’s mind.

In addition, by analyzing the extracted brain information, we can model the thinking itself—such as human brain recognition and decision-making—and reproduce and visualize it on a computer to share thoughts and artificially improve the model. Thus, it will be possible to realize brain functions that exceed the cognitive thinking ability.

Furthermore, by realizing bidirectional communication of brain information, it will be possible to strengthen ability.

At present, it is possible to acquire data from the brain and perform simple tasks such as moving a virtual car, by using brain implant devices or non-invasive devices such as EEG and fNIRS. The problems and required developments are as follows:

- Current brain-sensing and data-acquisition systems are expensive and cumbersome. Invasive brain–machine interface (BMI) require new microfabrication, packaging, flexible electronics, low-power local processing, and new implantable sensors with wireless data paths. Non-invasive BMI requires low-cost and ergonomically designed wireless EEG and fNIRS systems.
- Non-invasive BMI involves problems in dealing with artifacts of noncerebral origin. The data-processing challenge is also associated with the fact that cortex folding differs between individuals, as do relevant functional maps. Furthermore, brain dynamics can be intrinsically nonstationary.

(3) Freedom from space limitations and time limitations

By 2050, any person in the world can connect to avatars limitlessly, which will make them feel as if they are everywhere in the world without moving, by utilizing real-time transmission and regeneration of sensory information.

At present, visual and audio transmission technologies have been established. However, transmission technologies for tactile and force sensations are still being developed as “haptics technology”. Existing devices can transmit and indicate tactile sensation with vibrations to fingertips, or temperature sensations with a small heater [7]. It is necessary to expand the area and density for presenting tactile sensation and force sense. For olfactory and gustatory sensations, technologies are still in the embryonic phase.

Furthermore, in order to transmit sensory information in real time between humans and avatars, higher-capacity, lower-delay bi-directional communication technologies beyond “5G communication” are necessary. The required developments for this are as follows:

- Flexible skin-like tactile sensor arrays that have a sensor density equivalent to that of humans, in order to expand the area and density of sensations.
- Expansion of tactile sensation to the real sensations, such as smooth or slimy textures, instead of pseudo-sensations using vibration.
- New lower-delay, larger-capacity communication technologies surpassing 5G communication, and prefetching and prediction technologies enabling delay-free communication.

The three freedoms, through technological innovation, will enable people from diverse backgrounds to pursue diverse lifestyles, achieving a sustainable and diverse society, where everyone can pursue their dreams.

The targets for achieving this goal will be realized not through research and development of single technology, but through integration of research and development of several technologies in related fields. For wide dissemination of the results to the society, discussions on the ethical, legal, and social issues (ELSI), standardization of technologies, and creation of platforms will be critical. If Japan takes the lead in these activities, not only industrialization of the core products, but also creation of new knowledge-intensive industries based on lifestyle data collected on platforms can be expected.

It is important for Japan to address this issue as it faces serious labor shortages due to the declining birthrate and aging population, and the depopulation and hollowing out of local towns.

4. Changes in industry and society

The MS Goal of augmentation of human competence will realize a society in which people from diverse backgrounds and having different values—from elderly persons and persons with disabilities, to young persons—can pursue various lifestyles.

In the future, people themselves will be diversified by augmentation of competence, and a society where various forms of augmented creatures and artificial creatures that coexist in a cyber-physical space will be achieved.

The basis for this is a platform that enables international collaboration based on human-centered thinking. On the platform, functions for expanding human movements and sensations, functions for amplifying human intelligence, and functions for expanding human capabilities such as robots and avatars remotely controlled by humans are connected via a network. It collects, stores, and processes information, and is used to utilize human abilities.

The platform will be a place for various companies, organizations, and individuals to participate and create new businesses. C-Avatar Capitalism for diversity and inclusion is a new production and service space that connects companies, places, and workers beyond space and time constraints. C-Avatar Life is also a place to connect players, media, and companies through competition. Further, we believe that a new intellectually intensive industry based on human-life data gathered on the platform will be born, and that start-ups will be nurtured as a new growth industry based on it.

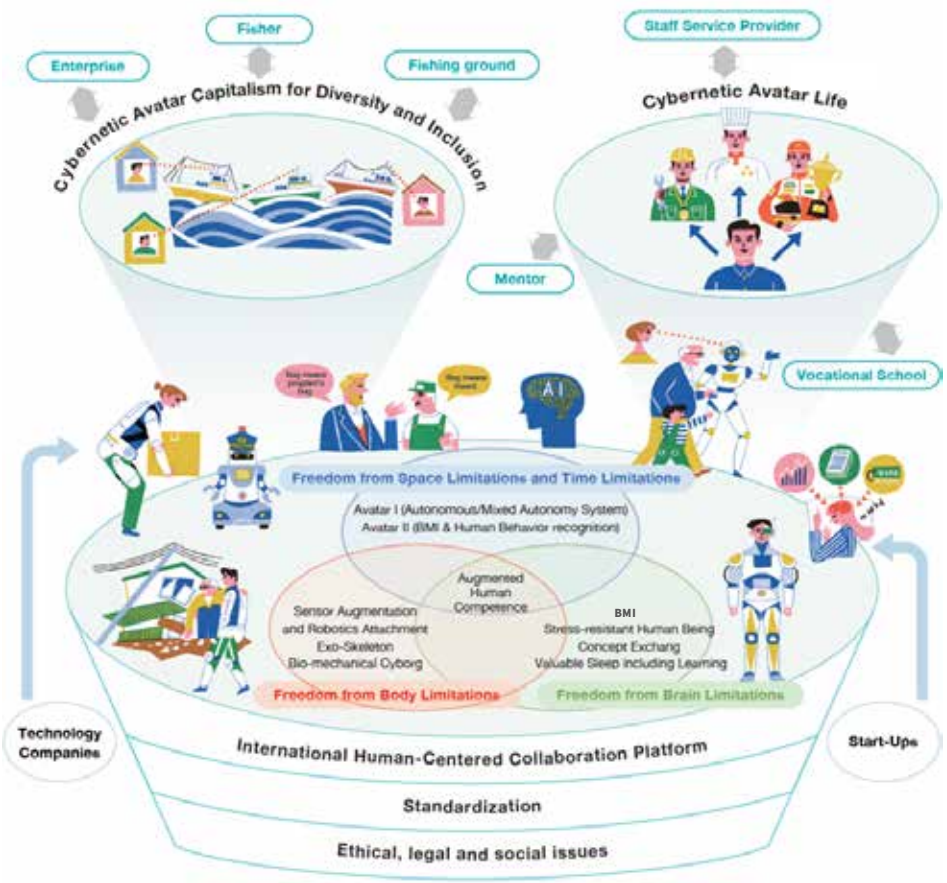

Fig.3. Vision of a society

II. STATISTICAL ANALYSIS

1. Structuring of MS Goal

As described above, the body, space, time, and other elements can be considered as restrictions on human abilities.

C-Avatar Capitalism for Diversity and Inclusion and C-Avatar Life which prove a higher-level concept will be realized, by combining the elemental technologies to overcome these restrictions. The relationship between these two proofs of concept is shown in Fig. 4.

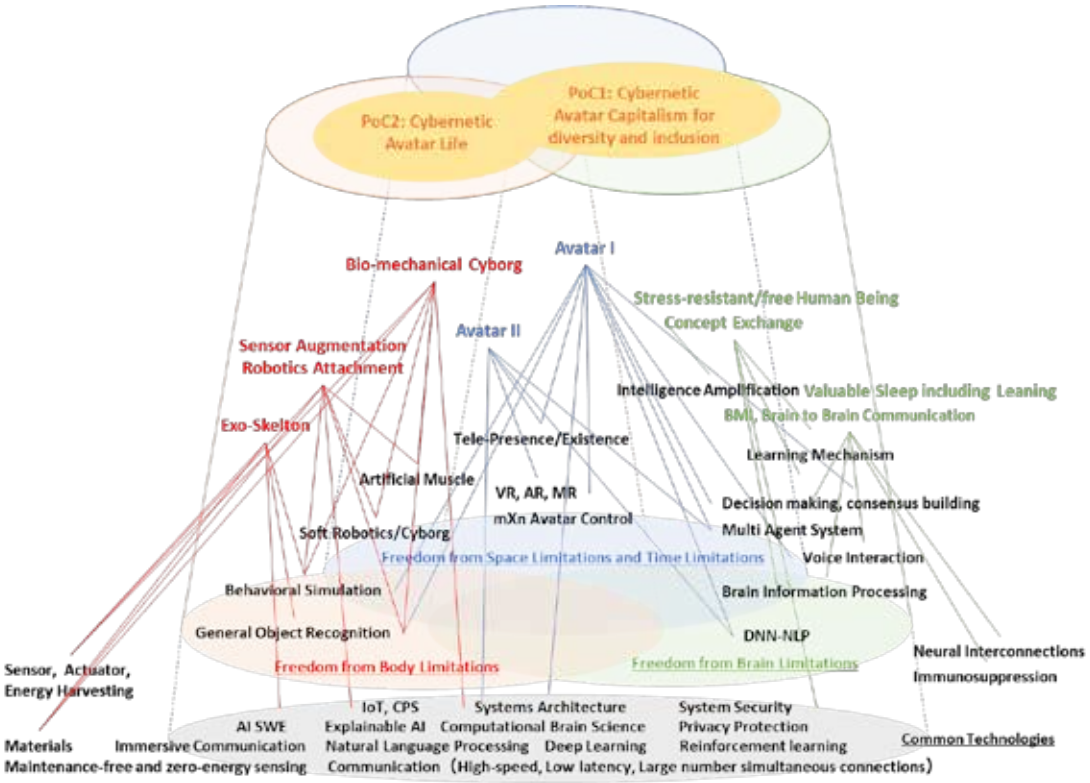

Fig.4. Structuring of MS Goal

In order to prove the concept, it is necessary to research and develop various elemental technologies, integrate them, and thus solve specific social issues. In order to solve social issues, research in several disciplines, such as materials and robotics, artificial intelligence, and life sciences, must be utilized in addition to performing research and development on the necessary elemental technologies.

In addition, the proof of concept is not limited to the two examples listed here, and we expect various activities other than these examples, to solve the social issues.

2. Science and Technology Map

[Overview of technology]

The related overview of technology is presented in Fig.5.

The lowest layer consists of the basic academic fields such as physics and mathematics, or life sciences and humanities. The base layer, located above the lowest layer, contains technology base layers such as human and computer, communication, system construction, and software. These include technical areas such as artificial intelligence and interaction, which are areas that have experienced significant developments.

These disciplines are academically established. Fig.5 shows their relation to concepts, “Freedom from Body Limitations”, “Freedom from Brain Limitations”, “Freedom from Space Limitations and Time Limitations”, and technologies such as avatars, BMI, and exoskeletons . It is important to note that these technologies are rooted in the underlying technology base and the underlying academic domains.

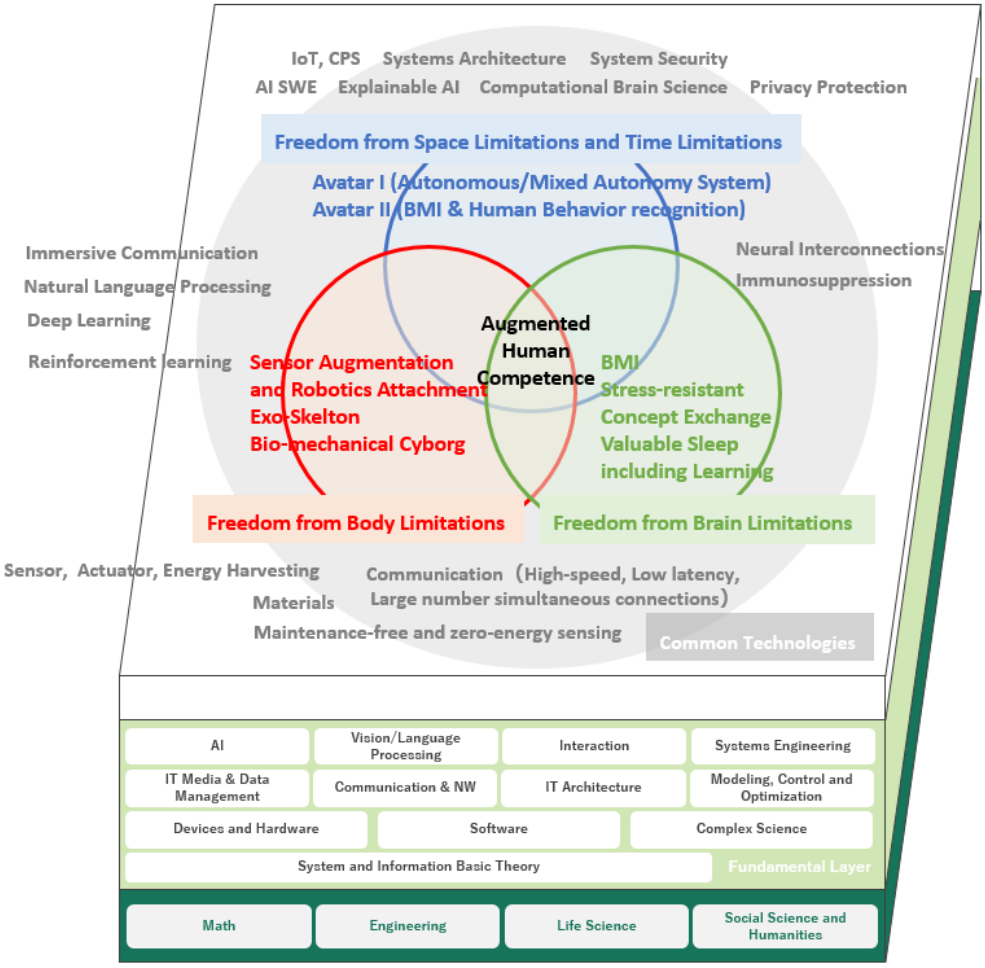

Fig.5. Science and Technology Map

As these technologies are deeply connected with each other, the proof of concept will exhibit a significant ripple effect. Appropriate PoC taking into account the broadening of the technological base can maximize the contribution of technology to society.

[Technology trends]

The trends in technology are shown in Fig.6.

Communications, computers, and various machines can be considered to be originally created as a result of the attempts to augment human capabilities. They have been invented and developed to help humans' computational and memory skills across distances and time barriers, and to compensate for the weak body of humans.

Based on basic and general-purpose common technologies, application technologies that reduce time, space, body, and brain constraints, and further augmentation and enhancement of these technologies and system services have been provided.

It is envisioned that this movement will progress continuously; however, it is essential to set appropriate goals and promote the research and development. It is desirable to set goals that have a large impact when they are attained, have a broad technical base, and have a considerable impact on industries.

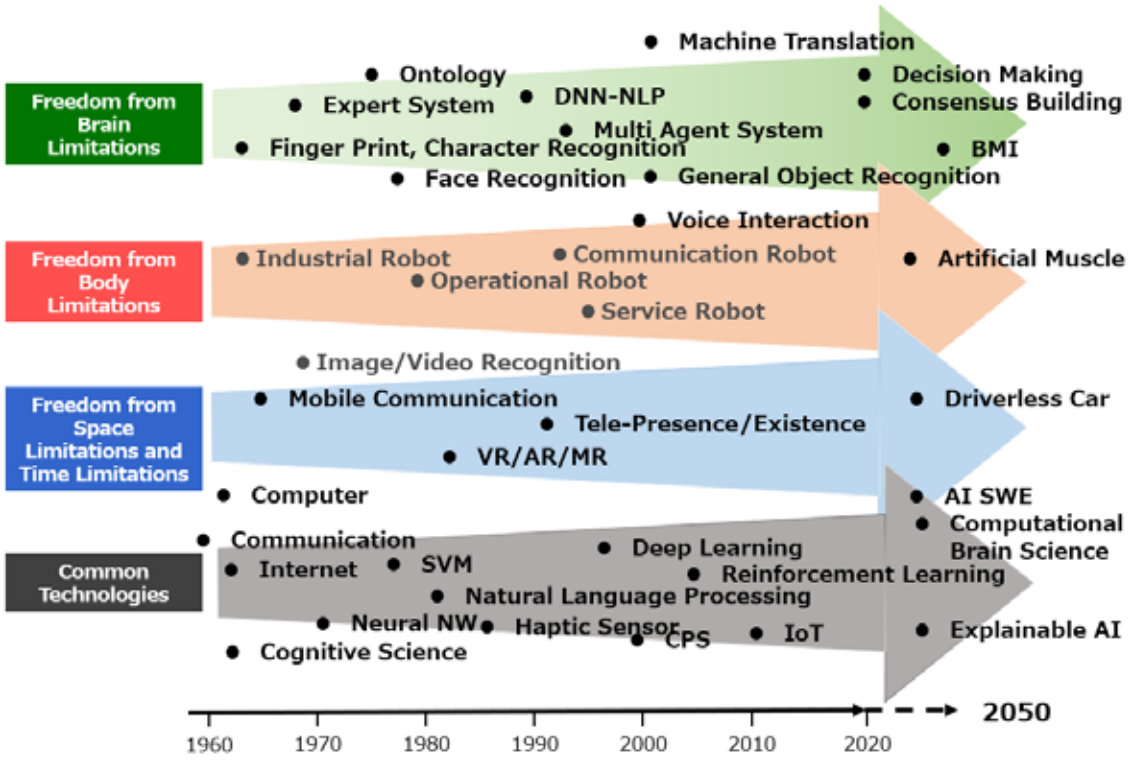

Fig.6. Technology Trend so far

New theories of computational brain science and machine learning are particularly important from the perspective of augmenting human capabilities and freeing humans from the limitations of the body, brain, time, and space; hence, the development of new applications backed by these theories is essential. In addition, as the relation between man and machines is considerably strong, it is necessary to focus on social relationships, decision-making and consensus building, and the safety of artificial intelligence.

Furthermore, life support, welfare, and medical robots are also important. Unlike industrial robots that have been at the forefront of the robotics world in the past, service robots that deal with humans should have new characteristics such as kindness, softness, and flexibility. Therefore, basic research areas such as soft robotics and biologically inspired robots are important.

[The current state of science and technology related to the freedom from Limitations of Body, Brain, Space, and Time]

With the progress in IoT technologies, we are now at a stage where we can create scientific and technological scenarios toward the realization of the MS Goal candidate in 2050.

Regarding the accumulation of technologies to achieve this goal, in recent years, the robot suit HAL controlled by biological signals has been introduced in Japan's medical field. Additionally, the work support suit ATOUM MODEL Y has been introduced for transporting and sorting baggage at airports. Body complementation based on ICT technology has been implemented for practical applications [10] .

A novel non-invasive readout technology for brain activity and intervention technology for brain function employing neurofeedback have also been introduced.

In addition, by using tele-existence technology that can "teleport" one's presence to anywhere in the world, a social experiment was conducted by "Self-Robot Cafe DAWN," where ALS patients interacted with customers via remote-controlled avatars [11]. Moreover, the launch of the avatar service platform "avatar-in" is scheduled for 2020 [12].

The global attention is focused on assistive and human augmentation technologies. In 2016, a sports tournament called CYBATHLON was conducted, and the competitors in this tournament donned state-of-the-art assistive (prosthetic) devices employing ICT technology. A total of 56 teams from 25 countries competed in the 6th event involving such as virtual races controlled by BMI and contests of speed in everyday tasks (cutting bread, drying clothes, changing lightbulbs, and driving nails with a hammer) using an electric prosthetic hand[13].

In 2018, the ANA Avatar XPRIZE was announced as a competition to develop technologies that benefit the human race, and was sponsored by the XPRIZE Foundation. As of October 2019, 820 teams from 81 countries announced that they will participate in this competition of creating high-performance general-purpose avatars capable of performing tasks ranging from simple to complex work[14].

Issues that must be solved for the further development of these technologies have also been indicated. As milestones to be achieved by 2031, the Roadmap for US Robotics: From Internet to Robotics (2016) concerning the research and development of robots, which was compiled by the US National Science Foundation and several other institutions, proposed "high-complexity hands with tactile array densities approaching that of humans and superior dynamic performance," which will be capable of "human-like dexterous manipulation."

Understanding the user's intentions is an essential requirement for realizing avatars and exoskeletons. An avatar system can integrate various forms of implicit and explicit user inputs and instantly model the user's targets and errors. As a simple example, if the hand of a surgeon shakes when performing remote surgery, the avatar can judge that the shaking is not intentional and generate a scalpel movement in line with the surgeon's true intentions. This technology will also enable social implementation of exoskeletons that support the daily lives of paralyzed patients and telepresence technologies enabling operation from remote sites, where the operator's comfort and safety are not endangered[15].

3．Strengths of Japan, Overseas trends

Fig.7 depicts the annual trends in the number of conference papers with respect to countries, at the Augmented Human International Conference*, which is an international conference on human augmentation.

As shown in the figure, Japan has a high presence and continuous formation and enhancement of the research community.

* One of the international conference series hosted by Association for Computing Machinery (ACM). ACM is known for hosting international conferences such as SIGGRAPH and SIGMOD, and science awards such as the Turing Award.

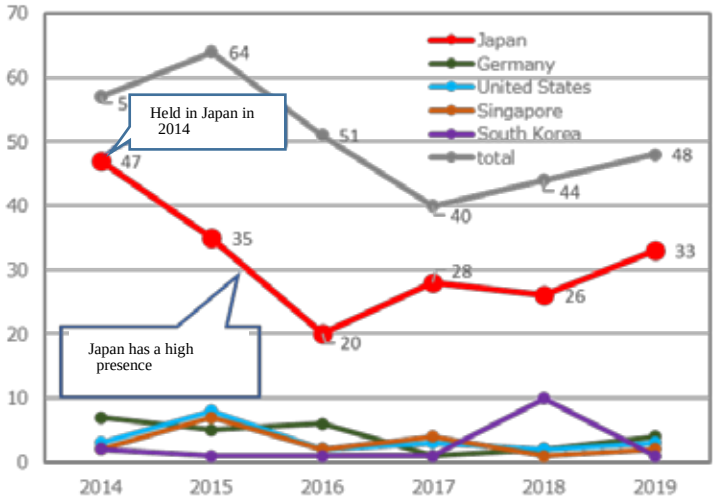

Fig.7. Number of conference papers by country at Augmented Human International Conference

＊Counts are duplicated for international joint presentations.

(Source) Calculated by JST based on Elsevier's Scopus custom data.

In Fig.8, considering the individual elemental technologies related to human augmentation as the keywords, the number of documents worldwide (i.e., the number of presentations at the proceedings of this international conference) is plotted on the horizontal axis, and the share of Japan is plotted on the vertical axis; thus, Japan's strengths and weaknesses are extracted. Japan is also leading the world in terms of research quality, including receiving international science awards. These elemental technologies are considered to be an important basis for achieving the goal of this MS. Fig. 8 shows five areas where Japan's strengths were observed. Fig. 9 summarizes the annual trends in the number of the announcements in each country (the top 4 countries for each elemental technology) for a total of six fields, including BMI, which is considered to be an important elemental technology for human expansion.

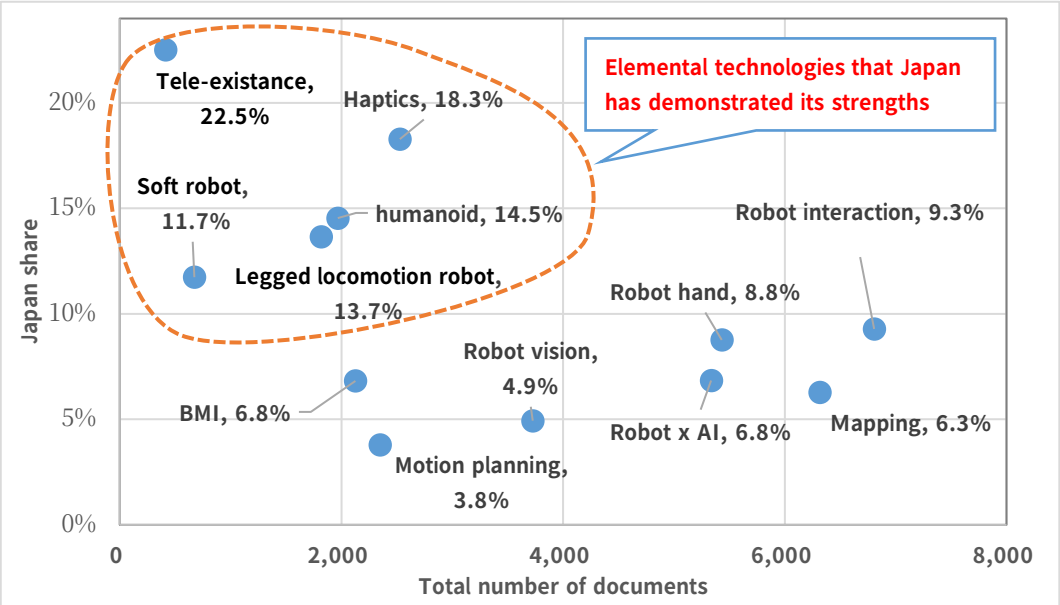

Fig.8. Japan's share in the number of conference papers for International Conference(2016-2018)

Reference type: Proceedings

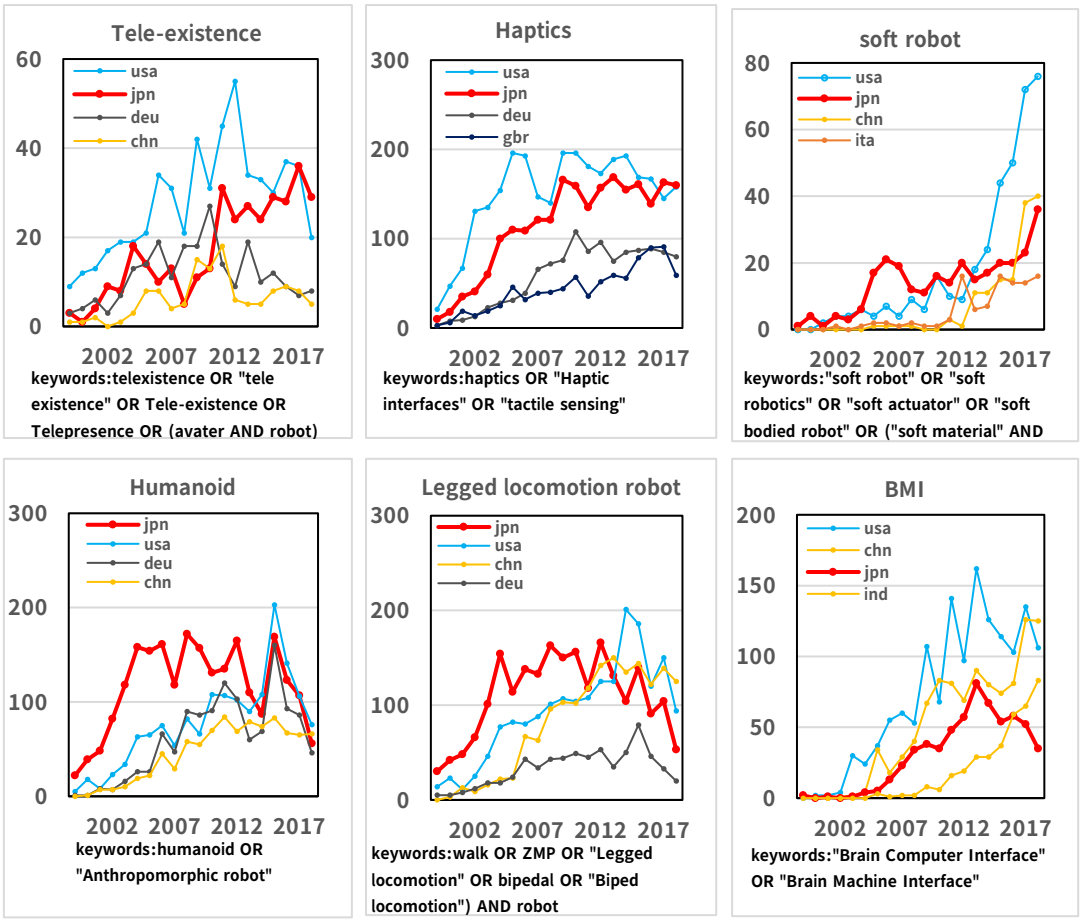

Fig.9. keywords Trends related to human augmentation

In addition, an international comparison of related technical fields was compiled based on the CRDS overview report[8]. Regarding “Computational Brain Science”, which is the foundation of BMI, Japan has demonstrated its strength in basic research. Japan is at the forefront in creating basic methods for measuring and understanding the processing of brain information, such as the DecNef method and the

whole brain simulation by K computer. The country promotes basic research projects pertaining to brain science at multiple levels, and it is recognized internationally as Brain / MINDS.

In addition, “Life Support Robots” need to be organically linked with robot technology, which has traditionally been a strength of Japan along with interaction technologies such as an appropriate understanding of human behavior and appropriate intervention for symbiosis with humans.

Japan has demonstrated a strength in basic research, such as improving interpersonal affinity and developing robot element technology using new materials.

“Soft robotics” is expected to be the fundamental technology to ensure that future tele-existence robots have the same degree of freedom and flexibility as humans and are capable of sharing living spaces with humans. Launched in 2014, the Softrobotics magazine presents the top impact factor in robot-related magazines. Similarly, the international conference IEEE RoboSoft was launched in 2018. Hence, this field is developing rapidly worldwide.

However, Japan has not been able to keep up with the current, rapid expansion of research in the United States and Europe, despite pioneering research in the 2000s. However, research is expected to accelerate in the future due to the establishment of the Robotics Research Special Committee of the Robotics Society of Japan in 2017 and the launch of the new scientific area “Soft Robotics” (2018-2022).

TABLE1. International comparison of related fields

	Country or region	Japan		United States		EU		China	
	Phase	Basic research	Applied research/development	Basic research	Applied research/development	Basic research	Applied research/development	Basic research	Applied research/development
Computational brain science	Current level	◎	○	◎	◎	◎	◎	○	○
	Trend	→	→	→	→	→	→	↗	↗
Life support robot	Current level	◎	○	○	◎	◎	◎	△	○
	Trend	↗	↗	→	↗	↗	↗	↗	↗
Soft robotics	Current level	○	○	◎	◎	○	○	△	×
	Trend	→	→	↗	→	→	→	→	→

(Note 1) Phase

Basic research phase: Range of basic research by universities, national laboratories, etc.

Applied research/development phase: Range of technology development (including development of prototypes)

(Note 2) Current level

*Absolute evaluation, not a relative evaluation based on the current level in Japan.

◎: Particularly remarkable activities and results

○: Remarkable activities and results

△: No remarkable activities or results

×: No activities or results.

(Note 3) Trend

↗：Upward trend →：Maintaining current level ↘：Downward trend

（Source）Panoramic View of the Systems and Information（2019）

4. Further Estimations

A roadmap for robot research and development “Roadmap for US Robotics: From Internet to Robotics” (2016) was compiled by the US NSF in 2016.

From here on, we summarize the milestones up to 2031 and the issues related to human augmentation technologies that need to be solved, such as “dexterous hands similar to that of humans,” “human-like walking and running,” and “understanding human intentions using avatars.”[15]

[Human-like dexterous manipulation]

2021: Low-complexity hands with a small number of independent joints will be capable of robust whole hand grasp acquisition

2026: Medium-complexity hands with tens of independent joints and novel mechanisms and actuators will be capable of whole-hand grasp acquisition and dexterous manipulation

2031: High-complexity hands with tactile array densities approaching that of humans and with superior dynamic performance will be capable of robust whole hand grasp acquisition and dexterous manipulation of objects found in the manufacturing environments involving human workers

[Human-like walking and running]

2021: Experimental robots capable of walking outdoors and indoors and isolated demonstrations

2026: Improved understanding of the science behind legged locomotion enables efficient and agile locomotion demonstrations

2031: Initial application of legged walking avatars for commercial use

Challenges in development

- The development of new sensors, actuators, and power transmission mechanisms employing soft materials. High-level integration of the dynamics of soft materials and robot motion control.
- Skin-like tactile sensors, short-range LIDAR /appearance sensor for dexterous operations.
- Development of higher accuracy and cheaper torque sensors for actuator control.
- Improved understanding of legged locomotion by introducing bio-inspired methods and the development of new walking mechanisms.

[Understanding human intentions using avatars]

2021: Integrate multiple explicit forms of user input to perform user-guided actions. Users can select from different levels of autonomy.

2026: Recognize implicit user inputs to determine user goals and implement an active learning approach to engage the user in supporting these goals and choosing the level of autonomy required for the performance.

2031: Integrate and fuse various forms of implicit and explicit user inputs, model user goals and error in real time, and vary the levels of autonomy as necessary, while communicating with the users.

Challenges in development:

- Development of methods to enable avatars to utilize a broad range of control signals from users, including inputs from brain-computer interface.
- Extensive research to develop sensing and perception techniques for human physiology and behavior.
- Development of models for interpreting what is perceived in the context of the task, application, and domain.

Ⅲ. SCENARIO FOR REALIZATION

1. Realization of Goals

Targets of (1) C-Avatar Capitalism for Diversity and Inclusion, and (2) C-Avatar Life were set as demonstration images to achieve the goal.
These are realized by integrating the necessary functions from the R&D of three freedom technologies.

The following are examples of R&D scenarios to be triggered towards realization of the above stated two goals.

Scenario 1
C-Avatar Capitalism for Diversity and Inclusion
By 2050, develop technologies and infrastructure to carry out large-scale complex tasks using combinations of large numbers of avatars and robots that are teleoperated by multiple persons.

[Achievement image in 2030]
<Milestone>
One person can operate more than 10 single-task avatars (shared avatars) with the same speed and accuracy as one avatar.

<Ripple effect>
- By using the time difference of each region around the world, 24-hours working with global time shift is possible, and it resolves the problem of labor shortage, thereby providing work-life balance.
- Increasing employment opportunities in the global market.
- Complementing the decline in the labor population on-site who are forced to work hard at night.
- Initiative of special professional work by elderly and veteran craftsmen who are physically weak.
- Reducing carbon footprint by reducing travel.
- C-Avatar Capitalism's economic and social theory is established, and a Japanese global avatar
- platformer may appear.

[Achievement image in 2040]
<Milestone>
One people can operate more than 100 multi-task avatars (shared avatars).

<Technical issues to overcome>
- Maintenance-free and zero-energy sensing technology.
- Decoding and Comprehension technology of brain information captured through BxI for realizing perception and actuation from/to various kind of ‘Things’.

[Achievement image in 2050]
<Milestone>
M people can operate more than 1000 avatars including different models, or the avatar system can be operated by more than M people (multi-task avatars), and the task to solve is completed by cooperation from remote sites (real human and Avatar).

<Technical issues to overcome>
- Sharing the situation among teleoperators (sharing on-site situation in real time).

- Switching between autonomous operation mode and non-autonomous operation mode of avatar according to the environment.
- Prediction according to on-site environmental change.
- Multiple avatars coordinate and execute the tasks in cases of collaboration.
- Cloud-based human resource and avatar matching.

<Ripple effect>

- Work adapted to weather, soil, fishing areas, pests, etc. in remote agriculture and remote fishing.
- A large number of specialists perform tasks in a limited time, such as large-scale disaster relief.
- An extremely advanced foundation for realizing a society that encompasses diversity has been formed and implemented in society.

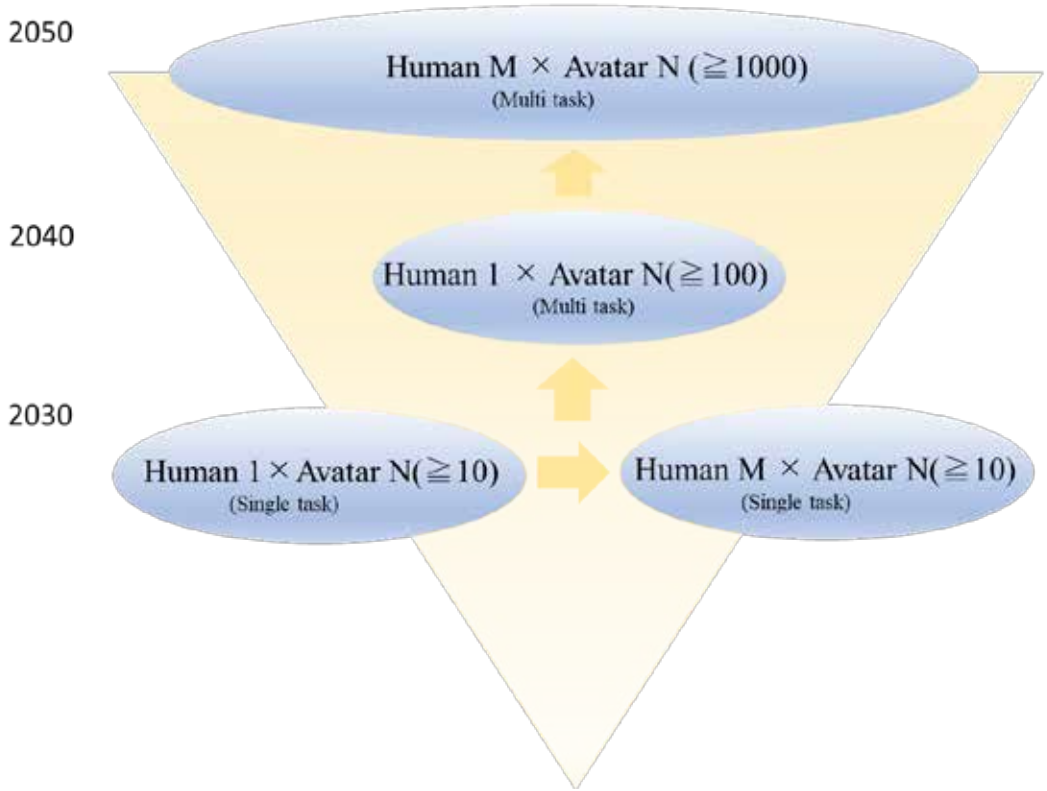

Fig.10. Step of the avatar development

Scenario 2

C-Avatar Life

By 2050, anyone willing shall be able to augment their physical, cognitive, and perceptional capabilities to the level of the best experts of selected domains.

[Image of 2030]

<Milestone>

Anyone willing shall be able to augment their physical and perceptional capabilities using empowerment devices.

<Technical issues to overcome>

- Development of human-centered material device.
- Inclusive design.
- Development of soft cyborg that does not get damaged even if it comes in contact with people.
- Development of actuation technology that can be embedded as Cyborg.
- Establishing computational models of various kinds of brain functions like cognition, decision making and feeling emotions in the brain's functional areas, and analysis of the effects of different kinds of stresses to the model dynamics.

[Image of 2040]

<Milestone>

Anyone willing shall be able to augment their physical, cognitive, and perceptional capabilities to the level of experts.

<Technical issues to overcome>

- Extraction of issues for social implementation of human augmentation technology.
- Development the technology to link the cognitive information and human linguistic narration.
- Elaborating computational brain functional model at the level of brain functional circuits for its utilizations.
- Establish a stable long-term implantation of neuro-link and development of materials and architecture of augmentation components consistent with biological counter-parts.

[Image of 2050]

<Milestone>

Anyone willing shall be able to augment their physical, cognitive, and perceptional capabilities to the level of the best experts of selected domains.

<Technical issues to overcome>

- Audio-Visual expansion.
- Implantable technology that can control imitation memory and its management system, ELSI.

Some of the R&D of C-Avatar Capitalism for Diversity and Inclusion and C-Avatar Life are common from the viewpoint of elemental technology of R&D. Each R&D team should share and collaborate, and the necessary functions should be constructed by integrating the elemental technologies.

In R&D, in addition to the elemental technologies originating from it, development in related fields such as robotics should be undertaken, standardized, integrated as a platform, and applied in various fields.

2. International Collaboration

To utilize global technology and infrastructure to perform large-scale and complex tasks using a large number of avatars and robot combinations, it is important to harmonize them with the world through international standardization of hardware, software, their interfaces and the common base on which the system operates. In terms of regulations and systems, it is also important to establish regulations and systems that can be applied throughout the world by harmonizing the regulations of Japan and the world. For this reason, it is necessary to promote international cooperation from the beginning.

3. Cooperation with other WG

Regarding development of augmented human technology, some technologies are common to WG3 and WG5. Therefore, WG1 plans to proceed with development by sharing information with WG3 and WG5.

4. Security

Ensuring security is essential in the current ICT system. Even in systems that remotely operate avatars and systems that utilize cyborg technology, it is necessary to work on ensuring security from the research and development stage. Also, since there are technologies in common with other WGs in this effort, it should cross WGs.

In addition, for realizing the advanced avatar and cyborg, various kinds of personal information relating to brain, body and life has to be digitalized and transmitted to the system outside of person both consciously and unconsciously. Currently, IoT security technology is being developed, and in the future, this IoT security technology should be expanded for new type of information utilizing, transferring, and storing.

5. ELSI

To use technology to remotely control a large number of avatars and cyborgs for society it is also necessary to consider compatibility with existing laws and regulations (occupational safety, medical care, road traffic, radio waves, etc.), and ethical considerations such as human dignity, rights, freedom and cultural diversity of cyborgs. Furthermore, recommendations to the relevant ministries should be made.

As part of efforts contributing to the solution of social problems, dialogue and cooperation will be initiated with a diverse range of stakeholders so as to link various activities to research/innovation and policy formulation.

Ⅳ. CONCLUSION

Of the 25 related examples of moonshot goals presented at the visionary council, WG1 study started to consider 2), 3) and 6), centered on 1) Create and deploy “Cyborg technology” to augment human capability by 2050.

2) Fully ubiquitous and inclusive mobility by 2040

3) Create and deploy advanced avatars enabling most daily life can be done through avatar by 2040

6) Universal medical access at the global scale by 2040

In reviewing the situation, the MS Goal candidate will be accepted by many people as a goal to be achieved by the year 2050. Discussions have been undertaken from various perspectives, such as clarifying the image and the spin-off expected in the process of R&D.

Based on the above discussions, WG1 has set up the following MS Goal candidate: “By 2050, realization of a society in which human beings can be free from their limitations of body, brain, space and time with harmonious empowerment”.

WG1 proposes C-Avatar Capitalism for Diversity and Inclusion as well as C-Avatar Life as two concrete targets to promote this realization.

REFERENCES

[1] Yuval Noah Harari, Homo Deus: A Brief History of Tomorrow, Vintage, London, 2017
[2] Thomas Piketty, Le capital au XXIème siècle, Seuil, Paris 2013
[3] “In South-East Asia, Grab and Go-jek bring banking to the masses”, The Economist, May 2nd, 2019
[4] Cabinet Office, The Ageing Society: Current Situation and Implementation Measures FY 2017, https://www8.cao.go.jp/kourei/english/annualreport/2018/pdf/c1-1.pdf
[5] The Prime Minister of Japan and His Cabinet, Council for Designing 100-Year Life Society, Aims and Main Themes of “Council for Designing 100-Year Life Society”, http://japan.kantei.go.jp/ongoingtopics/pdf/2017/09/11/AimsAndThemes.pdf
[7] https://tachilab.org/jp/projects/13.html
[8] Panoramic View of the Systems and Information Science and Technology Field (2019), CRDS, JST
[9] “The grand challenges of Science Robotics”, Yang et al., Sci.Robot, 3, (2018)
[10] “Break through: Cyborg just by wearing”, NIKKEI ELECTRONICS 2019.06, pp26-46, https://tech.nikkeibp.co.jp/atcl/nxt/mag/ne/18/00042/00001/
[11] AVATAR ROBOT CAFÉ DAWN Ver.β, http://dawn2019.orylab.com/
[12] ANA Press releases: “ANA HOLDINGS Unveils Technology Behind its Avatar-powered Social Infrastructure Service”, https://www.ana.co.jp/group/en/pr/201910/20191014.html
[13] The Premiere CYBATHLON 2016, https://cybathlon.ethz.ch/about-cybathlon/cybathlon-2016.html
[14] https://internet.watch.impress.co.jp/docs/interview/1212358.html
[15] A Roadmap for US Robotics From Internet to Robotics, https://cra.org/ccc/wp-content/uploads/sites/2/2016/11/roadmap3-final-rs-1.pdf
[16] T. Yanagida, et al., Brain Science for Future AI and ICT, vol.59 no.1, IPSJ MAGAZINE 2018, pp.34-71

(websites were accessed at December 4, 2019)