(1) New Concepts in Communication —In Pursuit of HC^3—

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Researchers at NTT DoCoMo Multimedia Laboratories are designing human-centered interfaces that will enable people to use devices, objects, information and other things at will just as if they were a part of one's own body. They are also designing human-centered service-usage environments that will enable people to find information with ease and retrieve it in a form suitable to one's needs. Technologies and systems for these interfaces and environments are now being researched in earnest. The role of this research, associated issues and strategies, and specific research themes are described.

1. Introduction

NTT DoCoMo's corporate philosophy is to "create new communication services that will revolutionize the way we communicate, and make the new way of communication become a new culture of human society." To this end, DoCoMo proposes the concept of Human Centered Communication and Computing (HC^3) and is researching and developing innovative technologies to turn this idea into reality.

Our aim is to enrich communication and enhance human capabilities through interface technologies that can transfer sensations and sensitivity as well as intentions and thoughts as physically experienced by the user. These technologies are not about manipulating equipment which requires close attention and clear intention of an operator. They are rather technologies that will enable people to enjoy the benefits of information technology in a more natural and unrestricted way, that will facilitate mutual understanding in a more physical way, and that will represent and support people physically and intellectually. In this regard, due consideration must be given to the feasible way to realize new information-communication technologies to satisfy all sorts of new requirement including "being able to use something in the way one wishes," "being able to share information and feelings in the way one wishes," "supporting and complementing a user by inferring his or her thoughts or context," and "ease of use in very natural way to any people." Furthermore, from the viewpoint of promoting innovative research in a corporation, it is important to establish a formation that facilitates mutual understanding and cooperation among individual researchers in line with corporate principles and that promotes the continuous research conducted even by different researchers. To this end, various activities at DoCoMo aim to pass on accumulated technologies and knowledge to new researcher of the next generation and to cultivate them.

This introductory article surveys the needs of society and resulting technical requirements, presents a future image of communication, and describes issues that must be addressed to satisfy these technical requirements. The other articles in this issue describe specific research activities and their current state of progress.

2. Needs of Society (Technical Requirements)

The 21st century has come to be called the "age of people," the "age of environmental management," and the "information age" [1]. In the following, we first discuss the needs of the 21st century based on the features associated with these keywords. We then organize these needs in terms of future mobile communications that must be developed, describe resulting technical requirements, and examine the role of technology in this century.

2.1 Toward the Age of People: "Going Easy on People"

The 21st century is said to represent a move from an age of "materialism" to one of human-oriented "spiritualism" in which people pursue ways of satisfying internal, spiritual needs in an age where physical needs have been generally met. Here, a human-centered system is basic for a people to be able to exist as human, and we believe a communication and computing system that works for people in a truly human way will play a very important role to realize such a system.

In everyday face-to-face communication, a person uses a variety of human organs and functions such as hands, legs, eyes, and ears in an attempt to convey sensations, emotions, and intent and to establish some degree of mutual understand-

ing with the other party. Such a natural means of communication is also desirable in the field of telecommunications, and expectations are high for communication technology that could enable sensations, emotions, and intent to be inputted, transmitted, and reproduced naturally in a similar manner as face-to-face communication to facilitate understanding between two parties. There are also high hopes for computing technology that is embedded in a physical body with sensing functions and that performs intelligent processing all with the aim of supporting and enhancing the five senses, the thought of a human, and the movement of human body parts. The following two technical requirements must be met to achieve the above functions.

(1) Communication that Facilitates Mutual Understanding and Content that is Impressive and Emotionally Satisfying

Conventional forms of communications that use speech, text, and video are sometimes felt to be insufficient for conveying sensations, emotions, and intent and establishing understanding. One solution to this is true multimodal communication that can convey the five senses (possibly through the use of new media) and has embodiment characteristics (by using a physical entity to express gestures and facial expressions more impressively). This will facilitate greater understanding and empathy between two parties.

This requirement includes the provision of high-reality as for communication service quality that make a deep impression on users and hold their attention and diverse content-based services appealing to both mind and body (rich content enabled by the use of a new media and improved quality is a point).

(2) Easy-to-Use Interfaces that Enhance Human Capabilities (including support and improvement of one's health)

In recent years, information-communication devices have become quite advanced and services have become quite sophisticated while their operation has turned to be very complicated and difficult to use. This problem will be solved by achieving interfaces that can manipulate and instruct devices and services by efficiently inputting and conveying what one is thinking or what one wants to do (i.e., intent) thereby making it unnecessary to remember operation techniques or procedures.

They will make devices feel as if they are a part of one's body and available for use at any time.

In addition, to enhance a person's information-processing capability and powers of movement and enable a broad range of activities, these interfaces will aggregate neighboring resources including other people and things if necessary, and will provide the user with support and complement appropriate to the context of the user. And, in support of the aging society, they will support and complement internal organs and motor functions to preserve a healthy mind and body and even provide a sense of fulfillment and satisfaction.

2.2 Toward the Age of Environmental Management: "Going Easy on the Global Environment"

A large part of human activities generates some sort of load on the surrounding environment. While this is unavoidable, it is necessary that environmental load be managed as much as possible [2]. This calls for technologies that can reduce environmental load in various ways. For example, there might be technologies that collect and analyze information that would be useful in protecting and preserving the environment (that daily and ubiquitously operate environment monitoring functions similar to the five senses of human, and that filter and store obtained data). There might also be technologies for reducing environmental load such as a technology to control automobile traffic by optimizing travel routes or by providing alternatives to travel such as video conferencing.

2.3 Toward the Information Age: The Era of the "Super Environment" where the Information World and Real World Converge

It is also said that we are moving toward a ubiquitous information-communications environment in the 21st century [3]. The objective here is to merge the information world in communication networks and the real world of human activities instead of separating them. This will be accomplished by making it easy to acquire real-world information and to perform communication based on that information, and by replacing some endeavors in the real world with telecommunications. Here, in a world where vast amounts of information and devices exist in various forms, it would be desirable if information and devices appropriate for each individual person could be easily found and if they could be used in an enjoyable and satisfactory manner. Words like "enjoyable" and "satisfactory," however, have meaning only in the context of the individual. In this regard, individual support from a human-centered point of view is important, and to this end, support and agent technologies for achieving selectivity and adaptability here are essential. At the same time, while this

"super environment" can provide enjoyment and comfort, it may also have negative effects such as infringements on privacy and reduction in arrest rates due to an increase in cleverly and surreptitiously committed crimes. To ensure privacy, there is a need for technology that enables information to adapt to the space where the information is used, i.e., individual space or shared community space, so that information is either possessed by restricted member or open to the public. And to prevent and detect crimes, there is a need for technology that are allowed to use only for public benefit to detect information and events related to criminal activity from among the huge amounts of stored information, or in other words, technology that supports selectivity and substitution in regards to information. Needless to say, encryption and security-protocol technologies are also important here.

3. Technical Issues and Future Image of Communication

3.1 Classification of Technical Issues by Human Characteristics

Table 1 summarizes technical requirements originating from social needs as described in the previous section as well as the technical issues that must be addressed to satisfy those requirements. In the table, these issues are arranged according to human characteristics in relation to the input, processing, and output of information. These characteristics are divided into three main systems: "sensory organ system" that deals with the input of information, "brain and intelligent-processing system" that deals with the processing of information, and "motor and behavior system" that deals with the expression and presentation of information, emotions, and intent. The characteristics are arranged along the horizontal axis of the table, and each of these systems are further divided into innate functions corresponding to naturally endowed characteristics and acquired functions that are learned and remembered through experience. (See Ref. [4] for details on the method used to arrange this table.) The vertical axis of the table, meanwhile, lists needs of society and technical requirements. Each table entry describes technical issues that must be addressed to satisfy the need and requirement for that row within the system for that column.

(1) Sensory Organ System

The sensory functions that manage the five senses are innate functions, and the role of technology here is to assist and extend them. Elucidating the characteristics and mechanisms of the five senses is a basic research problem. On the other hand, input and reproduction in support of the five senses, media conversion to convert the sensations obtained through the five senses to others sensations (representations), and improving the quality and reality of such representations are issues common to all technical requirements from an engineering perspective. If solutions to these issues can be found, we can expect new media dimensions and more realistic sensations and sensitivity, a goal that has been difficult to achieve in the past by simply improving audio and video quality. Another important issue here is the development of interface technology that enables direct input and direct reproduction of sensations felt by one's own body. Solving this issue will satisfy the requirement for interfaces that can be felt in a natural way.

(2) Brain and Intelligent-Processing System

The functions involved in intelligent processing consist of the innate functions of memory, recognition, inference, and learning and acquired functions such as establishing preferences, making value judgments, and feeling comfortable and content. A major issue here common to all technical requirements is researching and elucidating the cognitive characteristics of these two types of functions and to use the knowledge gained as technology for information-processing mechanisms. The problem, in other words, is how to achieve intelligence from explanations of brain and neural mechanisms. At the same time, facilitating smooth interaction between man and the environment is important based on the idea of "distributed cognitions" [5] whereby "man becomes aware of the world by interacting with the environment." In particular, cooperating with devices that exist in the environment and collecting and utilizing various types of information can help improve interaction with the environment, and achieving intelligence in this way is also a common issue with respect to technical requirements but one addressed from different approaches. Here, considering that issues related to the brain and intelligent-processing system are relatively difficult to solve, it is important that useful application domains be selected and issues narrowed down. In this way, technologies that can provide at least some solutions can be implemented and evaluated and progress can be made in a step-wise and steady manner.

(3) Motor and Behavior System

The results of internal human activities such as emotions and thoughts are observable on the surface as external activities

Table 1 Main Technical Issues in Achieving HC³ (for responding to the needs of society in the 21st century)

Human Characteristics / Needs of Society / Technical Requirements		Input (Sensory Organ System)	Processing (Brain and Intelligent-Processing System)		Output (Motor and Behavior System)	
		Innate Functions	Innate Functions	Acquired Functions	Innate Functions	Acquired Functions
		Five senses: hearing, sight, touch, smell, taste	Memory, recognition, inference, learning	Preferences, value judgments, comfort and contentment	Physical form/functions	Speaking, expressing intent, interactive behavior
Age of People	Communication conducive to mutual understanding and empathy Impressive and moving content	• Raise magnitude of media quality →Convey ultra reality • Input, convey, reproduce as new dimensions in media →Expand range of conveying and sharing sensations and sensitivities (communication and content based on five senses)	• Improve translation functions →Overcome language barrier <Outside of scope of this research>	• Search out agreeable conversation partners →Support and provide enhanced selectivity for individual use • Search out desirable content →Support and provide enhanced selectivity for individual use	• Create embodied expressions (gestures, hand movements, facial expressions, etc.) →Integrate emotions, intent, and atmosphere (form a collaborative space where context can be shared)	
	Easy-to-use human interface Enhanced human capabilities (including health support)	• Input, convey, and reproduce directly what your body feels as sensation information →Direct five-senses interface • Input and reproduce by sensation-based devices and enable media conversion between senses →Indirect five-senses interface (by either an interface attached to your body or one attached to a remote robot) • Sense and convey internal physical functions and motor functions by fulltime-wear devices →Interface for monitoring your physical condition	• Deal and respond flexibly with searching/adjusting requirements and conditions mainly based on language and images (cope with a variety of expressions; adapt to insufficient information with appropriate questions, etc.) →Intelligent agents • Record one's own behavior automatically, and select and use desired information at will. →Intelligent memory support • Automatically record data obtained by monitoring behavior and physical conditions, detect changes, and issue alerts →Intelligent health monitoring	• Directly input, convey, and reproduce what one is thinking, what one wants to do (intent) without having to manipulate devices →Ultimate thought interface	• Satisfy "immediacy" in which functions can be used just as soon as one thinks about them; "wearability" in which devices are always wore on one's body in a comfortable manner, and "usability" in which input can be performed instantly without impeding the thought process. →Fulltime-Wear Interface ready to use • Manipulate information by manipulating physical entities →Intuitive interface through real entities • Use ordinary physical actions to manipulate and instruct devices naturally and easily →Use part of the human body as an interface mechanism • Sense physical functions and motor functions and physically support and complement those functions →Physical function support • Project physical sensations and emotions and manipulate at will a remotely located robot sensitive to your five senses →Pseudo-teleportation (for security, nursing, remote operations, exploring undeveloped space, etc.)	
Age of Environmental Management	Collection and use of information useful for environmental management Reduced load on the environment	• Achieve sensors (compact, low-power, zero-install, cooperative operation) corresponding to the five senses and install, operate, and collect data according to objectives →Information platform using an ubiquitous sensor network (using sensors embedded in buildings, roads, vehicles, people, etc.)	• Efficiently store large amounts of collected data →Ultra-large-scale database based on hierarchically distributed and centralized role-sharing management • Filtering of vast amounts of data to obtain required information and ultra-large-scale data mining to discover new relationships →Support and provide ultra-large-scale analysis of real-world information		• Use results of human behavioral prediction and natural phenomena prediction to select optimal means of human activity and alternative means →Reduce and control energy consumption optimally by using information on a world-wide scale	
Information Age	Improved information selectivity taking individual characteristics and context into account Improved information adaptability taking individual characteristics and context into account Improved environmental adaptability for enjoyable use of services	• Sense and utilize information on your five senses as a means of extracting your individuality and as a means of determining your current context →Understanding individuality and context by sensing the five senses • Sense and utilize five-senses information about your environment using wearable devices and those located nearby as a means of determining surrounding conditions →Understanding surrounding conditions by sensing the five senses	• Store five-senses information and behavioral information collected on the individual and learn and infer individual characteristics (preferences, comfort and contentment) →Support and perform learning and inference of individual characteristics • Infer current context from five-senses information and behavioral information collected on the individual →Support and perform inference of individual context • Filter out optimal information or process information adaptively for the individual based on learned individual characteristics and on five-senses information, behavioral information, and surrounding conditions currently being collected. →Support and perform adaptive information selection taking individual characteristics and current circumstances into account.		• Control methods of expressing, uttering, and presenting information based on individual characteristics and context and current surrounding conditions →Support methods of expressing and presenting information taking individual characteristics and context into account • Construct an optimal service-usage environment for the individual by selecting and combining resources from the peripheral resource groups using individual characteristics and context and current surrounding conditions →Support and perform optimization of service-usage environments taking individual characteristics and context into account	

in the form of movement and behavior. Here, the elucidating and modeling of the mechanisms behind information-based behavior and movement in humans constitute basic research problems, while satisfying the technical requirement for providing impressive multimodal communication for greater mutual empathy and understanding is a technical issue [6]. Specifically, ways must be found to present various types of expressive behavior, gestures, hand movements, and facial expressions in accordance with human norms of communication in order to convey and share emotions and intent. There are also issues that must be solved to satisfy the technical requirement of supporting and enhancing human powers of expression and movement. These concern the understanding of human physical characteristics and the development of novel technologies that can enable devices to be operated as if they ware a part of the human body while enabling the human body itself to be used as an interface

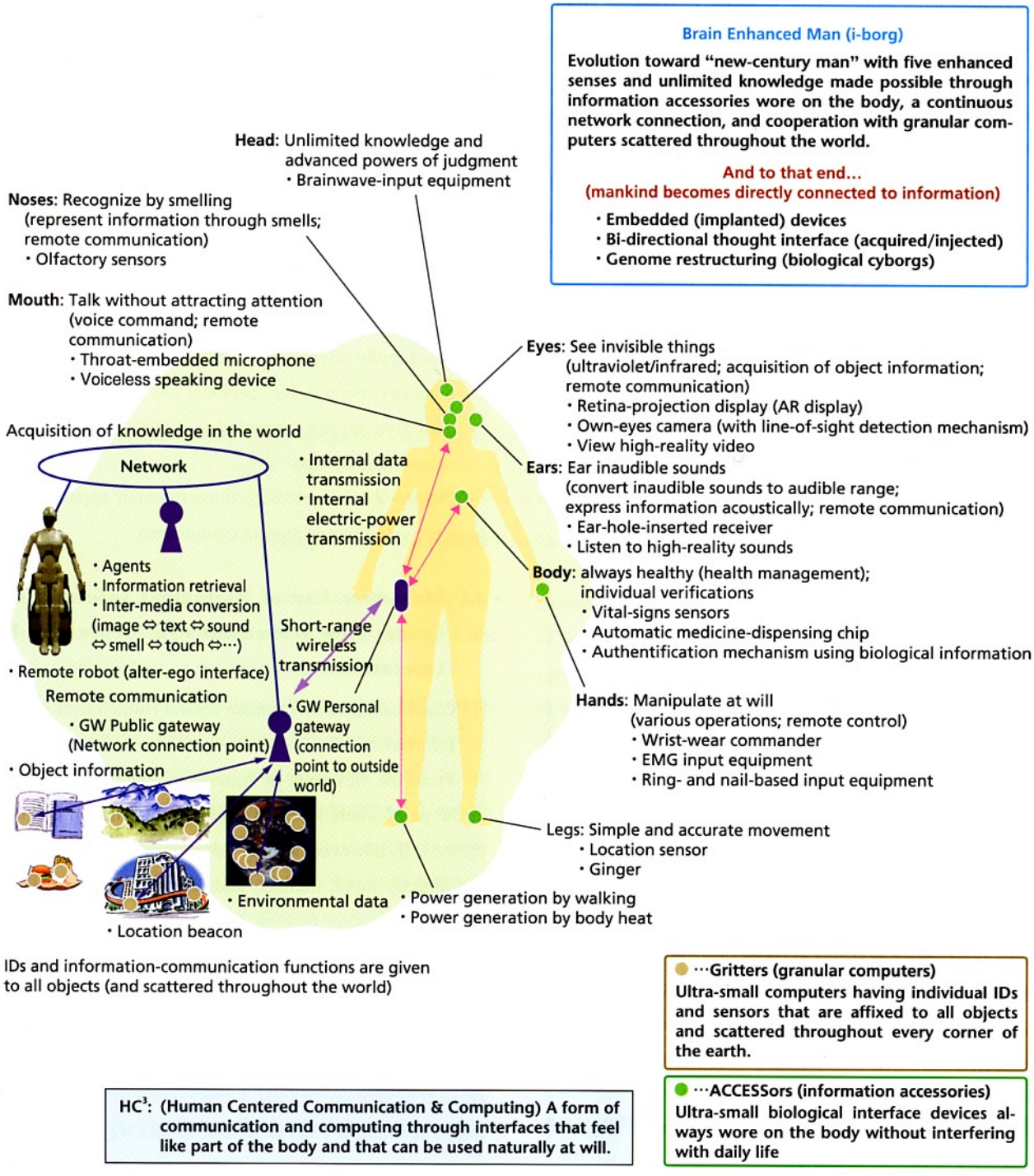

Figure 1 Future Image of Information-Communications in the 21st Century toward HC³

for instructing those devices. There is also a need for technologies that can support and complement physical functions. Still another important issue is support and enhancement of means for cooperating with and using "things" in the environment to make them all the more useful.

3.2 Future Image of Human Centered Communication and Computing (HC^3)

Given that the above technical issues arranged by human characteristics have been solved, **Figure 1** shows the future image of HC^3 that will enhance human capabilities and enrich human life.

Here, we have the birth of a "new-century man" (i-borg) with enhanced senses and no limit to acquired knowledge. This is made possible through fulltime-wear information accessories and a 24-hour network connection that enables an individual to interact with a wide range of information-communication devices located throughout the world.

This is, in other words, the realization of communication and computing through interfaces that make it feel as if information, devices, and the network are an integral part of one's body and that enable such resources to be used naturally and at will. With HC^3, devices can be manipulated naturally without having to be conscious of how to manipulate them and whether they are wore on one's body or are simply present nearby. It is also possible to convey and deeply share not only information but sensations and emotions as well. Still yet, an unlimited amount of information can be accessed via the network as desired for use as personal knowledge. There will also be agents that, by familiarizing themselves with the preferences, way of thinking, and other characteristics of the individual, will be able to support and even represent the individual in some intellectual activities. It will even be possible to project one physical movements, sensations, emotions, and intent to a remotely located robot and interact with and manipulate that robot as one's alter ego thereby extending one's physical presence elsewhere in the world. In short, one's presence expands into the world and, conversely, the world collapses into one's mind, i.e., communication and computing in which everything is integrated seamlessly with oneself.

4. Research Objectives and Strategies

With an eye toward future human-centered communication and computing as shown in Figure 1, the following three research approaches are being adopted to solve technical issues arranged as described above by human characteristics.

(1) Clarify the mechanisms behind biological information to provide uniform solutions to technical issues concerned with the sensory organ system, brain and intelligent-processing system, and motor and behavior system, and to enable human biological information to be fully utilized. Apply the knowledge obtained to the engineering of interface technology to create new dimensions in media and device operation.

(2) Pursue ultimate expression and quality in media to solve the technical issues surrounding hearing and vision (the senses of the sensory organ system that play the most important role in communication). Aim for a substantial jump in the quality of voice/acoustic/video media to provide a driving force for the creation of novel services.

(3) Facilitate comfortable use of the service and information-communications environment in accordance with individual preferences and context and current surrounding context. Enable people to use the information and devices that exist in a rapidly advancing ubiquitous information-communications environment for "personal use" at will just as if one's own five senses, knowledge, hands, and legs could be extended as desired.

Figure 2 arranges these three research approaches/themes from the viewpoint of system components.

4.1 Maximize Use of Biological Information and Create New Dimensions in Media and Device Operation

(1) Clarification of Mechanism behind Human Biological Information

From the viewpoint of "interface," we have not yet arrived at the point where human biological information can be freely utilized. If, however, we can develop interface technology that can directly input, transfer, and reproduce biological information, it will become possible to use touch, smell, and other senses as new forms of media. This, in turn, should bring about radical changes in the way we communicate. In addition, direct input of body movements will enable the body itself to be used as an interface. That is to say, one's own natural movements can be used to give operational instructions resulting in an interface that is dramatically easier to use. In this way, biological information becomes the driving force behind the creation of novel interfaces and opens the door to the construction of totally new

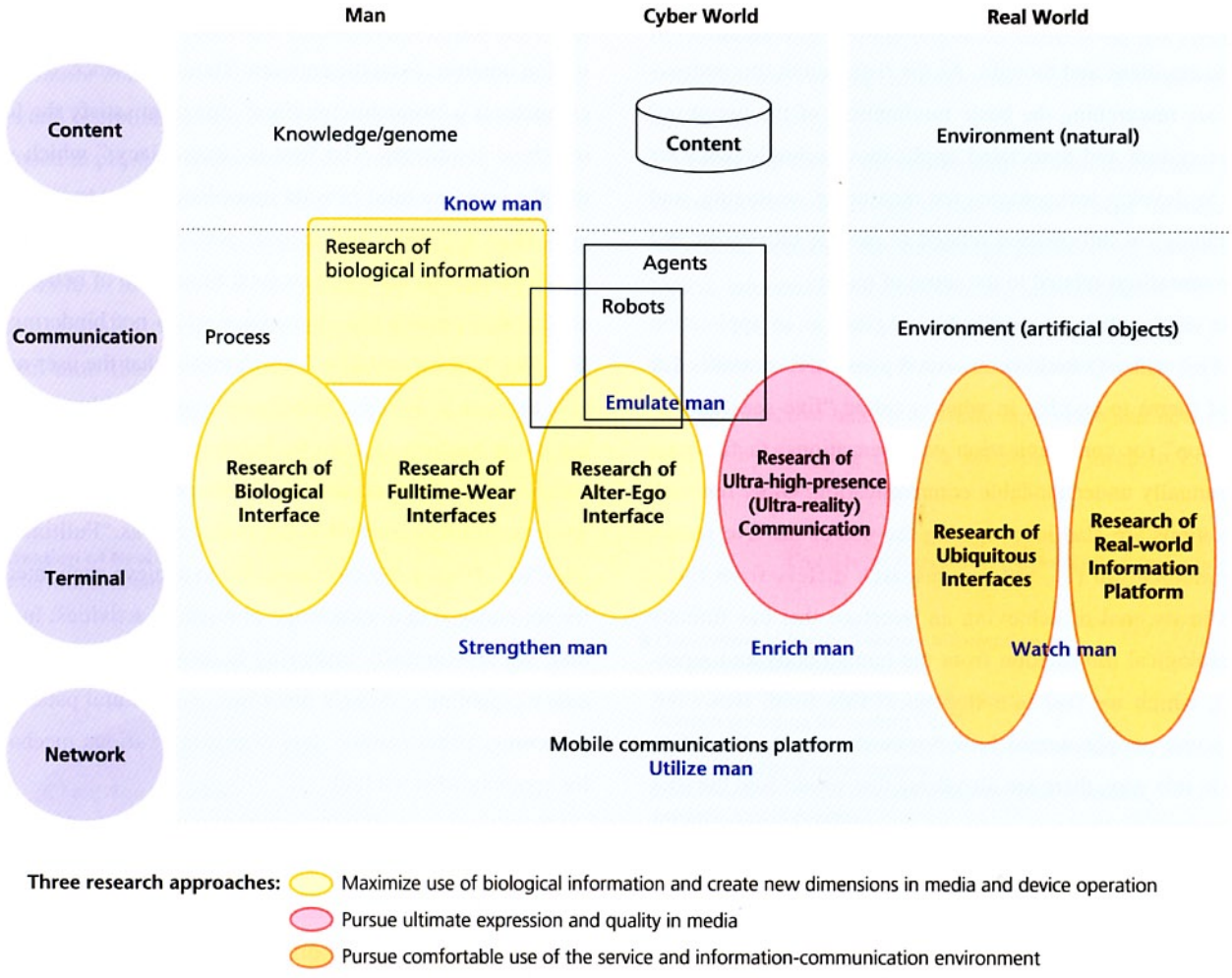

Figure 2 Role of Research Themes in the Realization of HC[3]

relationships among people, objects, devices, and information. Basic to the above developments is a clear understanding of the mechanisms behind human biological information, and to this end, highly accurate measurements of brain, nerve, and muscle activities are essential. These activities are represented by electric currents that in turn generate small magnetic fields. In this regard, we have adopted the Superconducting QUantum Interference Device (SQUID) as a biological magnetic-measurement system. This device can measure these small magnetic fields at high temporal and spatial resolutions without harming the body, and can also be used as an interface. In current R&D efforts, we are designing SQUID for use in measuring peripheral nerves and developing high-accuracy analysis techniques while investigating the mechanisms behind biological information in parallel. Our aim here is to achieve a multiplier effect through mutual feedback between these two avenues of research.

In comparison to the central nervous system, the peripheral nervous system is simple in structure and function while also being relatively easy to measure since it does not exist deep within the body. Knowledge of the peripheral nervous system, moreover, should be very useful in developing interfaces. For the above reasons, we have begun research on biological information with a focus on the peripheral nervous system. Incidentally, the measurement of dynamic transfer phenomena in nerve signals is itself an unknown research area, and clarification of that mechanism can be expected to have a major impact in various fields.

(2) Research of Biological Information Interface Technology

In this research, we aim to add new media axes that enable the five senses and operation-by-movement to be used in communications, and to this end, we will measure, analyze, and apply biological information. Here, we can expect abundant and highly accurate information to be obtained by making measurements near the source of biological information generated as a result of certain operations or behavior. In the future, more-

over, the direct acquisition of biological information from the central nervous system will be indispensable for expanding our target to emotions and thought. As the first step in this endeavor, we are researching the basic mechanisms of the peripheral nervous system and associated application technologies. Our aim is to develop technologies for measuring, analyzing, and using biological information related to muscle movement and surface sensations related to the sense of touch.

One service that can readily be imagined as an application of the five senses would be to convey one's five senses (or some of them) to another in what is called "five-senses communication" (or communication with sensations) to facilitate more mutually understandable communication. Other research organizations are also investigating the use of the five senses in communication [7], but our research differs from those studies in its goal of achieving an interface that can directly input biological information from the human body and reproduce it, which we feel is a step-up in this field. However, while some people would look forward to using their five senses in this way, there are also those that would find the idea of conveying their senses to another disagreeable. Accordingly, conditions like the application, usage scenario, and the other party would dictate not only what information a person would like to convey but also which of the five senses to attach. Under these circumstances, the social receptiveness of such possibilities must be studied simultaneously with technical issues. For example, given that an individual's five senses are kept within his or her own space, should that person nevertheless be allowed to use those senses constructively to make measurements and enhance his or her abilities? And even when sharing one's senses with someone, the degree of intimacy with the person may dictate the range of senses conveyed. Such various levels of receptiveness will also apply to other interfaces, and detailed studies and tests must be performed.

(3) Research of Fulltime-Wear Interface Technology

Considering that society of the near future will have reached the stage of high-speed wireless networks, there will not be a great need for wearable computers that store information to each and every human body. In short, continuous connection by wireless networks will enable people virtually "wear" large-scale memory and high-speed processing equipment on the network side. This means that the minimum requirement of wearable equipment on the body will be to provide interfaces (devices) that convey the intent of the user to the network side and, conversely, to present the user with various kinds of information obtained from the network. Thus, in essence, a wearable computer is a "wearable interface" that must satisfy the following three conditions. The first is "immediacy," which means that the interface must provide immediate access to information as soon as you think you need it. The second is "wearability," which means that the interface must be capable of being wore at all times to provide this immediacy while not hindering daily life. The third is "usability," which means that the user must be able to input and output information rapidly without interrupting his or her flow of thought. In other words, an interface that satisfies these three conditions simultaneously and that can be wore at all times ready for use is defined as "Fulltime-Wear Interface". This is our objective, and to achieve such interfaces, we are engaged in a wide range of research activities. In particular, we are carefully observing human organs, mechanisms, motor capabilities, thought processes, and cultural patterns, and proposing, implementing, and evaluating various mechanisms for applying what we find.

Furthermore, implant devices (embedded in the body) of the future have the potential of creating new ways of operating interfaces and even of changing our lifestyles. The use of implant devices is being proposed as one means of directly inputting and outputting nerve signals, and in this capacity, they might play an important role as technology for achieving biological interfaces. Before implant devices spread to general users, however, their technology must advance far enough to make them sufficiently compact and safe, and at the same time, they must be subjected to an evaluation and verification process to achieve acceptance by society.

(4) Research of Alter-Ego Interface Technology

In contrast to conventional audio and video, a real interface can convey a sensation of posture, actions, and behavior via a robot entity to which one's self has been projected. Such an interface has the potential of creating new ways of communicating, and with this in mind, we have undertaken the research of interfaces and are proposing new directions in this field. In this regard, changing from "word-based communication to emotion-based communication" is expected to play a big role in the evolution of the cellular telephone. An interface with great powers of expression and the ability to introduce emotion can be achieved by projecting one's physical sensations and emotions as gestures, hand movements, and facial expressions to a robot

entity and, conversely, by measuring and obtaining information on one's five senses. These are also interfaces that can overcome distance and perform physical operations by transmitting actions and operations to a robot, which means that information is extended to physical operations in the real world.

In particular, we are researching technology for a natural robot-operation interface. As opposed to operating equipment, our aim here is to operate a robot freely by directly inputting biological signals from one's own physical activity and projecting them onto the robot, and then directly feeding back the results of such actions to one's own senses. Other research organizations such as Advanced Telecommunications Research Institute International (ATR) are also researching "communication robots" [8], but the emphasis there is on the creation of autonomous, intelligent existence, which differs from our approach.

Figure 3 shows the relationship of various research themes in the approach described in this section. These themes, which arise from applying the knowledge gained from analyzing biological-information mechanisms, are all interrelated.

4.2 Pursue Ultimate Expression and Quality in Media

The objective here is to create new value and new roles for content by bringing about a substantial jump in expressive

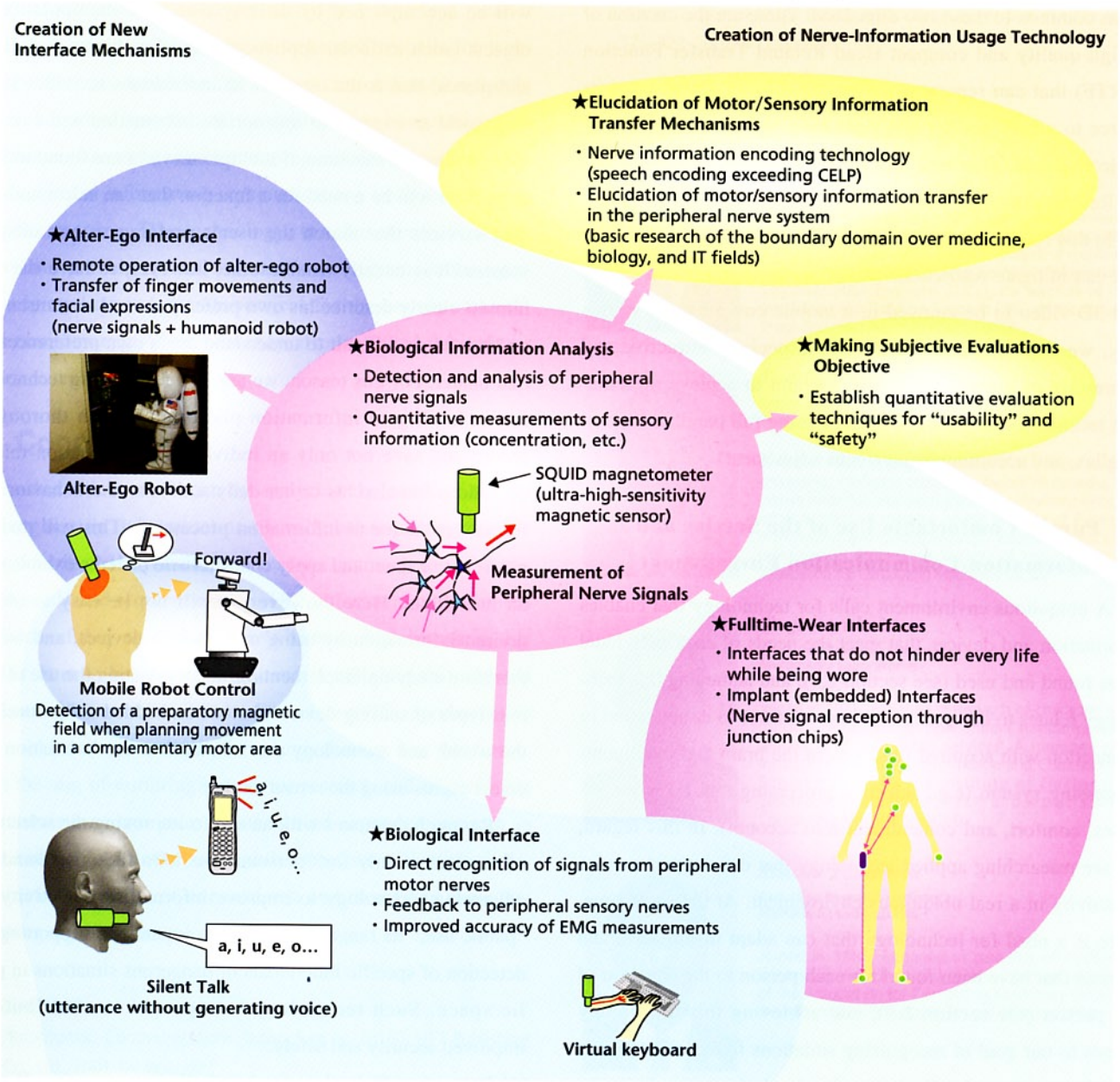

Figure 3 Relationship of Interface Research Themes Centered about Biological Information Analysis

power and quality in media.

(1) Research of Ultra-Real 3D Speech/Audio Communications

One direction taken by this research is to reproduce a 3D sound field for each person, according to the sensed movement of the person and that of another person to whom the person is talking, in a mobile environment. This research direction includes "over-reality" in which a user is given experiences above and beyond what he or she actually senses. Another direction is the creation of artificial 3D sound fields that, in a three-way calling, for example, would make it appear that the voice of one speaker is coming from the left and that of another from the right. While we are presently at just the initial experimental stage of this research, we focus on specific research items common to these two directions. These are the creation of a high-quality and compact Head Related Transfer Function (HRTF) that can represent the propagation of sound from its source to a person's left and right ears, and the preparation of subjective evaluation measures for 3D acoustics.

(2) Research of Ultra-Real 3D Video Communications

In this research, our objective is 3D presentation technology that can mitigate restrictions related to attachments and enable real 3D video to be enjoyed in a mobile environment. In this way, we expect content to become especially attractive and impressive to users. Specifically, we aim to achieve presentation technology for natural 3D video using full parallax, motion parallax, and accommodation (focus adjustment).

4.3 Pursue Comfortable Use of the Service and Information-Communication Environment

A ubiquitous environment calls for technology that enables information and devices that meet the needs of each individual to be found and used (see section 2.3), and achieving this technology relates to our goal of finding solutions to issues raised in connection with acquired functions in the brain and intelligent-processing system (e.g., selective processing that takes preferences, comfort, and contentment into account). In this regard, we are researching applied technology that can support service selectivity in a real ubiquitous environment. At the same time, there is a need for technology that can adapt information and devices that have been found for each person to the situation of the person (see section 2.3), and achieving this technology relates to our goal of recognizing situations from various kinds of information and inferring optimal solutions in relation to innate functions in the brain and intelligent-processing system. Here, we are researching technology that can understand situations in a ubiquitous-sensor environment and construct an optimal service-usage environment in an adaptive manner.

(1) Research of Technology in Support of Service Selectivity in a Ubiquitous Environment

In real world situation, manipulating command-input keys or the cursor of a device to access desired services is not only troublesome but may also interrupt or even suspend the user's primary activity. This would be a problem when attempting to expand the use of services to various kinds of scenarios. To solve this problem, we are researching technology that will enable needed services to be found by extremely simple operations as an integral part of user activities in the real world. This will be accomplished by directly using the manipulation of objects (such as tools, appliances, vehicles, books, buildings, and places) that is the target of an individual's activities in the real world as triggers to appropriate information and / or services access. At this time, if multiple services are found as suitable, there will be a need for a function that can select and present services that match the user's preferences and circumstances. It is usually troublesome, however, to have the user himself clearly describe his own preferences and circumstances, and it is often difficult to understand one's own preferences for that matter. For this reason, we are also researching technology for an intelligent information platform that can thoroughly record and save not only an individual's information-related operations but also his or her daily activities and behavior in a format conducive to information processing. This will make it possible to extract and apply characteristic patterns exhibited by an individual. Here, however, it will not be easy to obtain desired information by using only mobile devices, and we are therefore studying, implementing, and evaluating the use of various types of sensing devices that are embedded ubiquitously in the world, and technology that can track a user's location and detect events using the sensor devices.

Research continues with an eye to improving the selectivity of services mainly for "personal use." On the other hand, by advancing technology to improve information selectivity for "public use," its range of application expands to supporting the detection of specific individuals or dangerous situations in public space. Such technology is expected to contribute to improved security and safety.

(2) Research of Technology for Adaptively Constructing an Optimal Service-Usage Environment in a Ubiquitous Environment

When a user is moving about, it must be kept in mind that information and services that had been carefully selected may become unusable as the usage environment changes. There is therefore a need for a service usage environment on which a selected service is performed always in best to the situation where the user exists while considering user preferences and circumstances. Here, the service usage environment is constructed by adaptively selecting available resource from information-communications resource groups (consisting of interface mechanisms, terminal devices, communication devices, information-processing devices, networks, and network service quality (QoS: Quality of Service)) that can be used under the various environments in which the user may exist. Services can then be used optimally in a seamless manner without interruption just about anywhere. This calls for technology that can determine the current circumstances not only of an individual but also of the information-communications environment so as to combine various resources and reconfigure an optimal information-communications environment in an adaptive manner. This technology, in other words, will construct and provide optimal information-communications interfaces to execute and operate services for the user in a ubiquitous environment. As such, it may also be called "ubiquitous interface technology."

5. Conclusion

In this article, we began by analyzing the needs of society and organizing them in terms of technical requirements. We then described HC^3 of the future as an approach to satisfying these needs and requirements. In HC^3, information and devices are felt as if they are a part of one's body through interfaces that enable them to be used naturally and at will. We also outlined the issues that must be addressed to achieve HC^3, approaches to their solution, and associated research themes. For the future, with the aim of nurturing innovative research and of justifying our convictions and investments behind expanded research in line with DoCoMo's corporate philosophy, we will strive to disseminate the results of our research and to explain their far-reaching significance.

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