
New Healthcare Society Supported by Wearable Sensors and Information Mapping based Services

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Abstract: Collecting and analyzing various personal biological and environmental sensing data is important for various medical services, for example, lifestyle self-check support, personalized medical support and medical studies for the public purpose. We aim to deploy in 5 to 10 years and are studying on a physiological and environmental information processing platform based on wearable sensors, for services to countermeasure to metabolic syndrome, and such lifestyle-related disease. In this paper, firstly we identify issues of daily healthcare support system. Then, we present the initiative of our research, which is composed by a unified health-related information processing platform, new wearable sensors for lifestyle-related information collection, and flexible application architecture for development of new kind of healthcare services that offer merits to both patients and service providers (physicians, health-related institutions, and public organizations).

Keywords: Health Information Monitoring, Healthcare Community, Wearable Physiological Sensors, Information Processing Platform, Metabolic Syndrome.

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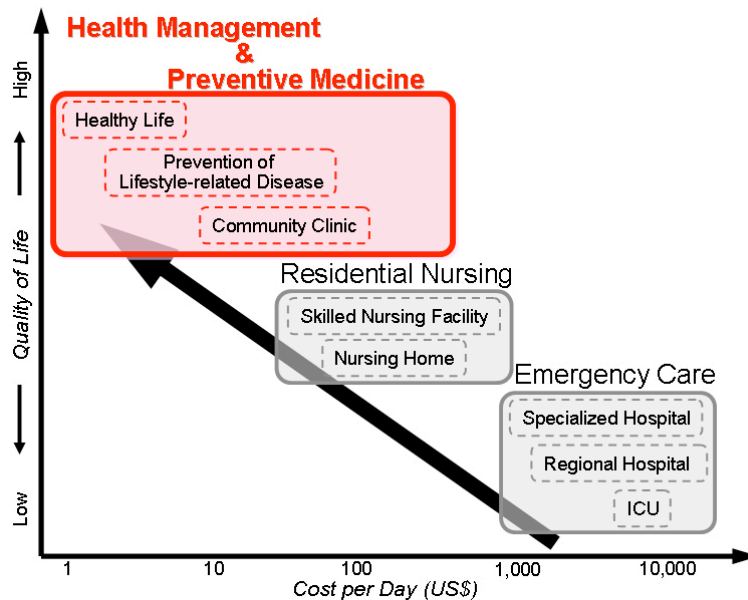
1 Introduction

1.1 Social background

Nowadays, the whole world population aged over 60 reached 600 million people, and there are about 900 million chronic disease patients, which is accompanied by increasing medical fees every year. In Japan, the proportion of population aged over 65 years old is exceeded 20% in 2007, and is expected to exceed 30% by the year 2030¹. With the increasing medical expenses resulting from the coming very aged society, it will soon become impossible for the nations to pay huge medical expenses in the future. Until now, in Japan, the medical system has been centred on the hospitalization therapy for ill patients, and the present cost related to hospitalization accounts for 45% of citizens' medical expenditure. A new form of medical care is required.

To reduce hospitalization and its related expenses, the Ministry of Health, Labour and Welfare, has been promoting a medical revolution centred on the use of independent medical treatment facilities and medical care at home. From the point of view of first prevention, is appealing to citizens on preserving health, rather than cure after falling ill, to improve quality of life² (see figure 1). Accumulation of small efforts in everyday lifestyle is important. Exercise, rest, meal, smoking, and drinking alcohol are set as lifestyle's five factors.

Figure 1 Relation between type of care, quality of life, and cost



¹ Source: Ministry of Health, Labour and Welfare of Japan

² Source: Japan Health Promotion and Fitness Foundation, "National movement for health promotion in the 21st century" <<http://www.kenkounippon21.gr.jp/>>

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Also, according to the results of public opinion polls in Japan about citizens daily life worry and anxiety, “Myself Health”, “Family Members’ Health”, get the second and third position for three consecutive years, which shows how much peoples awareness and interest in healthcare is growing. In these days, with such people's concern for a healthy life, there is a rising need for a health monitoring system available anytime, anywhere. We can expect encouragement of actions turned towards health promotion, if it were possible to accurately and continuously understand one’s own health condition.

1.2 Ubiquitous technology for healthcare support

On one hand, information technology has enabled the introduction of a broad range of applications such as tele-radiology, tele-consultation, and tele-surgery to support wellness and independent living (Hung, and Zhang, 2003). On the other hand, sensors embedded in patient’s environment, can provide global health information by continuously monitoring and analyzing people’s home activity (Stanford, 2002). However, such pervasive systems are still limited to a closed environment, and it does not sense vital signs directly. Abowd, Mynatt, and Rodden (2002), identified three goals to achieve a human centred vision of ubiquitous computing.

- Understand and support human daily life and activity
- Reinforce the environment of current society by the creation and use of various devices that can provide interactive experiences to individuals in several ways.
- Manage and control in a skilful way all the devices that are connected to the network, to provide a deeper everyday personal experience to the user.

Dealing with human activity and interactions in daily life, leads to the necessity of wearable sensing devices that can follow and integrate with few burden human lifestyle in any conditions (see table 1).

Table 1 Traditional medical services and new healthcare services’ evolution with IT

Treatment Type	Hospitalization / Emergency Care	Residential Nursing / Home Care	Ubiquitous Health Monitoring
Cost / Performance	Low (treatment medicine)	Medium (regular monitoring)	High (preventive medicine)
Care place	Limited to Medical Organizations	Any individual’s home	Anytime, Anywhere
Care Level	basic ~ high-risk patients	Nursing prevention (elderly)	health management (lifestyle support)
Available Medical Devices (size)	Any (Big)	Designed for home use (Portable)	Wearable Sensors (tiny & light)

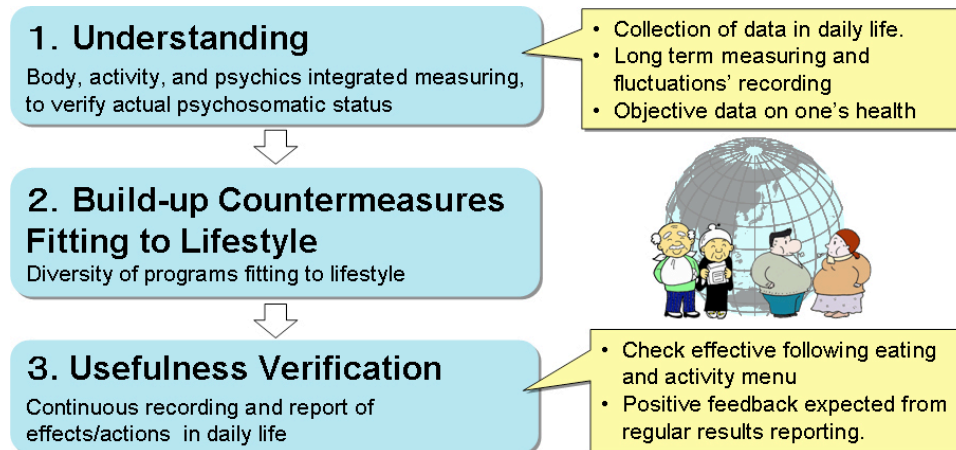
Recent advances in micro-mechatronics make it possible to develop very small wearable physiological sensors. Wearable healthcare systems are non-obtrusive, which allow overcoming the limitations of emergency medicine technology, and address the need of monitoring individuals over long periods (see Kunze et al., 2002, Sachpazidis et al., 2002). They typically rely on wireless, miniature sensors enclosed in items that can be worn such as a ring (see Asada et al., 2003).

However, in the rigorous world of healthcare, it is still mostly unclear how good information technology and systems should look like (see Ammenwerth et al., 2003). It should also be considered that with new sensors successively appearing in addition to the great variety of existing sensors, make it difficult to select the adapted one. Moreover, the special characteristics of sensors are individual to each and change depending on the method to grapple with it, resulting in the necessity to develop repeatedly from scratch processing tasks to deal with each data structures. Finally, most sensors do not provide connectivity to global networks, which restrict the usability environment in practical situations (indoor, wired...).

2 Issues to shift to daily healthcare and preventive medicine

When interviewing physicians, the issue of healthcare and preventive medicine, is first of all to grasp the current situation (figure 2). For example, as it happens that in some cases symptoms do not appear at hospital, there is a strong demand for collecting vital data in daily life, recording the fluctuations components of continuous data measured for long period, or collecting objective and not subjective data about patient during medical interview. Grasping the current situation will consist in measuring in an integrated way body, mind, and activity, as well as in verifying individual characteristics, physical constitution, and current status of mind and body. Next, it is necessary to build-up countermeasures and to establish programs adapted to very diverse personal lifestyle and preferences. Then, it is also important to confirm the effectiveness, and it is expected to record and present continuously the effects in daily life, which will be used as a positive feedback for future analysis and diagnosis. For example, physicians want to know is their patient handles appropriately therapeutic exercises and dietary menu.

Figure 2 Issues to shift to daily healthcare and prevention medicine



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The authors, since 2007, are advancing a 5 years project¹, aiming at the development of a physiological and environmental information processing platform, which would enable constant monitoring of physiological and environmental information on long period of time in daily life, so that people can look back themselves their lifestyle in an objective way. The goal is the development of a structure to collect, store, and make practical use of one's own health information, with individual preservation and improvement of one's own quality of life (QOL). Through developed comprehensive health information system, individual could accurately know his own health condition, leading to personal objectives of health preservation and lifestyle disease prevention, which will promote active health management. Also, with the maintenance of an IT environment to enable to share as necessary all this information, with family members, medical institutions, or appropriate health service Business Company, we can expect to be able to provide more effective and efficient medical and health services.

3 Content and initiative of the research

3.1 Development of the health information processing platform

3.1.1 Platform requirements

Currently, information on each individual's health is straggling in various places: exercise information at fitness club, clinical records at medical institutions, periodical physical examination results at specialized organization or insurer, weight scales and such information at home. All these health information should be available in a unified way for management and practical use by individual's intention. We have to build up the common basic information processing platform of a comprehensive health information system that will enable management, control, and practical use in a unified way, by individual's intention, comprehensive information about health (clinical records, physical examination, exercise, weight and any other vital data), for validation of lifestyle in an objective point of view. Although the comprehensive health information system is a structure that collects individual's health information, we assume that information collected, accumulated, and managed will differ depending on age-group, health condition, and such parameters, since required service is different. Hence, we can raise three functions for the health information processing platform:

- An architecture that will enable each individual to collect, store, and use his own health information, with QOL preservation and promotion as objective.
- Together with the possibility for each individual to carry out total control, it should provide information sharing capabilities, so that each health related actor (physician, nurse, healthcare institution, health insurance societies, etc.), will be able to have practical use of information accumulated in the system, such as information visualization, processing, analysis.

¹ JST strategic sector for creation of advanced integrated sensing technologies for realizing safe and secure societies: research project on "Development of a Physiological and Environmental Information Processing Platform and its Application to the Metabolic Syndrome Measures". <<http://www.jst.go.jp/kisoken/crest/en/area02/1-01.html>>

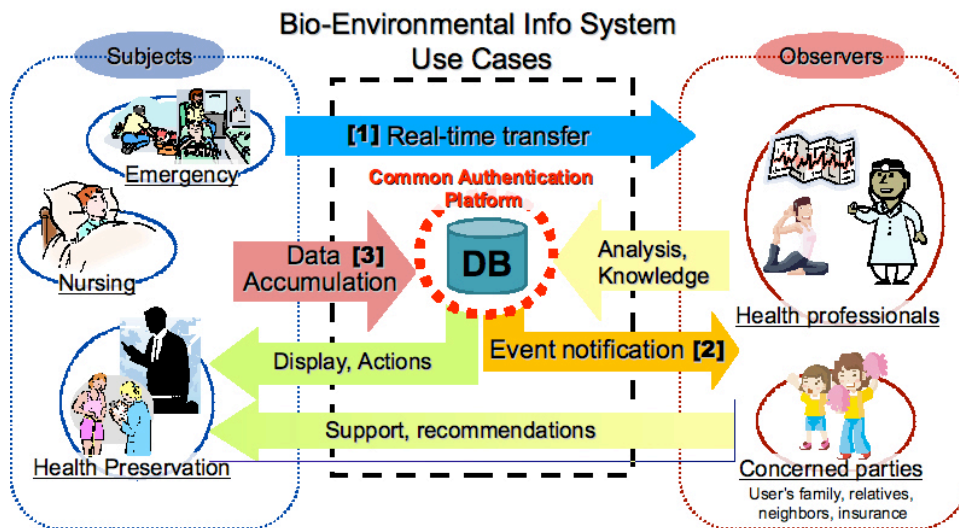
- Targeted health information should have a wide range, covering on one’s lifetime daily health preservation, preventive medical care, and treatment.

3.1.2 Architecture for information collection and storage

A software environment is required to enable easy gathering of information on everyday meal, and exercise, in addition to so far assumed health information such as height, weight, waist, blood pressure, heart rate, and maximum physical strength measures. A system to guarantee easy to use functions from simple process for data accumulation by user instruction, agent-like data input process for paper information, and middleware that enable automatic collection and accumulation of vital signs using wearable sensors is being developed, as well as software module that can evaluate the lack of exercise, lack of sleep, irregular meal, stress level, and such situations repeated in daily life, which are known to be at the origin of metabolic syndrome.

There have been several proposals for health monitoring systems (Anliker et al., 2004), but they are too dedicated to a specific environment. Standard-based middleware proposed by Blount et al. (2007) only supports vital data transfer using HTTP, which make it difficult to address real-time monitoring and event-driven services. Through the survey of related works, we identified three necessary functions of the health monitoring system, which are real-time transfer, event notification, and data accumulation. One of the partner laboratory in our project, designed and prototyped an open, secure, and functional platform that can provide seamless health monitoring services (Rikitake et al., 2009). The basic design and use cases of this platform are shown in figure 3.

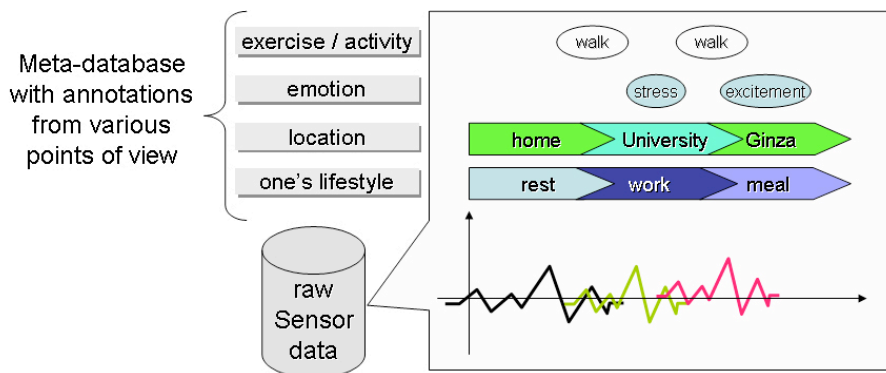
Figure 3 Physiological and environmental information processing platform basic use cases



In order to provide them in a unified way, they adopted an approach based on “IP Multimedia Subsystem” (IMS) services in the framework of “Next Generation Network” (NGN) service oriented interconnection, which is a potential platform to fulfil these required functions because it is a standard based open platform that provides AAA (Authentication, Authorization and Accounting), quality of service support, event notification, and a data management server.

Also, functions should be developed to analyze health information (exercise information, physiological information) continuously accumulated and managed, following rules based on knowledge of medical doctors, the result of simplified automatic diagnosis algorithm conjecture as assumed patient's current condition, can be timely transmitted to the physician, together with converting it in a format understood in a blink by the physician. We plan to deal with that issue through the construction of a meta-database structure to accumulate annotation information integrated with physiological and environmental data, in the way suggested by schematics on figure 4.

Figure 4 Physiological information database augmented with multi-dimensional annotation



3 Wearable sensing for healthcare and lifestyle-related disease prevention

The core part of the system that enables collection of physiological and environmental information in daily life is composed by wearable sensors and signal analysis technology, developed through a strong collaboration with partner medical institutions. Using wearable sensors enable to implement monitoring without restriction feeling, and to extract human high-order information from multivariate analysis of multiple sensor data, including physical conditions such as activity and behaviour, mental conditions such as stress and emotions, and context description. Considering wearable sensors, rather than taking a bottom-up approach of creating new sensor devices from scratch using MEMS (Micro Electro-Mechanical Sensor), our approach consists in effective top-down sensor devices development, by skillful service oriented integration of available technologies owned by each of our research partners. We have been developing sensors that enable to get physiological data useful regarding the metabolic syndrome, the application field targeted by our project. In Japan, the metabolic syndrome diagnosis criterion depends on a abdomen fat, and two of the three following items.

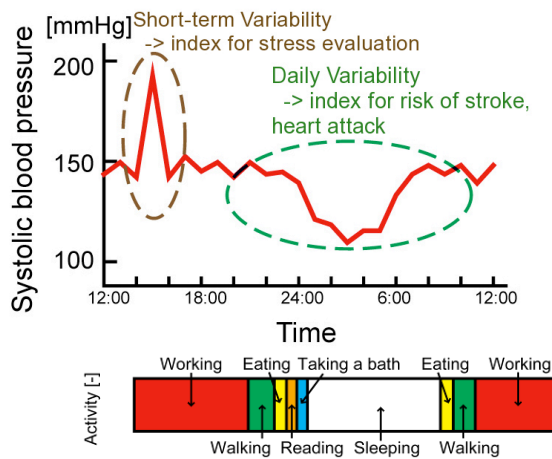
- Blood Pressure > 130/85mmHg
- Neutral Fat > 1.5g/L, and HDL cholesterol < 0.40g/L.
- Fasting Blood Sugar > 1.1g/L

According above criterion, we considered the development of sensors for continuous monitoring of blood pressure variation and eating habits.

3.1 Blood Pressure Sensor

Conventional ambulatory blood pressure monitoring (ABPM) equipment can measure blood pressure at regular intervals for 24 hours, but is limited by long measuring time and constrained measuring posture more than 15 minutes interval between each measure, which is too long to perceive short-term variations of blood pressure that are related with cardiovascular system diseases (see figure 5). Recently, blood pressure estimation from PWV calculation, as done by McCombie et al, (2007) has attracted considerable attention, but it lacks clear definition of measuring conditions (Wong et al, 2009), and accuracy for high values.

Figure 5 Example of blood pressure variability in time.



We developed a new wearable sensing method for accurate and non-invasive measurement of blood pressure in daily activities, including during exercise, to obtain new medical knowledge with respect to blood pressure variability. Our method is based on Pulse Wave Velocity (PWV) calculation, which formula we improved to take into account changes in the inner diameter of blood vessels. Blood pressure estimation results using our new method showed a greater stability of measured data during exercise, and a better relevance than typical one. Moreover, our sensing device, which is composed by a wearable electrocardiogram at the chest and a pulse wave sensor at the earlobe, is less influenced by motion and postural changes, as well as it can extract blood pressure measuring context from embedded motion sensor's data patterns (see Lopez et al., 2009).

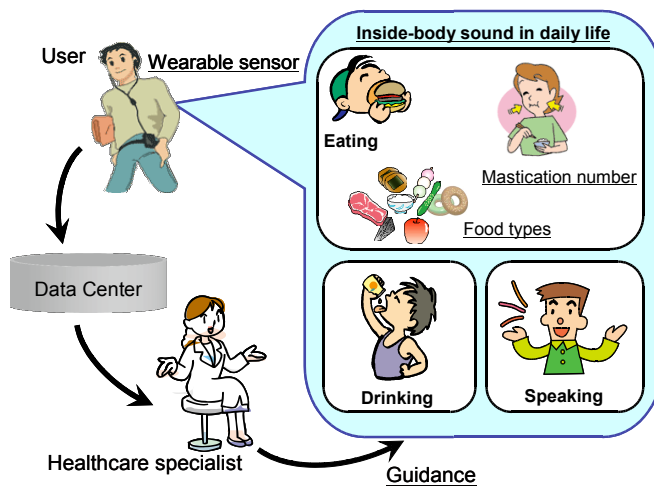
3.2 Eating Habit Sensor

No objective method has been clearly established, continuous monitoring of eating habits could be useful in preventing lifestyle-related diseases such as the metabolic syndrome. Healthcare specialists identify chewing, regularity of meals, and types of foods eaten as medically meaningful factors. Mastication frequency calculation from myoelectric potential of the masseter muscle, results in a significant burden for the user (Kohyama et al, 2003). Recently, analysis of internal body sound spectra as attracted attention, to differentiate biting and speaking activity (Mizuno et al, 2007), and classify automatically several aliments (Amft et al, 2005). However, performances are too much influenced by individual differences and limited to specific aliments.

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We have been developing an objective and non-invasive sensing system that can record eating habits over a long period of time, as well as robust analysis methods that can accurately monitor eating habits in daily life (see figure 6). Our original sensing system is composed by two bone conduction microphones placed in the ears, from which sound data are collected. Applying frequency spectrum analysis on collected sound data, we could not only count the number of chewing stroke during eating, but also accurately differentiate eating, drinking, and talking activities, which can be used to evaluate the regularity of meals. Moreover, using hierarchical clustering of sound spectra, we found it is possible to classify types of foods eaten regarding their texture (see Shuzo et al., 2009).

Figure 6 Schematic of the eating habits monitoring system.



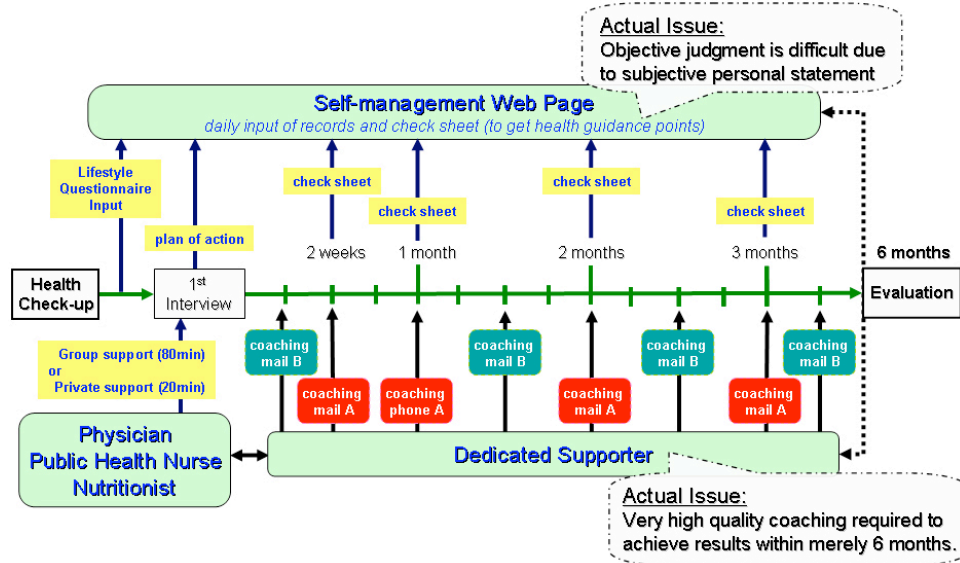
4 Development of services for daily healthcare

Concretely, aiming at application to metabolic syndrome, we are carrying out the development of services matching with needs (visualization, health promotion tool, simplified auto-diagnosis tool...) of each user (patient, relatives, physician, health-related institution...), and flexible healthcare services customized to individuals, contributing to prevention and treatment. Also, we will plan in scene experiments to inspect the validity of new comprehensive information system and each application.

4.1 Program for healthcare promotion and support

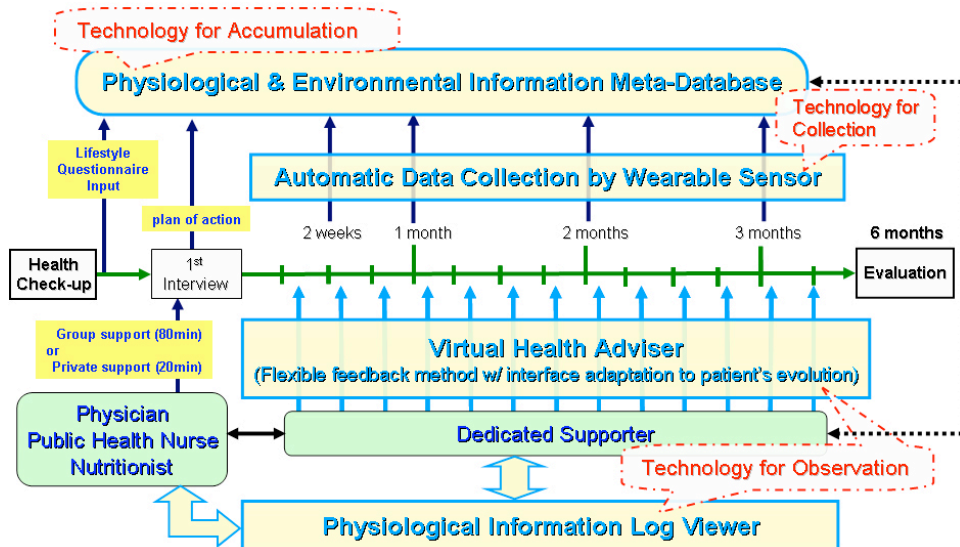
In Japan, as a preliminary countermeasure to metabolic syndrome progression, a specific health examination program for all people between 40 and 75 years old has started in April 2008. The typical procedure of this specific health examination is shown on figure 7. Though, as a concrete problem, physicians', public health nurses', or nutritionists' coaching is only based on patient's personal statement information, relying on a simple check sheet, since lacking of objectivity to be efficient. Moreover, results have to be raised into merely six months, which in counterpart requires very high quality coaching.

Figure 7 Current checkups procedure for metabolic syndrome coaching



There, we consider that capitalization on formerly described technologies for collection, accumulation, and observation of physiological information, is a key to improve the quality and objectivity of such service. Using wearable sensors, collection of objective data, their regular long term accumulation in databases, and the cross integration with clinical records, medication records, and such medical information for better interpretation and following, become possible. Figure 8 shows a schematic proposition of an improved system for metabolic syndrome coaching.

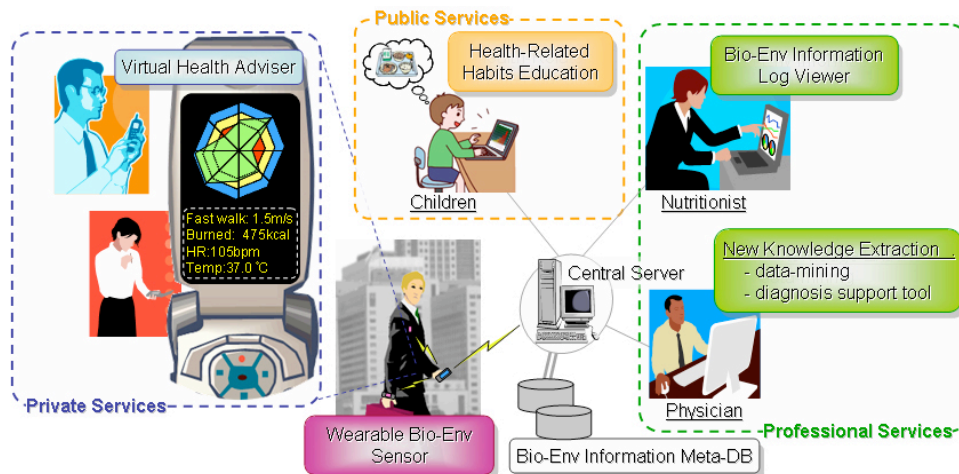
Figure 8 Proposed improved system for metabolic syndrome coaching



4.2 Definition of the type of healthcare services to develop

So far, we have been working on the prototypes of several sensors and basic information processing platform development. Now, we are considering their integration into practical applications, aiming at new healthcare services playing an efficient role as countermeasures for metabolic syndrome, from simple vital data log viewer to support physicians' diagnosis, to a virtual health advisor application to stimulate specific health coaching target persons to take actions of their own initiative (see figure 9).

Figure 9 Example of healthcare services as countermeasure to metabolic syndrome



Among the huge amount of possibilities concerning health-related information visualization, the real issue is to detect which one, on which format, and into which layout it will be the most efficiently displayed. Visualization optimization is the key to usability and service success, and we identify two points to evaluate services interface.

- Continuous support and stimulation (encouragement, competition, incentive, and game...) to avoid unsteady use, by dynamically composed virtual communities.
- Metamorphosis of representation on a long period of time, to avoid getting tired with the system, and optimization of information visual, use, and transmission.

5 Future perspectives

Concerning indexation, prevention, treatment, and countermeasures of metabolic syndrome, we will carry out empirical experiments of the various healthcare services developed, and verify the validity as for each user (individual, health service Business Company, physician, etc.). We also plan to create real services as listed following, which can play a role as countermeasures for metabolic syndrome:

- Virtual health adviser (private use)
- Physiological and environmental information log viewer (professional use)
- Healthy habits experience tools (public use)
- Healthcare management and stimulation application (community use)

References

- [1] K. Hung, Y. Zhang, "Implementation of a WAP-Based Telemedicine System for Patient Monitoring," *IEEE Transactions on Information Technology in Biomedicine*, vol. 7, no. 2, pp. 101-106, June 2003.
- [2] V. Stanford, "Using Pervasive Computing to Deliver Elder Care," *IEEE Computer Society, Pervasive computing magazine*, vol. 1, no. 1, pp. 10-13, Jan.-Mar. 2002.
- [3] G.D. Abowd, E.D. Mynatt, and T. Rodden, "The Human Experience," in *IEEE Pervasive Computing*, Vol. 1, No. 1, pp. 48-57, January-March 2002.
- [4] C. Kunze et al., "Application of Ubiquitous Computing in personal health monitoring systems," in papers of the 36th meeting of the German Society for Biomedical Engineering, pp. 360-362, 2002.
- [5] I. Sachpazidis, "@Home: A system for real time monitoring of patients' vital parameters," in *Proc. of the 2002 Korea-Germany Joint Workshop on Advanced Medical Image Processing*.
- [6] H. H. Asada et al., "Mobile Monitoring with Wearable Photoplethysmographic Biosensors," *IEEE Engineering in Medicine and Biology Magazine*, vol. 22, issue 3, pp. 28-40, 2003.
- [7] E. Ammenwerth et al., "Evaluation of Health Information Systems-Problems and Challenges," *International Journal of Medical Informatics*, vol. 71, issues 2-3, pp. 125-135, Sep. 2003.
- [8] U. Anliker, et al., "AMON: A Wearable Multiparameter Medical Monitoring and Alert System", *IEEE Transactions on Information Technology in Biomedicine*, Vol. 8, No. 4, December 2004.
- [9] M. Blount, et al., "Remote health-care monitoring using Personal Care Connect", *IBM Systems Journal*, Vol. 46, No. 1, 2007.
- [10] Koichiro Rikitake, Yasuhiro Araki, Yoshihiro Kawahara, Masateru Minami, Hiroyuki Morikawa, "NGN/IMS-based ubiquitous health monitoring system," *6th Annual IEEE Consumer Communications & Networking Conference (CCNC 2009)*, Jan. 2009.
- [11] Masaki Shuzo and Ichiro Yamada, "Development of Biological/Environmental Information Processing Platform," in proceedings of the 2009 Japan Electrical Engineering Society Technical Meeting, Hokkaido University, 17-19 March 2009.
- [12] D. B. McCombie, P. A. Shaltis, A. T. Reisner, and H. H. Asada, "Adaptive Hydrostatic Blood Pressure Calibration: Development of a Wearable, Autonomous Pulse Wave Velocity Blood Pressure Monitor," *Proc. EMBS 2007*, pp. 370-373, 2007.
- [13] M. Y. M. Wong, E. Pickwell-MacPherson, and Y. T. Zhang, "The Acute Effects of Running on Blood Pressure Estimation Using Pulse Transit Time in Normotensive Subjects," *European Journal of Applied Physiology*, Online First, 2009.
- [14] G. Lopez et al., "Continuous Blood Pressure Monitoring in Daily Life," in *Proc. of the 2009 Conference on Micromechatronics for Information and Precision Equipment (MIPE 2009)*, Tsukuba International Congress Center, Ibaraki, Japan, pp. 223-224, June 17-20 2009.
- [15] K. Kohyama, L. Mioche, and P. Bourdio, "Influence of age and dental status on chewing behaviour studied by EMG recordings during consumption of various food samples," *Gerodontology*, vol. 20(1), pp. 15-23, 2003.
- [16] H. Mizuno et al., "Wearable sensor system for human behavior recognition," *Proceedings of Transducers & Eurosensors '07*, pp. 435-438, 2007.
- [17] O. Amft, M. Stager, P. Lukowicz, and G. Troster, "Analysis of chewing sounds for dietary monitoring," *Proceedings of 7th International Conference on Ubiquitous Computing*, pp. 56-72, 2005.
- [18] M. Shuzo et al. , "Wearable Eating Habit Sensing Using Sound Information," in *Proc. of the 2009 Conference on Micromechatronics for Information and Precision Equipment (MIPE 2009)* , Tsukuba International Congress Center, Ibaraki, Japan, pp. 221-222, June 17-20 2009.