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Human Indicator and Information Display using Space Human Interface in Networked Intelligent Space

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Abstract

This paper describes a new data-handing, based on a Spatial Human Interface as human indicator, to the Spatial-Knowledge-Tags (SKT) in the spatial memory. the Spatial Human Interface (SHI) is a new system that enables us to facilitate human activity in a working environment. The SHI stores human activity data as knowledge and activity history of human into the Spatial Memory in a working environment as three-dimensional space where one acts, and loads them with the Spatial-Knowledge-Tags(SKT) by supporting the enhancement of human activity. To realize this, the purpose of SHI is to construct new relationship among human and distributed networks computers and sensors that is based on intuitive and simultaneous interactions. In this paper, the specified functions of SKT and the realization method of SKT are explained. The utility of SKT is demonstrated in designing a robot motion control.

Key Words : Spatial-Knowledge-Tags(SKT), Spatial Memory, Spatial Human Interface(SHI), Intelligent Space

1. Introduction

The Spatial Human Interface (SHI) is a new system that facilitates us to do high quality activity such as strategic decision in business, and to be creative with production design of new technology and so on, in a working environment. The SHI stores the human data as knowledge and activity history of human into the Spatial Memory in working environment as three-dimensional space where one acts, and loads them with the Spatial-Knowledge-Tags(SKT) by supporting the enhancement of human activity.

In recent years, with advent of distributed networked computers and sensors (DNCS), there are many possibilities to revolutionize ordinary relationships between human and machines [1]. Thus, in every situation a new relationship must be reconstructed to maintain and develop our life and work. This leads to many novel and high quality of the activity on our daily life. We have defined the characteristics of this new relationship as intuitive and simultaneous interactions among human and DNCS which are detect the information of human activities and then process the gathered information.

Also, the application works concerned with the intelligent space have been developed [1]-[5]. they referred the interface between human and mechatronics, that is the interface is to operate the mechatronics smoothly corresponding to human action [6]. however, the usage of human knowledge as the important role of advanced human activity has not been considered.

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This paper describes a new data-handing, based on a human indicator as human motion, to the Spatial-Knowledge- Tags (SKT) in the spatial memory. the SKT is generally produced from a digital data in a computer, the spatial memory is constructed in a the dimensional space where one is able to move freely, and the human indicator is regarded as an indication in data-handling to the SKT for the spatial memory as if to digital data for a computer memory. And, the SKT is related to a real object itself such as a telephone, door, filing box and so on.

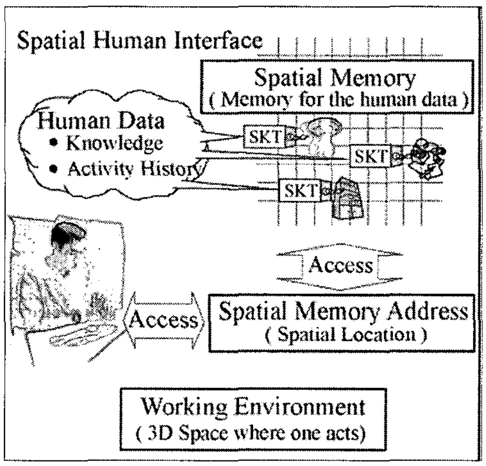

Fig. 1. Concept of SKT in SHI.

Human-computer/machine interface including multimodal interfaces have been studied [2]-[5]. In these literatures, the human interfaces have been primarily designed for a very limited and restricted interaction between human and a certain computer/machine such as a mouse or a keyboard, and so on. Those factors are only focused on the input/output relationship based on sensor fusion, but are not based on intuitive and simultaneous interactions.

Human will spend the high quality activity if one is able to obtain and store this knowledge intuitively and simultaneously, using this knowledge for a certain specific activity. The SHI which gives the high quality of activity for human must be composed of a number of elements. In this paper, SKT is an element of the SHI is proposed as the first step of our research about SHI.

The SKT is a virtual tag, which is determined by spatial locations, which are represented as a human data address i.e. knowledge, information and activity history in the working environment in which SHI sets up. The environment where human data is stored is similar to memory space in a computer system, and the location of SKT is made up within this memory environment, so we call this address the Spatial Memory Address and call the environment the Spatial Memory. To access the Spatial Memory intuitively and simultaneously, certain new indicators are needed. These indicators use human action such as movement with the tip of index finger or to gaze at a particular location. Namely, those actions are treated as a memory tag, this is the SKT. The illustration of SKT and SHI are shown in Fig.1.

In regards to the working space as Spatial Memory, it is possible that humans utilize the spatial positions as a cognitive trigger to store human data. For example, humans are able to take notes toward a speaker direction, or to save schedule on a calendar. Situations associated with human data and the action when this data is stored maintain an impression for several days. This impression or memory tag becomes a essential key to ascertain the stored human data, even if one's memory vanishes gradually.

From this, humans will be able to intuitive load SKT. In addition, humans will be able to indicate intuitively and simultaneously some SKTs using their body, for example, moving one's arms, gazing at a object and so on. It is preferable that humans are able to access the Spatial Memory wherever one works in a working environment. From this, SKT is defined in a coordinate system where a position of human body is in relation to the origin. Using the human body indicators sometimes creates an indication error between SKT and an indication position.

That is the reason why humans may not indicate the SKT precisely. Moreover, the indication error will vary as time passes because of uncertainly of one's memory. Thus, indication error which is defined as the distance between SKT and an indication position is investigated. The utility of SKT is demonstrated in designing a system which needs complex knowledge. To confirm it, it is applied to design motion control of a four legged robot. In the following chapters, two types of SKT are proposed, and the specified functions of SKT system and its realization method are explained. The experimental results utilizing SKT for robot motion control design are shown and its evaluations are considered.

2. Definitions of SKT based on the Coordinate Systems

Two types of SKT are defined and named "Local SKT (LSKT)" and "World SKT (WSKT)". They are distinguished by a coordinate system which is used to define them. It is preferable that humans are able to access the SKT wherever one works in a working environment. From this, LSKTs are defined at a local coordinate system where a position of human body is in relation to the origin, and moves with the human. The origin of the local coordinate system where a position of human body is in relation to the origin, and moves with the human. The origin of the local coordinate system is defined at the center of the human heart. On the other hand, in the case that humans store SKT at static locations in the working environment, SKT should be stored in the world coordinate system. There, WSKT storable regions are defined, and WSKT address is defined by the position on the region.

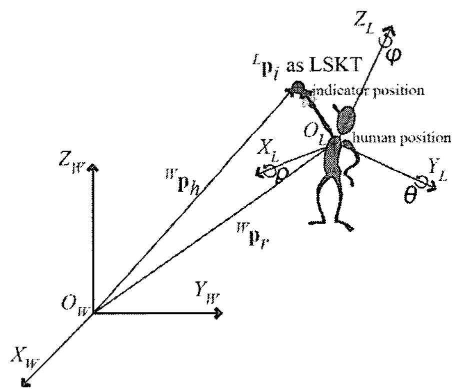

Fig. 2. The definitions of coordinate systems and LSKT.

2.1 Definition of LSKT

Fig.2 describes the coordinate systems of the SHI. To realize that human is able to access the Spatial Memory wherever one works in a working environment with the world coordinate system (X_W, Y_W, Z_W), human in it has a local coordinate system (X_L, Y_L, Z_L), and the position for human indicator position such as the tip of index finger, line of sight and so on are in the local coordinate system.

Here, the origin represents the human position, which is located at the center of the heart. In the following notation, the superscript refers to the coordinate system, i.e, is the world coordinate of the SHI, and is the coordinate system after conversion. $^{W}P_r = (x_r, y_r, z_r)^T$ represents a human position in the world coordinate, i.e, this point is the origin O_L in the local coordinate system via coordinate transformation. ${}^{W}P_h=(x_h, y_h, z_h)^T$ represents an indicator position such as the tip of index finger in the world coordinate, i.e, this point is an indicator position ${}^{L}P_i=(x_i, y_i, z_i)^T$ in the local coordinate system. ${}^{L}P_i$ obtained by (1), and it defines the spatial location of LSKT.

$$\begin{pmatrix} {}^{L}P_i \\ 1 \end{pmatrix} = \begin{pmatrix} {}^{L}P_i & -{}^{W}P_r \\ 0 & 1 \end{pmatrix}^{-1} \begin{pmatrix} {}^{W}P_h \\ 1 \end{pmatrix} \tag{1}$$

where ${}^{L}R_W$ is a 3x3 matrix which is a coordinate transformation matrix in (2).

$${}^{L}R_W = R(z,\phi) \cdot R(y,\theta) \cdot R(x,\psi) \tag{2}$$

where ψ, θ, ϕ are the rotation angles around x, y and z axes, and $R(x,\psi)$, $R(x,\theta)$, $R(x,\phi)$ are the rotation matrices around x, y and z respectively.

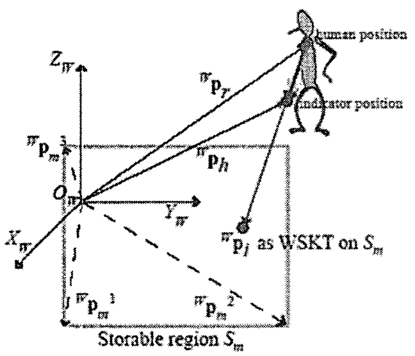

Fig. 3. The definition of WSKT in the world coordinate system.

2.2 Definition of WSKT

In order to store WSKT at static location, WSKT storable regions are setup in the working environment. A storable region S_m is defined by three vectors ${}^{W}P^1_m$ ${}^{W}P^2_m$ ${}^{W}P^3_m$ as shown in Fig.3, where m is the number of the storable region. Vector equation of WSKT storable region S_m is given by (3). The position ${}^{W}P_i$, which defines a spatial location of WSKT, is obtained by calculating the intersection point of the line, which contains ${}^{W}P_r$ and ${}^{W}P_h$ as shown in (4), and storable region S_m.

$${}^{W}P_i = {}^{W}P^1_m + j({}^{W}P^2_m - {}^{W}P^1_m) + k({}^{W}P^3_m - {}^{W}P^1_m) \tag{3}$$

$${}^{W}P_i = {}^{W}P_i + t({}^{W}P_h - {}^{W}P_r) \tag{4}$$

The coefficients j, k, t are the parameters to specify the region and line, respectively.

3. System Components of SKT

SKT consists of four units: (A)Human tracker, (B)Human data Input unit, (C)SKT Manager and (D)Output applications.

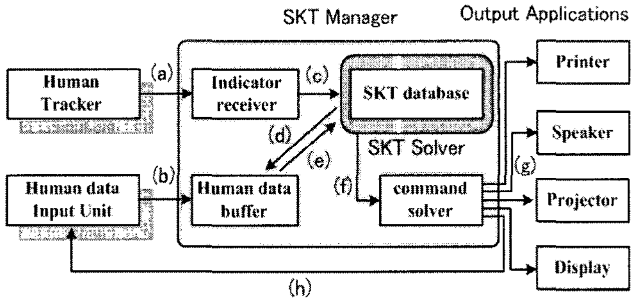

Fig. 4. Whole system components of SKT and data flows.

Fig.4 shows system components of SKT and data flows (a)~(h). The specified functions of each unit and the realization method of it are explained using Fig.4.

3.1 Human tracker

A decision method of human's "indication" action is explained. The human tracker calculates the average of each N measurements in human and indicator positions.

TABLE I: IS-900 SPECIFICATIONS

Degrees o Freedom	6
Resolution	**Typical:**
Position(X/Y/Z)	1.5mm RMS
Angular(P/R/Y)	0.05^0 RMS
Stability	**Typical:**
Position(X/Y/Z)	4mm RMS
Angular(P/R,Y)	0.2^0, 0.4^0 RMS
Interface Protocol	**RS-232 to 115.2k baud**

N is the number of measurements. That's because it is hard that human's indication action is recognized by one measurement compared to many indicator position in continuous measurement. The condition of counting N is used to satisfy the motionless condition for a certain time. The motionless condition is $|v_h| < V_O$ where v_h is a velocity of an indicator position and V_O is a design parameter. ${}^{W}P_r$ and ${}^{W}P_h$ in (1)(3)(4) are reset as ${}^{W}P'_r$ and ${}^{W}P'_h$ respectively, and then indicator positions ${}^{L}P_i$ and ${}^{W}P_i$ are obtained.

$${}^{W}P'_r = \frac{1}{N}\sum_{k=1}^{N} {}^{W}P_r \qquad \text{if} \quad |v_h| < V_O \tag{5}$$

$${}^{W}P'_h = \frac{1}{N}\sum_{k=1}^{N} {}^{W}P_h \qquad \text{if} \quad |v_h| < V_O \tag{6}$$

When indicator positions ${}^{L}P_i$ and ${}^{W}P_i$ are obtained, Human tracker notifies the indicator receiver in the SKT Manager of them at data flow(a) in Fig.4.

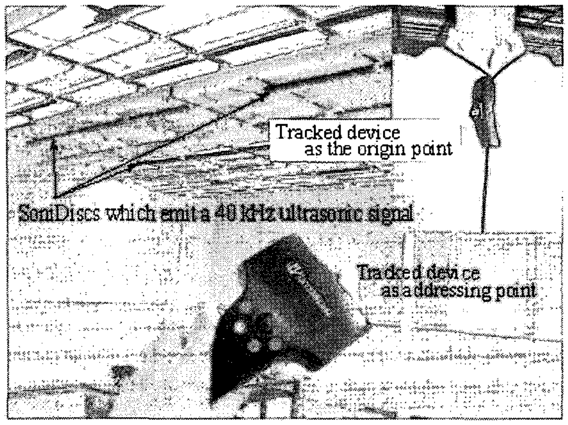

Fig. 5. InterSense IS-900 Precision Motion Tracker IS-900 is a hybrid acoustic-inertial 6 DOF position and orientation tracking system.

TABLE II: RECORD COMPONENTS OF SKT DATABASE

Contents of field
SKT ID
type of SKT (LSKT or WSKT)
type of human data (data or command)
human data
spatial location (x, y, z)
storable region ID
access frequency
time stamp

In this paper, Human tracker is realized by IS-900 (InterSense, Inc [7]) which is built into a room as shown in Fig. 5. The IS-900 system gives us 6 DOF position (x, y, z) and orientation (yaw, pitch, roll). The specification of IS-900 is shown in Table I.

3.2 Human data Input unit

All human data is stored from Human data Input unit. Two types of human data are defined. One of the human data type is a type of data file such as documents, products, reports which are including text, image and movie. The other human data is a type of command to operate a computer/machine such as print out, display, copy, and so on. Two types of human data are named "data type human data" and "command type human data" respectively.

Humans create or select human data and its type by using networked computers, and then indicates at suitable spatial location by moving one's arm. Human data and its type are sent to human data buffer in SKT Manager at data flow(b) in Fig.4. In addition, Human data Input unit has functions for providing auditory feedback messages received from SKT Manager and exception handling.

3.3 SKT Manager

SKT Manager consists of relational database and a SKT solver application. Recorded components of database table are shown in Table II.

The functions of SKT Solver are described as following

- receiving indicator positions from indicator receiver
- checking human data buffer and getting human data
- determining SKT ID from the indicator positions

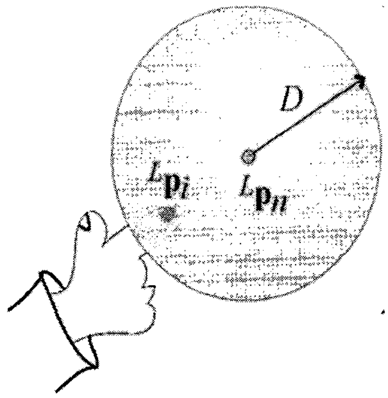

Fig. 6. Illustration of the condition to load LSKT n.

The sequence of these procedures is explained. SKT Solver receives indicator positions $^{L}P_i$, $^{W}P_i$ at data flow(c) in Fig.4, and then refers SKT databases. In the case of WSKT, it is difficult for humans to indicate individual WSKT from distant place. For that reason, when humans access storable region S_m, all WSKTs on S_m are loaded. In the case of LSKT, the condition to determine LSKT ID based on $^{L}P_i$ is needed. That's because human may not indicate the LSKT precisely. To deal with this, the region which is defined by a sphere with center at $^{L}P_n$ which is the position of LSKT n with a radius of D is considered. The region is shown in Fig.6. If the distance between $^{L}P_i$ and $^{L}P_n$ is smaller than D, LSKT n is loaded to command solver at data flow(f) in Fig.4. The parameter D must be decided through investigating human indication action. The investigations are shown later.

$$| \, ^{L}P_i - \, ^{L}P_n | < D \tag{7}$$

In the case that SKT is not stored in the corresponding spatial location, SKT Solver checks human data buffer and stores human data as new SKT in database according to recorded components. When human data is not stored in human data buffer, SKT Manager notifies Human data Input unit about the error. Command solver executes command according to types of human data and sends human data to Output applications.

3.4 Output applications

Output applications are DNCS including printer, large size display, liquid crystal projector and PDA to present human data and control device connected with it.

4. Evaluation of Indicator

In this experiment, the relationship between the indication error, which is defined as the distance between LSKT and an indicator position, and the passing of time is investigated so as to ascertain the radius D as the decision condition to load SKT in (7) and Fig.6.

The conditions of experiments are explained. An indicator position ${}^{L}P_{i}$ depends on a human position ${}^{W}P_{r}$. Human position should be located at a place almost free from any additional vibrations and motions so as to prevent any false indicator positioning errors. The center of human position is located at the center of the heart. In relations indicator position and human position are tracked by IS-900 system shown in Fig.5. To identify one's aiming points, a user interface on the SKT has four buttons to control input.

In other words, user distinguishes each LSKT by pushing corresponding button. The interface can store up to four LSKTs, i.e. $n=1,\cdots,4$, which is indicated at an interval time which is not specified. The indication error $d_{n}(t)$ is defined as a distance between ${}^{L}P_{n}$ which is a position of LSKT n as the memory address and ${}^{L}P_{i,n}(t)$ which is a position that human indicates it at time t, and shown in (8).

$$d_{n}(t)=|\ {}^{L}P_{n}-{}^{L}P_{i,n}(t)\ | \tag{8}$$

where time t is operating time from $t=0$ when the experiment starts.

The coefficient of correlation r_{n} between the indication error $d_{n}(t)$[cm] and operating time t[min] is obtained. Table. III shows the coefficient of correlation r_{n} between the indication error $d_{n}(t)$ and operating time t for five subjects (S1 ~S5). Total time in Table. III is observation term [min] of each subject. From the observations of the subjects in Table III, the linear relationship between the indication error $d_{n}(t)$ and operating time t is hardly recognized though individual variation as shown. Maximum indication errors and the time of each subject is shown in Table. IV which shows that the relationship between the time recording the maximum indication errors and the end of the experimental term is irrelevance. The correlation between the maximum indication error and operating time of the experiment is weak.

TABLE III: THE INVESTIGATION FOR FIVE SUBJECTS OF THE COEFFICIENT OF CORRELATION r_{n}

Subject	r_1	r_2	r_3	r_4	Total Time[min]
S1	0.5625	0.5156	0.4581	0.6619	210
S2	0.5226	0.6904	0.3996	0.5118	210
S3	0.5544	0.1901	0.3525	0.7218	210
S4	0.5444	0.8326	0.7686	0.6165	1190
S5	0.4855	0.2270	0.2976	0.6235	1190

TABLE IV: MAXIMUM INDICAITON ERROR AND THE TIME

Subject	Maximum $d_{n}(t)$[cm]	t [min]
S1	28.82	81
S2	16.34	131
S3	23.6	187
S4	20.24	433
S5	23.55	189

The investigation results show that it is possible that humans can indicate the location of a LSKT within a error of about 20cm 20 hours later, though the error margin gradually grows as time passing. But the indication error sometimes becomes bigger than 20 cm when a human probably forgets or misindicates the location of a LSKT.

Fig.7 is an example of the observation of the indicator position to each LSKT and the result of S4. The color of points represents the age in hours. In this figure, red triangle mark represents LSKT location. Fig.8 is a time series chart showing indication errors of S4 observation. The ordinate represents the indication error $d_{n}(t)$ and the abscissa represents time[min] which have a logarithmic scale. This figure shows that the indication error is about 20cm 1190min after the experiment starts.

The radius D of the condition to determine LSKT ID based on human indication, ${}^{L}P_{i}$ in (5) is defined as 20 though the indication ${}^{L}P_{i,n}$ not necessarily exist around LSKT.

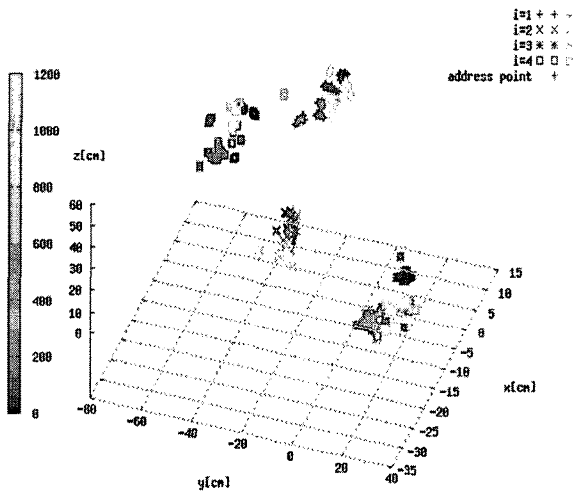

Fig. 7. The observation of the indicator position to each LSKT in the case of subject S4.

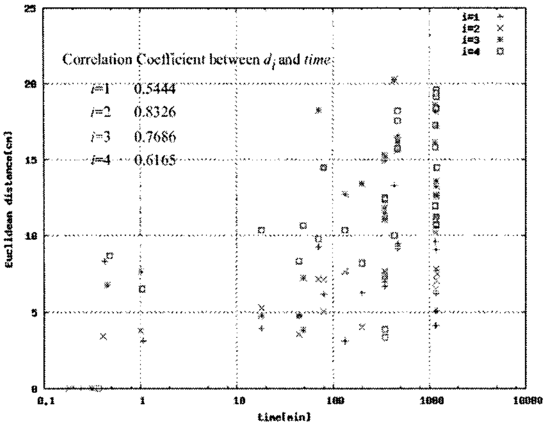

Fig. 8. The time series of the indication error of subject S4.

5. Design of Robot Motion Control

In this section, a design method for four legged robot as SKT application is shown. SKT is applied to the development tool of robot software. The design of robot motion control requires immense and complex knowledge. For efficient design, utilizing SKT enables human to store necessary knowledge, watch it in parallel and recognize relations among the knowledge, whenever they require.

As an example, a remote mobile monitoring system by utilizing the Sony entertainment robot AIBO[8] as shown in Fig.9 is realized. Human who puts on HMD in the room set up SHI can walks while looking at image which is obtained from AIBO vision. The remote mobile monitoring system is realized by synchronizing AIBO movement with human movement such as walking direction and head posture through the Internet. The essential functions for the remote mobile monitoring system are shown as following:

1) Image transfer from AIBO vision to remote PC
2) Control joints to synchronize walking direction and head posture of AIBO with human movement
3) Communication between remote PC and AIBO

Here, AIBO and its development tool are explained. AIBO has four legs and one head, each of which has three degree of freedom, and many various sensors and equipment such as a color camera and wireless LAN. We can develop original AIBO software by utilizing the OPENR SDK[9] which has released by Sony. The OPEN-R SDK discloses the specifications of the interface between the 'system layer' and the 'application layer'. The system layer provides a set of services such as input of image data, output of control data to joints, input of data from various sensors and input/ouput of sound data as the interface to the application layer, and also provides the interface to the TCP/IP protocol stack. The application layer consists of several OPEN-R application objects, which user creates, such as sensor data processing, motion control and so on. The essential knowledge to realize functions using OPEN-R objects is shown as following:

- Activation of hardware devices by specifying CPC(Configurable Physical Component) Primitive Locator which describes each device.
- Creation of control data to actuators such as LEDs and joints
- Obtainments sensor data including image data
- Procedure of communication between system object and application object , which is called inter-object communication
- Communication by utilizing the TCP/IP protocol

Each knowledge consists of many terms. Each term, which is implemented by html files including program explanation and illustrations as shown in Fig.10, is utilized as the human data. To show the knowledge, multiple displays are prepared. Type of SKT and its spatial address is defined by user. User openhandedly designs motion of AIBO while recognizing and connecting each knowledge which is displayed. Detailed motion should be designed by utilizing ordinary computer interface. Utilizing SKT, however, will expand the process of openhanded design for even beginner which can not utilize complex knowledge in parallel.

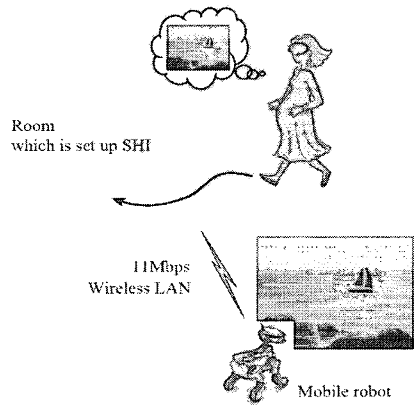

Fig. 9. Illustration of the remote mobile monitoring system.

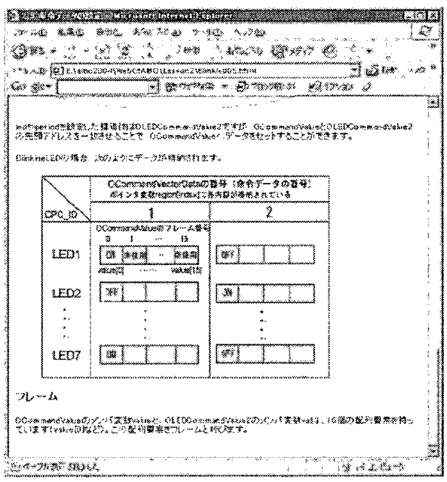

Fig. 10. An essential knowledge for the developing OPEN-R objects - This knowledge is stored as human data into Spatial Memory.

6. Conclusion

This paper demonstrates the Spatial-Knowledge-Tags (SKT) based on the Spatial Human Interface (SHI) and its application concerning robot software development. This new system reviews the new relationship among human and distributed networked computers/sensors (DNCS) by using spatial location of the SKT. Namely, intuitive and simultaneous interactions among them are realized by the utilization of human action. The experimental results of the indication error shows that the linear relationship between the indication error and operating time is weak, and the max indication error is about 23cm in the experiments. From this, the decision condition of aimed LSKT based on human "indication" action is defined as a distance between the location of LSKT and the indicator position. Though human can not indicate a LSKT precisely, one is able to access an aimed LSKT by preparing the permissible region for access.

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