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Parallel Processing System for Sensory Information Controlled by Mathematical Activation-Input-Modulation Model

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1. Introduction

It is required for intelligent robots like humanoid robots (AIST) (Honda) (tmsuk) (Ogura et al., 2006) to be equipped with several and many kinds of sensors for executing variety tasks. Especially, audio and visual information is important for these intelligent robots. In recent years, personal computers and audio and visual devices improve their performance and their costs become cheaper. In lots of audition and vision systems, however, perceptual information obtained by external sensors is processed by procedures designed previously depending on their tasks or purposes. These kinds of perceptual information processing system are not suitable to use in dynamical and complex environments. Moreover, perceptual information is processed at full power regardless of use or non use. This wastes computer resources and electric power.

On the other hand, human beings have external and internal information processing systems that are flexible about dynamical and complex environments. External information is obtained by external sensory organs, and internal one means memories stored in a brain. External and internal information processing systems of a human being are in parallel and multi-layered. In philosophy, Freud proposed that there were three levels of human mind, that are conscious, preconscious and unconsciousness (Solms, 2004). In the unconsciousness state, internal and external information processing modules are executed independent of human intentions in parallel. In the preconsciousness state, information is stored as memories, which can be easily summon into consciousness. In the consciousness state, particular information is processed intentionally in serial. In physiology, cycle models between rapid eye movement (REM) sleep and non-REM sleep have been proposed (Hobson et al., 1986) (McCarley et al., 1995), and these models are relative to the unconsciousness. Moreover, Hobson has proposed the Activation-Input-Modulation (AIM) model that is able to express several statuses like waking and sleeping of human beings (Hobson, 2000). In visual neuroscience, five visual areas related to low level vision have been identified in visual cortex. Primitive image features, edges, forms, colors or motions, are processed in these visual areas, V1, V2, V3, V4 and V5, independently from each other in parallel. In the consciousness, moreover, several complex processing related to high level vision are also executed.

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Memories of human beings also have important role in information processing in his/her brain. Memories are used as knowledge for processing external information when waking, and also they are processed when dreaming. Plural external and internal information processings run in parallel regardless of waking or sleep, and human beings control behaviors of these processings consciously or unconsciously and can process important information as needed. It is important for processing external information intellectually that the external information is stored as internal information in a memory system. The internal information is utilized as knowledge. It is known that a human has two kinds of memories: a working memory (WM) and a long-term memory (LTM) (Baddeley, 1982) (Klatzky, 1984). And a short-term memory (STM) is included in a concept of WM.

In the robotics and computer science fields, several memory models have been proposed for intelligent systems equipped with external sensory devices. A collaborative development system equipped with WMs for an interactive robot has been proposed by Matsusaka and Kobayashi (Matsusaka & Kobayashi, 2001). Functional modules for the interactive robot have working memories, that are used in their self modules or referred by other modules. Zhang and Knoll have developed two manipulator control system based on human instructions for interactive assembly tasks (Zhang & Knoll, 2002). This system includes functions of scene recognition, dialog preparation and action. Knowledge stored in STM is used in these functions. Kawamura and et al. have developed the humanoid called Intelligent Soft-Arm Control (ISAC), whose memory architecture consists of STM, LTM and the Working Memory System (WMS) (Kawamura, 2005) (Ratanaswasd et al., 2006) used for a human-robot interaction.

The purpose of our study is to develop an intelligent perceptual information processing system equipped with plural external sensory devices, in which plural information processing runs in parallel. One feature of our perceptual information processing system is that the system is equipped with our proposed mathematical Activation-Input-Modulation (AIM) model (Mikawa & Tsujimura, 2005) (Mikawa et al., 2006), which can express consciousness states such as waking, relaxing, Rapid Eye Movement (REM) sleep or non-REM sleep. The mathematical AIM model, that is newly designed based on Hobson's AIM model as described before, can control each execution frequency of plural external and internal information processors independently and dynamically based on degrees of external stimuli detected by external sensors. For example, when external stimuli are detected by some of external sensors, information processing tasks related to the sensors should have a priority to be executed in real-time, and the stimuli are stored in a memory system. When no external stimulus is detected, the execution frequencies of almost external information processing decrease, and information stored in the memory system is organized by internal information processors. The other feature is that our system is equipped with the three kinds of memories: WM, STM and LTM. All perceptual information is stored in the WM for a few seconds at all times. When external stimuli are detected by some of external sensory devices, the contents of the WM included the stimulus information move into the STM temporarily. After no external stimulus is detected, all external information processors sleep, and internal information processors begin to organize information stored in the STM and move important information into the LTM and stored permanently. These behaviors are also controlled based on the state of the mathematical AIM model as well as the external

processing. In this chapter, we use both a multi channel microphone a stereo vision system as the external sensory devices. Since auditory external stimuli are detected by using both amplitude and frequency characteristics, several audio information can be stored in the memory system. Some experimental results reveal the validity and effectiveness of our proposed perceptual information processing system.

2. AIM state-space model

We describe the Activation-Input-Modulation (AIM) state-space model that has been proposed by Hobson (Hobson, 2000 & 2001), that is the origin of our proposed mathematical AIM model, in this section. The AIM state-space model is able to express several states of human's consciousness in a three dimensional space as shown in Fig. 1. He describes that human's consciousness states are able to express by levels of three elements, Activation, Input and Modulation of which the AIM model consists. Activation controls an amount of information which is being processed. Input switches information sources. Where, External means that information is obtained from external sensory organs, and Internal means that it is obtained from internal sources such as a memory in a brain. Modulation switches external and internal processing modes. When an aminergic level becomes higher, external information is mainly processed. When a cholinergic level becomes higher, internal information is mainly processed.

For example, it is able to express normal states of waking, relaxing, rapid eye movement (REM) sleep and non-REM sleep in a three dimensional space as shown in Fig. 1. It can also express abnormal mental conditions such as coma, hallucination or delirium. In the waking, external information is processed actively. In the relaxing, processing power is less than that in the waking. In REM sleep, internal information stored in a memory is processed actively. In non-REM sleep, input and output gates are closed and the processing power declines totally. When a normal person falls asleep, at first the sleeper enters non-REM sleep, which is a deep sleep. After the first non-REM, he/she enters REM sleep and non-REM sleep alternately until he/she awakes naturally or large stimuli interrupt the sleep. As mentioned, a consciousness state of normal human moves along the gray line as shown in Fig. 1.

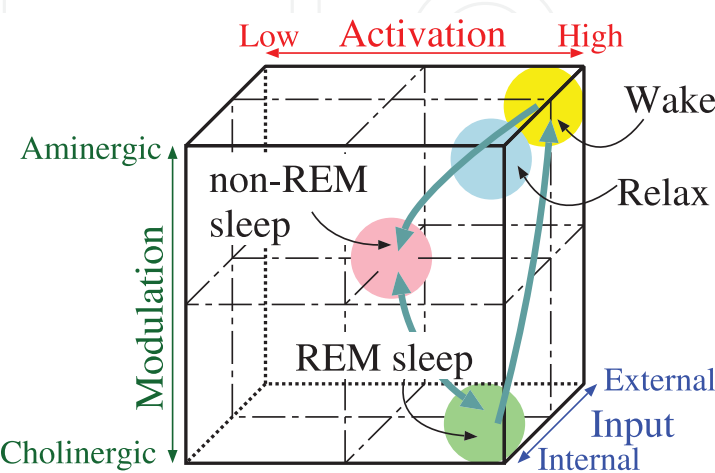


Fig. 1. Conscious states expressed by Hobson's AIM state-space model

3. Perceptual information processing system and mathematical AIM model

3.1 External and internal information processing systems

Figure 2 shows a relation among external and internal information processing systems, a mathematical AIM model and an internal memory system. One set of an external information processing system consists of an external sensor device, a data sampler and external information processors. It is important for the external information processing system that data obtained by the external sensor device is processed in real-time and translates to meaningful information as soon as possible. A number of the external information processing systems depends on a number of external sensor devices and required tasks.

An internal information processing system consists of memory storing processors, a data sampler and an internal information processor. In the internal information processing, following kinds of data are treated. One is a kind of data that it is difficult to process in real-time, because it takes much time to process it. Another is what it is not necessary to process in real-time. The third is lots of data such as time-series data that must be processed all together.

Information obtained by external sensors is stored by memory storing processors in an internal memory, and also utilized by the internal information processors. This internal memory system is described in the subsection 3.4.

Each execution interval of external and internal samplers or processors is controlled by the mathematical AIM model independently and dynamically. The details are described in the subsections 3.2 and 3.3.

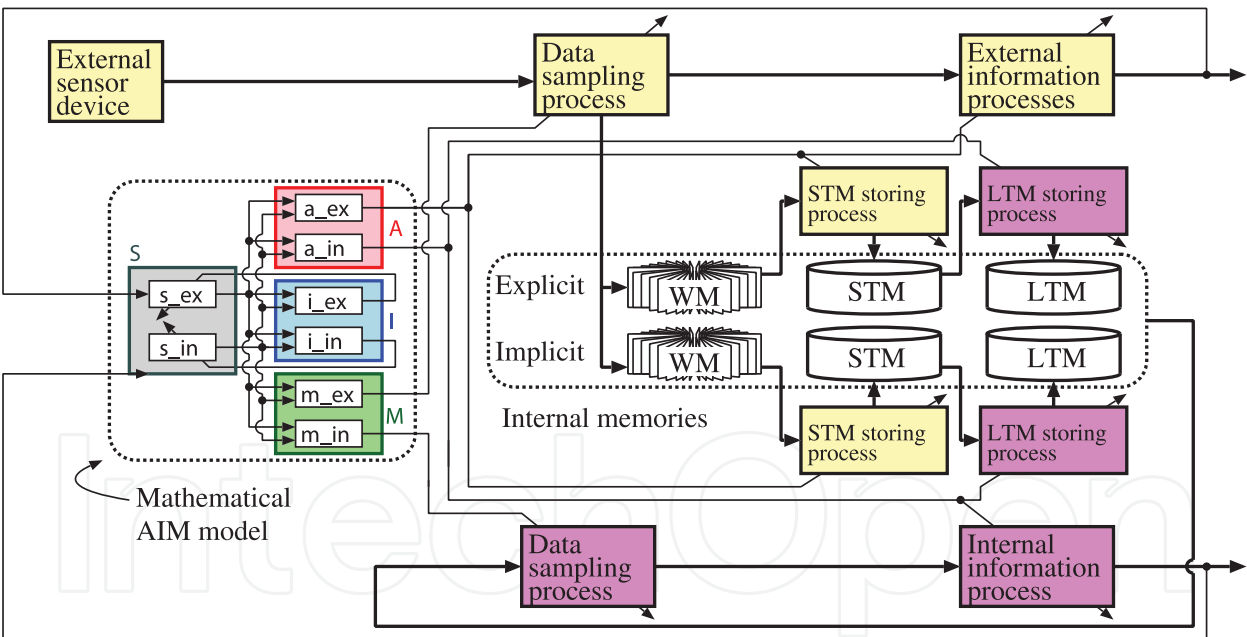


Fig. 2. Relation among external and internal information processing system, mathematical AIM model and internal memory system

3.2 Mathematical AIM model

We have designed the mathematical AIM model based on the AIM state-space model described in the section 2. As shown in Fig. 1, several conscious states of human beings are able to be expressed by levels of three elements: Activation, Input and Modulation. Activation controls an amount of information which is being processed. Input switches information sources. Modulation switches external and internal processing modes.

The mathematical AIM model controls each execution interval of the external and internal data samplers, the information processors and the memory storing processors. The AIM model consists of elements S , A , I and M . The element S calculates stimuli based on sampled data. The element A decides execution frequencies of external and internal information processing and memory storing processing. The element I decides parameters used for calculating stimuli in the element S . The element M decides an execution frequency of each data sampling. Each element consists of two sub-elements as shown in Fig. 2. The subscript ex or in of the sub-elements a , i and m means that each sub-element is related to the external or internal respectively.

Figure 3 shows an example of variations of the sub-elements with time. Statuses of each sub-element change depending on external stimulus. When the detected external stimulus sm_{ex} is larger than the threshold th_s ($sm_{ex} \geq th_s$), the levels of the elements related to the external are higher than those related to the internal. After the external stimulus becomes lower than the threshold ($sm_{ex} < th_s$) at t_0 , the state is shifted the relaxing. The relaxing is kept while the external stimuli are detected by the other processes run in parallel are larger than the threshold ($sm'_{ex} \geq th'_s$). All the levels of the external stimuli become lower than the threshold ($sm_{ex} < th_s$ and $sm'_{ex} < th'_s$) at the time t_3 . After T_a [sec], all the levels become lower, then the state is shifted to the non-REM. Moreover after T_n [sec], each level increases and decreases periodically. In the REM, the levels of the elements related to the internal are higher than those related to the external. Once again the external stimulus sm_{ex} becomes larger than the threshold th_s at the time t_7 , the state is shifted to the waking.

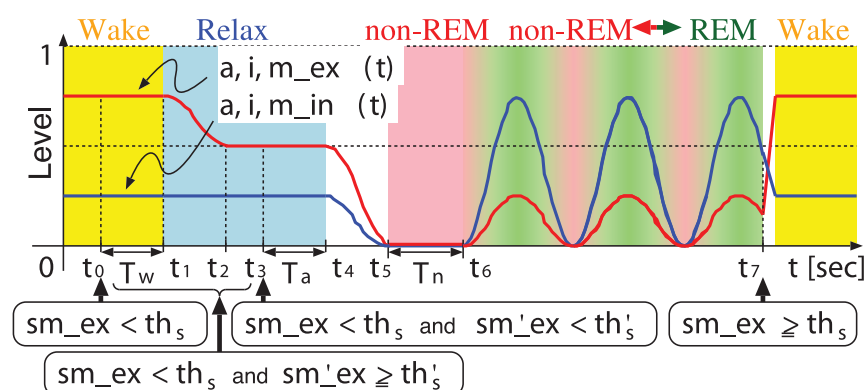


Fig. 3. Variations of sub-elements A , I and M with time

The sub-element $a_{ex}(t)$ is given by the following equations.

$$a_{ex}(t) = \begin{cases} L_w + b & (t < t_1) \\ \frac{L_w - L_a}{2} \left(1 + \cos\left(\frac{2\pi(t - t_1)}{f_w}\right) \right) + L_a + b & (t_1 \leq t < t_2) \\ L_a + b & (t_2 \leq t < t_4) \\ \frac{L_a - L_n}{2} \left(1 + \cos\left(\frac{2\pi(t - t_4)}{f_a}\right) \right) + L_n + b & (t_4 \leq t < t_5) \\ L_n + b & (t_5 \leq t < t_6) \\ \frac{o_r}{2} \left(1 - \cos\left(\frac{2\pi(t - t_6)}{f_r}\right) \right) + L_n + b & (t \geq t_6) \end{cases} \quad (1)$$

Since it is able to express the other sub-elements in the same way, their equations are omitted here. The parameter $T_w, T_a, T_n, L_w, L_a, L_n, f_w, f_a, f_r, o_r$ and b are constant and independent each other. It is able to design several sleep patterns by choosing these constant parameters properly depending on applications. For example, the sleep pattern shown in Fig. 3 was designed based on a human's normal sleep pattern by using the following values. In other words, it is designed that the state of the mathematical AIM model moves along the gray line as shown in Fig. 1.

$$L_w = 0.75, \quad L_a = 0.50, \quad o_r = 0.25, \quad L_n = b = 0.00 \quad (2)$$

Let the numbers of the external information processors, the internal information processors, the external sensory organs and the internal memories be p_{ex}, p_{in}, q_{ex} and q_{in} respectively, then the elements A, I and M are shown by the following equations. The AIM model shown in Fig. 1 can be expressed by these equations. Figure 4 shows the variations of these elements with time. This example was designed based on a human's normal sleep pattern.

$$\begin{aligned} A(t) &= \frac{1}{2p_{ex}} \sum_{i=1}^{p_{ex}} a_{ex_i}(t) + \frac{1}{2p_{in}} \sum_{j=1}^{p_{in}} a_{in_j}(t) \\ I(t) &= \frac{1}{p_{ex}} \sum_{i=1}^{p_{ex}} i_{ex_i}(t) - \frac{1}{p_{in}} \sum_{j=1}^{p_{in}} i_{in_j}(t) \\ M(t) &= \frac{1}{q_{ex}} \sum_{i=1}^{q_{ex}} m_{ex_i}(t) - \frac{1}{q_{in}} \sum_{j=1}^{q_{in}} m_{in_j}(t) \end{aligned} \quad (3)$$

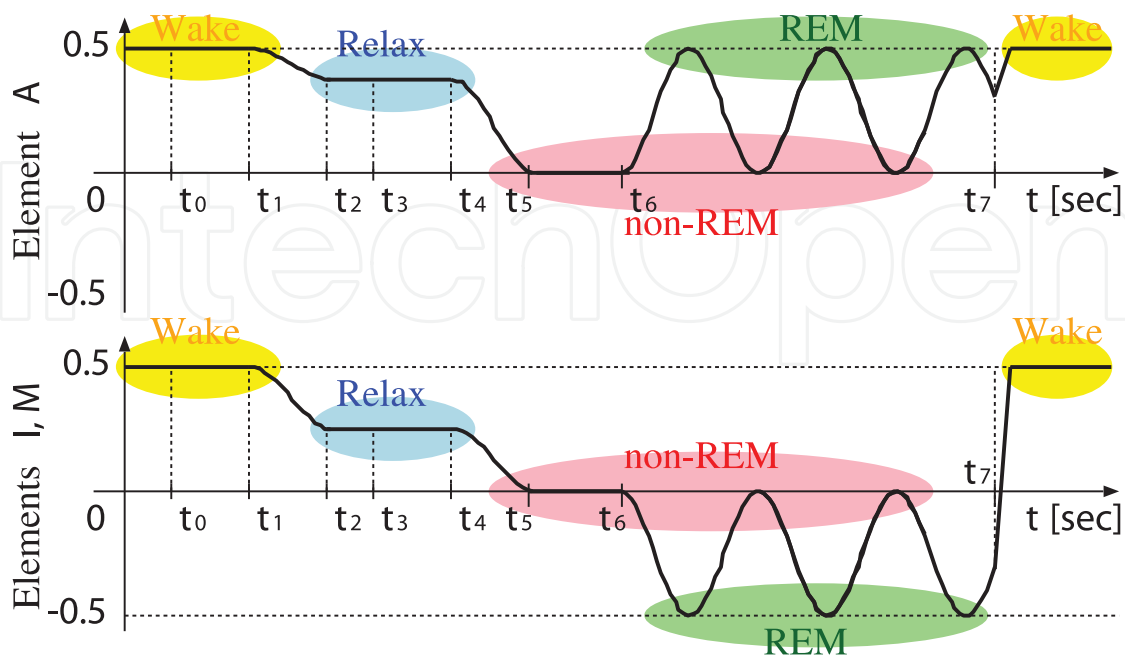


Fig. 4. Variations of elements A, I and M with time

3.3 Dynamic control of information processing systems by mathematical AIM model

Behaviors of the external and internal information processing systems and the memory system are controlled based on the states of the sub-elements of the AIM model as shown in Fig. 2.

The execution frequencies of the external and internal information processing are determined in proportion to each level of the sub-elements a_{ex} and a_{in} , respectively. For example, when a_{ex} becomes higher, the external information processing frequency increases. As a result, more external information is processed. When a_{in} becomes higher, the internal information processing frequency increases. In the same way, the external and internal data sampling frequencies are determined by the sub-elements of M . The element I decides the threshold th_s and the resolution rs_s in order for the element S to detect stimuli from the external sensors or the internal memories. Here, the thresholds th_s are values for determining whether stimuli are included in obtained information or not. And the resolution means a number of skipped data to be processed in a frame. These thresholds and resolutions vary in proportion to each level of the sub-elements i_{ex} and i_{in} . For example, when i_{ex} increases, th_s and rs_s increases. This means that the system becomes more sensitive about smaller changes.

The storing frequencies of the explicit and implicit WM are the same with the frequency of the external data sampling and depend on the level of the sub-element m_{ex} . When external stimuli are detected ($sm_{ex} \geq th_s$), the explicit STM processor transfers information stored in the explicit WM to the explicit STM. Its execution frequency depends on m_{ex} . When no stimulus is detected ($sm_{ex} < th_s$), the implicit STM processor transfers information stored in the implicit WM to the implicit STM periodically. When the state of the AIM model is in the REM sleep, the explicit and implicit LTM processors are executed.

3.4 Internal memory system

A memory system of human beings is so complex and not unveiled yet completely. So we have designed a new internal memory system by rearranging a part of human's memory functions. As shown in Fig. 2, the internal memory system consists of an internal memory and memory storing processors. The internal memory consists of working memories (WMs), short-term memories (STMs) and long-term memories (LTMs). Each memory is classified into an explicit or implicit type respectively. When dynamic changes are detected as external stimuli by an external sensor, the changes are stored in the explicit memories. Gradual changes that are not detected by real-time information processing or static information are stored in the implicit ones. In the case of human beings, perceptual information is symbolized by high-order functions of a brain and stored in memories efficiently. In our system, however, let raw signals obtained by external sensory devices store in the internal memory.

All information obtained by external sensory devices are stored in these WMs in real-time. Let memory size of the WMs have an upper limit, old information is overwritten by newer one sequentially. Since an explicit STM is a memory in consciousness states, when external stimuli are detected by external sensory devices, all the contents of the explicit WM are transferred into the explicit STM. Since an implicit STM is a memory in unconsciousness states, when no external stimulus is detected, all the contents of the implicit WM are transferred into the implicit STM periodically. Human being's LTM is classified into a procedural or declarative type (Kellogg, 1995), and its functions are complex. Redundant or useless information are included in the STM. Then the contents of the STM are organized

and transferred into the LTM by the LTM storing processors. When no external stimulus is detected and the state of the mathematical AIM model is in REM sleep, the AIM model starts to execute these LTM storing processors. Since the explicit STM and LTM storing processes detect external stimuli, dynamical information is stored in the explicit memories. Since the implicit STM storing process stores information periodically while no external stimulus is detected, the implicit LTM storing process is able to detect static or gradual changes and store the changes in the implicit LTM by analyzing the implicit STM stored for long period. Let the memory capacities of the explicit and implicit WMs be N_{wm} [frame] respectively. There is no limit to the capacity of the STMs and LTMs as far as the system permits.

4. Experimental system

4.1 System configuration

Figure 5 shows a configuration of an audition and vision system. This system is equipped with two CCD cameras and a stereo electret condenser microphone, that are fixed in an experimental room. Analog video signals are converted to digital video (DV) signals through media converters, and captured by a personal computer (PC) through an IEEE 1394 interface board. Audio signals are captured by the PC through a USB audio interface. The operation system (OS) of the PC is Fedora Core Linux, and the versions of the OS and the other libraries are also shown in Fig. 5.

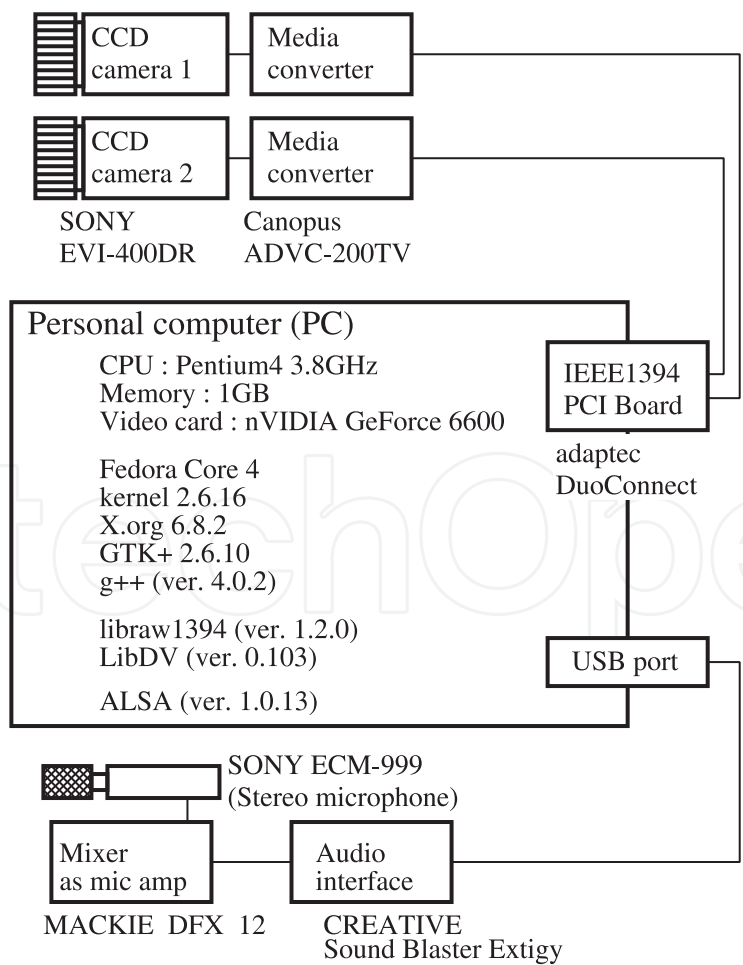


Fig. 5. Configuration of experimental audition and vision system

4.2 Multi-threaded application program

We made an application program to evaluate a validity of our proposed perceptual information processing system. The application programming interface (API) developed in (Mikawa, 2003) was used for implementing the program. It is able to capture audio and video signals from plural audition and vision devices in real-time. Color images were captured at a frequency of 1/30 [sec], and the resolution was 720 x 480 [pixel] with 8 [bit] per each color. A sampling rate of stereo audio signals was 44.1 [kHz], a bit depth was 16 [bit], and one frame length was 100 [msec]. Plural external and internal processes run in parallel are multi-threaded by using this API.

Figure 6 shows all the threads and their relations. As shown in Fig. 5, video capturing, DV decoding, image displaying and AIM state calculating processes, external and internal information processes were multi-threaded by using the API. The execution intervals of the video and audio capture threads are constant, their values are 1/30 and 1/10 [sec] respectively. These capture threads send commands to the other threads. The execution intervals of the decode threads are decided by the element *M*. The execution intervals of the external and internal information processing threads are decided by the element *A*.

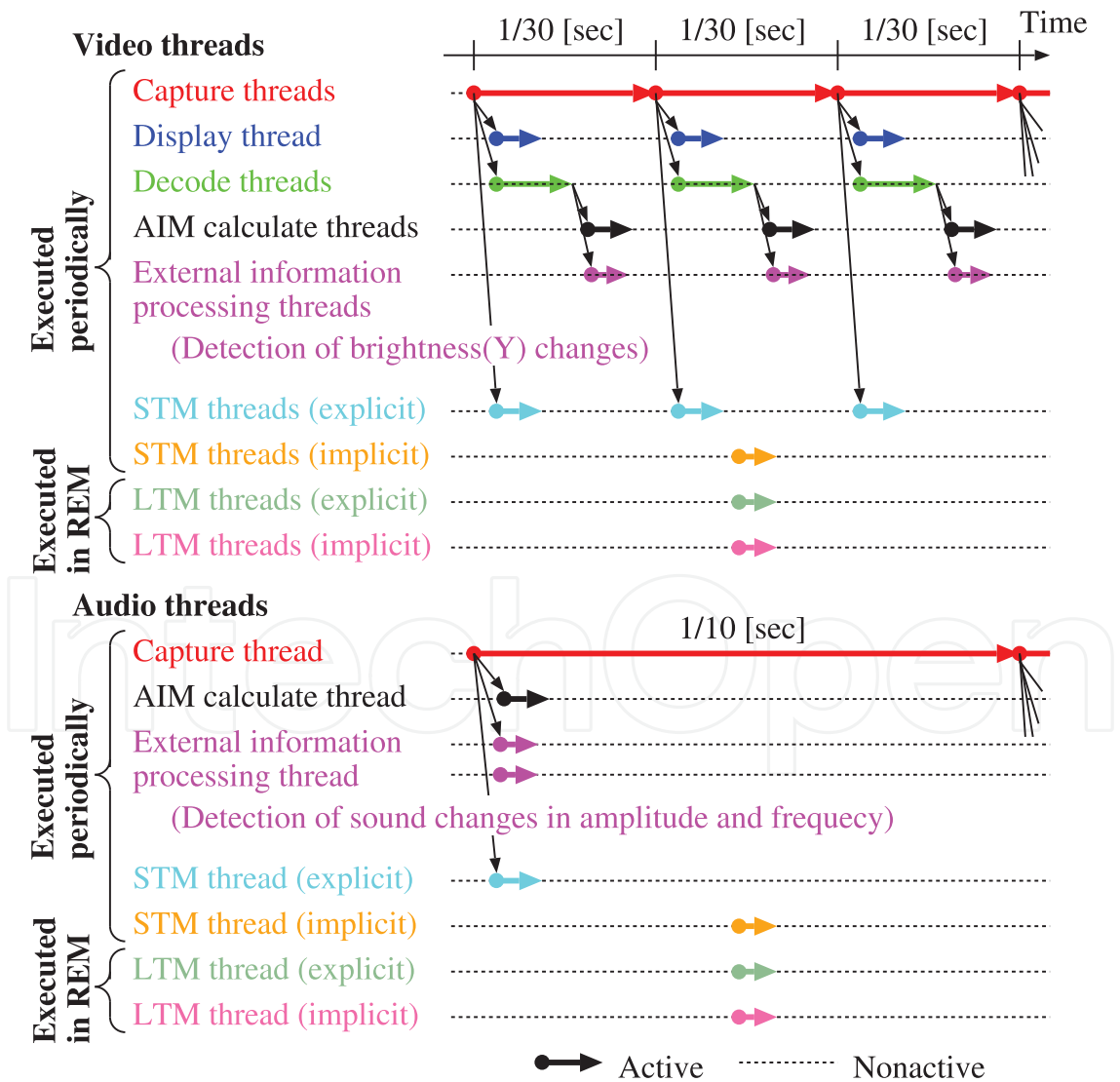


Fig. 6. Threads implemented in application program

Two kinds of the external stimuli are detected by the external information processing threads related to the vision and audio. One is brightness changes of captured image. Brightness is Y component of color images, and the changes are detected by comparing each pixel included in two time-series image frames. The other is magnitude of captured sound. The value of th_s related to images changes from 80 to 200 depending on the value of the sub-element i_{ex} . The value of th_s related to audio signals changes from 600 to 2000.

The explicit and implicit WMs storing processes are included in the audio and video capturing threads. The explicit STM storing processes are executed when brightness changes are detected. Let the capacities of the WMs related to vision be $N_{wm} = 99$ [frame]. The WMs can hold image frames for 3 [sec]. And let the capacities of the WMs related to audition be $N_{wm} = 50$ [frame]. The WMs can hold audio frames for 5 [sec]. The STMs related to vision are stored in DV format, of which size are 12000 [byte/frame], in a hard disk drive (HDD). The LTMs related to vision are converted by the LTM storing processes and stored in YUV format. The WMs, STMs and LTMs related to audio are stored in WAVE format.

The implicit STM storing threads are constantly executed at a frequency of 1 [sec] in all states of the AIM model, and store captured image in the HDD. When $sm_{ex} \geq th_s$, the explicit STM storing process transfers all the explicit WMs to the HDD as the explicit STM. This means that the last 99 image frames can be stored. When $sm_{ex} < th_s$, the implicit STM storing threads constantly stores captured frames in the HDD as the implicit STM. And the explicit and implicit LTM storing threads are executed in the REM sleep. When the system is in the REM sleep ($a_{in} \geq 0.375$), the explicit and implicit LTM storing threads are executed, and store vision and audio frames, in which changes are detected by comparing each pixel included in two time-series STMs. This means that only images, that include dynamic changes for brief periods of time, are stored in the explicit LTM, and only images, that include gradual changes for long periods, are stored in the implicit LTM.

The following values and Eqs. (2) were used for the constant parameters included in the AIM model as shown by Eq. (1). Each unit is second. These values determine the pace of change from one state of the AIM model to another state.

$$T_w = T_a = T_n = 5, \quad f_w = f_a = 20, \quad f_r = 60 \quad (4)$$

Figure 7 shows a screen shot of the application program. The resolution of the display was 1600 x 1200 [pixel]. Since no external stimulus was detected by the camera 1, the conscious state related to the camera 1 was in the relaxing. Since some external stimuli indicated in purple were detected by the camera 2, the camera 2 was in the waking. It is determined whether brightness change is more than the threshold th_s or less at each green points. In this application, the resolution rs_s described in the subsection 3.3 means the distance among green points. In the waking, all pixels in the image function as sensors for detecting external stimuli, and every captured image frames are processed. Moreover, as the threshold th_s decreases, the sensitivity to stimuli increases. The distance among green points becomes largest in the non-REM, the process execution frequency becomes lowest, the threshold th_s increases, and as a result, the sensitivity to stimuli decreases. The audio threads are executed in the same manner.

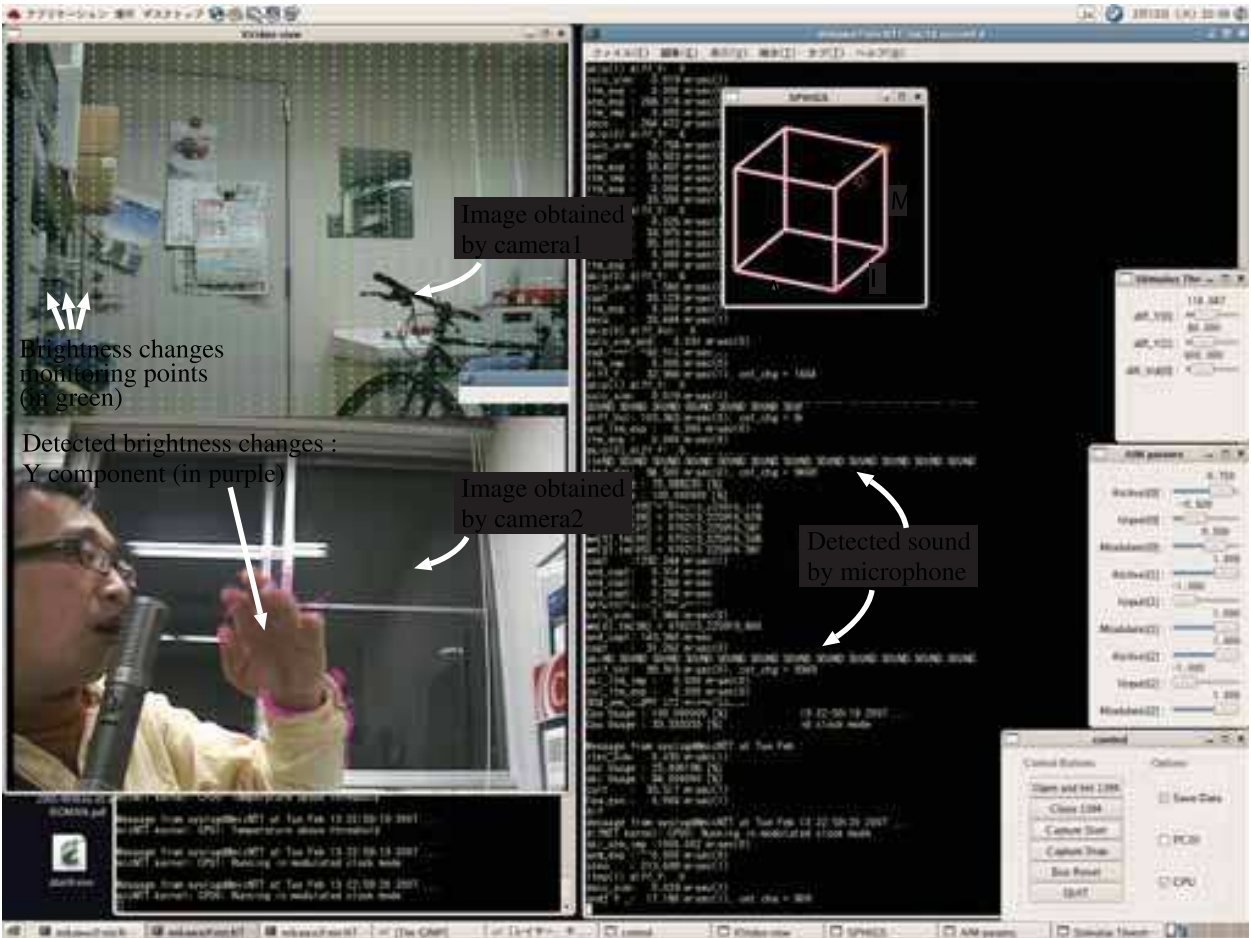


Fig. 7. Screen shot of sample application in waking & relaxing

5. Experimental results

5.1 Simplest application program processes only external information using monocular camera

We describe an expeiment result using a simplest application program to show the effectiveness of our proposed mathematical AIM model. This application program had the only external information processing using only one CCD camera, no internal information processing and no memory such as WMs, STMs and LTMs. Brightness changes were detected as external stimuli in an external information processing as shown in Fig. 8. Pentium 4 (2.4 [GHz]) and Red Hat Linux 9, that had no Hyper-Threading (HT) function, were used only in this experiment.

Figure 9 shows the variation of the CPU utilization with time while the program was running. In the waking, image data was processed in real-time (30 [frame/sec]), as the result, the CPU utilization was more than 90 [%]. After the change of image, in other words, stimuli from external information had disappeared at the time t_0 , the CPU utilization fell around 15 [%] in the relaxing. After another T_n [sec], it fell below 10 [%] in the non-REM sleep. In the REM sleep, it became around 15 [%]. When the change of image was detected again at the time t_7 , the external information processing began to be executed in real-time again. The function of the AIM model makes it possible to make a margin of the CPU power for other processing while no external stimulus is present.

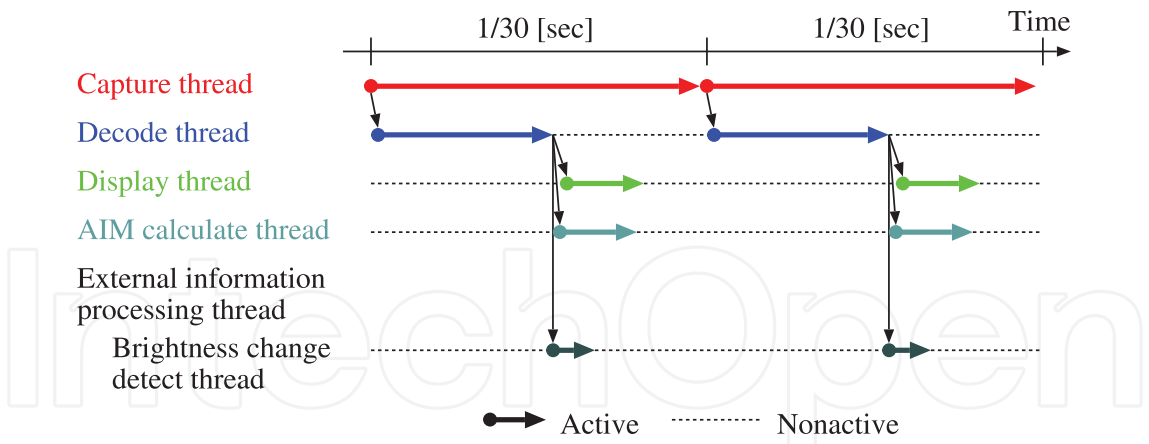


Fig. 8. Variation of CPU utilization with time

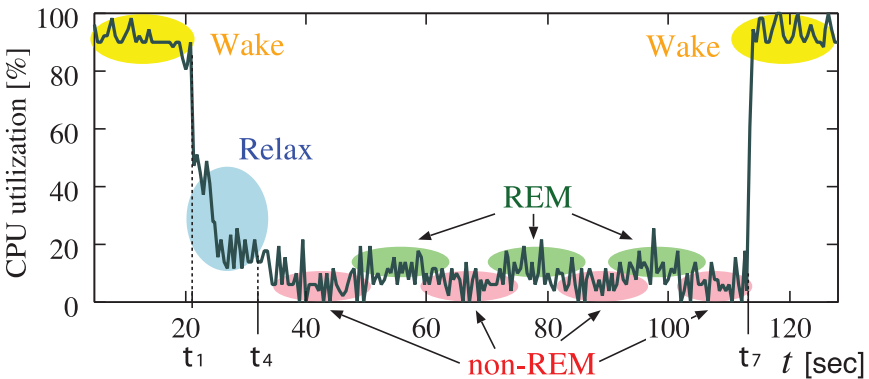


Fig. 9. Variation of CPU utilization with time

5.2 Execution of application program for brief period

In this experiment, the application program, that has several threads shown in Fig. 6, was executed for about 170 [sec] in order to confirm the behaviors of all threads run in parallel. Figure 10 shows the variations of the execution intervals of all the threads related to the camera 1, the camera 2 and the microphone. The camera 2 detected external stimuli in a period of 0 ~ 25 [sec]. The states of the camera 1 and the microphone were shifted to the relaxing at 15 [sec]. When the microphone detected external stimuli at 35 [sec], the state of the microphone was shifted to the waking and the states of the camera 1 and 2 were shifted to the relaxing. After no external stimulus was detected at 40 [sec], the states of the both cameras and the microphone were shifted to the sleep state, that REM/non-REM cycle was repeated periodically, through the relaxing. In the REM sleep, the frequency of the external information processing became lower, and the explicit and implicit LTM storing processes were executed. Here, the explicit and implicit LTM are not executed periodically but depending on the status of the AIM model. When the execution intervals of the explicit and implicit LTMs indicate non 0 [sec] respectively, it just means that they are executed and the values mean nothing. And when the execution intervals indicate 0 [sec], it means that they are not executed. When the microphone detected external stimuli again at 145 [sec], the microphone was shifted to the waking, and the camera 1 and 2 were shifted to the relaxing. Figure 11 shows the variation of the CPU utilization with time. Since a HT CPU was used, the numbers of the CPUs was two. Although changes of the CPU utilization were more complex than that using the non-HT CPU in the previous subsection 5.1, this result showed that the function of the AIM model could control plural threads run in parallel well, and make effective use of computer resources.

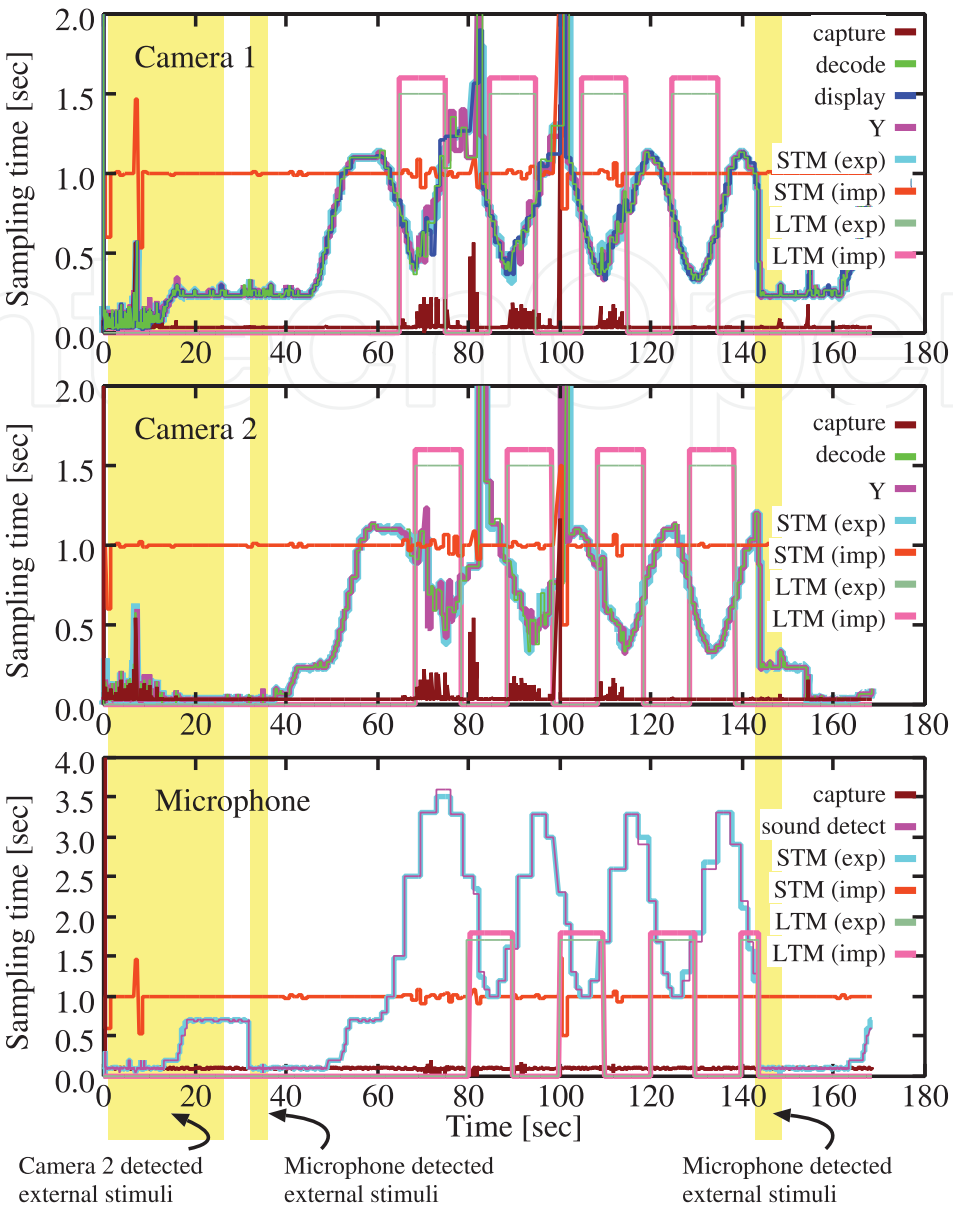


Fig. 10. Variation of execution interval of all threads with time

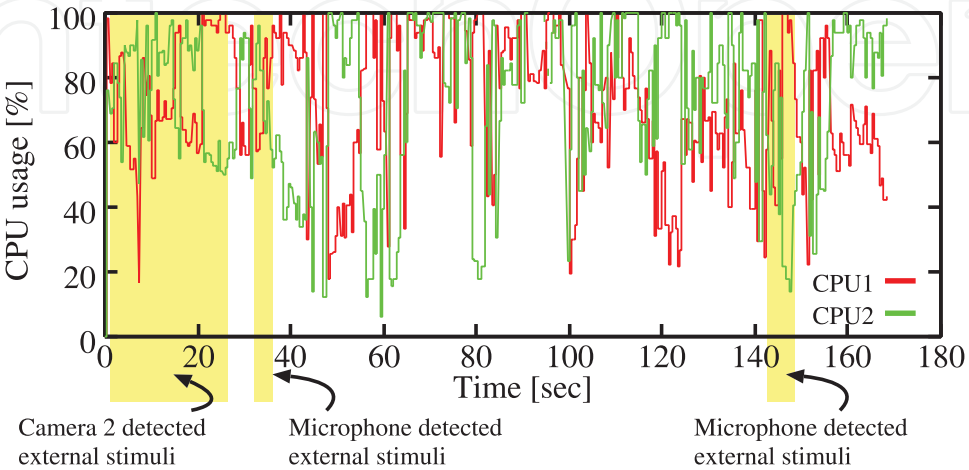


Fig. 11. Variation of CPU utilization with time

Table 1 shows the numbers of audio and image files stored as the memories while the application program was executed. These results mean that the memory system related to the camera 2 and the microphone can store dynamic stimuli detected for brief periods of time in the explicit memories, and that related to the camera 1 can store gradual changes over long periods of time in the implicit memories.

devices	STM		LTM	
	explicit	implicit	explicit	implicit
camera 1	14	168	7	1
camera 2	805	148	646	3
microphone	313	160	157	3

Table 1. Numbers of image and audio frames stored as STM and LTM

5.3 Execution of application program for long period of 12 hours

The application program was executed for about 12 [hour] in this experiment. The camera 1 was trained on a door in an experimental room in order to monitor person who came in and out. The camera 2 was trained on a window in the room in order to monitor gradual changes of outdoor conditions.

Figure 12 shows a part of the explicit LTM stored in the HDD. When these dynamical changes were detected as external stimuli, the system state was shifted to the waking, and the changes were stored in the explicit STM. When the system was shifted to the REM, the explicit STM was transferred to the explicit LTM while deleting redundant images.



Fig. 12. Dynamic change for brief period detected by explicit LTM storing process

Figure 13 shows a part of the stored implicit LTM. Gradual changes of a sunset sky could be detected. Although it is difficult to detect these kinds of gradual changes by the explicit memories that is processed in real-time, it is easy to detect them by using the implicit memories. Since the explicit memories related to the microphone monitored amplitude of sound signals, large sound generated in the experimental room could be detected. Since the implicit memories monitored frequency characteristic changes of sound signals, not only amplitude changes but also changes of different kinds of small sounds, for example engine sound of a motorcycle or talking voice outside the experimental room, could be detected.



Fig. 13. Gradual brightness changes of sunset sky detected by implicit LTM storing process
These results also indicates that our perceptual system controlled by the AIM model works well.

6. Conclusion

We proposed a new architecture for an intelligent perceptual information processing system that has sleep and wake functions, and applied it to an audition and vision system. Plural perceptual information processes and storing processes run in parallel and these processes are controlled by the mathematical Activation-Input-Modulation (AIM) model. The memory architecture consists of a working memory (WM), a short-term memory (STM) and a long-term memory (LTM), that can store environment information in its memories efficiently. The advantage of our proposed architecture is that required processes are executed only when needed and only useful perceptual information are stored. As a result, the system is able to make effective use of computer resources.

The validity and effectiveness of our proposed system were confirmed with three kinds of experimental results using an application program equipped with a monocular vision system or a stereo vision and a stereo microphone system.

In future works, we will try to use more kinds and numbers of sensors and implement more kinds of information processing modules in this system.

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This book presents research trends on computer vision, especially on application of robotics, and on advanced approaches for computer vision (such as omnidirectional vision). Among them, research on RFID technology integrating stereo vision to localize an indoor mobile robot is included in this book. Besides, this book includes many research on omnidirectional vision, and the combination of omnidirectional vision with robotics. This book features representative work on the computer vision, and it puts more focus on robotics vision and omnidirectional vision. The intended audience is anyone who wishes to become familiar with the latest research work on computer vision, especially its applications on robots. The contents of this book allow the reader to know more technical aspects and applications of computer vision. Researchers and instructors will benefit from this book.

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