# Ubiquitous Sensory Intelligence

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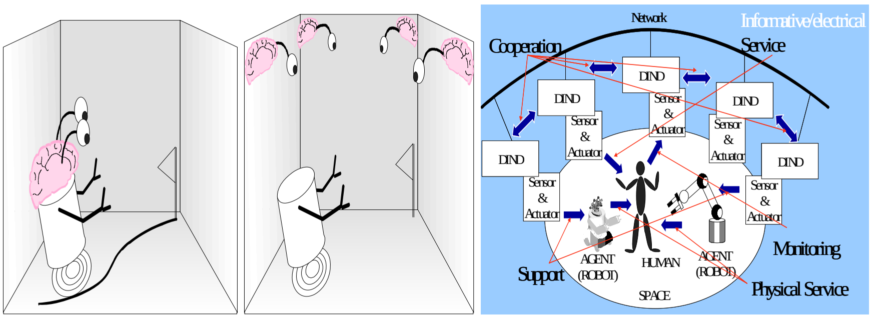
*Abstract: The paper presents an Intelligent Space (room, corridor or street), which has ubiquitous sensory intelligence including various sensors, such as cameras, microphones, haptic devices (for physical contact) and actuators with ubiquitous computing background. The Actuators are mainly used to provide information and physical support to the inhabitants, with the help of speakers, screens, pointing devices, switches or robots and slave devices inside the space. The various devices of ubiquitous sensory intelligence cooperate with each other autonomously, and the whole space has high intelligence based on ubiquitous computing, which is used manly for welfare support. Intelligent Space can guide and protect a blind person in a crowded environment with the help of a mobile agent. In emergence case such as fire, the Intelligent Space can guide the crowd to avoid accidents and tragedy.*

## 1 Introduction

A conceptual figure of the Intelligent Space with ubiquitous sensory intelligence is shown in Fig. 1. The Ubiquitous Sensory Intelligence is realised by Distributed Intelligent Networked Devices [1], robots, which are physical agents of the Intelligent Space, and Human. In the Intelligent Space, DINDs monitor the space, and achieved data are shared through the network. Since robots in the Intelligent Space are equipped with wireless network devices, DINDs and robots organize a network. The Intelligent Space based on Ubiquitous Sensory Intelligence supply information to the Human beings and it can help them physically by using robot agents. Conventionally, there is a trend to increase the intelligence of a robot (agent) operating in a limited area. The Ubiquitous Sensory Intelligence concept is the opposite of this trend. The surrounding space has sensors and intelligence instead of the robot (agent). A robot without any sensor or own intelligence can operate in an Intelligent Space. The difference of the conventional and Intelligent Space concept is shown in Fig 1. There is an intelligent space, which can sense and track the path of moving objects (human beings) in a limited area. There are some mobile robots controlled by the intelligent space, which can guide blind




Conventional concept Ubiquitous Sensory Intelligence concept

Fig. 1. Comparison of conventional and Ubiquitous Sensory Intelligence concept

persons in this limited area. The Intelligent Space tries to identify the behaviour of moving objects (human beings) and tries to predict their movement in the near future. Using this knowledge, the intelligent space can help avoiding the fixed objects and moving ones (human beings) in the Intelligent Space A mobile robot with extended functions is introduced as a mobile haptic interface, which is assisted by the Intelligent Space. The mobile haptic interface can guide and protect a blind person in a crowded environment with the help of the Intelligent Space. The Intelligent Space learns the obstacle avoidance method (walking habit) of dynamic objects (human beings) by tracing their movements and helps to the blind person to avoid the collision. The blind person communicates (sends and receives commands) by a tactile sensor. The prototype of the mobile haptic interface and simulations of some basic types of obstacle avoidance method (walking habit) are presented. Some other Intelligent Space projects can be found in the Internet [2,3,4,5].

The structure of this paper is as follows. Section 2 summarizes the basic components (DIND, Virtual Room, Ubiquitous Human Machine Interface) of the existing Intelligent Space. Section 3 gives an impression of what kind of service this Intelligent Space can offer. The last section concludes the paper.

## 2 Basic Elements of Ubiquitous Sensory Intelligence

Three interesting elements of the current Intelligent Space with Ubiquitous Sensory Intelligence

- Distributed Intelligent Network Device
- Virtual Room
- Ubiquitous Human Machine Interface

are selected and briefly described here.

## 2.1 Distributed Intelligent Network Device

We can use as a definition: A space becomes intelligent, when Distributed Intelligent Network Devices (DINDs) are installed in it [1]. IND is very fundamental element of the Intelligent Space. It consists of three basic elements. The elements are sensor (camera with microphone), processor (computer) and communication device (LAN). DIND uses these elements to achieve three functions. First, the sensor monitors the dynamic environment, which contains people and robots. Second, the processor deals with sensed data and makes decisions Third, the DIND communicates with other DINDs or robots through the network. Fig. 2 shows the basic structure of human decision and DIND. In actual system, six Sony EVI D30 pan-tilt CCD camera and general bt848 based image capture board is adopted as a sensor [6]. For the processor, industrial standard Pentium III 500MHz PC is used and general 100baseT LAN card is used as a network device. Robots are able to use resources of DINDs as their own parts. However, robots with their own sensors may be considered mobile DINDs.

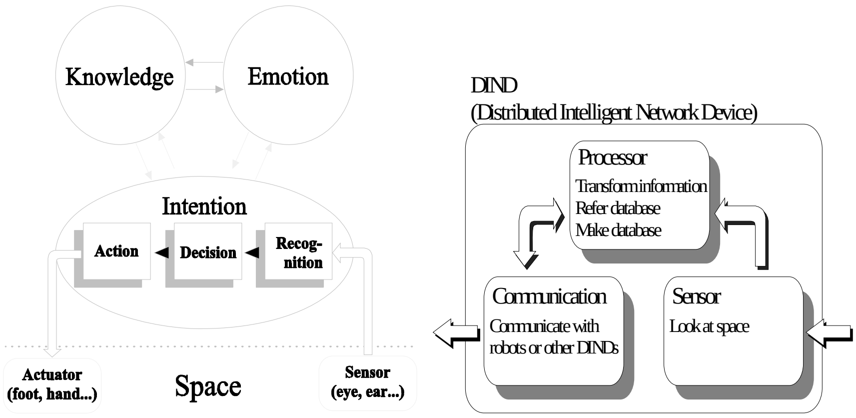



Fig. 2 Fundamental structures of human decision and DIND

## 2.2 Virtual Room

The aim of Virtual Room (VR) research project is to recreate an environment of a physical experimental space for studying different motion control and vision algorithms for a given robot before real world implementation.

The room currently contains the following objects:

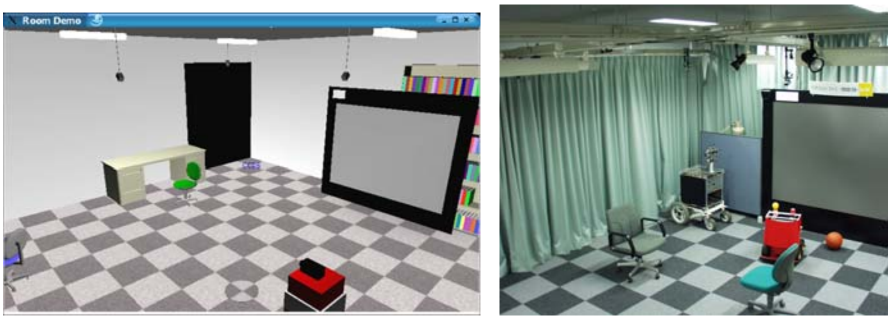
- Passive objects: desks, chairs
- Active objects: Three robot agents
- Sensors: CCD cameras
- Actuators: Large Screen

### 2.2.1 Simulation Framework

The project is developed in C++, and graphical implementation of the objects is achieved using Coin/Open Inventor library. Inventor's foundation is supplied by OpenGL and UNIX, Inventor represents an object-oriented *application policy* built on top of OpenGL, providing a programming model and user interface for OpenGL programs. The current development operating system is a Suse Linux 8.1, and Coin3D version is 1.0.4 2.2.2

**Simulation examples**

The present state of the Virtual Room includes graphical representations of the objects mentioned above. The graphical environment allows a 'walk through' the virtual space and it is also possible to visualize the virtual image of each camera with this configuration. The images of a virtual camera and a real camera are compared in Fig. 3. Both rooms (virtual and real) have 6 pan-tilt cameras [].




Virtual Room Real Room

Fig. 3 Virtual and real Room from the 1st CCD camera's point of view

## 2.3 Ubiquitous Human Machine Interface

There are three mobile robots in the current Intelligent Space. The most interesting one is a special mobile human-machine interface [7]. There are three basic communication channels, which the people use in daily conversation: audio, visual, and haptic. All three communication-channels are implemented on the UHMI. The design concept is shown in Fig. 4. The human user, who is in the Intelligent Space has an aim in his/her mind, which he/she want to realize. Then the user makes different type of commands to reach his/her aim. Some commands are associated with certain parts of the human body. UHMI has special devices to make connections with certain part of the human body. A video Camera and a TV Screen are mounted on the UHMI for visual communication. Speaker and microphone realize the audio communication. Haptic Interface is mounted on the robot to realize a physical connection. The UHMI can be seen on Fig. 4. This UHMI is able to move to the user or it can guide him/her. A very special application is the guidance of blind people. A blind person can communicate (send and receive commands) with a tactile sensor.

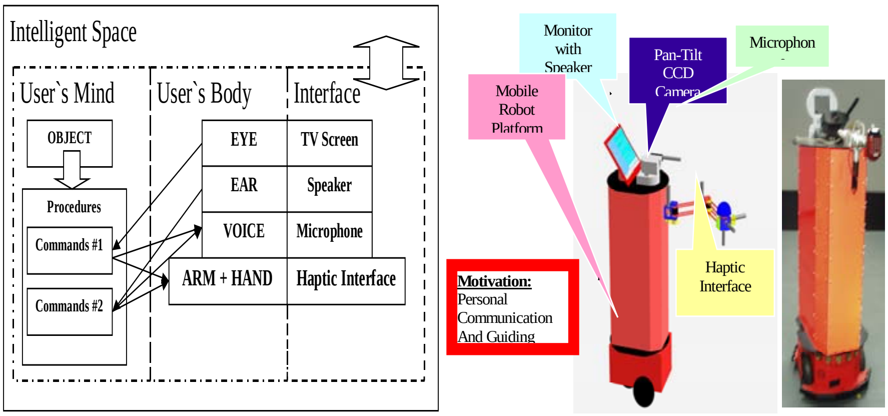



Fig. 4 Ubiquitous Human Machine Interface: concept and picture

# 3 What Can Be Done In Intelligent Space?

## 3.1 3D Positioning of Human

To support humans in the space, the Intelligent Space tracks them. Recognition of a human is done in two steps [8]. First, the area or shape of a human is separated from the background (Fig. 5). Second features of the human as head, hands, feet, eyes etc. are located (Fig. 5). Taking the images of three pairs of cameras, the 3D position of the human beings can be calculated (Fig. 6). The scanned areas of camera pairs are overlapped. To calculate 3D from several camera views point correspondences are needed. To establish these correspondences directly from the shape of the human is difficult. Instead of it, the head and hands of the human beings are found first and their centers is used for matching. A second motivation to further analyse the shape is that adaptive background separation in complex scenes detects recently displaced objects. The above algorithms are implemented in three different software modules (Camera Server, 3D Reconstruction Module, Calibration Client) of the Intelligent Space.
The error of the estimated position of an object changes with the distance from and pose of the camera. The error is influenced by several factors; the performance of each camera, the method of image processing, etc. Kalman filter is applied to smooth the measured data.

Fig. 5 Separation of Human beings from the background

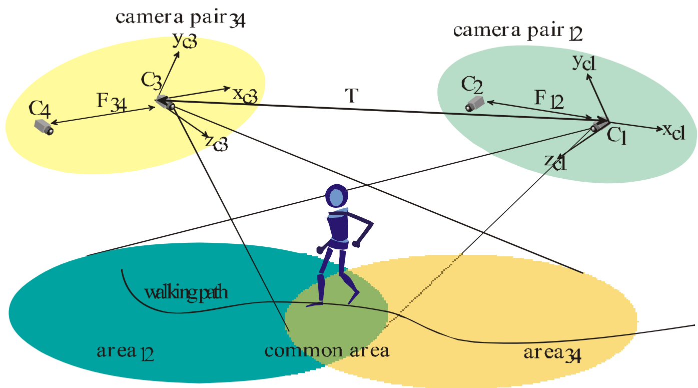



Fig. 6 Localization of Human beings by two pairs of cameras

## 3.2 Map Building by Looking at People

Mobile robots need maps of their environment for navigation, localization and task specification. Mobile robots can navigate robustly without a precise geometrical model if some other way of localization is given and a topological map is supplied. The suggested approach is to look at the movements of people in the room. In indoor environments people and robots consider similar things as obstacles. This method has the additional advantage that it detects obstacles that most sensors fail to notice. Examples are trapdoors, yellow lines on the floor or signs saying "Danger - Don't Enter". Positions of moving persons were obtained with about 20 Hz. Only positions with a vertical height between 1.65 and 2.00 meters and only blobs with at least 0.6 times the size of a head were taken into account. In Fig. 7, the different stages of the algorithm are shown. Filtering out all suspected non-head positions reduce some hand blobs everywhere. Here positions were filtered out as head and hands are much lower than that of walking people. The Fig. 7(b) shows the topological map of the room. The topological map correctly avoids all static obstacles as well as the dynamic ones that were not in the world model.

(a) Position of heads (b) Blurred pixels (c) Topological map of the room
Fig. 7 Procedure of generating topological map

## 3.3 Mobile Robot Localization

Neither range sensors to detect obstacle around the robots, nor position-sensors to estimate position and orientation of the robots are needed in the Intelligent Space. The robots only require passive colour bars and a communication device to communicate with DINDs. Due to communication between robots and DINDs, robots are able to use sensors of DINDs freely. It is a kind of resource sharing and this feature leads to low cost robots, since expensive sensors, such as gyroscope sensor, laser range finder, etc are not needed. Only simple PLC board, motors and wireless LAN (IEEE 802.11b) are installed in the robots. In Fig. 8, the a robot that has space to load a burden on the top is shown.

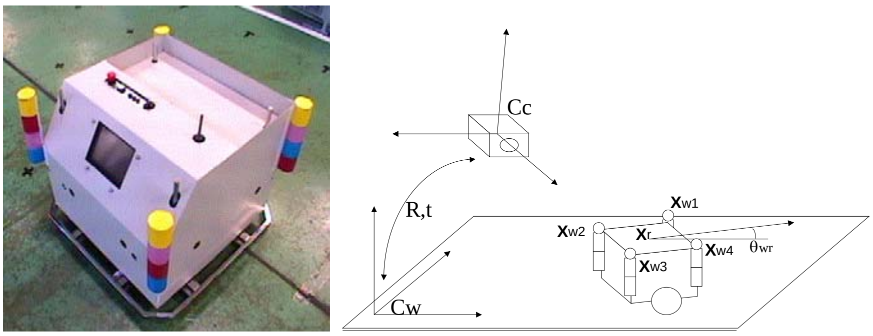



Fig. 8. Mobile Robots with colour bars and its recognition and transformation

Unlike the case of detecting a human, to localize a mobile robot in the Intelligent Space, only one DIND is required. Because the height (z-axis) of the targets is known, only one camera is needed for a precise 3D construction. Two procedures are compared in Fig. 9. From the acquired image, searching colour region and background separation is performed simultaneously. In this system, since the colour of target is yellow, the regions of yellow are searched. Background separation module compares current image and background image, and selects only the region where the movement happened. Adaptable background is selected to make the background separation module work robustly [8]. Outputs from these two modules are compared in the clustering process. Only common regions are conveyed to calculation of moment module, and 2D positions of the regions are calculated. Since a DIND has a database of height of colour bar, one DIND is able to estimate the position of a colour target. The 2D positions of colour targets in image coordination are converted to 3D position in camera coordination. According to Fig. 8, the following relation can be written to transform coordinates from the camera's coordinate system to the world coordinate system, where x is position, $R$ is rotational matrix and $t$ is translation matrix.

$$\mathbf{x}_w = R\mathbf{x}_c + t \tag{1}$$

$$x_r = (\frac{x_1 + x_4}{2}) - \frac{l_2}{2}\cos\theta_r,\ y_r = (\frac{y_1 + y_4}{2}) - \frac{l_2}{2}\sin\theta_r$$

$$x_r = (\frac{x_2 + x_3}{2}) + \frac{l_2}{2}\cos\theta_r,\ y_r = (\frac{y_2 + y_3}{2}) + \frac{l_2}{2}\sin\theta_r$$

$$x_r = (\frac{x_1 + x_2}{2}) + \frac{l_1}{2}\sin\theta_r,\ y_r = (\frac{y_1 + y_2}{2}) - \frac{l_1}{2}\cos\theta_r$$

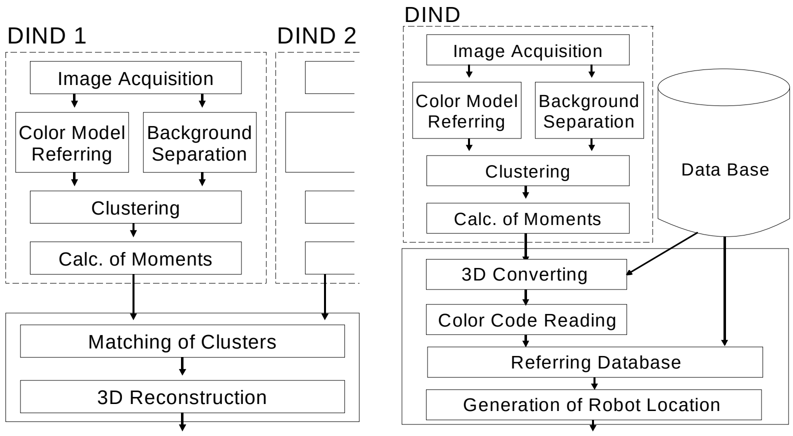
$$x_r = (\frac{x_3 + x_4}{2}) - \frac{l_1}{2}\sin\theta_r,\ y_r = (\frac{y_3 + y_4}{2}) + \frac{l_1}{2}\cos\theta_r$$

$$\theta_r = \tan^{-1}(\frac{y_1 - y_2}{x_1 - x_2}) = \tan^{-1}(\frac{y_4 - y_3}{x_4 - x_3})$$

$$\theta_r = \tan^{-1}(\frac{y_4 - y_1}{x_4 - x_1}) + \frac{\pi}{2} = \tan^{-1}(\frac{y_3 - y_2}{x_3 - x_2}) + \frac{\pi}{2}$$

These matrixes are found from the calibration process of a DIND, based on Tsai's algorithm. After target detection procedure, the 2D Euclidean distances between detected targets are checked to get rid of errors. If the distance is too long or too short, the detected targets are neglected. Even after this, the result may stil contain recognition errors. According to the database of the DIND, each colour- code, placed below the yellow target, is checked. If a colour-code, which is not shown in the database, is detected, it is removed from the list. From this process the DIND is able to recognize which robot it is too.

The geometrical relations, stored in the database, are compared between the colour-codes and it generates the pose of the robot. The pose of the robot is calculated from the pairs of colour-codes, with the same time stamp. Pose of a robot is estimated from geometrical relation, if at least one pair is recognized.




(a) Procedure for human beings or obstacles (b) Procedure for mobile robots

Figure 9. Comparison of positioning of a human beings and mobile robot

## 3.4 Active Resource Supplement for Mobile Robot

Because DIND always watches mobile robots in the space, it can support them according to their current situation. DIND can supports different mobile robots with different resources simultaneously. Thus, even a toy, if it has basic elements such as communication device, actuator, and rough controller, can be utilized as a robot in the Intelligent Space. An experiment is carried out to show an example of what DIND can do for the mobile robot [9]. In this experiment, self-localization behaviour of a mobile robot was inactivated intensively. Since it has no way to measure neither position nor speed, it is no more than a toy, which has a radio receiver. A human operator indicated desired target points to DIND and it translated this information to the robot. The robot just followed the order from DIND whether the output was correct or not. DIND continuously tried to fix position errors of the robot and it finally reached the goal. Fig. 10 shows how the robot gets to the goal. According to the position, domain DIND for the robot is decided. The whole area of the laboratory was divided into five areas and each area is watched by DIND. When a mobile robot traverses one area to another, DIND sends information of the robot to the next DIND, which are the domain DIND of the area where the robot will appear.

## 3.5 Human Motion Compression

The scenario, shown in Fig. 11, is that the Intelligent Space recognizes what human is doing in it and separates the real video data into index images and actions with time stamp. It will cause enormous data compression and help to make database. This function is expected to be utilized in surveillance camera system in shops or banks.

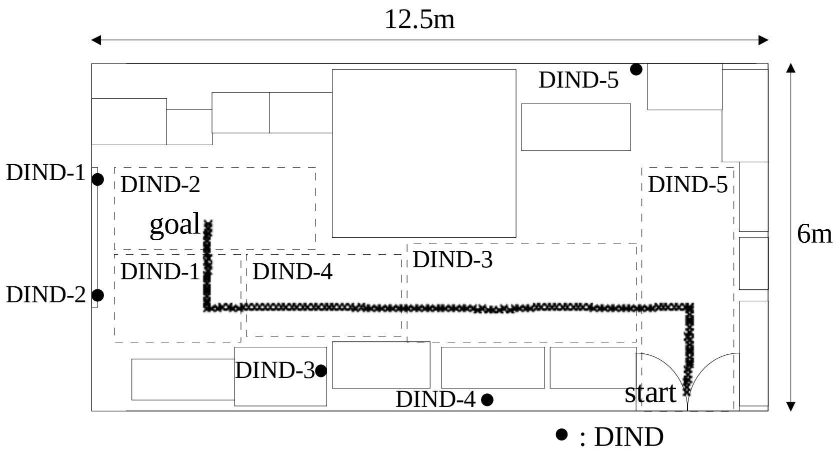



Fig. 10 Trajectory of Mobile Robot

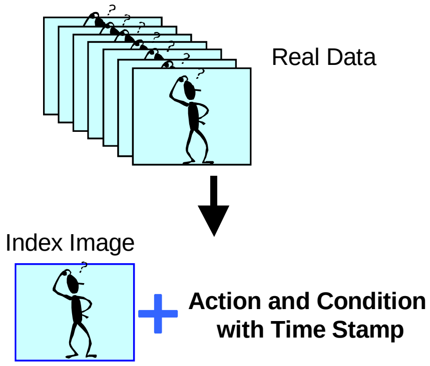



Fig. 11 Intelligent Video Recording

## 3.6 Interpreter between Human and Robot

A human interface is a necessary part of an intelligent system, which interacts with a human operator. However, since the human interface depends on the system, a human operator should learn human interfaces of each system. In the Intelligent Space, a human interface module is located in the Intelligent Space, not in each intelligent system. Thus, development efforts of systems are lessened and a human operator can control many systems with only a single human interface. Fig. 12 shows the concept. The Intelligent Space works as an interpreter between a human operator and systems including robots.

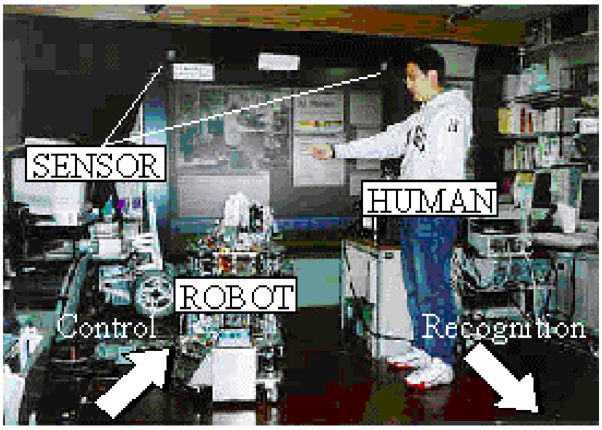



Fig. 12 Interpreter Function of Intelligent Space

## 3.7 Learning walking habits [10]

A simple example to illustrate the importance of this knowledge. Let's assume that a Japanese and an American person are walking towards each other. Recognising this situation, they try to avoid each other. Using their general rule, the Japanese person keeps left and the American keeps right and they are again in front of each other. In the end they may even collide (Fig. 13). If the Intelligent Space can learn the walking habit of a human being, it can send a proper command to the robot in such situation.

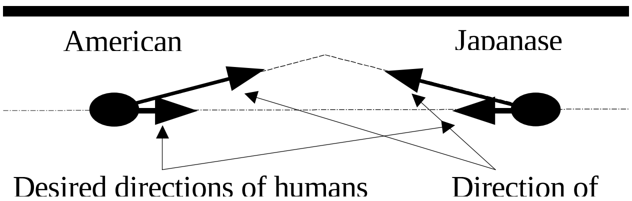



Fig. 13. Example for the problem of two different default avoidance styles

### 3.7.1 Basic walking styles

The main guiding rule of an aircraft carrying dangerous material is to keep “as far from the mountains as possible” (see Fig. 14. a). Remaining in secret while an inspector is seeking for a criminal leads to the opposite behavior, namely, “get as close to the object as possible” (see Fig. 14.b).

A simple combination of these can describe the main rule of a traffic system: “keep close to right or left side”

a.) Keep "as far as possible" b) Keep "as close as possible"

Fig. 14. Obstacle avoidance styles

### 3.7.2 Mathematical description of walking habits [10]

The Intelligent Space can detect objects around the robot (Fig. 15). The scanned area is divided into *n* scanned lines that are pointed into directions of $-\vec{e}_Z$ (unique vectors, where $z = 1 \ldots Z$ ). The different walking habits (obstacle avoidance methods) can be described by the repulsive (or attractive) forces as a function of obstacle distance. The walking path is defined by the sum of repulsive forces. The magnitude of repulsive forces, *F*, in the different directions can be described by a potential field (Fig. 16). The magnitudes of repulsive forces are usually inversely proportional to the distance but they can be described by any non-linear potential field. To achieve "keep as far as possible" walking style, a symmetrical potential field is necessary (Fig. 17.a). In the case of a "keep close to left side" style (Fig. 17.b), the repulsive force must be bigger at the right side of the moving object than that of the left side. An attractive force might be generated at the left side to get close to the obstacle, if the moving object is far from it.

The Intelligent Space tries to learn the walking habits (obstacle avoidance methods) of the moving objects.

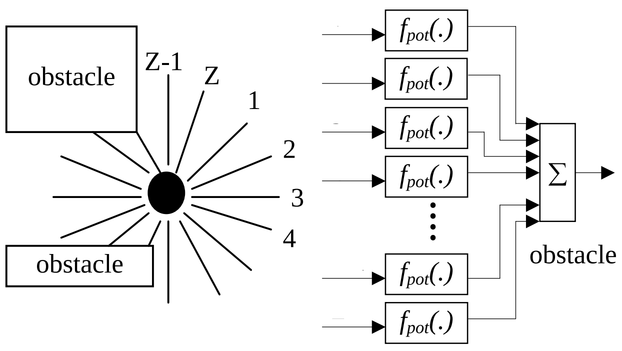



Fig. 15 Generating trajectory

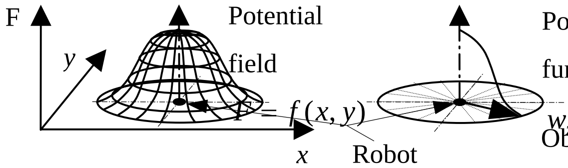
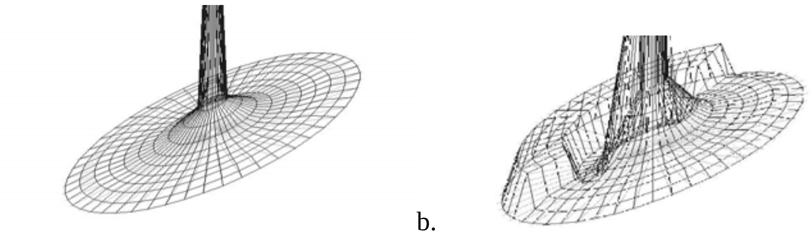



Fig. 16. Potential field of repulse forces



a. Potential field of "keep as far as possible" style

b. Potential field of "keep left" style

Fig. 17. Potential fields of two different walking habits

# 4. Conclusion

This paper presented an impression of Ubiquitous Sensory Intelligence in Intelligent Space project. With the progress of technology, some of previously unbelievable systems appeared first in science fiction literature have actually become a part of everyday life like for example space rockets and robots. In our laboratory we are developing such a system, which is motivated by a high intelligence computer named HAL from the movie Space Odyssey 2001. We believe, robots under the control of Intelligent Space have many good features. Human operators can communicate with the robots with the help of Intelligent Space. We would like to emphasize that Intelligent Space is an intelligent system to support robots as well as human beings. The Intelligent Space as a technology, might change our living environment. There are two directions, which must be enhanced. One is enlarging the area, which is able to apply the Intelligent Space concept. Currently the Intelligent Space is realized only in an experimental environment. An Intelligent railway station could the next target. The other is industrialization of all possible technologies used in the Intelligent Space. It enables wider and commercial applications.

## 5 Acknowledgement

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