Development of an intelligent Container Prototype for a Logistical Support Robot System in Living Space

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ABSTRACT

This paper reports development of an intelligent container, a unit of the logistical support robot system in living space. The container not only supports human to fix and arrange their commodities, but also supports robots to achieve their logistical tasks. In other words, the intelligent container is a mediator between human's request and robots' capabilities. The container has four major roles in our logistical support system. (1) Taking several commodities in and recognizing and acquiring contents' information. (2) Supporting human and robots to transfer the container. (3) Receiving users' command as a simple user-interface. (4) Communicating to a host computer and informs the contents of the container and users' command. To realize those roles, the container is equipped with a grasping navigation mechanism for robot handling, RFID reader for the recognition of contents, and LCD device to display supporting information to human and robot. Finally, a primary function is evaluated in experiment to confirm that an acceleration sensor enables the container to detect being transferred by human.

In the future, the intelligent container will play a role of contact point for human and robots in our target system, that enables human-robot symbiotic life.

I. INTRODUCTION

Facing problems with aging population combined with diminishing number of children, people become to expect robots to support their daily life. To this end, Intelligent Cooperative Laboratory at the Univ. of Tokyo are developing "a logistical support robot system in living space" as Fig.1 shows. The system is an environmental robot (i.e. intelligent environment) that daily supports our access to commodities. As commodities, we suppose books, magazines, CDs, preservative foods, grocery stock and so on. The system consists of four sub-systems, (1)intelligent containers for human to place commodities, (2)a ceiling mobile robot[1] to transfer the containers, (3)shelf type (or upper ceiling) rack system and (4)a stacker crane robot to take out and put in containers from the rack system.

There are two kinds of advantages in the system. The first ones are advantages in robotic (physical) support and the other ones are advantages in informative support. In robotic or physical support, upper ceiling rack system and ceiling mobile robot achieve space saving, i.e. people cannot use the upper ceiling space efficiently until now, but these systems enable people to use it with no special care. In addition, robots need to deal with only the containers (not

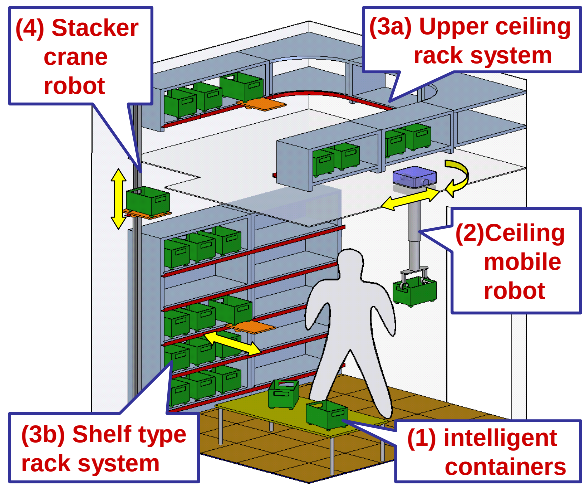


Fig. 1. Conceptual sketch of the logistical support robot system

commodities themselves). Thus the mission can be easier and more practical for robot than dealing with complex commodities.

While in informative support, if the intelligent container can acquire a log of commodities' use, we can obtain never lost memories of commodities' arrangement, i.e. the system will remind you, when and where you fixed a thing. Furthermore, high level fixing (arrangement) of daily commodities must be possible. By data-mining the log, the system can sort things whether frequently used ones or not. The system may arrange the frequently used tools at shelf type rack, and rare used objects at upper ceiling rack.

To realize such advantages, the intelligent container plays a significant role of contact point for human and robots in the system, i.e. the container not only supports robots to complete tasks, but also supports humans to enrich their life.

The framework of this paper is as follows; Firstly, in section II, related researches are listed. Secondly, in section III, required functions of the intelligent container are discussed. Thirdly, in section IV, implementations of required functions are explained. Finally, section VI is the conclusion.

II. RELATED RESEARCHES

From 1990's to now, there were several works that tried to make a robot system for office/home logistics. Prassler et al.[2] and Cosma et al.[3] constructed a mobile robot system for office or indoor logistics. In the paper, Prassler concluded that "No single method suffices for solving any of these (variety of the conditions and objectives) problems".

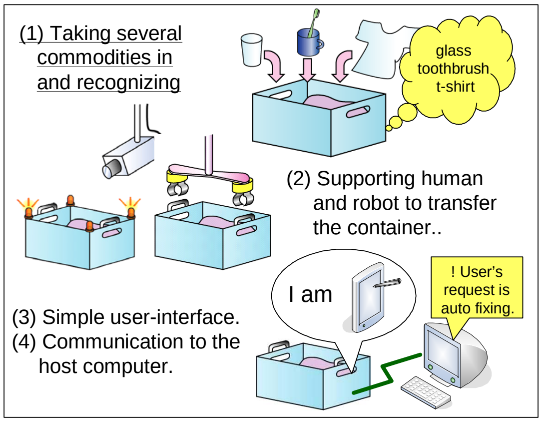


Fig. 2. Four major roles of the intelligent container

He also described the importance of an equipment with an array of methods. Whitney[4] pointed that real world is not so simple for robot, so robot control with passive compliance is essential to handle some complicated objects. Passive compliance is a significant factor for robot to achieve real application. Thus the intelligent container is designed to perform a compliant element in our complex living space.

In another topic, there are many intelligent environment researches that aim to achieve real task in our daily life by supporting robots with some environmental utilities; Chong et al.[5] constructed a knowledge network for robot with RFID tags. In the network, robot can obtain some information that is essential to achieve their object handling task. On the other hands, Katsuki et al.[6] adopted a visual marker to let robots know the strategy of handling. These two researches aim to support robots only in informative area, contrary to this the intelligent container intends to support them in not only informative but also physical area.

III. Required functions of the intelligent container

The functions required for the intelligent container will be discussed in this section. The container has four major roles as shown in Fig. 2.

(A) Taking several commodities in and recognizing and acquiring the contents' information (ex. log of use)
(B) Supporting human and robots to transfer the container
(C) Receiving users' command as a simple user-interface
(D) Communicating to the host computer and informs the contents of the container and users' command

In the next subsections, the specifications of each role are described in detail.

A. The specification required for the taking objects in

To accomplish taking objects in the container, we determined the following three functions.

- **Object stocking function**
  The container should stock 5[kg] contents at max.
- **Object tag recognition function**
  The container should be able to read and understand RFID tag information of the contents.
- **Load measuring function**
  To avoid over-load for robots, the container must be able to sense the weight of contents.

B. The specification required for supporting human and robot to transfer container

To realize transferring the container by human and robots, the following six required functions are determined.

- **Easy carrying function for human**
  The container should have shape and structure suitable for human to carry easily.
- **Carry sensing function**
  The container should sense transferring by human, so that the system can know the necessity of updating the container position information.
- **Container stackable function**
  Like as a general container case, the intelligent container should be stackable for the space saving, i.e. user can put a container on another container.
- **Container position measurement support function**
  The ceiling mobile robot must measure the position of containers to achieve a transferring task. The container should support robots to realize high accuracy measurement.
- **Grasping support function for robot**
  The container should have a structure for supporting the robots' task of grasping container.
- **Surface condition recognition function**
  A surface condition (ex. flat or rough) where the container is settled, is important for handling the container by robots. Therefore the container must sense its condition.
- **Stacker crane support function**
  The container should have a mechanism to support the stacker crane's transporting tasks.

C. The specification required for user-interface

Two functions are required for the simple user-interface on the intelligent container.

- **Users' command receive function**
  As a ubiquitous device, the container should receive several simple users' command.
- **Service information displaying function**
  The container should be able to display the contents and self-status information.

D. The specification required for the communication with the host computer

The host PC has two main roles. The first one is to make a log of containers' state(position, contents etc...) and set up the look-up table of logs for contents' searching by user. The other one is to receive and recognize the user's request and send commands to each sub-systems.

For these roles, two functions are required for the container.

- **Internal condition report function**
  Periodically, the container should report internal state changes (ex. contents change, transferred by human).
- **User command transmit function**
  The container must inform the host computer of the user command input as soon as possible.

IV. Implementation of Intelligent Container Prototype

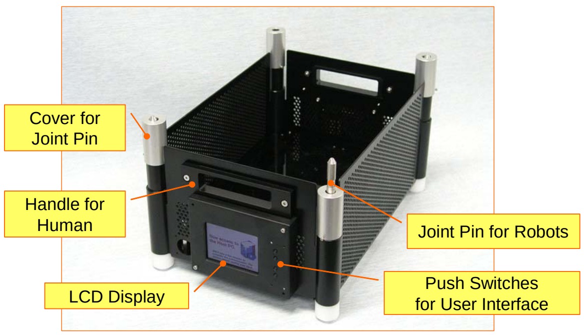


Fig. 3. Overview of intelligent container prototype

This section describes the implementation of the intelligent container prototype to realize required functions discussed in section III. Fig.3 shows the overview of the intelligent container prototype. While Fig.4 displays the upper view of container without a loading plate. Fig.5 indicates the block diagram of the intelligent container system. In the next subsections, the implementation of each functions will be explained in detail.

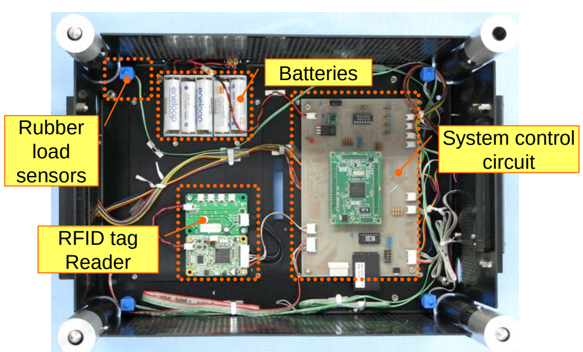


Fig. 4. Upper view of the intelligent container without a loading plate.

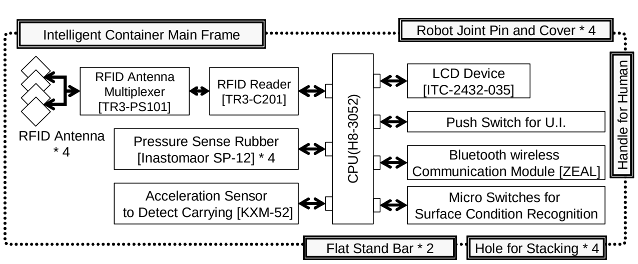


Fig. 5. The block diagram of the intelligent container

A. Implementation of object stocking function

First of all, the size (volume) of the container will be discussed. Some container cases in the market have almost the same size of A4 paper. The intelligent container refers the size of those market products, and is set to W:250, D:350, H:170[mm] as Fig.6 shows. Secondly the basic structure will be considered. Almost all mass product container cases are made by plastic injection modeling, because it can construct ribs easily. Consequently the structure can be not only rigid but also light weight. However the injection method is not suitable for prototype. So in this trial production, the main frame is produced by bending a aluminum sheet and the four corner join parts are made by machining plastic poles. The bottom of the main frame is removed and two plastic plates are settled for the RFID antenna communication, i.e. RFID cannot communicate when it's too near metal.

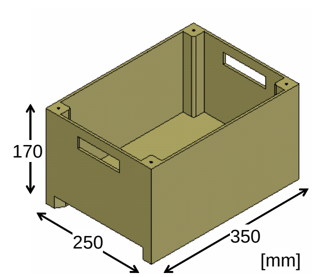


Fig. 6. Abstract of the container size

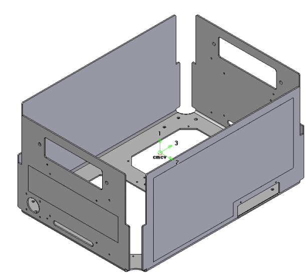


Fig. 7. Main frame structure

B. Implementation of object tag recognition function and measuring load function

Firstly, RFID tag reader and antenna are essential to read the RFID tags attached to commodities. In this prototype, market products of the RFID reader (TR3-C201, produced by Takaya Corp.) as shown Fig.8 are adopted for cost and time reduction. On the other hand, since an antenna decides the size and shape of communication area, we tried to produce the antenna by ourselves. The layout of the antenna is required to communicate with all tags on the container with no error. To realize this request, the Takaya corp.'s antenna product (TR-A101) is referred , because the TR-A101 can communicate with a tag in the condition that the tag is 180[mm] far from the antenna. Secondly, four load sensors are placed at the bottom of the container to measure the contents' weight. The container has double bottom plates, and the sensors are settled on the lower plate. The upper bottom plate is made of plastic to ensure the RFID communication. Four RFID antenna coils are placed under the upper bottom plate as Fig.9 shows. As load sensor, strain gage or load cell is used generally. But amp circuit is essential to measure small strain, and they are expensive. In our usage, the load sensor should only has the potential to distinguish overload or not, so we adopt much simple rubber load sensor (SP-12, produced by Inaba Rubber Corp.) that can sense load but non-linearly. Four rubber sensors are settled at the bottom corners of the container as Fig.10 shows.

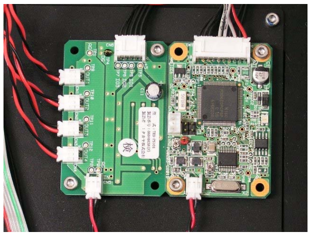


Fig. 8. RFID reader TR3-C201

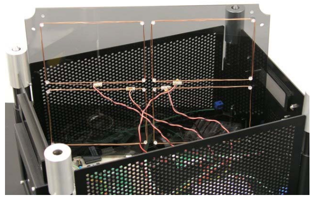


Fig. 9. The upper bottom plate

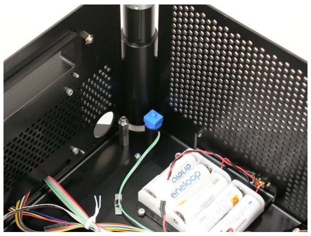


Fig. 10. Rubber sensors at corners

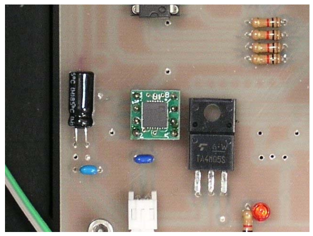


Fig. 11. Acceleration sensor

C. Implementation of carry sensing function

There are three ways to recognize the human to carry a container; (1)A method to measure the position of the container. (2)A method to measure the inclination of the container. (3)A method to measure the vibration of the container. Among these three methods, the third method that measures vibration is the easiest way, because the vibration (acceleration) sensor becomes much cheaper by the progress of MEMS technology in these days. In this research, a three-axis acceleration sensor “KXM-53” (Fig.11) is adopted and settled at the bottom of the container. When the acceleration exceeds threshold, the container is recognized to be carried. In general, an acceleration sensor can detect the gravity acceleration 9.8[G], so when a user declines the container, the sensor can detect the incline of the container subsequently.

D. Implementation of grasping support function for robot

Human eye and hand can recognize and handle complicated shape of objects by utilizing their flexible knowledge. But so far robots have not yet achieved such complex object recognition and handling. Therefore the intelligent container should not require robots complex procedure in handling objects. In this research, we adopted an approach that the container has an easy structure or mechanism for grasping by robots. There thought to be several ways to realize this approach, for example a method using magnet, fork insert method and so on. In this prototype, we utilize pin and hole joint method as shown in Fig.12. For this method, four pins are implemented on the top of corner poles, and guard covers for safety are attached around the pins. Fig.13 shows the pin and the cover at one corner.

E. Implementation of container position measurement support function, users’ command receive function and service information displaying function

Firstly, for realizing these functions LCD device was adopted, because the LCD has the potential to become the marker for the container position measurement and of

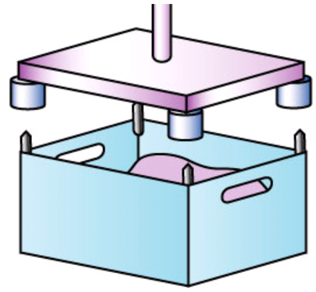


Fig. 12. Pin and hole joint method

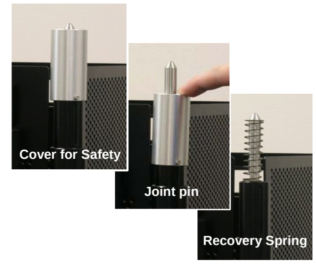


Fig. 13. Joint pin and its cover

course the device for displaying information to users. In this prototype, a LCD device on the market ”ITC-2432-035” (produced by Integral Electronics Corp.) was utilized. This is 3.5 inch TFT LCD device, that has 320×240 pixels’ resolution. The characteristics of the device are (1) the device has font data in itself, (2) the device can display an image data that is stored in a compact flash media. From these characteristics, some simple micro controllers can display complex text and image data.
Secondly for realizing user-interface, push switches are implemented at the side of LCD device. These push switches and LCD compose user-interface for command selection. For simple usage, only four push switches (OK, NG, Up, Down) are adopted. As Fig.14 shows, several use-interface displays are implemented. Fig.15 shows the implemented LCD device.

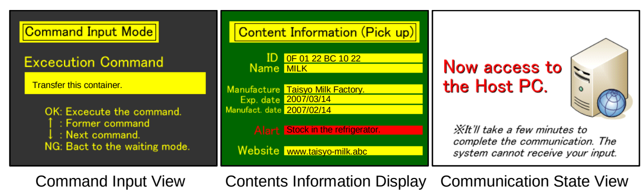


Fig. 14. Contents of the LCD display

Fig. 15. LCD device and push switched for UI

Fig. 16. Handle for human

F. Implementation of easy carrying function for human and container stackable function

A simple handle parts can realize easy carrying function like general container case. The main frame sheet metal has only 2[mm] thick, so plastic parts are used as handles. Fig.16 shows the handle part. To realize the container stackable function, we utilize joint pins for robot grasping. As Fig.17 shows, a hole for inserting the joint pin is prepared at the bottom of each corner pole. By inserting the holes on pins, user can put a container on another container.

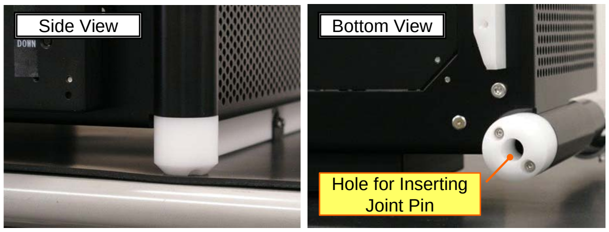


Fig. 17. A hole for inserting pin

G. Implementation of stacker crane support function and surface condition recognition function

Stacker crane will transfer containers by sustaining the bottom of containers like a fork lift. Therefore the container has space under the bottom of the container for inserting forks. To make such space, two plastic stand bars are implemented under the container that make the container 20[mm] up to floor. Fig.18 shows the bottom of the container. The stand bars are made of low friction plastic that make it easy to pulling containers from a rack. In addition, for realizing surface condition recognition function, a micro switch is settled at the center of the stand bar as Fig.19 shows. When the switch is "ON", the surface where the container is placed may be flat and has sufficient stiffness to sustain the container.

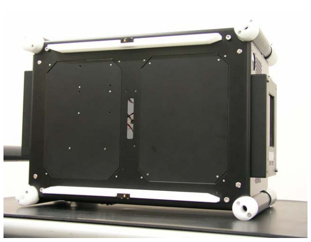


Fig. 18. Flat stand bars (white) at the bottom of container

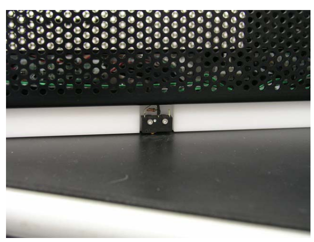


Fig. 19. Micro switch at the center of a bar

H. Implementation of internal condition report function and user command transmit function

Since the host computer must communicate with several different containers, the intelligent container should adopt a wireless multi-communication method. To this end, this research utilizes Bluetooth wireless communication. A Bluetooth communication module "ZEAL" (produced by AD Technology Corp.) is implemented on the intelligent container.

I. Implementation of system control circuit

As a main CPU, a micro controller "H8-3052F" (produced by Renesas technology Corp.) is selected and mother board is implemented like Fig.20 shows. As a power source, five Ni-MH batteries are utilized. But the batteries can supply the power of the container during only a few ours, so the energy save mode is installed to make the operating time long.

V. Evaluation test of primary functions

This section describes evaluation tests of object tag recognition function and sensing function of carrying.

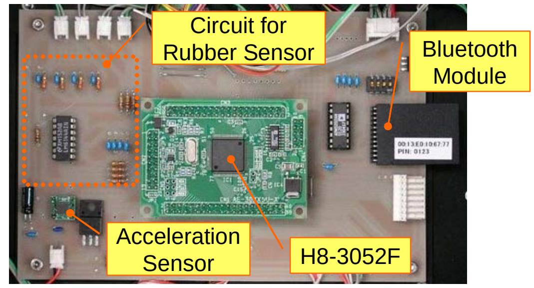


Fig. 20. System control circuit

A. Evaluation test of object tag recognition function

This test examines communication distance between RFID antenna and a tag. The communication distance depends on the installation location and incline of tags and so on, so it's difficult to evaluate with generality. In this test, the maximum communication distance at best effort is evaluated. Fig.21 shows the RFID tag for this test. The size of tag is 45×45 [mm], so it can be installed to a lot kind of commodities. In the test procedure, a tag is moved down vertically from

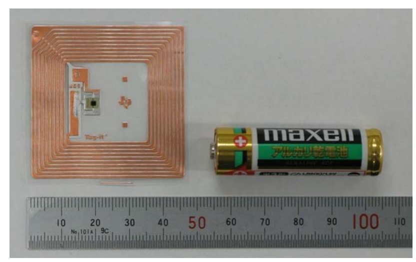


Fig. 21. Sample of RFID tag (Right: size AA battery)

the top of container, and the first point where the antenna can communicate with the tag is defined to be a maximum communication point. The distance between the maximum communication point and the antenna plate is measured as the maximum communication distance. Fig.22-(1) shows measured points and the maximum communication distance at each points. The figure shows that some points can almost cover the depth of container (150[mm]), but some points on the boundary of multiple antennas cannot satisfy the required specification. To reduce an effect of inter-influence of multiple antennas, only one antenna module is activated and maximum distance is examined. Fig.22-(2) shows the result. Since there is no major change from the result of multiple antennas, the effect of inter-influence of multiple antennas is not dominant in this case.

To evaluate a relation between antenna size and communication distance, three different type antennas are produced for trial. Fig.23 shows the overview of antenna prototypes. According to "RFID Handbook"[7], the communication distance is almost the same as the radius of antenna, that means the larger radius of antenna is the longer communication distance will be. But too large radius of antenna makes energy transfer invalid and makes it difficult to tune a resonance frequency, because it needs a too small size capacitor. In this trial, antenna No. 3 is too large to make 3 coils, so has only 2 coils. Table I shows the result of communication test. The result indicates that a large antenna doesn't always make the communication distance long. More detailed design of antenna size and layout is our future task.

TABLE I
RESULT OF VARIOUS ANTENNA COMMUNICATION TEST

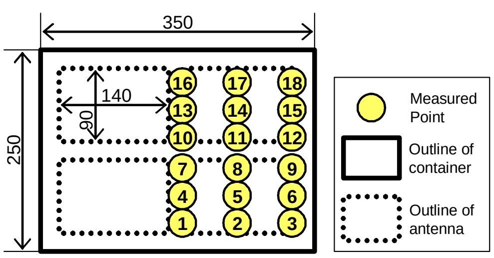
Antenna	Width	Height	No. of Coils.	Communication distance *1
1	95	95	3	110
2	90	140	3	110
3	200	300	2	110

*1 : measured at center of coil. Unit : mm

B. Evaluation test of carry sensing function

This test evaluates the capability of sensing to be carried by human. In this test, three subjects (20's males) lift up the container from a desk and place it on the desk again. This procedure is repeated four times per a subject, and vibration of the container is measured by an acceleration sensor on the container.

Fig.24 shows an example data of vertical acceleration when human lifts up and place a container. In general, much acceleration is detected at placing phase than picking phase. In the placing phase, the minimum acceleration value is 0.3[G] by subject A, 0.2[G] by subject B, 0.7[G] by subject C respectively. When a container is placed on a desk in a living room for 1 hour, the maximum acceleration value was 0.06[G]. So the acceleration value generated by transferring can be distinguished. From this result, we confirmed that monitoring the acceleration of the container enables us to detect the container being transferred by human.



Maximum Communication Length [mm]

(1) Four antennas are available.

NO.16	50	NO.17	100	NO.18	90
NO.13	70	NO.14	90	NO.15	90
NO.10	60	NO.11	70	NO.12	90
NO.7	50	NO.8	60	NO.9	70
NO.4	50	NO.5	90	NO.6	100
NO.1	50	NO.2	110	NO.3	100

(2) Only right-down antenna is available.

NO.7	50	NO.8	80	NO.9	70
NO.4	80	NO.5	90	NO.6	90
NO.1	80	NO.2	110	NO.3	100

Fig. 22. The maximum communication distance at each measured point

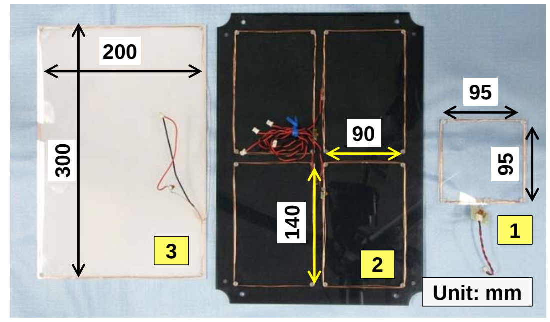


Fig. 23. Comparison of 3 different type RFID antennas

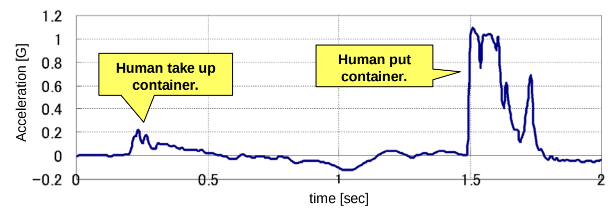


Fig. 24. An example data of vertical acceleration when human transfers a container

VI. CONCLUSION

Facing problems with aging population combined with diminishing number of children, we aimed to realize a robot system that can support human actually. As a target, we focused on a logistical support robot system, that casually supports human to access and arrange commodities in living space. This paper reports development of an intelligent container, a unit of the logistical support robot system. The intelligent container will play a role of contact point for human and robots in the robot system. In the evaluation test of primary functions, we confirmed that monitoring acceleration is effective to detect container to be transferred by human, and detailed antenna design is essential to realize more accurate object tag recognition function.

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