A Navigation System Using Ultrasonic Directional Speaker with Rotating Base

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Abstract. This paper proposes new method for object reference which enables a person to find surrounding objects and develops a navigation system named CoCo. CoCo employs an ultrasonic directional speaker with a rotating base. Ultrasonic wave transmitted by an ultrasonic directional speaker is converted to audible sound when it reflects on floor, wall, or object. Based on this property, CoCo can emit audible sound from arbitrary place using a rotating base. When CoCo navigates a person to an object, CoCo transmits ultrasonic wave so as to hear audible sound continuously from the line between the ultrasonic directional speaker and the object. We designed and implemented an object management system as an application using 3D position sensors and a navigation system CoCo. This paper shows how CoCo navigates a person to an object using position data from an object management system.

Keywords: object reference, ultrasonic directional speaker, ultrasonic wave, position sensor.

1 Introduction

Recent sensor technology has realized small and light position sensors which can be attached to surrounding objects [1], [2]. Using those sensors, we can manage the positions of surrounding objects. In such a situation, we can find an object which we want even if a person forgot where he/she put away the object or another person moves the object.

In general, position data acquired from position sensor are coordinates on each sensor system. Those who are not specialists in sensor system can not directly realize a real world position from corresponding coordinates. It is essential that a system which refers real world objects has an interface which enables a person to realize a real world position directly.

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There are previous works for object reference system by intuitive method instead of position coordinates. [3] generates a natural language sentence based on a priori rule and displays the sentence. [4] develops a robot which points to an object and speaks to a person. [5] throws light on an object. [6] attaches a speaker and an infrared receiver. When a person with an infrared transmitter approaches to a receiver attached object, an infrared receiver receives an infrared signal and a speaker emits sound.

In case of natural language display, a person has to find a real world area where is corresponding the displayed sentence. In addition, since this system employs RFID tags with landmark sub-stations rather than position sensor, this system cannot recognize actual position. In case of pointing by a robot and light projection, if some objects occlude the line between the referred object and the robot or light source, it is difficult to detect the referred object. In case of attaching speaker, the speaker doesn't emit sound unless a person with an infrared transmitter approaches to an infrared receiver.

In this research, we propose a navigation system named CoCo. CoCo employs an ultrasonic directional speaker [7] with a rotating base. Ultrasonic wave transmitted by an ultrasonic directional speaker is converted to audible sound when it reflects on floor, wall, or object. Based on this property, CoCo can emit audible sound from arbitrary place using a rotating base. When CoCo navigates a person to an object, CoCo transmits ultrasonic wave so as to hear audible sound continuously from the line between the ultrasonic directional speaker and the object. Using this system, a person can directly find a real world area since audible sound is emitted from real world. CoCo takes advantage in case of occlusion since a person can hear audible sound continuously from the line between the ultrasonic directional speaker and the object rather than one point reference such as pointing or spotlighting. In addition, since our system knows the position of the referred object, CoCo can emit sound before a person approaches to the referred object.

We designed and implemented an object management system as an application using 3D position sensors [1] and a navigation system CoCo. This paper shows how CoCo navigates a person to an object using position data from an object management system.

The rest of this paper is organized as follows. Section 2 describes conditions and definitions. In section 3, this paper proposes new method for object reference and describes the details of a navigation system CoCo. Section 4 describes an object management system using position sensors and CoCo. Section 5 discusses the advantages and limitations of CoCo. Section 6 concludes this paper with our future plans.

2 Conditions and Definitions

2.1 Conditions

We assume that following conditions in the environment in which our system is used.

- Absolute object position can be acquired from position sensor
- There is space to install our system where the speaker look on the room
- There is no loud sound in the room

The first condition comes from the object reference method. Our object reference method is realized by changing the direction of the speaker in its tracks. The system has to know where to turn. It is different from the landmark reference method as in [3] or the exploratory method as in [6].

The second condition comes from the property of ultrasonic wave. Ultrasonic wave goes straight through in the air. In order to make sound from the object, ultrasonic wave must get through to the object although our method can be robust over occlusion to some extent.

The third condition comes from using sound for object reference. A person can interpolate the sound for split-second mishearing, since the person can hear audible sound continuously from the line between the ultrasonic directional speaker and the object. In the situation that continuous loud sound exist in the room, however, a person can not hear the sound from the speaker.

2.2 Definitions

This section describes definitions of terms used in the rest of this paper.

System user is used for the person who uses CoCo for object reference or the object management system to find surrounding objects. We also use simply *user* for this meaning.

System employer is used for the person who sets up CoCo or the object management system.

Reference line is used for the line between the ultrasonic directional speaker and the object. CoCo transmits ultrasonic wave onto this line.

3 CoCo

3.1 Hardware Configuration

We developed CoCo from an ultrasonic directional speaker [7] and a rotating base with 2 DOFs. Fig. 1 shows CoCo appearance. Each rotating unit has a DC motor controlled by a DC motor controller with an encoder. White rotating base rotates by 2 rotating units and change the direction of the ultrasonic directional speaker to arbitrary direction. The ultrasonic directional speaker produces an ultrasonic carrier wave modulated by an audible sound. Ultrasonic wave transmitted by the ultrasonic directional speaker goes straight through in the air. Ultrasonic wave is converted to audible sound when it reflects on floor, wall, or object. Based on this property, CoCo can emit audible sound from arbitrary place. Since human can not hear ultrasonic wave, human feel as if floor, wall, or object makes a sound.

3.2 Software Configuration

Fig. 2 illustrates system configuration of CoCo. CoCo receives object position and rotates its base with transmitting ultrasonic wave. CoCo consists of 3 software modules: command interpreter, motor control module, and sound control module. The rest of this section describes the details of each soft module.

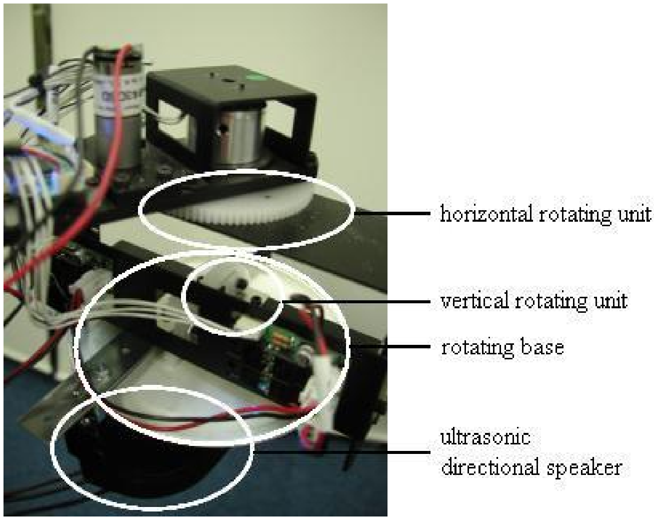

Fig. 1. CoCo appearance

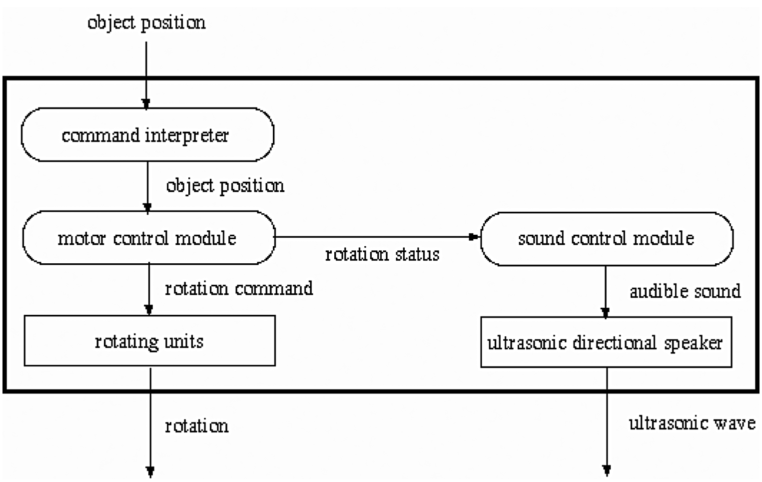

Fig. 2. System Configuration of CoCo

Command Interpreter. Command interpreter receives operation command with object position as input. When command interpreter receives operation command, it stores operation command in its internal queue. If no command is in operation, the stored command is immediately executed. Otherwise, command interpreter picks up the head command in queue and starts operation after previous operation is finished.

Motor Control Module. Motor control module handles exact motion of the motors of rotation units. Motor control module turns rotating base so that the reflecting point of ultrasonic wave moves on reference line from its feet to object position. It calculates goal encoder counter so as to direct the speaker toward object position. After that, it linearly moves motors.

Sound Control Module. Sound control module manages the original sound which is modulated and transmitted by the ultrasonic directional speaker. It receives rotation status of rotating units, and changes pitch of the original sound depending on rotation status. If the reflecting point of ultrasonic wave is near the speaker's feet, sound control module passes low pitch sound to the ultrasonic directional speaker. The more the reflecting point of ultrasonic wave approaches to object position, the higher pitch sound is passed to the ultrasonic directional speaker.

3.3 Navigation by Sound

This section describes overall behavior of CoCo. CoCo set motor to base position when the previous operation is finished. In this case, the ultrasonic directional speaker is pointing its feet. After receiving reference position, the ultrasonic directional speaker starts to turn toward reference object. Fig. 3 shows the appearance at that moment. In Fig. 3 the ultrasonic directional speaker is pointing its feet as the start point of the reflection.

White line in Fig. 3 means reference line, which is reflection trajectory of ultrasonic wave. The reflection point of ultrasonic wave changes position from start point to goal point. On the way to object position, the ultrasonic wave reflects on the floor, the chair, the desk, and the cup with transmitting higher pitch sound. Human hears the sound from the direction of the reflecting point and feels as if sound source is moving toward the object.

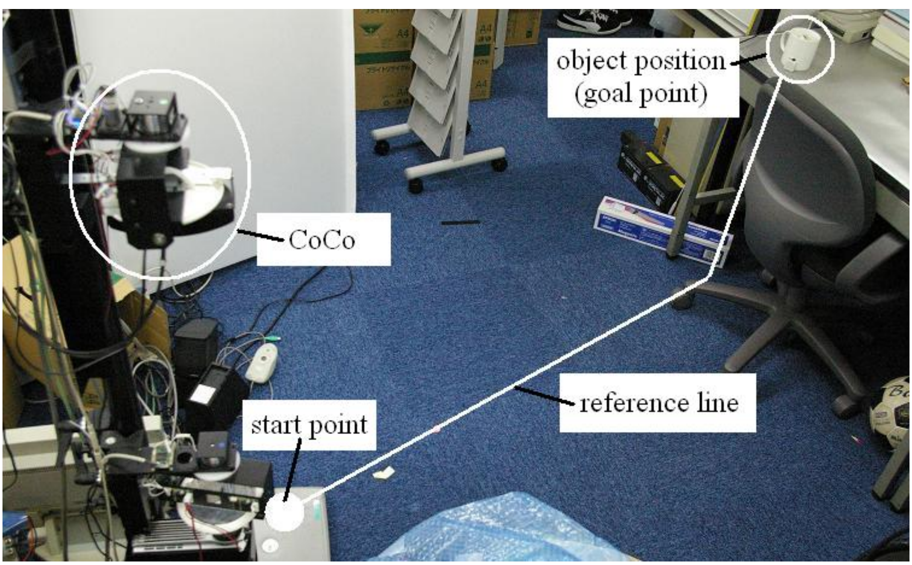

Fig. 3. Reflection Trajectory of Ultrasonic wave

At the point under the chair, the ultrasonic goes in the back of desk. In that instant, audible sound does not get to human ear. However, since human can interpolate the sound for split-second, human does not miss hearing sound movement in this situation. On the same score, CoCo can also navigate human toward the object position in case of occlusion. Human may hear as if sound source jumps other place, if some object including human gets into the way of the ultrasonic wave. However, human can recognize the direction toward the object.

4 Object Management Using CoCo

We designed and implemented an object management system as an application using 3D position sensors and a navigation system CoCo. This section describes configuration and behavior of the object management system.

4.1 System Configuration

Fig. 4 illustrates overall system configuration of the object management system. 3D position sensors obtain 3D positions of surrounding objects in background. Position data are stored in the corresponding tuple in object DB. Each tuple in object DB also has property information stored in advance such as object name, object color, object owner, object image, and so on.

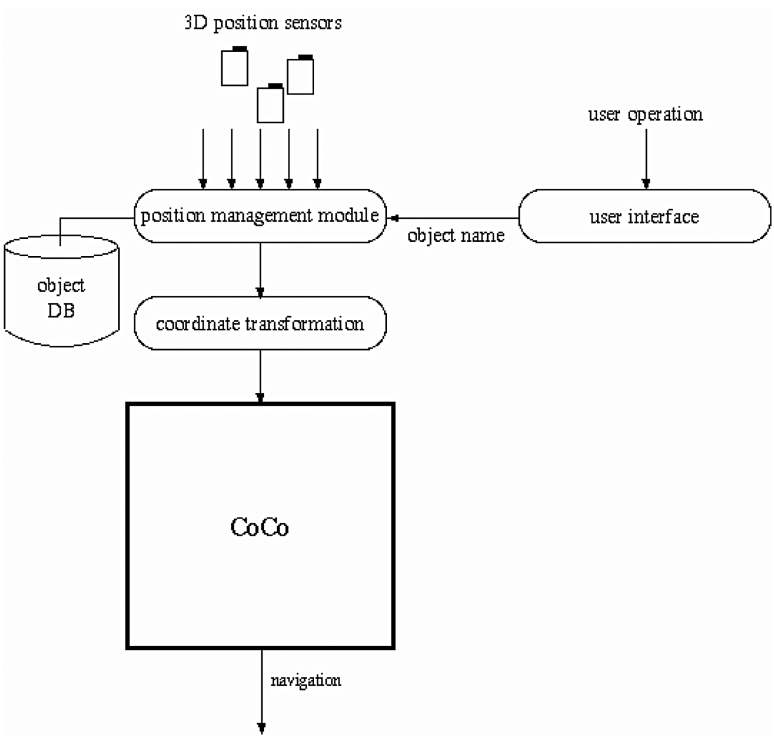

Fig. 4. System Configuration of the Object Management System

When system user want to find an object, system user operates the object management system via user interface. Position management module starts an operation when it receives reference object name from user interface. It loads object position from object DB and sends 3D position to CoCo after coordinate transformation.

In the following section, we show the details of each part of the object management system.

4.2 Position Management

We employ 3D ultrasonic tagging system [1] for position sensor. In this system, small tags emit ultrasonic wave and many ultrasonic receivers embedded in environment receive ultrasonic wave. We attached small tags to surrounding objects and installed ultrasonic receivers fixed to the ceiling. Fig. 5 shows sensor attached cup and installed ultrasonic receivers.

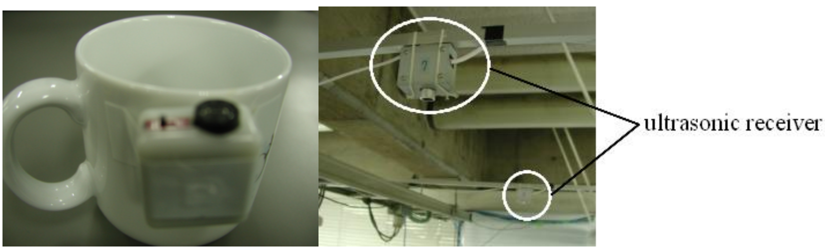

Fig. 5. 3D Ultrasonic Tagging System

Position management module has 2 functions: position update and position retrieval. Position management module updates 3D positions of surrounding objects acquired from 3D position sensors. Each position data has tag ID. Position management module updates position data which has corresponding ID stored in object DB. System employer has to build object DB in advance so that which object is attached to which position sensor. The update process continuously runs in background.

Position management module also has a role to start navigation by CoCo. It retrieves object position by object name from user operation. In object DB, object name is expected to be provided for this retrieval. System employer also has to store property information in advance. If the object position is obtained, object management module starts navigation by CoCo.

4.3 Coordinate Transformation

Before CoCo starts navigation, the system has to adapt object position to the coordinate system of CoCo. We assume sensor system can obtain absolute object position as described in section 2.1. In most cases, however, the coordinate system of sensor system is different from the coordinate system of CoCo. Equation (1) means a general space transformation.

$$\begin{pmatrix} x_C \\ y_C \\ z_C \\ 1 \end{pmatrix} = \begin{pmatrix} & \mathbf{R} & & \mathbf{t} \\ & & & \\ 0 & 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} x_s \\ y_s \\ z_s \\ 1 \end{pmatrix} . \tag{1}$$

Where (x_C, y_C, z_C) is the coordinates of CoCo, (x_s, y_s, z_s) is the coordinates of sensor sytem, **R** is 3 dimension rotation matrix, **t** is 3 dimension translation vector. System employer has to find rotation matrix and translation vector in his/her own environment.

4.4 User Interface

The object management system has a user interface with which system user can operate the object management system from remote host. The object management system has a web server, and system user can access the user interface as a web page. When user operates the web page, a CGI script runs to start navigation.

Fig. 6 shows appearance of the user interface. User can select an object in 2 ways: by name or by image. The page contains a drop-down list in its upper part. The drop-down list has object names. When user clicks the button beside the drop-down list, the system starts navigation to the selecting object in the drop-down list. The page also contains images of objects in its bottom part. If system employer prepared object images, the page shows object images. When user clicks an image or a button below the images, the system starts navigation to the selecting object.

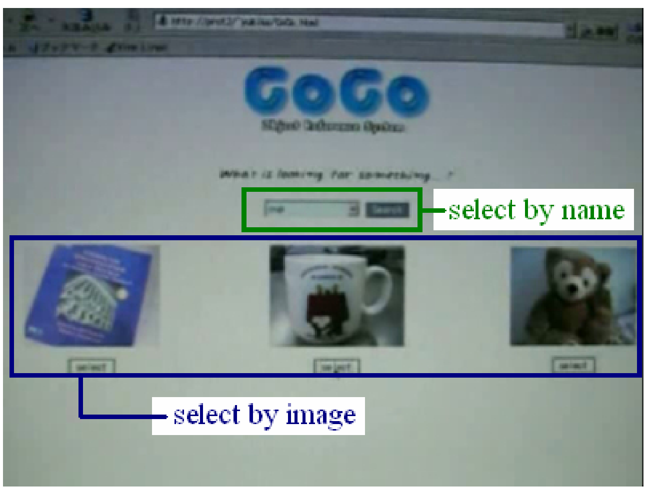

Fig. 6. User Interface of the Object Management System

4.5 Error Handling

The object management system has an extra function. Although user selects an object, there is a possibility that no corresponding position data is found in object DB.

Someone may bring the object outside the room, or the position sensor on the object may malfunction unfortunately. In those cases, the object management system informs user that there is no corresponding position data.

The object management system turns the rotating base toward the computer which user is accessing from. And then, the object management system says “the object is not found” with the ultrasonic directional speaker. The position of the computer is acquired from 3D position sensor in our system. Fig. 7 is a picture in this situation.

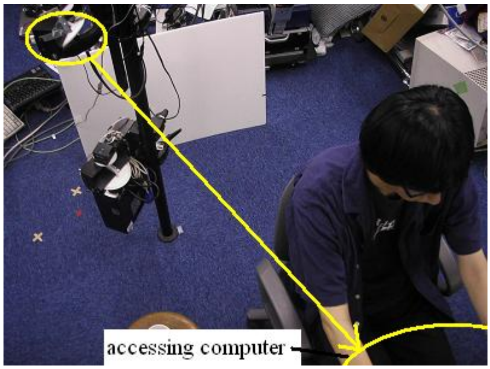

Fig. 7. A Extra Function to Inform Result

5 Discussion

We use sound for object reference. This choice provides many advantages. First of all, it makes this method an intuitive method. System user can recognize accurate position instantaneously by hearing sound even if he/she does not look at the object. Another advantage appears in fault situation especially in case of occlusion. Human can interpolate sound movement, and this property makes our method robust.

There are some limitations for our method. As described in section 2.1, we assume there is no continuous loud sound in the room. We can not use our method in a bustling environment such as an exhibition. We also have a limitation of space range. Although the ultrasonic wave goes straight through in the air, ultrasonic wave attenuates over distance. In addition, the longer distance ultrasonic wave goes, the more possibility of occlusion we have to consider.

We believe that our method is not an exclusive method. We believe that our method gets more powerful effect by combining other method such as spotlighting, pointing, or language generation.

6 Conclusion

We proposed new object reference method and developed an object management system using an ultrasonic directional speaker. In further research, we think we have to make an evaluation for this method, although our method make powerful effect for lost object searching.

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