Robot Auditory Search Realization Based on Virtual Reality

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Abstract. A novel robot auditory search system is proposed in this paper. The system consists of a robot which has a microphone array corresponding to human's ears and a virtual reality robot teleoperation system. Sound source localization is realized based on time delay of arrival (TDOA) estimation using microphone array. The sound source search is realized via virtual reality system. Virtual robot and virtual environment are set up according to the real scene. Virtual robot is the agent of the real robot. Data glove is used to operate the virtual robot to complete the control towards the real robot. It can make the operator control the real robot to find the sound source fast and conveniently. The system was tested in leaky chemistry container mending: robot could reach the leaky point successfully and accomplish the mending task smoothly. A great deal of experiments prove that this search system is reliable and efficient.

Keywords: Virtual reality, Sound source localization, Robot, Search.

1 Introduction

In recent years, with the rapid development of chemical technology, research on how to make robot work in dangerous and unknown surroundings has become a hot topic in the field of robotics.

Especially in mending leaky chemistry container, robot plays an important role. When accidents occur with a crash sounds, for example chemistry container leaks, the robot will be aware and localizes the sound source to find the leak point. The approach of using a moving microphone array to localize the sound source has been started recently as a challenging research topic of sound processing [1].There are a lot of advantages in using several microphones in any sound source direction estimation system that is applied to humanoid robot. Because the structure of the system is agile, the computational complexity is low.

But how to make the robot search the sound source includes a lot of complicated problems, such as path planning, collision detection and so on. So we propose a novel searching method by integrating robot audition and virtual reality.

This paper is organized as follows. In Section 2, we introduce robot auditory localization system and present the results of our initial localization experiments. Section 3 presents the virtual reality robot teleoperation system. Section 4 discusses the search realization based on integration of auditory and virtual reality. Section 5 presents our conclusions and plans for future work.

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2 Robot Auditory Localization System

There are several methods of sound source localization [2]. Considering for our localization system need real time realization, we adopt the localization method based on time delay of arrival (TDOA) [3].

The direction of a generated sound source can be estimated using the time difference between microphones and the characteristics of the sound. Most practical acoustic source localization schemes are based on time delay of arrival estimation for the following reasons: such systems are conceptually simple. They are reasonably effective in reverberant environment. Moreover, their low computational complexity makes them well-suited to real-time implementation with several sensors.

Time delay of arrival-based source localization is based on a two-step procedure：

(1)The TDOA between all pairs of microphones is estimated, typically by finding the peak in a cross-correlation or generalized cross-correlation function.

(2) For a given source location, the estimated TDOA and those geometry model could be used to evaluate the source location [4].

However, it is very difficult to create an estimation system using a computer and two microphones. Considering the microphone array would be fixed on the robot, it is also not appropriate to use a lot of microphones to localize the sound source. In this system we propose a novel sound source localization system. The squared microphone array in the proposed system consists of four microphones which are distributed on the front of the robot underpan. It is shown in Fig 1.

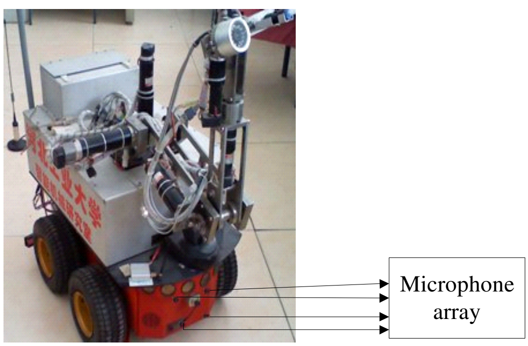

Fig. 1. Microphone array on robot

HEBUT-II robot consists of a mobile vehicle and a five-degree-of-freedom manipulator. The received signals of these four microphones are used to determine the position of the sound source.

Supposed there is a sound source in the working environment of robot. The position relationship between the microphone array and the sound source is shown in Fig 2. In the coordinate system, S denotes the sound source, M_1~M_4 represent microphones, R denotes radial distance, θ denotes azimuth angle, ϕ denotes zenith angle, and L denotes the side length of the squared microphone array.

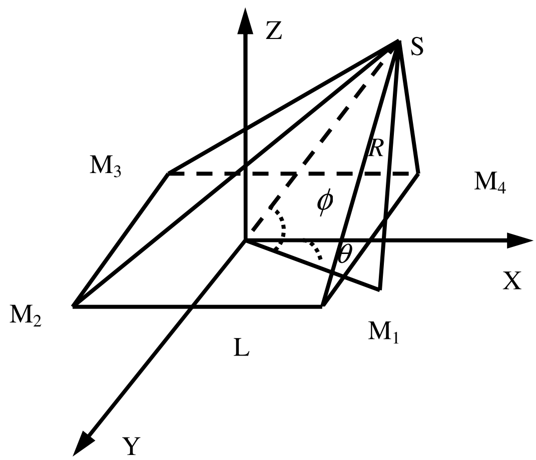

Fig. 2. Coordinate system of microphone array

We could get equations from coordinate system as follows:

$$\begin{cases} x^2 + y^2 + z^2 = R^2 \\ (x-\frac{L}{2})^2 + (y-\frac{L}{2})^2 + z^2 = R_1{}^2 \\ (x+\frac{L}{2})^2 + (y-\frac{L}{2})^2 + z^2 = R_2{}^2 \\ (x+\frac{L}{2})^2 + (y+\frac{L}{2})^2 + z^2 = R_3{}^2 \\ (x-\frac{L}{2})^2 + (y+\frac{L}{2})^2 + z^2 = R_4{}^2 \end{cases} \quad (1)$$

$$\begin{cases} x = R\cos\theta\cos\phi \\ y = R\cos\theta\sin\phi \\ z = R\sin\theta \end{cases} \quad (2)$$

The position of the sound source can be determined by calculating the radial distance R , azimuth angle θ , and zenith angle ϕ from equations (1)-(2). The parameters could be calculated and expressed as equations (3)-(5). Where R1~R4 denote the distance between sound source and microphone array M1~M4 and C denotes the traveling velocity of sound wave.

$$tg\theta = \frac{\tau_{41} + \tau_{31} - \tau_{21}}{\tau_{21} + \tau_{31} - \tau_{41}} \quad (3)$$

$$cos\phi = \frac{C}{L}\sqrt{\frac{\tau^2{}_{31} + (\tau_{41} - \tau_{21})^2}{2}} \tag{4}$$

$$R = \frac{C \cdot \left[\tau_{31}^2 + (\tau_{41} - \tau_{21})^2\right]}{4 \cdot (\tau_{41} - \tau_{31} + \tau_{21})} \tag{5}$$

The time delay corresponds with the peak value of cross correlation function. If the cross correlation function of the signals received by microphone i and j is represented as $R_{ij}(\tau)$ .The time delay could calculated by equation (6).

$$\tau_{ij} = \arg\max(R_{ij}(\tau)) \tag{6}$$

Sound signal is time variable actually. We usually process sound signal in a very short time, for instance in 20ms, in short a time, it can be considered invariable, and this is the basic point of processing sound signals.

We make some experiments to test robot auditory localization system. The sound source is placed at 4m away from the microphone array. A multi-channels recording card is used to simultaneously record the sound signals from four microphones. Signals are band pass filtered at 250-16000 Hz to remove both high and low frequency background noise. This range was determined so as to retain as much useful information as possible. Sound signals received are divided into several frames, each of which has 512 samples. The noises involved in the sound would affect the accuracy on calculating time delays, there are 256 samples overlapped in the neighboring frames to avoid the blocking effect [5]. Sound endpoint detection which has simple calculation is adopted to detect sound signals, which can improve the performance of the system. When there is no sound, calculate Power Spectrum of the noise, and then reduce it from sound Power Spectrum. The time delay corresponds with the peak of cross correlation function. When the time delay of every microphone pair is got, we use the values to calculate the sound source position in the environment. The radial distance R , azimuth angle θ , and zenith angle ϕ could be got through equations (3)-(5). The localization simulation results are shown in Table 1.

From Table 1, we could see that noise greatly affects the localization results. So far, it is still one of the most difficult tasks to reduce the noise influence to sound source localization. In future, we'll find more effective means to solve this problem.

Table 1. Experiments results of the localization

	Parameter	θ	ϕ	R
L=0.2m	Theoretical values	70°	60°	4m
Quiet environment	Measured values	69.3°	63°	3.8m
	Deviations	0.7°	3°	0.2m
Noisy environment	Measured values	66°	70.5°	3.3m
	Deviations	4°	10.5°	0.7m

3 Virtual Reality Robot Teleoperation System

Virtual reality teleoperation is a natural and efficient human-computer interaction fashion [6-7]. The virtual reality robot teleoperation system is made up of data glove and stereoscopic glasses combine together with virtual reality software. The virtual robot is controlled by operator using data glove to complete task, the virtual robot is the agent of real robot, and thus the control to the remote true robot is carried out by controlling the virtual robot. Every movement of the virtual robot is transmitted to the real robot through WLAN, so that the virtual robot and the real robot always move synchronously. Meanwhile, real robot feedbacks information constantly for operator determine next task. It is a good human-computer interaction system.

The virtual reality teleoperation realization principle is shown in Fig 3.

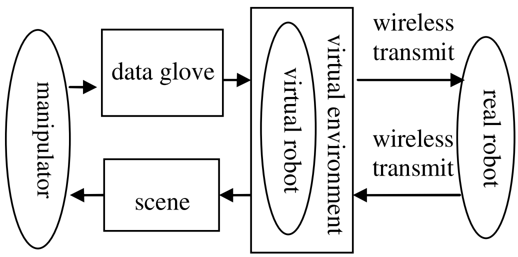

Fig. 3. Virtual reality teleoperation realization principle

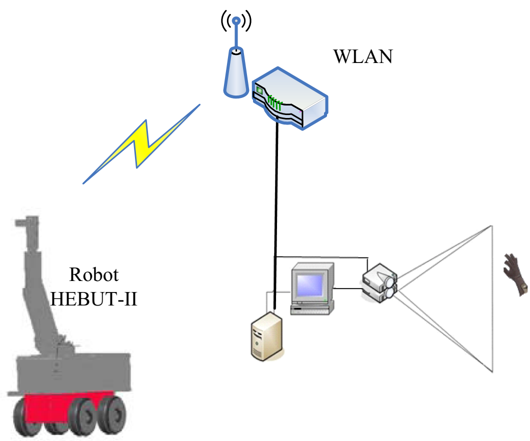

Fig. 4. Virtual reality robot teleoperation system

Operator in this system wears the data glove to send out instruction signals. That signals spread towards virtual robot. Virtual robot completes the corresponding action and feeds back to the operator. The virtual robot is the reflection to real robot, its move parameter of action and each joint can be passed to the remote real robot. The robot model in the virtual reality environment which acts as an agent to the real robot is the bridge of real robot contacting with operator. Virtual reality robot teleoperation system is shown in Fig 4.

In the whole operating process, the operator has to wear stereoscopic glasses, for our eyes could not see stereoscopic picture directly. The principle of producing a stereoscopic picture is light polarization. Two bunches of partial light are thrown to screen using two projectors. The operator then can see a stereoscopic picture using partial glasses. Data glove is used to operate target object in the virtual environment on the screen. The message is transmitted via WLAN between virtual environment and real environment. WLAN (Wireless LAN) has enough bandwidth; the bandwidth of this WLAN is 11Mbps, which is wide enough for our communication system.

The host computer is connected with two projectors, virtual environment can be thrown to projecting screen to produce stereoscopic picture. The data glove can operate stereoscopic picture directly. In the whole operating process, the operator has to wear stereoscopic glasses, for our eyes could not see stereoscopic picture directly. The principle of producing stereoscopic picture is light polarization. Two bunches of partial light are thrown to screen using two projectors. The operator only could see a stereoscopic picture using partial glasses.

Data glove which has 14 contact points is used to operate virtual robot in the virtual environment on the screen.

The robot model is set up using UG, for validating whether the module is similar to the real robot or not, we make simulation to the model. The experiment results prove that the model is very similar to the real robot. The environment scene is set up using 3dmax. The operation virtual environment based on EON is shown in Fig 5.

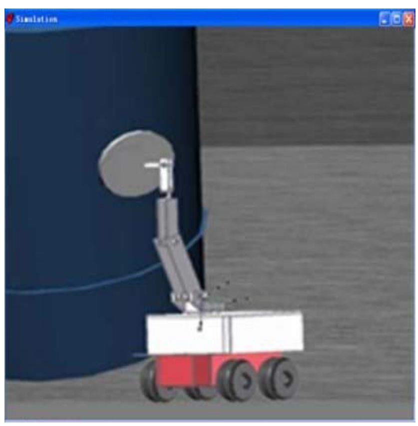

Fig. 5. Virtual environment based on EON

4 Search Realization Based on Robot Auditory and Virtual Reality

In the leaky chemical container mending task, when accidents occur with a crash sound, the robot will be aware and localize the leaky point. Sound source localization is realized by robot auditory localization system which is introduced in part 2. The leaky point position will be transmitted to the virtual environment via WLAN. The operator can use data glove to control the virtual robot to move in the virtual environment to the direction of leaky point, then the real robot also moves in the real environment to the leak point synchronously.

Because modeling error of the virtual environment and slide phenomena wheels exist inevitably, operators must use remote video guidance to eliminate these errors. The operator could judge whether position and pose of these two robots appear variance through observing remote videos and adjust them to keep consistent. The real environment inspecting interface is show in Fig 6. It can show videos from cameras on the robot and on the spot. The main window embedded in the interface display video from the camera on the spot, the other display video from camera of the manipulator. It is very effective for operator to manipulate the mending robot. The bandwidth of this WLAN is 11Mbps, which is wide enough for our communication system and video transmission. But we should avoid opening too many video windows at the same time considering for real time operation [8].

HEBUT-II robot consists of a mobile vehicle and a five-degree-of-freedom manipulator. The manipulator has five links which connected through rotary joints, so it is driven by five motors. Motors are controlled by PMAC (program multiple axis controller), and they occupy five of eight channels. Control signals of PMAC are sent to motor drivers, and then motors are driven by motor drivers to finish task. Because slide and slip phenomena exist inevitably, the real robot can hardly arrive at the leaky point accurately. With the operator's adjust; the robot can reach the leaky point successfully. When the vehicle arrives at the leaky point position and adjusts its posture, the leaky container can be repaired by constantly changing the postures of the manipulator.

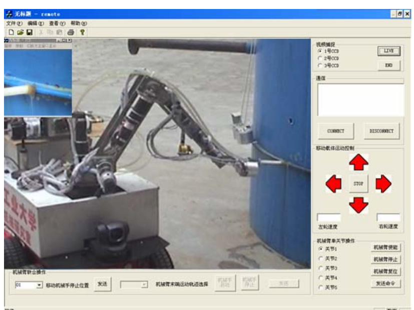

Fig. 6. Real environment inspecting interface

Operator's duty is to use data glove to control the real robot get to the leaky point position and to finish mending task. But this way may lead to collision between the robot and other objects because of operators' random operation. We install ultrasonic sensors on the real robot to protect the robot from danger. The robot should have the ability to avoid obstacle. Ultrasonic sensor is widely applied in obstacle voidance and navigation. In this system, ultrasonic sensors are used to form front and back sonar annulus which detecting obstacle in all directions. It is shown in Fig 7 and Fig 8. The characteristic of sensors layout is that they could provide a great deal of environment information.

Fig. 7. Mobile noumenon sonar array

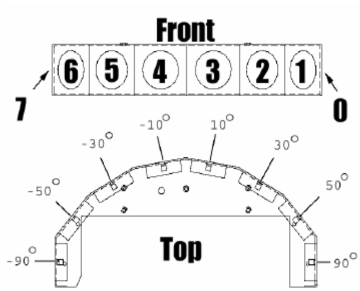

Fig. 8. Altrasonic sensors array

In the whole process, the mending robot can reach the leakage successfully and accomplish the mending task smoothly, no collisions happen. Experiments demonstrate that this method has good practicability and security.

5 Conclusion

In this paper, we propose a novel sound source search system. This system is composed of a robot which has a microphone array corresponding to human's ears and a virtual reality teleoperation system. The virtual robot is the agent of remote robot in the virtual environment. Data glove is used to operate the virtual robot to complete the control towards the real robot. The system can make the operator control the real robot to search the sound source fast and conveniently. The system is used in mending leaky chemical container; HEBUT-II robot can reach the leakage successfully and accomplish the mending task smoothly. It is proved to be practical and secure.

Acknowledgements

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