Applied Acoustics 126 (2017) 136–142

Contents lists available at ScienceDirect

Applied Acoustics

journal homepage: www.elsevier.com/locate/apacoust

The novel role of arctangent phase algorithm and voice enhancement techniques in laser hearing

He-yong Zhang [a,*], Tao Lv [a,b], Chunhui Yan [a,b]

[a] Changchun Institute of Optics, Fine Mechanics and Physics, Chinese Academy of Sciences, State Key Laboratory of Laser Interaction with Matter, Changchun 130033, China
[b] University of the Chinese Academy of Sciences, Beijing 10039, China

ARTICLE INFO

Article history:
Received 9 February 2017
Received in revised form 16 May 2017
Accepted 18 May 2017
Available online 30 May 2017

Keywords:
LDV
Laser hearing
Arctangent phase algorithm
Voice enhancement

ABSTRACT

At present, laser hearing has played more and more important role in the field of anti-terrorism and security defense all around the world. In order to acquire remote voice, a Laser Doppler Vibrometer (LDV) is established, the voice signal demodulation method is based on the arctangent phase algorithm. On the basis of the system, a kind of speech enhancement technology is used to improve the intelligibility of the noisy voice signals detected by the LDV system. First, based on the heterodyne detection theory, the detection principle and method which acquire voice by detecting throat vibration is introduced. Then a kind of speech enhancement technology is used to improve the intelligibility of the noisy voice signals detected by the LDV system. Finally, to validate this system and speech enhancement technology, some experiments are performed and the results indicated that the comprehensible speech signals within the range of 75 m can be obtained by self-made LDV. On the other hand, the speech enhancement technology can improve the intelligibility of the noisy voice signals detected by the LDV system effectively.

1. Introduction

Multimodal/multi-sensor surveillance systems are widely deployed today for security purpose [1]. Although a lot of progress has been made, particularly with the rapid improvements of color and infrared (IR) cameras and the corresponding algorithms for monitoring subjects at a large distance, audio information, as an important data source, has not yet been fully explored. A few systems have been reported to integrate visual and acoustic sensors. But in these systems, the acoustic sensors need to be close to the subjects in monitoring. Parabolic microphones could be used for remote hearing and surveillance, which can capture voice at a fairly large distance in the direction pointed by the microphone. But it is very sensitive to the noise caused by wind or sensor motion, and all the signals on the way get captured. Recently, all kinds of LDV have been widely used in industry inspection [2–7]. The prpducts such as those manufactured by Polytec and B&K Ometron can effectively detect vibration within two hundred meters with sensitivity on the order of 1 μm/s. For example, they have been used to measure the vibrations of civil structures like high-rise buildings, bridges, towers etc. at the distance up to 200 m. However, literature on remote voice detection using LDV is rare. Therefore, the study of the novel application of an LDV for remote voice detection will be the main focus of this paper.

LDV has the characteristics of long distance, non-contact and high sensitivity; it has been widely used in industry and military field [8,9]. Because LDV can detect and measure extremely tiny vibration of a target at a long distance, this motivates us to detect the tiny vibration of a target (vibration caused by the voice energy) at a large distance to acquire remote speech signal by LDV [10–14]. Most of the research results show that the commercial LDV based on 632 nm is applied for voice detection, this is not fit for realistic application due to its short detection range, also not convenient for the integration of demodulation and the voice enhancement algorithm. Therefore, this paper will focus on the arctangent phase algorithm and voice enhancement techniques in laser hearing. In fact, the realistic application system will be based on the near IR and eye-safe laser output, but this laser system has some troubles in target alignment in the wide field. So we will adopt the visible laser at 532 nm for the experiment to verify the demodulation and voice enhancement algorithm, and the all-fiber near IR LDV system is developing now in my LAB.

In this paper, a LDV system based on laser homodyne structure, arctangent phase demodulation algorithm and audio signal enhancement algorithms is developed, and it is used to detect long range audio signal. A few experiments are implemented to test its performance in the end.

* Corresponding author.
E-mail address: zhanghy@ciomp.ac.cn (H.-y. Zhang).

http://dx.doi.org/10.1016/j.apacoust.2017.05.024
0003-682X/

2. Experimental setup

Fig. 1 shows the schematic diagram of the LDV we developed. The LDV is composed of transceiver and signal processing units. The main parameters of the system are given in Table 1. A 50-mW single mode CW laser with the line-width less than 1 MHz at wavelength of 532 nm used as transmitted laser source. The output laser is divided into two beams by a beam splitter. One beam is modulated by Acousto-Optical Modulator (AOM) with 80 MHz frequency shift, this beam is taken as the local-oscillator (LO) beam. The other beam is transmitted to vibrating target perpendicularly through an optical circulator and telescope. Due to the vibration of the target (vibration caused by the voice energy), the reflected laser beam carries Doppler frequency shift, and it can be received by the same telescope, this beam is taken as the signal beam.

The LO and signal beam are mixed by a beam combiner then detected by a photoelectric detector. The detector output signal $\boldsymbol{u}$ is given as

$$u = \alpha A_o A_s \cos[\omega_{AO} t + \varphi(t) + \varphi_1 - \varphi_2] \tag{1}$$

where A_o and A_s are the amplitude of LO and signal beam, ω_{AO} is the frequency shift caused by AOM, φ_1 and $\varphi_2$are random phase, α is the photoelectric conversion efficiency, $\varphi(t)$ is the Doppler shift, which can be expressed as

$$\varphi(t) = \frac{4\pi S(t)}{\lambda} \tag{2}$$

where λ is the wavelength of laser, $S(t)$ is the vibration displacement. We can't get the object vibration characteristic directly because the detector output signal is optical beat signal. At this moment, we need quadrature demodulation circuit and arctangent phase algorithm to demodulate the beat signal to acquire the object vibration information. Fig. 2 and Fig. 3 show the demodulation and arctangent phase algorithm block diagram.

The detector output signal is halved by power divider in the demodulate process. The first part turns into u_I which mixes with the driving signal of AOM and passed through a low-pass filter. The second part turns into u_Q which has a 90°phase shift and mixes with the driving signal of AOM and passed through a low-pass filter. We use an acquisition card with 0.1 MHz sampling rate to sample u_I and u_Q. We can use arctangent phase algorithm to get the Doppler shift $\varphi(t)$ based on u_I and u_Q, then the vibration displacement can be recovered through $\varphi(t)$, also the speech signal will be output from the processing unit after some digital filtering. The baseband signal u_I and u_Q and the Doppler shift $\varphi(t)$ during in the process above are given as:

$$\begin{aligned} u_I &= \xi \cos[\varphi(t) + \varphi_1 - \varphi_2] \\ u_Q &= \xi \sin[\varphi(t) + \varphi_1 - \varphi_2] \\ \varphi(t) &= \arctan(u_Q/u_I) + m\pi + \Delta\varphi \end{aligned} \tag{3}$$

where ξ is the amplitude coefficient of the both signals, and the ambiguity of the arctangent function can be removed by a phase

Table 1
Main Parameters of the LDV System.

Parameters	Value
Wavelength	532 nm
Power	50 mW
Line-width	less than 1 MHz
Intermediate frequency (IF)	80 MHz
Detector	1 GHz bandwidth
Sampling rate	0.1 MHz
Effective range	50 m

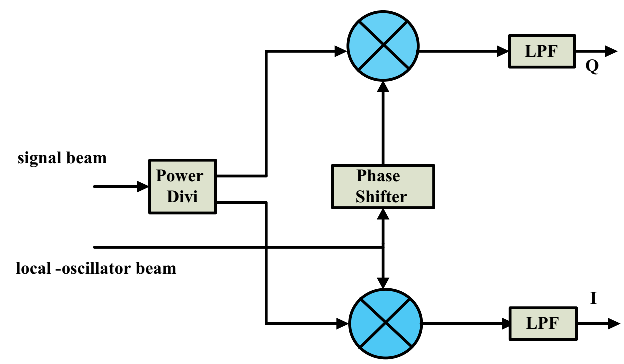

Fig. 2. The block diagram of demodulation.

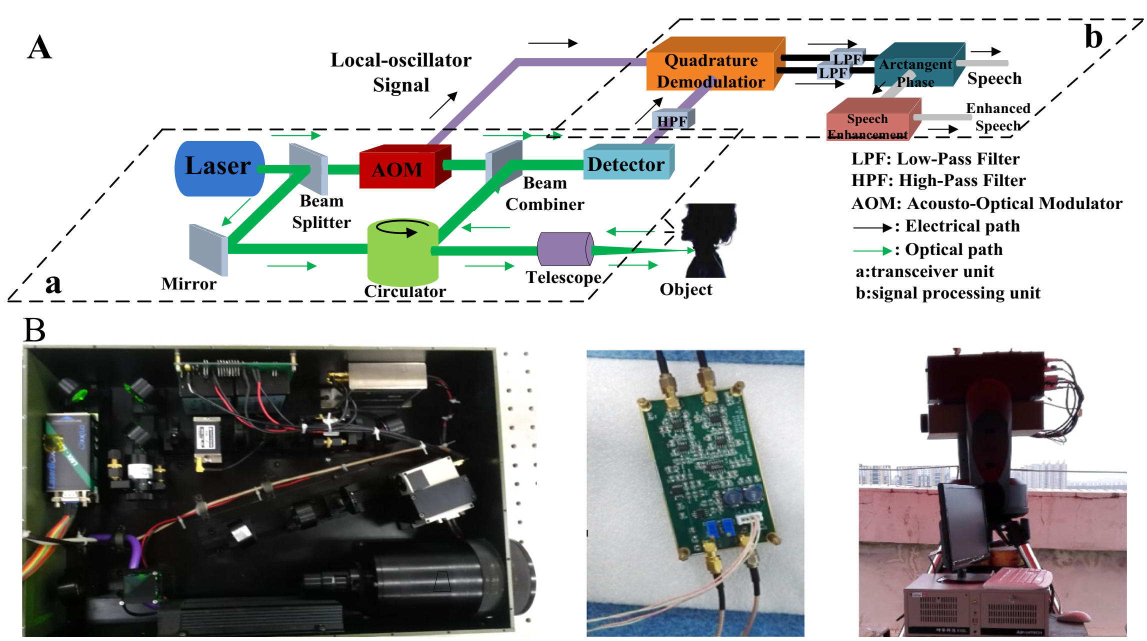

Fig. 1. (A) Schematic diagram of the LDV and (B) prototype of the LDV system.