Ultrasound sounding in air by fast-moving receiver

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Abstract. A method of ultrasound imaging in the air for a fast receiver. The case, when the speed of movement of the receiver can not be neglected with respect to the speed of sound. In this case, the Doppler effect is significant, making it difficult for matched filtering of the backscattered signal. The proposed method does not use a continuous repetitive noise-sounding signal. generalized approach applies spatial matched filtering in the time domain to recover the ultrasonic tomographic images.

1 Introduction
Ultrasonic sounding systems in the air are widely used in ultrasonic machine vision tasks for the robot orientation in space at different speeds [1]. Modern cars robots rely on lidar [1, 2] and radars [3, 4] in the orientation in space, but this solution is costly. Ultrasound systems are used only at low speeds [5–7]. In addition, the range of ultrasound systems is not large, making them difficult to use at high speeds. Limiting speed with ultrasonic sensing due to the small speed of sound. During the period until the signal returned from the target locator time to shift in space at a distance of more than a quarter of the wavelength [8, 9]. But for unambiguous images by monostatic sounding measurements necessary steps less than a quarter wavelength. If we apply a short pulse signal for sounding, it must be repeated each time the system is shifted by a quarter wavelength. Since the motion is fast repetition period is reduced so that the spatial distance in distance between adjacent pulses is much smaller than the depth sensing. This creates a ghosting of images of objects in range and does not allow one to visualize the object. The solution to this problem by increasing the pulse repetition rate leads to a sparse synthetic aperture, and consequently to an increase in the level of artifacts. One way of overcoming this problem would be the use of broadband probing signals of different shapes. Such signals allow to distinguish between the different positions of the probing system. For example, use of wideband signals with different carrier so that the signal spectra do not overlap. However, this method does not provide an ultra-wideband sensing and obtain the best resolution in range.

It is proposed to develop methods of ultrasonic sensing to visualize the scattering inhomogeneities in fast motion radar system on the basis of noise-like signals to enhance the uniqueness of the measurement. Since this signal is a UWB obtain the maximum possible range resolution. Furthermore, the signal is non-repetitive, increasing visualization unambiguous in range.

2 System overview
It is proposed to consider the scheme of measurements shown in Figure 1. In the scheme of measurement used linear scanner which moves the receiver with the speed V. In this case, the emitter is not mobile and is in the center of the range of movement of the receiver. The test facility is located in the h range.
We assume that the transmitter and receiver are not isotropic directed and describes the free space Green’s function. Consider the problem in the approximation of single scattering. Let the signal emitted by the function $S(t)$. We represent the distribution of the scattering inhomogeneities as a function $p(x, y)$. The signal $U(t)$ at the receiver in the approximation of single scattering can be written as:

$$U(t) = \int \int p(x, y) \frac{S\left(t - \frac{1}{c} \left| r_s - r \right| + \left| r_r - r \right| \right)}{\left| r_s - r \right| \left| r_r - r \right|} \, dx \, dy,$$

where $c$ – the speed of sound in the environment; $r_s = (x_s, b)$ – coordinates of the emitter; $b$ – distance of the radiator from the scan line; $r = (x, y)$ – the coordinates of the integration in the environment; $r_r = (Vt, 0)$ – receiver coordinates.

It was numerically modeled noise-sounding signal with a frequency band of 37 to 43 kHz. The waveform is represented in Figures 2 and 3.

On the basis of the direct problem solution by the equation (1) was modeled receiver signal in the presence of two scattering objects at a distance of 50 cm from the scan line. During the scanning receiver has moved a distance of 90 cm at a speed of 17 m/s. The speed of sound was taken to be 330 m/s.
It can be observed that the signal is always present, and it will not be repeated, while maintaining a broad band, and therefore has a lot of energy, which gives reason to expect a high level of signal-to-noise ratio.

3 Solving the inverse problem

Under the inverse problem solution refers to the determination by the measured signal $U(t)$ functions $p(x,y)$. To solve this problem has a method of spatial matched filtering in the time domain. According to this method, the solution can be written as:

$$p(x,y) = \int_{t_{\text{min}}}^{t_{\text{max}}} U(t)S\left(t - \frac{1}{c}[|r_1 - r|] + |r_2 - r|\right)dt,$$

where $t_{\text{min}}$ – the start time of the measurement; $t_{\text{max}}$ – end time of measurement.

According to this equation, it was restored image of two lenses at a distance of 50 cm, which is shown in Figure 4.

In Figure 4 you can see that the resolution obtained in the scanning plane of the order of 1 cm which is close to the diffraction limit for the considered frequency range. Of course, the presence of artifacts associated with the use of noise-like signal.

To estimate range resolution numerical simulation was carried out with two point lenses at ranges of 40 and 50 cm. Note that Spreader located opposite the center of the finish. Figure 5 shows the reconstructed image of two lenses at different distances.
According maxima width can estimate range resolution of 5 cm, which corresponds to the expectations for bandwidth.

Numerical simulation results show that the proposed method provides a resolution of the images is close to the theoretical limit. Also, the receiver allows to consider the movement speed at an arbitrary speed of sound.

To test the ability to visualize images of extended objects were numerically simulated probe at a speed of 4 m/s in the band between 20 and 26 kHz. The object length of 40 cm was placed at a distance of 50 cm from the scanning system parallel to the axis of motion. After processing according to the equation (1) was obtained image of the object represented in Figure 6.

It should be noted that the reduced signal to noise ratio by increasing the speed of the receiver. This is due to the fact that the duration of the signal is reduced with respect to the extent of the restored image.

4 Conclusion
The proposed method is an ultrasound probe in the air when moving at high speed receiver using noise-like probing signals. Image restoration method based on matched filtering. Numerical simulation results showed the possibility of obtaining the spatial resolution is close to the theoretical limit. By increasing the speed of movement of the receiver level artifacts in images produced increases.

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References
[1] Li J, Bao H, Han X, Pan F, Pan W, Zhang F, Wang D 2016 Multimedia Tools and Applications, 75(1) 1–23 doi: 10.1007/s11042-014-2221-x
[2] Barfoot T D, McManus C et al 2016 Springer Tracts in Advanced Robotics 114 487–504 doi: 10.1007/978-3-319-28872-7_28
[3] Schuster F et al 2016 IEEE Intelligent Vehicles Symposium Proceedings 7535485 doi: 10.1109/IVS.2016.7535485
[4] Zhu Y 2015 16th International Workshop on Mobile Computing Systems and Applications 75-80 doi: 10.1145/2699343.2699363
[5] Jong-Hann Jean et al 2013 IEEE International Conference on Mechatronics and Automation 1234 – 1238 doi: 10.1109/ICMA.2013.6618090
[6] Xuming Pei et al 2010 IEEE International Conference on Mechatronics and Automation 1245 – 1249 doi: 10.1109/ICMA.2010.5589942
[7] Bukhari Ilias et al 2016 IEEE Symposium on Computer Applications & Industrial Electronics (ISCAIE) 189 – 194 doi: 10.1109/ISCAIE.2016.7575061
[8] Aiordachioaie D et al 2014 Autonomous Vehicles: Intelligent Transport Systems and Smart Technologie 57–79
[9] Juha Ylitalo et al 1995 Ultrasonics 34(2–5) 331–333