Ultrasound in vehicle system for on-board monitoring

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Abstract: - Different types of technological devices have been proposed for indoor positioning but most are hindered by various kinds of interference, due to sources of light or heat in the environment. These might include infrared radiation and artificial vision, as well as radio-frequency, which often need specialized electronic circuitry in order to function properly. In restricted spaces (e.g. aboard vehicles), monitoring can be performed at low cost with small, reliable devices. These can be relatively simple electronic circuits, which implement various algorithms in order to obtain precise effective signal processing through the use of ultrasound waves. Ultrasound waves in air are affected much less than other forms of radiant energy; they are also efficient under different environmental conditions, besides being compatible with light, temperature variations, and electromagnetic fields. In particular they are very suitable for in-vehicle monitoring. This article treats the development of an ultrasonic sensor based on ferroelectric polymer technology which possesses all of the forementioned characteristics. A network of four transmitter/receiver elements is set up on-board a vehicle and is driven in the frequency range between 30kHz and 120kHz. Results on inside positioning are given by implementing cross-correlation algorithms and finally discussed.

Key-Words: - Automotive Engineering, Vehicle Safety, Position Control, Piezo-polymer, Ultrasonic Transducers, Sensor Networks, Signal Processing

1 Introduction

On-board monitoring for vehicles undoubtedly improves passenger and vehicle safety. In the last decade the development of instrumentation systems (which allow the assessment of driver and vehicle performance), have been amply investigated [1]. As far as the safety of the driver is concerned, intrusive devices for the evaluation of physiological indicators such as ECG-, EEG-, and EOG-based systems, as well as ethylometer (e.g. alcolock system introduced by Volvo[2]) have already been commercialized [3]-[5]. However, vehicles are not equipped with inside 3D positioning systems.

In many circumstances in which passengers are babies, people with reduced motor skills, elderly or, even in some cases, animals a 3D knowledge of the unstructured inside environment enhances safety levels. Many systems based on various sensorial technologies such as infrared radiation, radio-frequency, artificial vision and ultrasounds (US) have been proposed for positioning inside a restricted area. Almost all of these technologies are little suitable for inside positioning, and particularly for on-board vehicle monitoring, since they are expensive and unwieldy, in some cases, or are hindered by interference due to environmental light or heat sources. Furthermore, in many cases, they need specialized electronic circuits to function.

US sensors in an air seem, at present, to be the most reliable technology for on-board monitoring. This article covers the piezo-polymer ultrasound sensor, based on polyvinylidenefluoride (PVDF or PVF_2), previously investigated by authors in the field of bio-sonar mimesis [6].

First the working principle of the transducer and the electronic unit is briefly described, and then the operation of the 4-sensor network located on-board for indoor monitoring by the implementation of the cross-correlation technique is outlined. The US system is aimed at improving the performance of certain kinds of algorithms such as ANGEL (ANalyzer Gas Expiratory Level). The ANGEL system needs the distance of the alcohol source from the sensor to correctly measure the blood alcohol concentration of the driver.

2 The Ultrasonic Sensor

As far as acoustic wave generation and detection are concerned, only a restricted number of transducer technologies are suitable for the fabrication of reliable and competitive sensors for US application in air. In particular, ferroelectric polymer technology has demonstrated its worth with respect to standard piezoelectric materials [7], because of its very low cost, light weight, reduced dimensions, conformability, interference resistance, and ease of assemblage and mounting.

The PVDF hemi-cylindrical transducer has been fabricated and characterized at low frequencies in the range between 30 kHz and 120 kHz. Both the transmitter and the receiver were realized by curving a 15 mm x 3 mm strip of PVDF stretched along direction 1 (or “machine direction”) and polarized through use of a high electric field along direction 3 (or “transverse direction”) as shown in Figure 1.

The longitudinal motion of the flat sheet, having a thickness of 48 µm and including silver-ink metallization on both large faces, is converted into radial vibration by the curved geometry of the device allowing the generation of acoustic waves in direction 3. The resonance frequency depends on the physical characteristics of the PVDF , such as mass, Young’s modulus, etc., and the inverse of the bending radius. Change in the radius r can be seen as a change in the length l= πr of the curved piezo film. This peculiarity improves the performances of the polymer transducer which works in both constant frequency (CF: constant bending radius), and frequency modulation modalities (FM: varying the bending radius) [8].

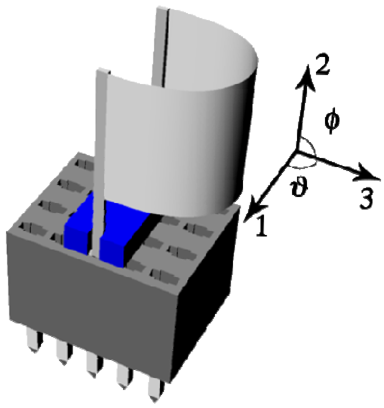

Fig.1. Assembling of PVDF curved transducer

Due to the low efficiency of the piezoelectric film, the driving circuit of the transmitter generates high output voltage (e.g. several hundred Volt) around the resonance. As shown in Figure 2, the circuit is principally composed of an operational power amplifier followed by a voltage booster transformer, which generates sinusoidal burst signals up to several hundred Volt, to drive the US transmitter working in the converse piezoelectric mode.

In reception, the same transducer is used, in the direct piezoelectric mode, and its weak voltage signal, generated by incoming ultrasonic waves, is conditioned firstly with a high-gain low-noise amplifier [9], then filtered and again amplified in order to carry out a suitable signal to be processed by computer.

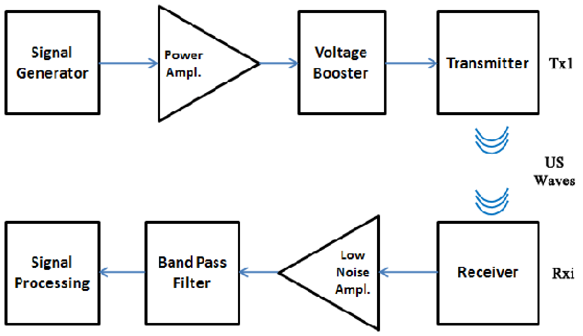

Fig.2. Block diagram of circuits used for conditioning the transducer signals in both transmission and reception.

3 Sonar Characterization

Thanks to its piezoelectric characteristics (such as a low quality factor, Q = 6) the PVDF transducer works in a broadband frequency around the resonance, which is preferable in the FM modality. FM signals are effectively used by bats for ranging, and similar techniques are under investigation at different frequencies (30kHz, 60 kHz, 90 kHz, and 120 kHz) in the attempt to emulate bio-sonar (Figure 3).

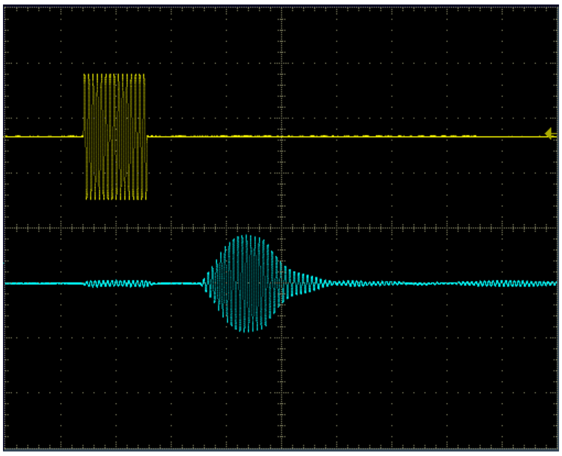

Fig.3. 60kHz burst signal applied to piezofilm (yellow), and echo received on a plane positioned at 0.3 m (blue).

The radiation pattern was characterized by measuring the sound pressure level, at the minimum distance of 0.30 m in two different planes <1,3> and <1,2> for θ and φ in the range angle of -90°/+90° respectively. The average pressure level of the 4 transmitters is shown in Figure 4.

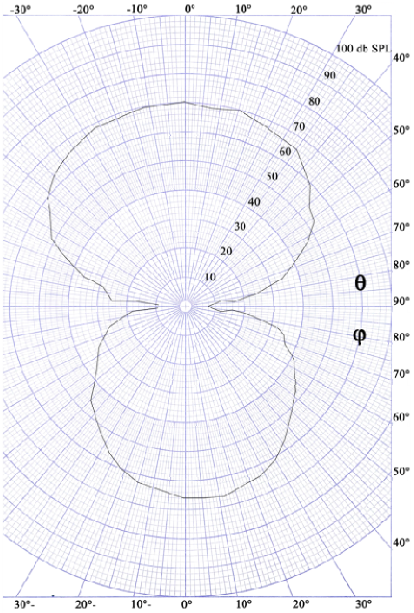

Fig.4. Transmitter radiation pattern in the per perpendicular planes <1,3> and <1,2>.

Assembling the piezo-film in an imperfect hemi-cylindrical shape originates spurious lateral radiation and generates secondary harmonics with consequent loss of radiating energy.

4 Monitoring Routine

To precisely locate the position of a specific body at a given time in a closed environment (such as the interior of a car), a data scanning of the surrounding objects already placed in that space is needed.

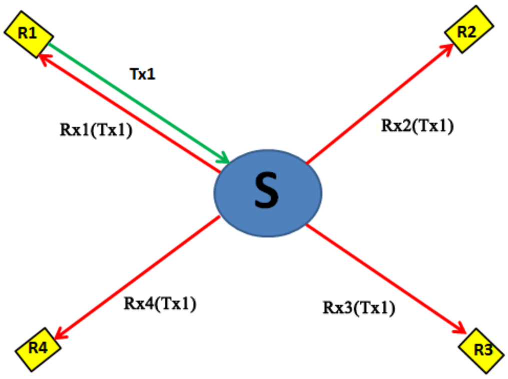

Fig.5. Ultrasonic positioning system based on four transmission and reception points. During a complete cycle each transducer operates both as transmitter Txj and receiver Rxj, while other n transducers (n≠j) work only in reception mode.

Figure 5 shows the setup used in order to monitor the position of a body S in the car compartment. Four PVDF sensors (R1, R2, R3, R4) are placed on board, each one, working in the converse and direct modalities, has capabilities of both transmitting and receiving US signals. While R1 starts to transmit an ultrasonic pulse (Tx1), R2, R3 and R4 work as receivers. After transmission, R1 switches in reception mode too. The US signal bounces back when it hits the target S, or is reflected with different angles, and is received by the sensors.

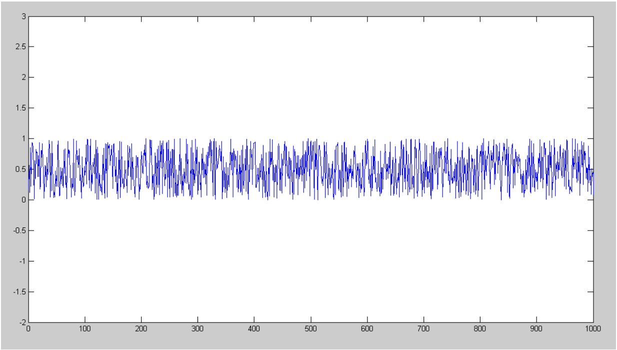

Fig.6. Broadband signals similar the pseudo-random pulses Tx1, Tx2, Tx3, Tx4

Each received signal is cross-correlated (Xcorr1) with the transmitted signal Tx1 (Figure 6). Every Xcorr1's maximum point represents a time delay of signal reflection from the target and other bodies (Figure 7). Hence any N relative maximum in the Xcorr1 is detected and the corresponding time is stored in a matrix (M1).

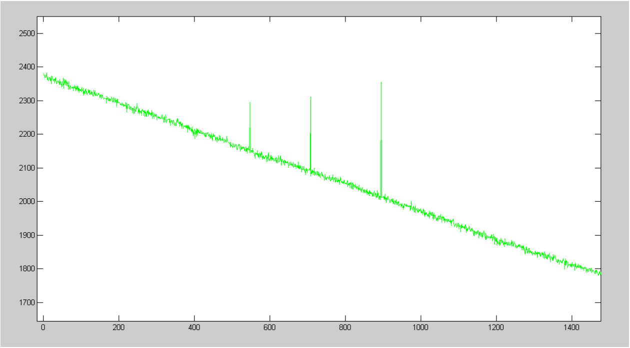

Fig.7. Xcorr1's maximum point represents a time delay of signal reflection from S and other bodies.

Then R2 sends a signal (Tx2) and switches into reception mode.

The sensors will receive four signals to cross correlate with Tx2 and determine Xcorr2's maximum points. The corresponding time is stored in a second matrix (M2).

Likewise M3 and M4 are determined by signals Tx3 and Tx4 emitted by R3 and R4, and received by all 4 transducers respectively.

At the end of the cycle one single matrix (Ms) including M1, M2, M3 and M4 is completed. The Ms contains all the data about the actual position of S. Cyclically performing these operations n times a template with n matrix (Ms1, Ms2, Ms3, Ms4, …Msn), the data are stored, which fully characterizes the system environment: position of sensors, wall position, sound speed, surrounding objects. In order to locate the target a measurement cycle is performed, then Ms is calculated, and finally it is compared with the stored template by a cross correlation index (CCi). The target is located when CCi reaches its maximum value.

5 Signal Characteristics

Sorting out the best signal to use is one of the most important factors in ensuring that the system is working properly. Indoor 2D or 3D positioning systems require that the signals transmitted by R1, R2, R3 and R4 satisfy a specific set of characteristics.

The main problems to deal with are the choice of:

- Signal wavelength λ
- Signal Bandwidth
- Signal time duration

In order to avoid the situation in which the signal overrides the target without hitting it, λ must be much smaller than the average size.

In the frequency range of operation, which goes from 30 kHz to 120 kHz, λ is in the order of a few millimetres, suitable for the most sophisticated, fine-grained location systems. In addition, the low quality factor $Q<6$ of the PVDF curved transducer is enough to send (and receive) broadband signals similar to the pseudo-random pulses Tx1,...Tx4.

The signal time duration of Tx1…Tx4 pulses is a key parameter in order to avoid partial overlapping of the transmitted signals with the received echoes. This could happen if the signal is too long with respect to the time needed to cover the distance to the nearest target.

6 Discussion

The investigation of a broadband ultrasonic location system for on-board monitoring using piezo-polymer US transducers was carried out in this paper. The sensor shows great potential for quickly becoming a benchmark for all the instrumentation systems that depend on a complete and reliable localization method to work. The presented transducer was characterized in detail in order to emphasize its ability to operate using broadband signals. Small, inexpensive piezo-polymer transducer elements were employed in the units using a compact mounting method. The easy placement, the fact that it is not cumbersome and is interference-free all make the implementation of this system feasible in any kind of car or van. A cross-correlation technique based on pseudo-random signals was implemented in order to highlight the performance of the transducers using a system of cyclic templates and a cross-correlation index. A better and more effective use of the existing passive safety systems could be achieved by the proposed device (e.g. time optimization of the airbags activation depending on the driver and passengers exact position at the moment of the impact), opening a new and unexplored field for all the possible, non-intrusive, on-board applications.

7 Conclusion

Preliminary results have shown that a system with US receivers and transmitters placed around a determined object and a centralized processing signal system results in an accuracy of less than 0.01 m compatible with normal movement of passengers. In this context it is of great importance also to measure the velocity of bodies displacement to reveal situation in which passengers aren’t in quite position. Further development of this system could set new standards in safe driving and the prevention of car accidents.

Acknowledgements

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