AN ACOUSTIC OBJECT RECOGNITION SYSTEM

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Abstract

This paper presents the results of a study on use rapid transform to analysis of acoustic echo signals in an acoustic object recognition system. The echo signals are analysed in the time invariant rapid transform domain and compared with reference patterns stored in memory. The application of fast shift invariant rapid transform in signal classification increase the capability of the system to distinquish and identify different objects.

Key words

Acoustic object recognition, rapid transform, echo signal processing

Introduction

Ultrasonic waves can be used for variety of sensor applications, such as distance measurements, velocity measurements, range finding, etc. [1,2,3]. A particular application is object recognition [4]. The ultrasonic scanning systems for rangefinding or imaging are based on either rotating transducers, or acoustic phased arrays. The speed of the former method is strongly limited by the mechanical scanning system. The later method has limited viewing angle. Generally, all ultrasonic imaging systems suffer from poor resolution, due to a number of unfavorable characteristic of ultrasonic waves and transducers, in particular for applications in air [3]. Therefore there is increasing interest for simple non-imager acoustic object recognition systems [4]. These systems use the relation between the shape of an object and the characteristic properties of its echo pattern. The object recognition system presented in this paper is based on the new method of analysis of echo patterns, i.e. acoustic waves reflected by the objects. The reflected signals are analysed in the time invariant rapid transform (RT) domain [5] and compared with reference patterns stored in memory. The application of fast shift (thus time) invariant RT in signal classification and recognition overcome some problems occuring in classical implementations of similar systems (signal mormalization and time reference) and increase of the capability of the system to distinguish and identify different objects.

System description

Block scheme of the proposed acoustic recognition system is on Fig.1. Because accurate imaging of the object is no necessary, we use only a low-cost electrostatic transducer produces an ultrasonic burst in the

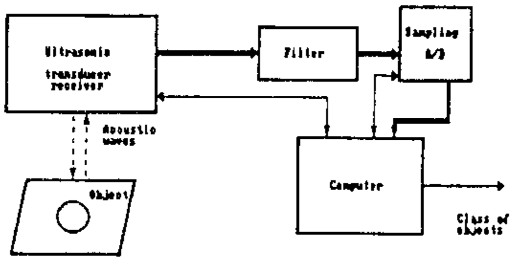


Fig.1 The system configuration

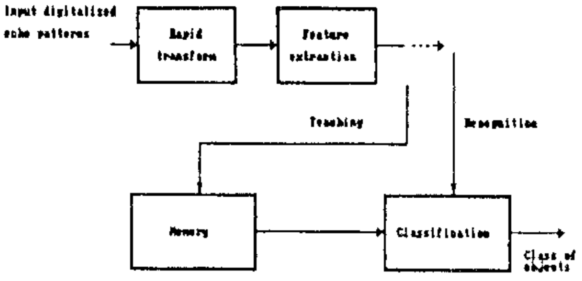


Fig.3 The recognition process

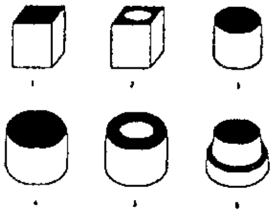


Fig.4 The six test objects

Fig.1
The system configuration

order of 70 kHz, with a pulse width of 0.2 ms. This transducer directs the ultrasonic burst downwards to the object placed on a base-plate. The acoustic wave is reflected by the object and is received by the same transducer/receiver which than sends its output signal through the filter and sampling & A/D converter to the micro-computer (control and analysing part of the identification system). According to the acoustic transducer/receiver characteristic the pass-band filter from 35 kHz to 120 kHz have been used. The signal corresponding to the acoustic echo patterns of the object have been sampled and digitalized to 256 samples with 8 bit dynamic range, at 1.2 MHz sampling frequency.

The sampling circuit imput receiver gain and bias are adjustable to obtain an optimal use of A/D converter range. The digitalized signal is supplied to the computer system, in which the rest of the recognition process takes place. The trigger for the acoustic burst is also generated by the computer.

Rapid transform

The rapid transform (RT) [5] is a fast shift invariant transform. The RT is useful for pattern recognition, if the position of the pattern is unknown or the pattern is moving [6]. In the following, we will quickly review the RT.

We will use the following notation: The set of input values $\{x_0, ..., x_{N-1}\}$ is represented by a vector x. The RT of x is noted as $\tilde{x}$ thus, we can write

$$\tilde{x} = RT\{x\} \tag{1}$$

Figure 2 is a four-point signal flow graph of the RT. It is similar than a four-point signal flow graph of the Walsh- Hadamard transform (WHT) in which operators $(x_i + x_j)$ and $(x_i - x_j)$ are replaced by operators $(x_i + x_j)$ and $|x_i - x_j|$. However, the properties of these transforms are quite different. WHT is fast orthogonal transform and RT is nonlinear fast shift invariant transform.The RT requires $N = 2^n$ input samples, where n is a positive integer. Each collumn in Fig.2 correspond to a particular computational step. n steps

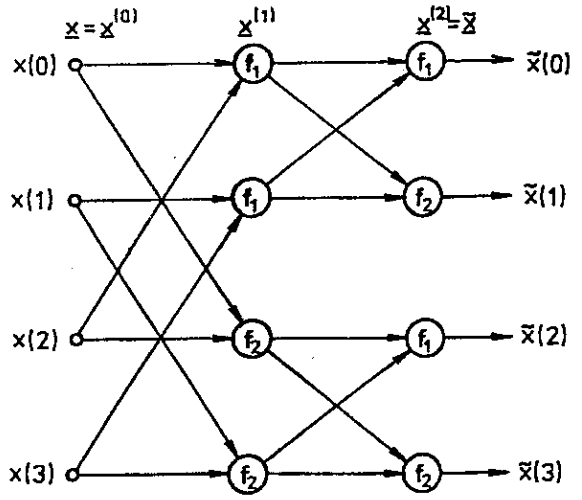


Fig.2
Signal flow diagram of the class of fast translation invariant transforms CT, for $N = 2^2 = 4$. For RT use operators $f_1(x_i, x_j) = (x_i + x_j)$ and $f_2(x_i, x_j) = |x_i - x_j|$

are required. In general the variables in any column $(r + 1)$ are calculated from the variables in the preceding column (r) by

$$x_i^{(r+1)} = \left(x_i^{(r)} + x_j^{(r)}\right) \tag{2}$$

$$x_j^{(r+1)} = \left|x_i^{(r)} - x_j^{(r)}\right| \tag{3}$$

with $n = \log_2 N$, $s = 2^{n-r-1}$, $t = 2^r$, $m = 0, ..., s-1$, $l = 0, ..., t-1$, $i = m + 2ls$, $j = m + (2l + 1)s$.

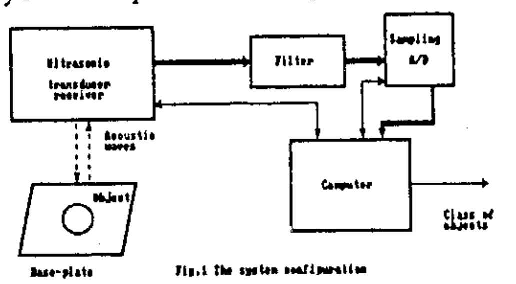
In [7] RT was generalized in which the two spetial commutative RT operators $(x_i + x_j)$ and $|x_i - x_j|$ (see Fig.2) are replaced by any two commutative operators

$$\begin{aligned} f_1(x_i, x_j) &= f_1(x_j, x_i) \\ f_2(x_i, x_j) &= f_2(x_j, x_i) \end{aligned} \tag{4}$$

such as $\max\{x_i, x_j\}$, $\min\{x_i, x_j\}$ or $(x_i + x_j)^2$, $(x_i - x_j)^2$, etc. Moreover, if the input patterns are binary, then logical operations, such as x_i .AND.x_j and x_i .OR.x_j, are also commutative and can be applied in the transforms. All the transforms which are based on two commutative operators can be referred to as a class of fast translation invariant transforms, denoted certain transforms (CT). This generalization is useful because some commutative operators f_1 and f_2, such as logical operations, can be implemented faster in digital hardware, than the two operators used in RT. Furthermore, the generalization offers additional flexibility [6]. Generally RT is the fast shift invariant transform, which is useful for shift invariant (and thus in our case for time invariant) signal classification and recognition. Because of recursive nature of calculation and use of very simple operators it can be simply implemented in both the software or in dedicated digital hardware [8].

Recognition process and experimental results

The echo pattern is characteristic for the shape and size of the object. The echo pattern of the object under investigation is sampled, digitalized and stored in the memory of the computer. The echo pattern is compared



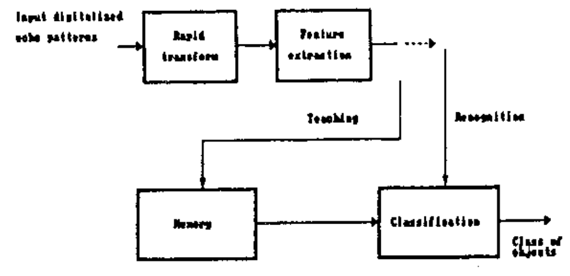


Fig.3
The recognition process

successively with a number of reference patterns. Identification is possible when there is a significant correlation between the received signal and one of the references. In classical implementations of similar systems [4], the matching is performed in the time domain.

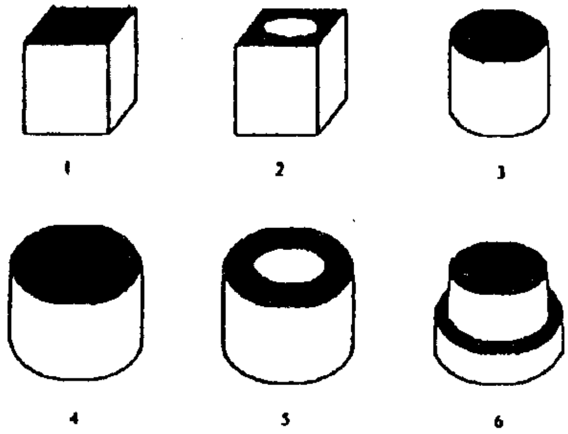


Fig.4
The six test objects

These methods suffer from drawbacks of pattern normalization and time reference, which rather complicate the classification process. To overcome these drawbacks we introduced a new method of echo pattern matching, which is performed in the time-invariant RT domain.

Fig.3 gives an overview of the recognition process. The first step in the recognition process is RT of the input digitalized echo patterns. As a result of this step we obttain time invariant RT coefficients (i.e. features) of digitalized echo patterns. The next step is feature selection, i.e. selection of those RT coefficients which carries the relevant information about recognized objects. According to the excellent pattern recognition properties of RT it is possible to choose only a very small amount of RT coefficients (usually less than 5%) [6]. In teaching mode of the process, the selected features are feeded to the computer memory. In recognition mode of the process, the selected features enter to the classification procedure. We choose a simple classification procedure based on the normalized Euklid distance

$$d_E\left({}^k\tilde{x}, {}^l\tilde{x}\right) = \sqrt{\sum_{i=1}^{M}\left({}^k\tilde{x}_i - {}^l\tilde{y}_i\right)^2} \tag{5}$$

and

$$d_E^0 = \max_{k,l}\left\{d_E\left({}^k\tilde{x}, {}^l\tilde{y}\right)\right\} \tag{6}$$

finally

$$d_{EN} = \frac{d_E}{d_E^0} \tag{7}$$

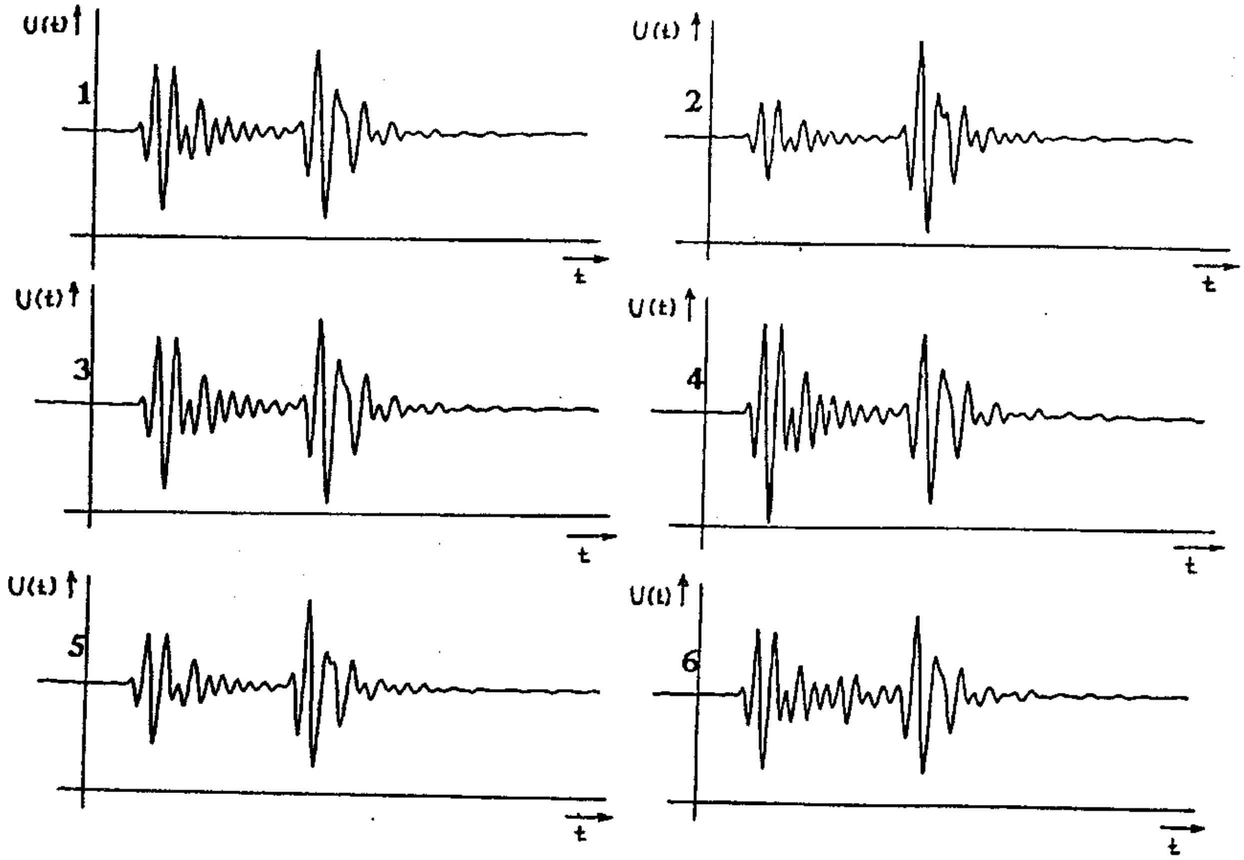


Fig.5
Samples of received echo signals of the six test objects

Where ${}^{k}\tilde{x}$, ${}^{l}\tilde{x}$ denotes the vectors of M selected RT coefficients (features) of echo patterns (i.e. objects) k, l. The verification of the qualities of the proposed system were derived from practical tests. Tests were done on six different objects (Fig.4). The objects have characteristic shapes and corresponding samples of received echo signals can be seen from Fig.5. For the experiment all the six objects are put into reference memory, after which an object is placed on the baseplate. A complete measurement and recognition process is repeated 400 times. For each measurement the choise made by the system is displayed, together with the normalized inter object Euklid distances vector. The influence on decreasing of number of RT coefficients (i.e. number of selected features) on detectibility of the test objects was also studied. The normalized inter object Euklid distances matrix for 5% of RT coefficients is on tab.1. As we see the objects are detectable in the RT domain, even if the number of used RT coefficients (features) is decreased rapidly from original 256 to 12. The demonstration of advantages of use of RT in acoustic object recognition can be made using confusion matrix of the recognition process (tab.2). In the first column the actual object is noted, followed by the decision (in percentages) made by the system. It is clear that the object 6 and 2 can be very well recognized but there is some confusion between objects 1 and 3, but in generally the results of recognition process are very satisfied.

Conclusion

The application of RT in signal classification and recognition increase the capability of the acoustic object recognition system to distinguish and identify different objects. According to the use of low-cost componets and subsystems it may be used for fast identification of an object out of a class of known objects in various industrial applications.

01	02	03	04	05	06	
0.0	0.794	0.619	0.858	0.909	0.794	01
	0.000	0.666	0.804	0.779	0.511	02
		0.000	0.770	0.861	0.571	03
			0.000	1.000	0.686	04
				0.000	0.651	05
					0.000	06

Table 1

Normalized inter object Euklid distances matrix for 5% of RT coefficients (i.e. 12 features)

Actual object	Decision (%)					
	01	02	03	04	05	06
01	90.2	9.3	0.0	0.4	0.1	0.0
02	0.0	100.0	0.0	0.0	0.0	0.0
03	8.5	0.0	91.1	0.0	0.2	0.2
04	0.2	0.0	0.0	96.2	0.0	3.6
05	0.0	1.6	0.0	0.0	98.4	0.0
06	0.0	0.0	0.0	0.0	0.0	100.0

Table 2

Confusion matrix of the recognition process

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