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System Identification Applied to Ultrasonic Detection Problems

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<i>Abstract</i> <p>The possibility of providing the robots with characteristics like flexibility and adaptability is dependent of how powerful its sensors systems are and how good are the techniques to extract and interpretate the collected information. In order to fulfill as much as possible such characteristics, an ultrasonic sensor system was previously developed in the department of Industrial and Electrical Engineering and Automation at Lund Institute of Technology. Based in the ultrasonic Information produced by the 200 KHz sensor of the system, a method for object identification is developed and presented as well as the guidelines for its use. The applicability to other kinds of information than the ultrasonic one, can be considered as well.</p>			
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1. Introduction

In this chapter an overview about the need for the robots to have available suitable information so that flexibility and adaptability can be added to the robots systems, is presented. The use of ultrasonics and the idea behind an ultrasonic equipment is described and in the end a problem will arise as being the main goal of this work.

1.1 Robots and the sensing ability

The idea of a robot reflect the human wish of developing machines capable of actions and behavior similar as much as possible to the man. Nevertheless, between these goals and the machines of today the gap is huge. It is of common knowledge that in the present robots are largely used in many areas, such as assembly lines in industry. The kind of tasks performed by these robots are typicly repetitive jobs executed continuously, one action after the other non-stop. Still they can do many tasks and are very useful, but also they are constrained to their working cycles not being able of adapting themselves to the working environment, take decisions, be "intelligent". One strong reason for it are the sensors of the the robot system. These sensors are usually based only in simple measurements (like scalar values) imposing important limitations to the systems using this information to control and decide their actions. However robots systems capable of making their own decisions, being flexible and adaptive to it own work space, are needed. It is thus necessary to develop new strategies, methods and measurement systems so that rich information can be supplied (rather than simple scalar information) and used toward the robots enhancing the range of possibilities.

The possibility of giving to a robot the chance to "see" in some way it own workspace is a characteristic of great potential. A popular method to provide the robot the capability of identify several characteristics of it own working space are the vision systems. Nevertheless there are several drawbacks that impose important restrictions to these kind of systems. The methods used to extract the required information form the images are complex. Image processing is difficult to perform resulting in limited information, big computational effort and a high coast associated with the systems. Also control action depending on this kind of information to be used in the feedback loop, become slow.

Systems based in ultrasonics are other kind of systems with several attractive features, that can provide information about the robot's workspace. The low coast of such systems, small dimensions, a fairly simple hardware compared with other systems and ultrasonic information based on the topology of the working space are some indicators of the capabilty of these systems.

An important point (for any sensor system) is the possibility of object identification. With in a certain universe of objects the decision about which object is being measured, or if it is a different kind of object, as well as other types of analysis would add a valuable source of flexibility and versatility to these kind of systems.

The present thesis is the result of the search for methods for the identification of objects using the ultrasonic sensor system developed by Mr. Gunnar

Lindstedt in the department of Industrial Electrical Engineering and Automation at the Lund Institute of Technology [4].

1.2 The Problem

The Figure 1.1 gives a brief description of the use of the equipment concerning how the measurements are made.

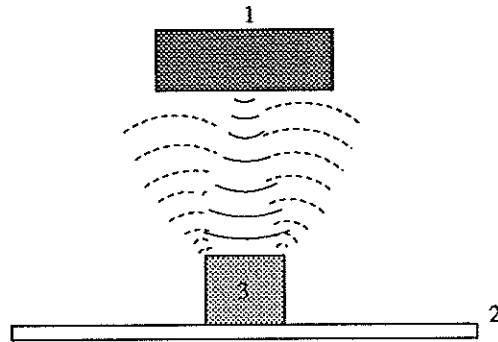


Figure 1.1 Ultrasonic Sensor System

1. **Sensor device:** It is composed by five ultrasonic sensors, one of 200 KHz (for short distances) and four of 40 KHz (for distances higher than 0.5 m). The ultrasonic signal can be set for a number of pulses between 1 and 16.
2. **Platform:** It support the objects for analysis
3. **Objects**

The platform together with the object form a surface that is going to reflect the ultrasonic waves. The idea is as follows: the sensor device sends an ultrasonic wave in the direction of the platform. This wave is going to find on its way, a certain surface and an echo is generated. The echo goes back in the direction of the sensor where is detected and stored by the system. This echo is a function of the shape of the surface of reflection. It is clear that the shape of this surface is defined by the position and shape of the object on the top of the platform. Hence the object shape and position will in some way be reflected by the echo.

A method presented by Lindstedt [4] is based in an energetic interpretation of the echoes. The *rms*-value of the samples composing the echo characterize it by a curve expressing the echoes energy. The identification procedure is based on learning the objects storing in memory the echoes energy curve of the several objects in question. Having these objects "pictures" in memory, new echos of unidentified objects can then be compared, if the position of the object to be identified is the same during the learning and identification sessions. On this stage a question can be rise: Is it possible to identify an object if the object is in a different position during the identification session? In a real case of identification it is easy to have small changes in position, like some millimeters. This will produce moderate to substantial differences between the echo collected from the object and the one previously stored in memory. The identification method now referred, as stated, can not handle such changes in position relatively to the sensor.

The possibility of solving the object identification problem here presented, using methods of control theory looked attractive as well as promising by the end of this thesis. Also the fact that no other approach of this kind had been tried before contributed to the decision of doing such kind of study.

- **Chapter 1:** The importance of developing systems and methodologies to supply information to the robots as well as the aim of this work, are presented.
- **Chapter 2:** Describe a state-space identification algorithm as the base of all identification process. It assumes the echo as an impulse response of a system and determine a balanced realization of such system.
- **Chapter 3:** Is about a first intuitive approach to perform identification making use of the systems transfer function coefficients.
- **Chapter 4:** By interpretation of the systems Bode gain curves describing the object and position, the identification method is presented.
- **Chapter 5:** The envelope echoes are considered to be the impulse response and again a balanced realization of such a system is determined. The identification method of chapter 4 is used in the new systems Bode gain curves with good results.
- **Chapter 6:** Gives an overview of the method and based on the results three rules for the use of the identification method are stated. Some remarks are made about further development of the method.

2. Tools

The algorithm used to simulate the echos is presented and a brief explanation of it's use on the echos is given. A discussion about it's implementation in Matlab is also presented.

2.1 The algorithm

A way of interpret the echos was presented by Johansson [2], using a state-space identification method the way Bayard used [1]. The algorithm in question is based on the impulse response of a system as a way of representing the transfer function $H(z)$ by the Markov parameters sequence H_k :

$$H(z) = \sum_{k=0}^n H_k z^{-k}$$

With the Markov parameters, and for the numbers r and s such that $r + s \leq N$ the Hankel matrices $H_{r,s}^{(0)}$ and $H_{r,s}^{(1)}$ can be built. Than, computing the singular value decomposition

$$H_{r,s}^{(0)} = U \Sigma V^T$$

the algorithm proposed by Juan and Pappa will determine a balanced realization for the system with m inputs, p outputs and order n on the form

$$\mathbf{x}_{k+1} = A_n \mathbf{x}_k + B_n u_k \quad (2.1)$$

$$\mathbf{y}_k = C_n \mathbf{x}_k + D u_k \quad (2.2)$$

where

$$A_n = \Sigma_n^{-1/2} U_n^T H_{r,s}^{(1)} V_n \Sigma_n^{-1/2} \quad (2.3)$$

$$B_n = \Sigma_n^{1/2} V_n^T E_u \quad (2.4)$$

$$C_n = E_y^T U_n \Sigma_n^{1/2} \quad (2.5)$$

$$D = H_0 \quad (2.6)$$

$$E_y^T = [I_{p \times p} \quad 0_{p \times (r-1)p}] \quad (2.7)$$

$$E_u^T = [I_{m \times m} \quad 0_{m \times (s-1)m}] \quad (2.8)$$

$$\Sigma_n = \text{diag}\{\sigma_1, \sigma_2, \dots, \sigma_n\} \quad (2.9)$$

$$U_n = \text{matrix of first } n \text{ columns of } U \quad (2.10)$$

$$V_n = \text{matrix of first } n \text{ columns of } V \quad (2.11)$$

So by taking the echos as an impulse response of a system and applying the algorithm to those echos, the result will be a system whose impulse response is the echo of the object, Figure 2.1

The system created is than a consequence of the echo and also a function of the surface of reflection. Hence it can be seen that the system itself reflect the characteristics of the associated object. By studying the properties and characteristics of the set of systems realizations associated with the set of objects and/or associated with the same object in several different positions like for example:

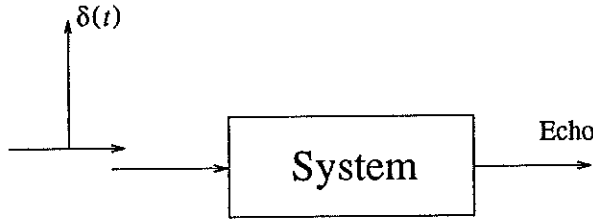


Figure 2.1 The system that simulate the echos from an impulse

- system coefficients
- A pole-zeros diagrams
- Bode gain and phase curves

one have available new ways of approaching this problem of object identification.

2.2 Implementation and efficiency

The implementation of the algorithm was made using MATLAB (see Appendix B). An important point of the algorithm presented in section 2.1 concerning its implementation, is the computation effort connected with the singular value decomposition. After the Hankel matrices have been created (which by itself take some part of the all computation), the singular value decomposition of $H_{r,s}^{(0)}$ will take place. This task takes the major part of all computation time and it depends on the length of the output data set. In the cases of the echos, for all computations, in general the overall time is considerable. The system order can be obtained by observing the curve system order vs. singular values magnitude, Figure 2.2.

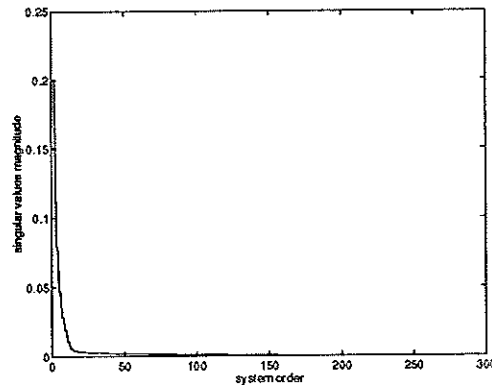


Figure 2.2 Systems order vs singular values magnitude

In order to obtain a reduced order realization the state vector components corresponding to singular values of higher magnitude than the ones around the knee of the curve should be considered. The others should be neglected, since the states of the system with them associated do not contribute significantly to the system dynamics. A choice like this gives a good enough system order and a good approximation from the simulated echo to the real one.

In Figure 2.3 the first column show the superposition of the real echo and the simulated echo produced by the system. The second and third column are

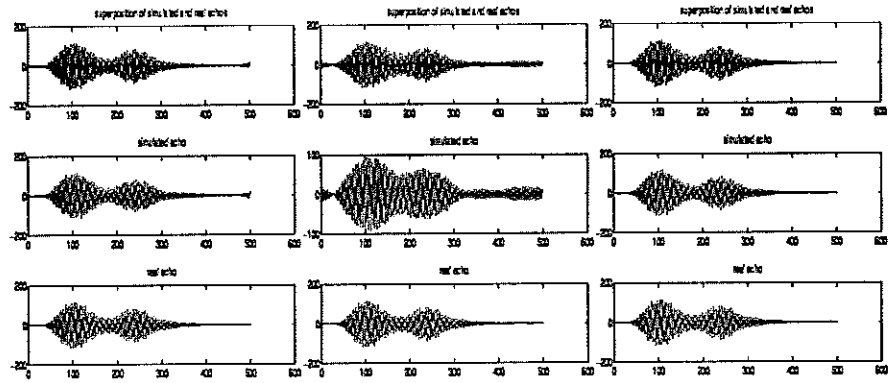


Figure 2.3 Singular values were chosed higher than: 0.01, 0.03 and 0.004 respectively. The resultant systems order were 12, 6 and 16.

respectively the simulated and the real echo. The figures show that a system of order 12 yield good approximation. By increasing the system order beyond 12 the improvements in the model fitting are not significant.

3. Heuristic Methods

In a first approach to object identification is presented. It is based on attaching to each object observation a vector for further comparisons. The is determined using the transfer function coefficients. This method show not to be effective, but a curious property concerning the norms came up and is presented.

3.1 Transfer Function Coefficient Analysis

Considering a certain number of different objects, to each object was associated a vector that is a function of the object's shape and position. Supposing that, say a cylinder is moved, than a new vector is created due to a change in position. Is this new vector closer from the previous cylinder vector that it is from the all other vectors? If the answer is yes than this new observation is identified also as a cylinder. Measurements were made with the 200 KHz sensor for input signals of 4,8,12 and 16 pulses. The four objects presented in Figure 3.1

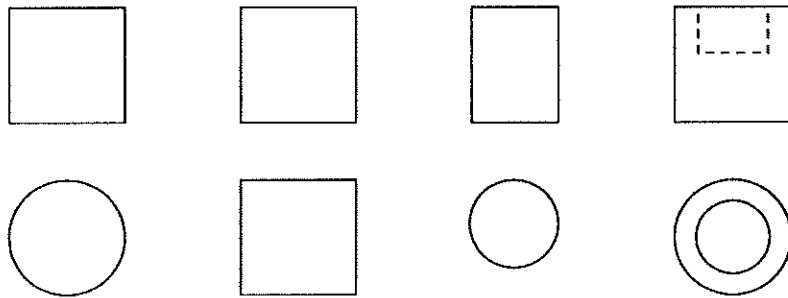


Figure 3.1 Objects used in the measurements: a cylinder, a cube, a cylinder with a smaller radius, a cylinder with a hole.

were placed in a vertical axle right under the sensor. The resultant echos are presented in Figure 3.2

After determination of the systems for each of these sixteen cases (by application of the identification algorithm presented previously) and taking the system on the form of transfer function:

$$H(z) = \frac{A(z)}{B(z)}$$

vectors of the form $V = [A \ B]$ were created. They are composed by the coefficients of the numerator and denominator polynomials of the transfer function $H(z)$ and in some way they should yield characteristics of the object with them associated. Two methods were used to investigate the differences between the vectors.

- **Method 1:** The difference between the norms of two vectors is used $\|A\|_2 - \|B\|_2$. It might not be a good method considering the case when

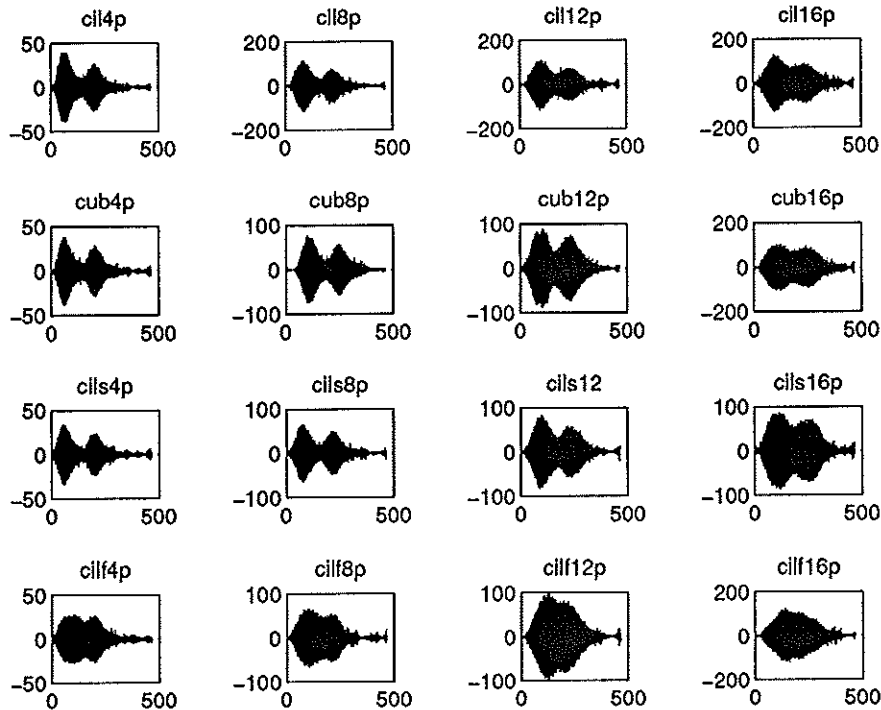


Figure 3.2 Echos of the four objects for the 4,8,12 and 16 pulse input signal.

two vectors have a considerable angle between them and are of the same length.

- **Method 2:** A second method is to use the vector resultant from the difference of two others.

None of these methods showed reasonable results. As the input signal changes the proportionality between the systems is not kept, a big difference between two objects for an input signal become a small difference for another input signal (Appendix A). One nice result would be to have for one input signal some kind of regular “large” differences between the objects in order to separate their “pictures” as far as possible, but that does not happen. New measurements were made for the four types of input signals with the cylinder and the cube shifted and tilted. The objective is to get the new vectors closer to the previous cylinder and cube vectors in order to identify them correctly. The result showed that not only the difference between the same objects in different positions is huge, but also these vectors are often close to vectors of other objects then itself leading to incorrect identifications.

Sum/subtraction Property

An interesting property is found by taking the difference between the 2-norm of vectors associated with too objects.

- Considering three objects, the difference between two of them is the sum or subtraction of the difference between the two objects that form the other two pairs within the triplet. Observing the Figure 3.3 one can see that the distance between the cube and the cylinder plus the distance between the cube and cylinder with a smaller radius is the distance between the cylinders: $1911 + 279 = 2190$

This property is only obtained by the use of the first method of comparison. Also the use of subtraction for an input signal can change to sum with another

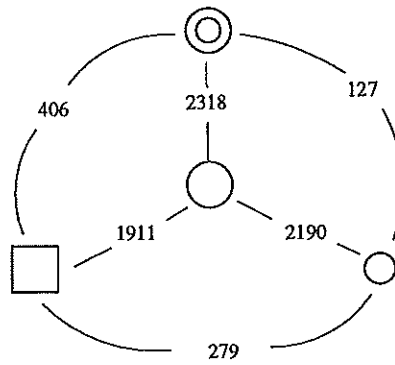


Figure 3.3 Distances between the objects considering the 2-norm difference method for the case of 12 pulse input signal.

input signal and vice-versa.

Comments

It can be seen that this method is not effective. An important point is that when a object is moved a resultant big change on its, which may make the ultrasonic response close to other ultrasonic object's responses . This situation is further interpreted in the next chapter.

4. Composition of Echoes

The approach presented on this chapter is based on the observation and composition of echoes using Bode diagrams of the systems describing the objects and its position. The LS-method is used with the Bode diagrams as a technique to compose the objects observations. As a result an object identification method is created.

4.1 Identification by Composition of Systems Responses

The analysis of the object “picture” by observation of bode curves is another possibility. For each new object or/and new position new gain and phase curves are plotted. By the other hand the idea of collecting several “pictures” from an object in different positions and in some way superimpose them it looks attractive. In a sense it might put in evidence some common characteristics between the echos that will also be yield by the object itself. The use of Bode diagrams is a good opportunity to try this idea by application of the least squares method (LS-method) as proposed by Johansson [3]. Measurements were made using a cylinder and a cube for input signals of 4 and 8 pulses. Observing the echos of these two objects obtained from previous experiments they are quite similar compared with the echos of other objects. Due to this “ambiguity” appeared correct to start by studying this case. For each of these cases eight echos were collected by fixing the objects from the central position along a radius line at 0,2,3,4,5,6,7 and 9 mm from the center, Figure 4.1

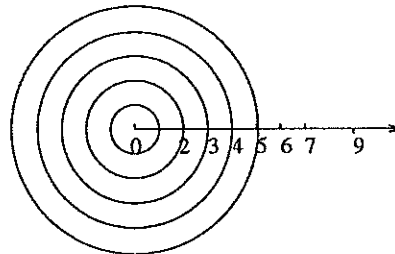


Figure 4.1 The target represents the platform on which the measurements were made. The objects were moved along a radius line like the one in the figure

The algorithm was applied and eight Bode diagrams were plotted for each case. Figure 4.2, Figure 4.3

Composition of “pictures”

The LS-method was used to compose the “pictures” of the objects represented by the bode curves of the systems that simulate the echos. Considering the linear regression model:

$$Y = \Phi\Theta \tag{4.1}$$

it can be solved as follows in order to obtain the estimate \hat{Y}

$$\hat{\Theta} = (\Phi^T\Phi)^{-1}\Phi^TY \tag{4.2}$$

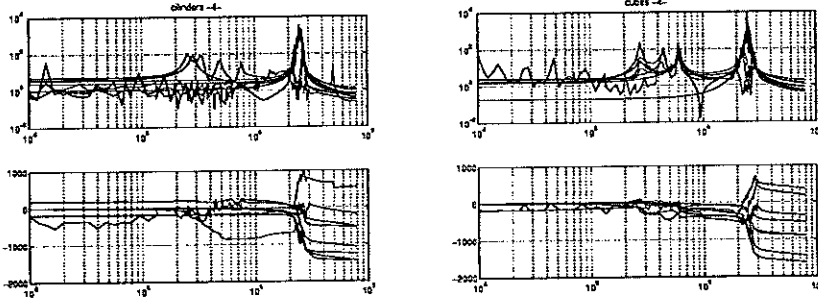


Figure 4.2 Bode curves for the eight echos collected from the cube and the cylinder for 4-pulse input signal

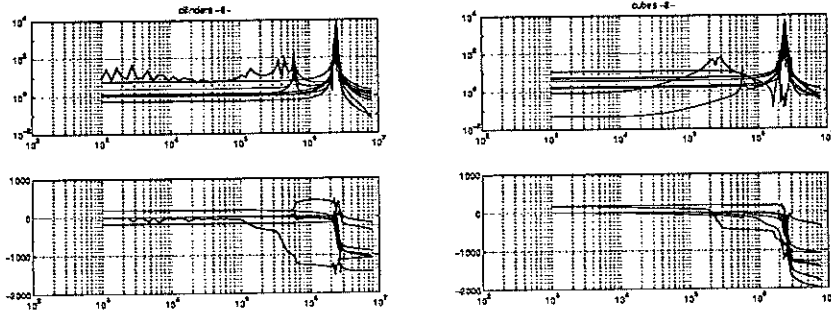


Figure 4.3 Bode curves for the eight echos collected from the cube and the cylinder for 8-pulse input signal

$$\hat{Y} = \Phi(\Phi^T \Phi)^{-1} \Phi^T Y \quad (4.3)$$

$$\varepsilon = |Y - \hat{Y}| \quad (4.4)$$

where:

- **Y object identity line:** The object will be represented by a certain line Y. This curve will be the “object identity” stored in memory for further identification. Y is the curve that one will always try to reproduce using observations of the object.
- **Φ observations:** In order to identify the object a certain number of observations will be made. These observations will act as regressors ϕ_i to form the regressor matrix $\Phi = [\phi_1 \dots \phi_n]$ for the linear regression of $Y = \Phi \Theta$
- **\hat{Y} object estimate:** This will be the resultant “picture” due to the regression of $Y = \Phi \Theta$. The curve \hat{Y} is the one that based on the observations Φ best-fit the object identity curve Y. In the ideal case of perfect model fit, one would have $\hat{Y} = Y$.
- **ε prediction error:** is the difference between the curve Y and its estimate \hat{Y}

4.2 Choice of the identity curve Y

Among all Bode diagrams for the four cases (two objects for four and eight pulse-input signal) which one should be chosen as Y? This analysis was made using the gain curves. A natural first step seems to be the choice of curves that represent the object in the central position. By observation of the Bode

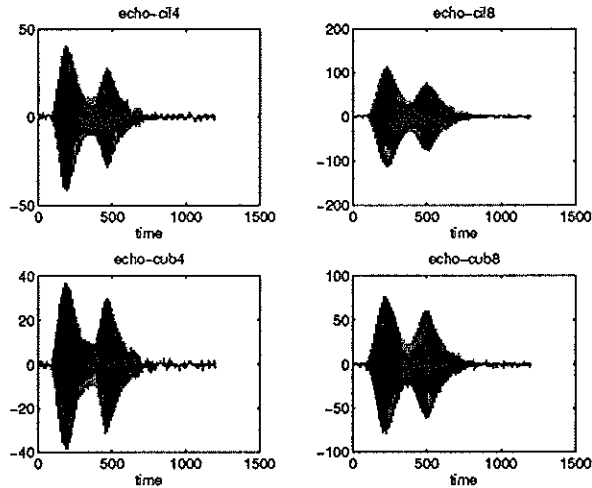


Figure 4.4 For the 4-pulse input signal where the echo amplitude is smaller, the importance of the noise amplitude is heigher.

diagram of the system representing the object in the central position one can see that the cylinder and the cube have only one resonant peak at 200 KHz and show approximately the same gain for 4 pulses and the same gain for 8 pulses. Apart of these there are the curves associated with the other positions and these ones show variations in shape. These variations can in some way yield information that make possible the identification of the object with them associated. Hence, an alternative is to built an “artificial” identity curve that in some way can reflect better the relevant points and variations of the observations of each object and better estimates of Y should be expected. A method of building an identity curve lay on the observation of several images and choice of those who yield the most important characteristics among all. Again, the LS-method is used to compose the curves and build Y . Of course, this choice is dependent of the interpretation that the one that is observing the curves will give to “important characteristics”. The chosen curve will be the basis of the regression and the others will stand for the regressors. The result is a curve that will be used as the “object fingerprint”.

4.3 The identification procedure

An identification procedure using the method presented previously to compose pictures can be resumed to:

- collect k echos
- create the k Bode plots that will act as the k regressors
- make i regressions using the k regressor for each i objects identity curves stored in memory
- choose the object for which the error $\varepsilon = |Y - \hat{Y}|$ is smaller

Observing the four and eight pulse-input signals it can be seen that the Bode diagrams for four pulses are much more irregular. After the application of the method the results show to be worse for the four-pulse input signal than for the eight pulse case.

By comparison of the echos figures in the central position Figure 4.4, where the larger amplitude take place and the weight of the noise is not so

important, it can be seen that the noise influence is much more prominent in the case of four-pulse input signal. Due to this the four pulse-input signal was abandoned.

4.4 Results of the method

This identification method was tested using the eight-pulse input signal. The objects used for the test were the cylinder and the cube with eight observations for each one as presented previously.

Identity curves

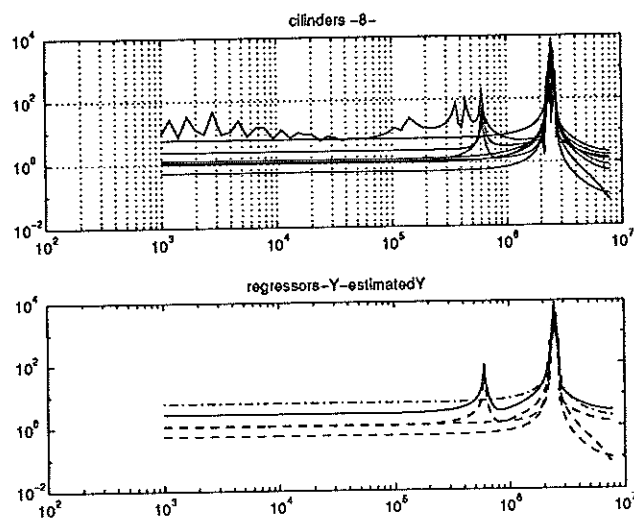


Figure 4.5 Gain bode curves for the eight echos collected from the cylinder. An identity line is presented based on the central position and for regressors the Bode diagrams for 2,4 and 7 mm (dashed lines)

Looking to the observations of the cylinder (Figure 4.5) there are some points upon which the choice of observations was made:

- All eight observations have resonant peaks at 200 KHz
- Five lines present a similar shape for all frequency range
- Two lines have one more resonant
- One observation is very irregular

According to this interpretation an identity line was estimated based on the following points:

- **Base of the Regression:** central position curve (at 0 mm)
- **Regressors:**
 - two lines of one resonant peak since they represent the majority. The lines for 2 and 7 mm were chosen.
 - One line of two resonant peaks, in order to put some of the influence of these two lines.
- The line with irregularities was abandoned.

The identity line is presented in Figure 4.5. The same kind of approach was used to build the identity line of the cube (Figure 4.6).

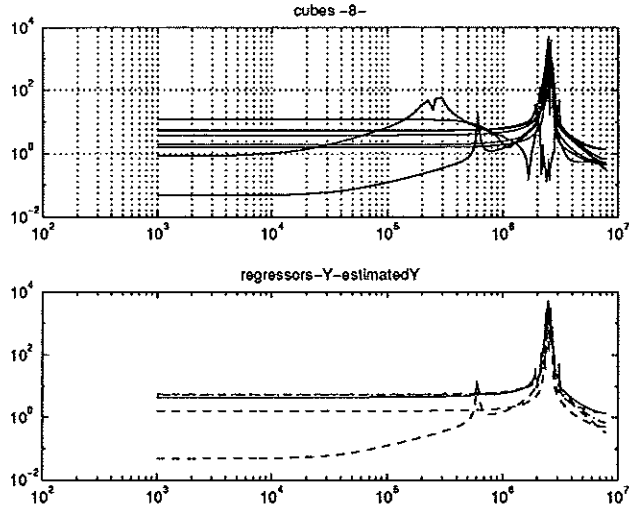


Figure 4.6 Gain bode curves for the eight echos collected from the cube. An identity line is presented based on the central position and for regressors the Bode diagrams for 3,4 and 7 mm (dashed lines)

Identification of the cylinder

In the first place sets of three “pictures” of the cylinder were taken in order to form the regressor matrix. Following the method described above two linear regressions took place using these “images” as regressors and respectively the cylinder and cube identity lines as a base of the regression. Some results are showed in Figures 4.7, 4.8

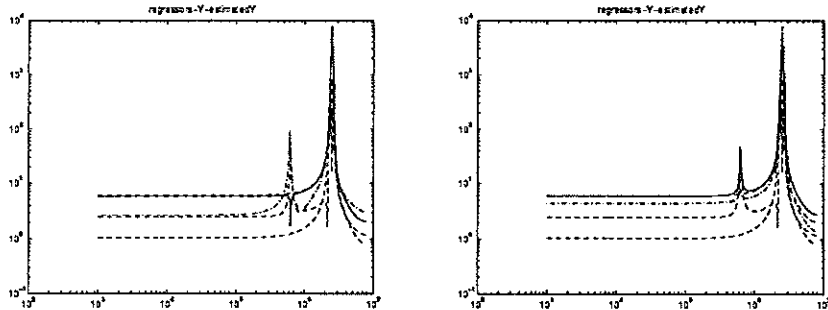


Figure 4.7 Regression using the 0,3 and 9mm echos as regressors and based on the identity lines of the cylinder and cube respectively. The fitted lines are 95.27% and 75.72% from the ID-lines respectively. Hence the object is identified as a cylinder.

Having eight Bode diagrams for each group of eight echos of an object and using p of those eight Bode diagrams as regressors for each regression C_p^8 cases are possible (see Appendix C).

$$C_p^8 = \frac{8!}{p!(8-p)!} \quad (4.5)$$

According to this, considering groups of three regressors from the eight Bode diagrams, fiftysix combinations of eight three-by-three ($C_3^8 = 56$) can be considered. Figure 4.9 is an histogram giving as a first column the number of

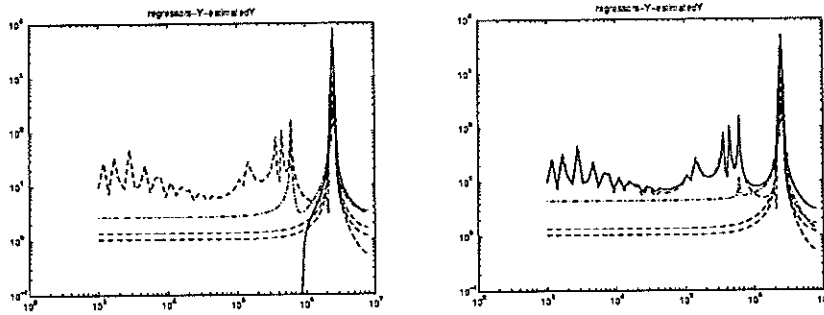


Figure 4.8 Regression using the 3,5 and 6mm echos as regressors and based on the identity lines of the cylinder and cube respectively. The fitted lines are 85.86% and 74.91% from the ID-lines respectively. Hence the object is identified as a cylinder.

cases were incorrect identification occur and were the second column gives the number of correct identifications (note that the sum of these two columns give the total number of cases).

Among these fiftysix possibilities, four of them do not use as regressors any of the Bode diagrams used in the construction of the identification-line of the cylinder. Since the result of the regression based on a certain ID-line is strongly dependent of the number of common regressors used in the identification regression itself and in the construction of the ID-line, the four cases that are free of this common regressors will yield worse results than the others fiftytwo cases. Due to this, is of particular interest the study of these four cases. Concerning the cylinder only one combination of three images was found not to work. All the other combinations showed that the estimations are closer from the identity line from the cylinder than from the identity line of the cube. Even when the irregular gain curve is used in one of the three images as a regressor the result tend to identify the cylinder (Table 1). For the other fiftyfour cases all of them at least include one regressor used in the construction of the ID-line of the cylinder. It can be seen in Figure 4.9 that all cases, except the one in table 1 are correctly identified.

Identification of the Cylinder			
Regressors	base Cylinder	base Cube	decision
3, 5, 6	0.8586	0.7491	ID
3, 5, 9	0.6021	0.6161	not-ID
3, 6, 9	0.9001	0.7447	ID
5, 6, 9	0.8929	0.7432	ID

Table 1 Results of the identification method using combinations of three regressors of the four regressors that were not used to compose the ID-line of the cylinder. ID stands for correct identification and not-ID stands for incorrect identification.

In fact, if all the regressors used in the construction of the ID-line are the ones used in for the identification regression the estimate \hat{Y} will be exactly the the ID-line from the object, than the identification will perfect. Nevertheless, this case will not happen in real identification since there is not place for the generation of two equal echos.

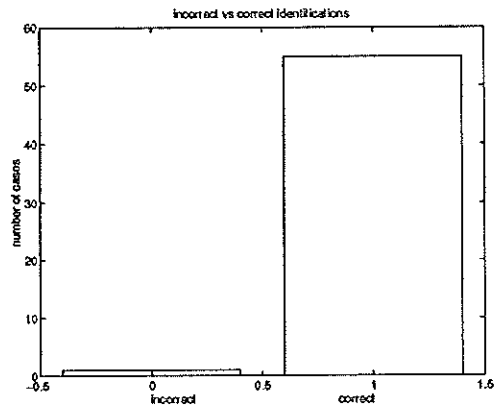


Figure 4.9 Number of incorrect identifications (first column) versus correct ones (second column) for the cylinder, when the second object ID-line is from the cube.

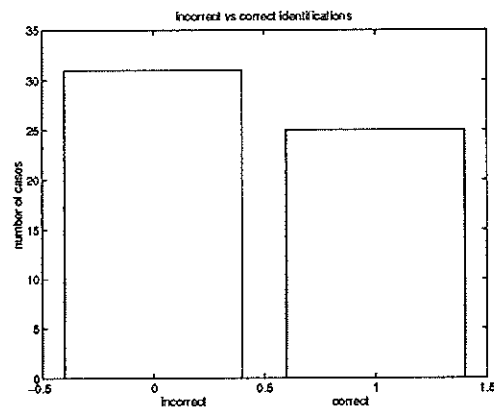


Figure 4.10 Number of incorrect identifications (first column) versus correct ones (second column) for the cube, when the second object ID-line is from the cylinder.

Identification of the cube

Here, in the same way, the procedure that was used for the identification of the cylinder is followed.

Identification of the Cube			
Regressors	base Cylinder	base Cube	decision
2, 5, 6	0.8497	0.7250	not-ID
2, 5, 9	0.7296	0.6290	not-ID
2, 6, 9	0.9498	0.7426	not-ID
5, 6, 9	0.9478	0.7325	not-ID

Table 2 Results of the identification method using combinations of three regressors of the four regressors that were not used to compose the ID-line of the cube. ID stands for correct identification and not-ID stands for incorrect identification.

Nevertheless in this case the results are quite different. Also using combinations of three curves, in this case from the cube, the results in too many cases were closer from the cylinder than from the cube Table 2. A way to improve this is to include as regressors, images that compose the identity line of the cube, but it can be seen observing Figure 4.10 the result was still not good enough, the number of incorrect identifications is superior to the number

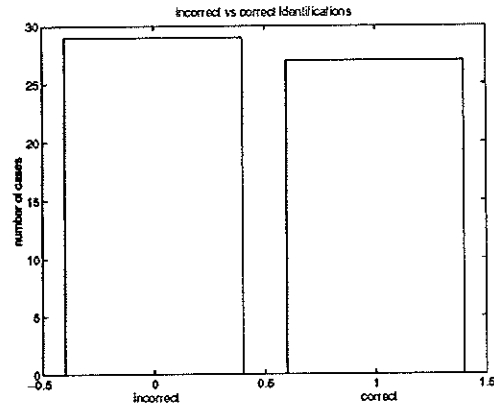


Figure 4.11 Number of incorrect identifications (first column) versus correct ones (second column) for the cube, when the second object ID-line is from the cylinder. In this case, the identification uses five regressors

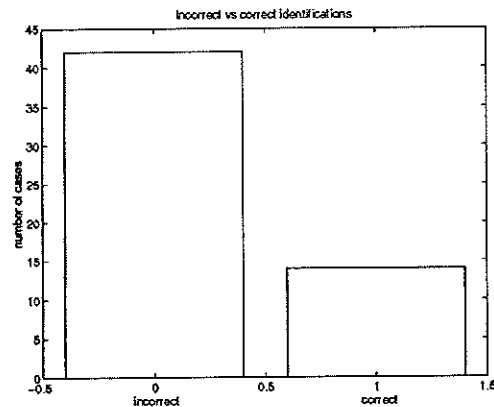


Figure 4.12 Number of incorrect identifications (first column) versus correct ones (second column) for the cube, when the second object ID-line is from the cylinder. Three regressors were used and a ID-line from the cube is a different one.

of correct ones. Anyway, this procedure is not correct, since in the real case the robot will take the pictures in a random way and will not know where is the right spot to take the same pictures used in the identity lines. Due to this the tests should be made with observations different from the ones used in the composition of the ID-line of object to be identified. By increasing the number of observations the improvement of the results is very small, because they are strongly dependent of the number of observations the compose the identity lines. Figure 4.11 show the result of cube identification when the ID-line of cylinder is used as the second ID-line and when groups of five regressors were used.

Also, new identity lines using the LS-method and other combinations of images were tried, but none of them gave satisfactory results. Figure 4.12 show the results using a different ID-line based in the central position of the cube and using the Bode diagrams in 2,5 and 9 mm as regressors. The number of incorrect identifications is even worse than using the previous ID-line of the cube. At this point, it can be seen that identification of these two objects often suggests the cylinder rather than the cube.

4.5 New measurements

The results obtained by application of the method to the cylinder and to the cube, have led to a new session of measurements. Observing the echos of the cylinder and the cube it can be seen that they are quite similar. Assuming for now that this ambiguity can constitute a/the problem new measurements were made with the same cylinder and with the cylinder with a hole. These were chosen because their echos (considering the previous pair cylinder/cylinder with a hole) show a larger difference. The same methodologies were used as before. For each object a set of eight measurements was made using the same positions, generation of a system the response of which could fit the original echo and composition of ID-lines using the influent Bode diagrams of each set. Again, regressions based on the ID-line with echos collected from the object were made.

Identification of the Cylinder			
Regressors	base Cylinder	base Cylinder with a hall	decision
0, 2, 6	0.8909	0.5818	ID
0, 2, 9	0.9235	0.5871	ID
0, 6, 9	0.6117	0.4547	ID
2, 6, 9	0.9234	0.5851	ID

Table 3 Results of the identification method using combinations of three regressors of the four regressors that were not used to compose the ID-line of the cylinder for the new set of measurements. ID stands for correct identification and not-ID stands for incorrect identification.

Identification of the Cylinder with a hole			
Regressors	base Cylinder	base Cylinder with a hall	decision
2, 5, 6	0.5398	0.7690	ID
2, 5, 9	0.5398	0.7691	ID
2, 6, 9	0.5132	0.7647	ID
5, 6, 9	0.1032	0.0693	not-ID

Table 4 Results of the identification method using combinations of three regressors of the four regressors that were not used to compose the ID-line of the cylinder with a hall. ID stands for correct identification and not-ID stands for incorrect identification.

Three regressors were used and in each combination only images that do not compose the ID-lines were used, in order to take the influence of common regressors since only occasionally this can happen in the real case. Table 3 and Table 4 show that the objects are correctly identified in most of the cases. A study of all fiftysix possible cases took place for the identification of cylinder, cube and cylinder with a hole. The results are presented in the Figures 4.13, 4.15, 4.14 and 4.15

By observation of the results again one can see that the identifications tend to identify the objects as a cylinder. In the case of the identification of the cube, the number of incorrect identifications is quite small compared with the number of correct identifications, but not small enough to guaranty a good performance of the method (Figure 4.14). The same conclusion can be taken from the identification of the cylinder with a hole, were the number of incorrect identifications is not low enough to guarantee a sufficiently low failure rate

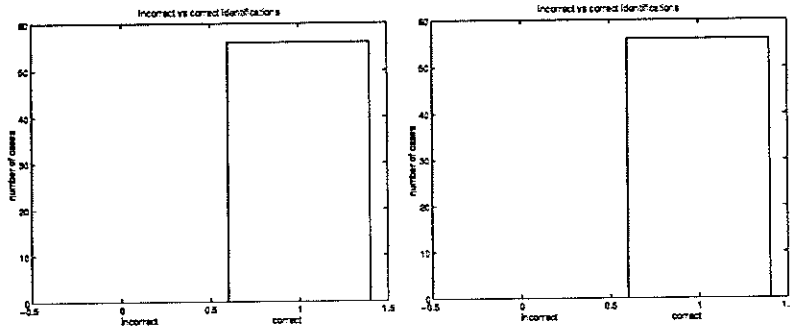


Figure 4.13 Number of incorrect identifications (first column) versus correct identifications (second column) for the cylinder, when the second ID-lines are from the cylinder with a hole and the cube respectively.

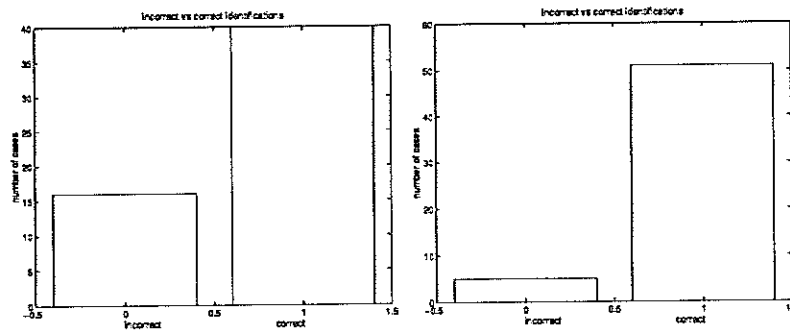


Figure 4.14 Number of incorrect identifications (first column) versus correct identifications (second column) for the cube, when the second ID-lines are from the cylinder and the cylinder with a hole respectively.

(Figure 4.15). On this stage, there are available two sets of data from the cylinder since this object was used in two different sessions of measurements. These last results were obtained using the second set to compose the ID-lines and to the object identification itself.

validation data

Let us now consider the first set of data as a validation one, since this data was not used in the ID-lines. The objective is to evaluate the capability of the method for identification since new data will not introduce common regressors belonging to ID-lines and to the identification regressors.

By Figure 4.16 it can be seen that in both cases where the second ID-lines

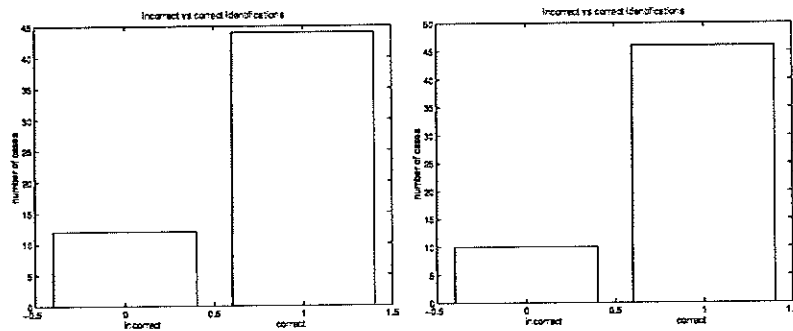


Figure 4.15 Number of incorrect identifications (first column) versus correct identifications (second column) for the cylinder with a hole, when the second ID-lines are from the cylinder and the cube respectively.

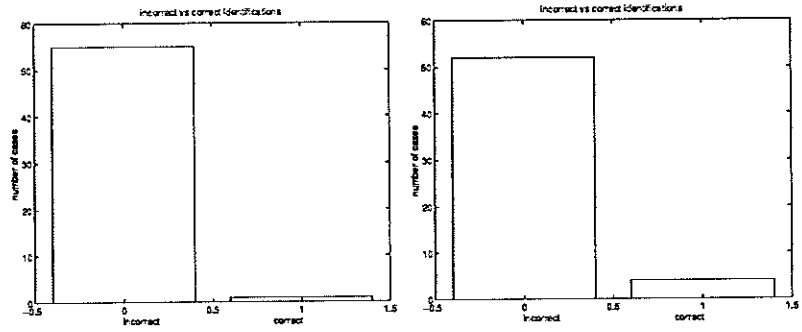


Figure 4.16 Number of incorrect identifications (first column) versus correct identifications (second column) for the cylinder using a different set of data different from the one used in the construction of the ID-lines. The second ID-lines are from the cylinder and the cube respectively.

are from cube and cylinder with a hole, that the cylinder in a major part of the cases is identified as its “partner”, (the cube and the cylinder with a hole) were the number of correct identifications is one and four respectively. The present results can not confirm a good accuracy for the method.

4.6 Identity curves by average

Another way for the composition of ID-lines was used. For each object the average of the set of eight observations was taken in order to compose the ID-line. For the cylinder the ID-line was built using the second set of data. In the same way all possible combinations of images were considered and some results are showed.

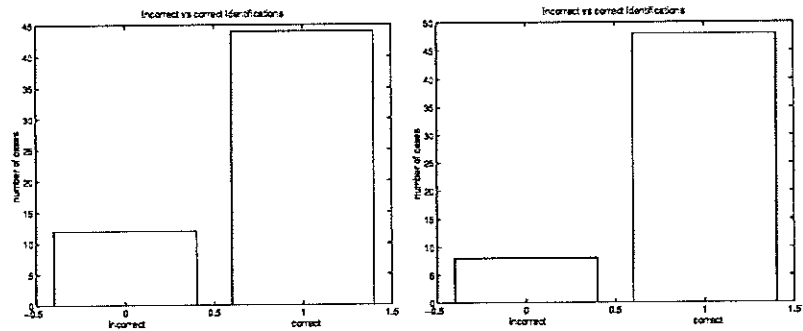


Figure 4.17 Number of incorrect identifications (first column) versus correct identifications (second column) for the cylinder when the second ID-lines are from the cube and the cylinder with a hole respectively.

In the case of the identification of the cylinder and considering the set of data that was used to construct the ID-lines (Figure 4.17) the number of incorrect identifications is small compared to the correct identifications, but could not be small enough to approve the method. The identification of the cube (Figure 4.18) yield better results. A perceptive way of making the method converge in order to give always correct identifications would be to include more regressors to the identification.

Identifications in Figure 4.19 were made using five and six regressors respectively. Here, the results seem to improve with the number of regressors, but again and since the ID-lines by average are composed by every “pictures”

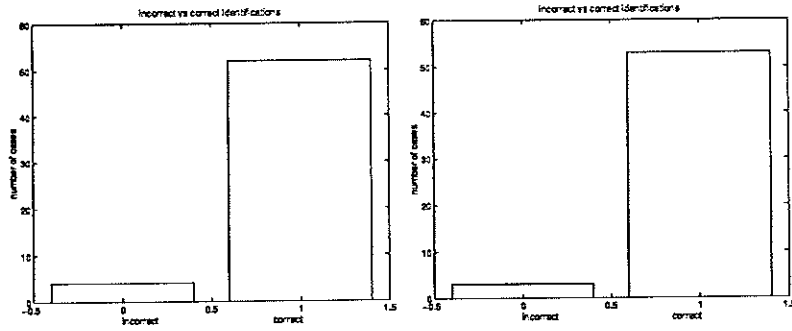


Figure 4.18 Number of incorrect identifications (first column) versus correct identifications (second column) for the cube, when the second ID-lines are from the cylinder and the cylinder with a hole respectively.

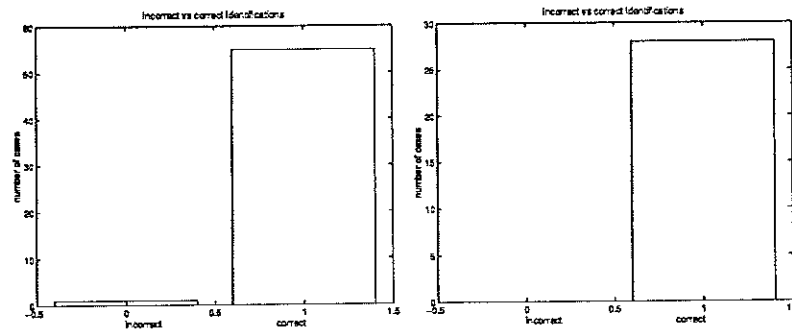


Figure 4.19 Number of incorrect identifications (first column) versus correct identifications (second column) for the cube when the second ID-line from the cylinder with a hole. In the first case five regressors were used and in the second case six regressors were used respectively.

of each set the number of common regressors is also increasing. Again, the validation data of the cylinder (first set) is used for regressions based on the ID-line of the cylinder built with the second set. Figure 4.20 show the fiftysix possible cases using three regressors and all cases stand for incorrect identifications when the second ID-line is from the cube and from the cylinder with a hole respectively

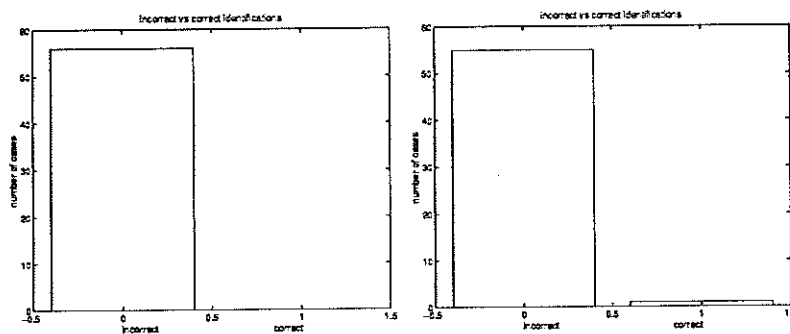


Figure 4.20 Number of incorrect identifications (first column) versus correct identifications (second column) for the cylinder when the second ID-lines are from the cube and the cylinder with a hole respectively, and the validation data set is used.

In order to try to improve this result regressions with six and seven regressors were made. Results are showed in Figure 4.21.

In this case (in opposition to the identification of the cube), the results

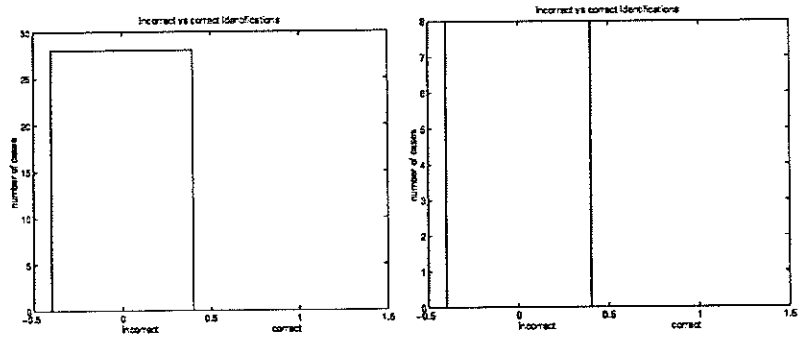


Figure 4.21 Number of incorrect identifications (first column) versus correct identifications (second column) for the cylinder when the second ID-line from the cube. Regressions were made with six and seven regressors respectively.

did not improve at all with the increasing number of regressors. This can understand since none of the new regressors were used in the ID-line of the cylinder. Hence, increasing the number of regressors in the identification, by itself do not improve the result of identification.

4.7 Some variations to these methods

Three approaches are presented. All of them use the Bode diagrams of the systems associated to each object. But now instead of using gain curves only by themselves the following curves were considered.

- **Phase lines:** The phase curves (Φ) of the Bode diagrams were considered and as before ID-lines created with these phase curves are the base for the regressions using also phase curves as regressors.
- **Gain Phase:** The gain vectors G that define the gain curve and the phase vector Φ (define the phase) were linked to create the vectors $[G^T \ \Phi^T]$. Again the procedure for identification was used in the same way as before.
- **Logarithm of the gain:** The gain of the Bode diagram was taken and the logarithm function was applied to it creating the vectors $\text{Log}(G)$. The same identification procedure was applied

The phase curves considering the results of the identification of the cylinder with the validation data every identifications fail when the second ID-line is from the cube. On the other hand every possible cases using as second ID-line the ID-line of the the cylinder with a hole give correct identifications. For the cube, the results of every possible case give correct identification The identification of the cylinder with a hole even using for identification the set of data used in the construction of the its own ID-line, all results give incorrect identifications.

Using the vectors $\text{Log}(G)$ considering the cases described for the phase curves, the majority of the results give a number of correct identifications higher than the number of incorrect ones, nevertheless the number of cases of incorrect identification is near of the number of correct ones ,hence not sufficient to guaranty the application of the method.

With the Gain Phase vectors there is no tendency for any particular side, the results yield many failures in cylinder, cube and cylinder with a hole.

Comments

The use of these new curves did not show good results. In fact, for the phase lines the results are inconsistent, for example considering the pair cylinder with a hole versus cube one have 0% of correct identifications, but swapping the objects and identifying the cube versus cylinder with a hole the results give 100% identifications.

5. Envelopes

The general idea behind the use of the envelopes of the echoes is presented. Two approaches for object identification are described and results are discussed. In the end a problem with the data is showed, as well as the way it influence the results of identification.

5.1 The shape of the echoes

In the previous chapter the approaches used for object identification did not showed to be sufficiently effective as can be seen observing the results in the end of the fourth chapter. Nevertheless if the echoes of several different objects are analyzed by simple visual inspection, there are differences between them, in some cases considerable ones that can be spotted.

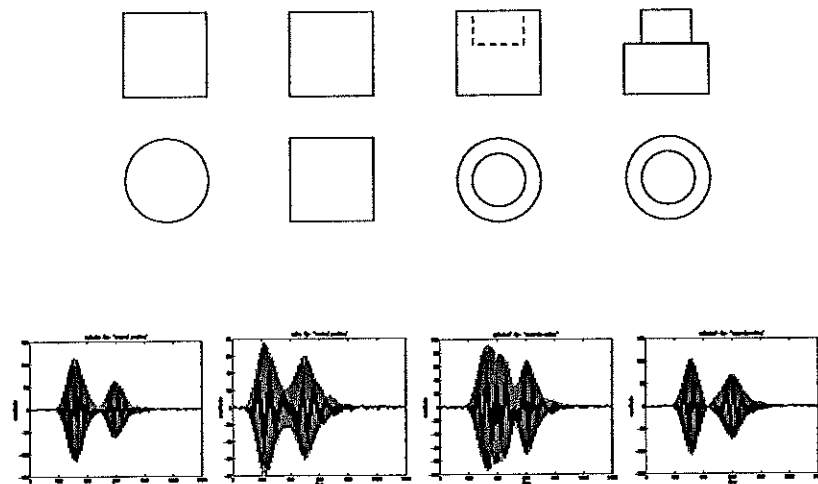


Figure 5.1 Objects used in the measurements and its echoes taken from the central position (center as presented in chapter 2)

Figure 5.1 show the four objects used in measurements as well as their echoes taken in the central position. The choice of this four objects was mainly based on:

- Considerable difference between the echoes of the cylinder with a hole (cylinderF) and the other three objects. It gives due to the separation of echoes a easy case of identification for the human. How low or heigh is the failure rate of the identification methods in an easy case can be analyzed.
- Similarity between the echoes of the cylinder and the cube. It gives an case of a certain ambiguity. The behavior of the identification method in a ambiguous case can be evaluated.
- The echo of the forth object (cylinderP) will stay somewhere between the two previous cases, in order to give an intermediate case to see how far the method can go between two extreme cases.

Again for each object, sets of eight measurements were taken along a radius line from the center of the target as described before in the third chapter (Figure 4.1).

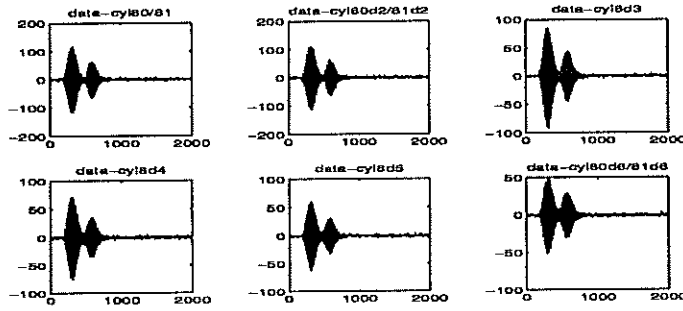


Figure 5.2 Set of echoes from the cylinder. The echoes are from to 0,2,3,4,5 and 6 mm positions respectively

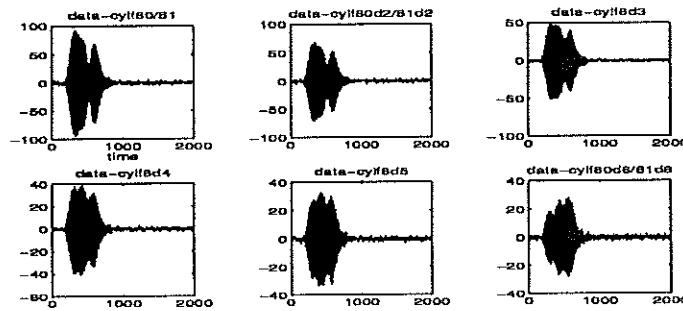


Figure 5.3 Set of echoes from the cylinder with a hole (cylinderF). The echoes are from to 0,2,3,4,5 and 6 mm positions respectively

Figure 5.2 and Figure 5.3, show two sets of echoes from the cylinder and the cylinder with a hole respectively. It can be seen that until a certain position the echoes shape can still be characterized as the echo shape of its own object in the central position and not as the echo of other object. For example for the first four echoes of the cylinder with a hole, the shapes are similar enough to say that each of these echoes are from the cylinder with a hole, were the other two observation yield some larger differences. But still if each one of these two last echoes tries to fit other echo, the difference between them is big enough to give a successful identification to the cylinder with a hole. For example the echo of the cylinder with a hole in the position for five and six millimeters clearly do not fit in to the echos for the cylinder in the same position.

Based in these observations one should ask: Will it be possible by analyzing the curve that describes the echo's shape rather than the echo it self to do a correct identification of the object?

The envelopes

In order to answer this question the curve that involves the echo (the envelop) was considered and interpreted as a signal in time (Figure 5.4). Applying the Hilbert transform to the data vector containing the echo and taking its absolute value an envelope of the echo is produced.

The envelope will be the new identity of the object. All the procedures for the identification of the object will make use of the envelop's echoes instead of the echoes themselves.

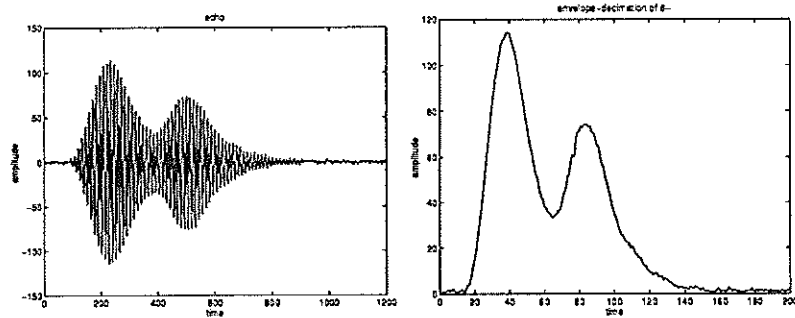


Figure 5.4 Echo and its envelope (absolute value of the Hilbert transform)

5.2 The envelop: an Impulse Response

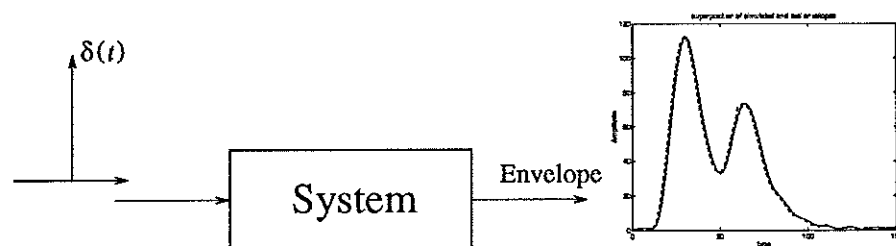


Figure 5.5 System whose impulse response fits the envelope. The solid line represents the envelope and the dashed line the impulse response.

Previously in the second chapter, echoes were interpreted as an impulse response of a system. Here and in the same way the interpretation given to the echoes envelopes is the same. Considering the identification algorithm presented in the second chapter and used in the echoes, it is applied now and in the same way to the envelopes data sets. The balanced realization of the system is determined and its impulse response will produce a curve that will fit the original envelope.

A strong point that contributed to adopt these approach of generation of systems was the fact that the envelope is not a oscillatory signal like the echo is. Therefore the absence of oscillations should eliminate the large resonant peak at 200 KHz that exists in the Bode diagrams of the identified systems based on the echoes. The peak was a common characteristic of every Bode diagrams, not depending on the position or even the object itself. This is important when the identification method based on the LS-method is applied to the Bode gain diagrams as before. A strong common characteristic for different objects like this peak mask the results of the regressions for different objects, then reducing the accuracy of the method.

Bode Diagrams

In order to make the objects identification by composition of responses using the LS-method in the same way as described in chapter 3, the Bode diagrams of the new systems were created. Since to each object is attached a set of eight envelopes, eight systems as well as eight Bode diagrams defining the object and position, were created (Figure 5.6 and Figure 5.7).

As described in the second chapter, during the application of the identification algorithm the singular values that were chosen were the ones around

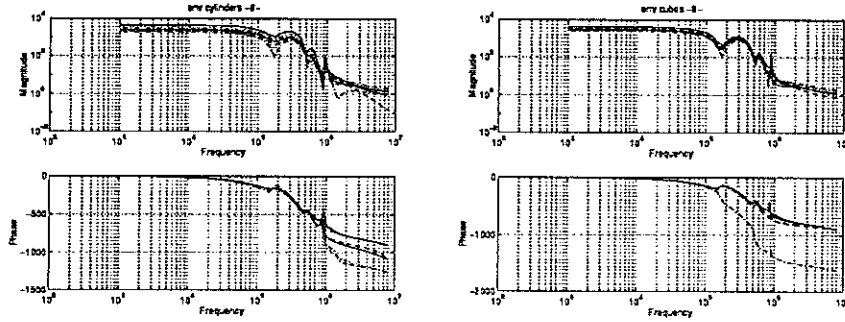


Figure 5.6 Bode diagrams for the systems whose impulse response fits the echoes envelopes. The objects are the cylinder and the cube

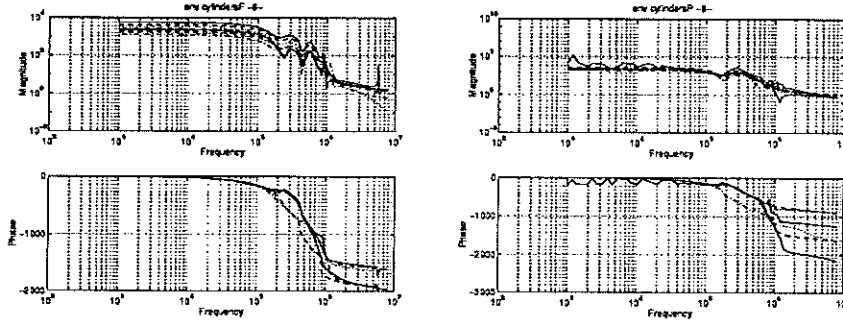


Figure 5.7 Bode diagrams for the systems whose impulse response fits the echoes envelopes. The objects are the cylinder with a hole and cylinderP

the curve presented in Figure 2.2. Then the real envelope and the system response are superimposed and new choices of singular values are made around the first choice, until the estimate fits in as close as possible the original envelope according to the criteria based on the prediction errors $\varepsilon = |Y - \hat{Y}|$ and its relative value:

$$100 \times \left[1 - \frac{|\hat{Y} - Y|}{|Y|} \right] (\%) \quad (5.1)$$

By observation of the Figure 5.8 the best choice based on this criteria is the one where the estimated envelop plays the role of the mean value for the small variations of the original envelope (Figure 5.8).

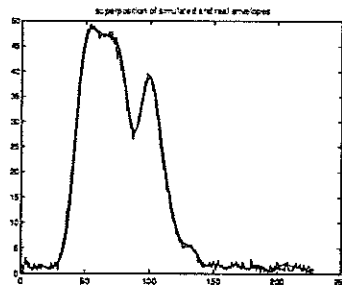


Figure 5.8 Superposition of the original envelope and the simulate one that was generated based on the prediction error criteria. The order is thirteen a 95.22 %

The systems order is than kept within nine and thirteen in almost every case. Only the system for the fourth object (cylinder-P) for the central posi-

tion has an order of sixteen. This kind of low orders are reflected in the Bode diagrams where the lines become regular (Figure 5.6 and Figure 5.7), keeping also low, the differences between the Bode diagrams of one single object. Observing the Bode gain diagrams of the cylinder-P, the system associated with the central position which have order sixteen, give the irregular Bode gain curve, different from the others.

At this point there are two important observations to make by observing the Bode gain diagrams.

- In the first place within one group of gain Bode diagrams for one object, the curves are similar and close to each other. A good example of this are the curves of cylinder-P.
- In the second place different groups of gain Bode curves for different objects are significantly different from the others.

The first point implies that several “signatures” of a single object should depend as less as possible on the position and rely only on the object itself. The second one implies that for different objects the “signatures” should not be close so that ambiguity between them should not occur.

The use of LS-method in lines with characteristics like this, should give good estimates of the identity lines since the lines used to generate the estimate are not too far from its own identity lines. On the other hand since each group of Bode gain lines are different from the other objects groups, the attempt to estimate an identity line of one object with Bode gain lines of other groups gives a poor estimate compared with the correct case, thus preventing cases of poor identification. The object can then be identified correctly in most of the cases.

Identification

Here and in the same way as presented in chapter 3 the object identification by composition of responses is used. For each object an identity-line is composed by means of LS-method, using the important Bode gain curves. New regression takes place using observations of the object (under the form of Bode gain diagrams) and as a base ID-lines every objects. Estimates of the ID-lines are produced and the one that best-fits its own ID-lines will indicate the correct object. Results of the identification are presented in the following section.

Results of the method

For each object are available eight observations. In order to make the identification the regressors are chosen among the eight observations in each set. Hence groups of one to seven regressors can happen. Taking sets of p regressors from the eight observations $C_p^8 = \frac{8!}{p!(8-p)!}$ cases for identification are possible (Appendix C).

Figure 5.9 shows the percentage of cases correctly identified for a number of regressors between one and seven.

Within the several number of regressors available the most important cases are three and four regressors. The reason for this is that the number of possibilities for three and four regressors are fifty-six and seventy respectively, where for the other groups there are less cases (except for five regressors). Hence there are more opportunities to test the method. On the other hand, a low number of regressors reduce the computation effort for each identification, since each regressor implies the use of the identification algorithm as presented in chapter 2.

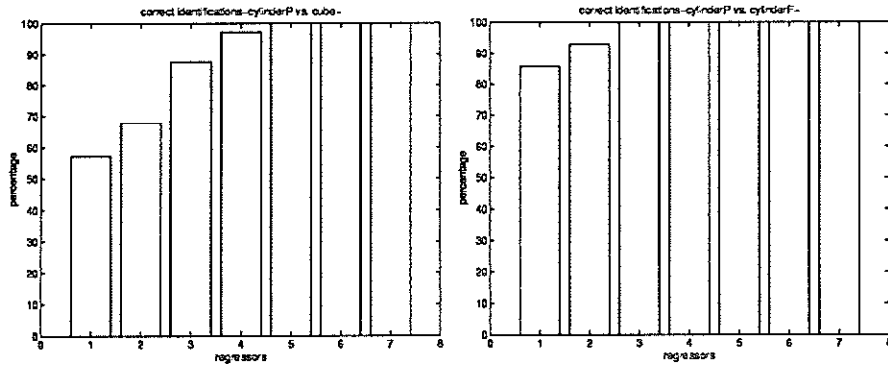


Figure 5.9 Correct Identifications of the cylinder-P when the second ID-lines are from the cube and from the cylinder with a hole respectively

In Figure 5.9 the identification of cylinder-P with the second identity line from the cube (first picture) and from the cylinder with a hole (second picture) are presented. Also this cases are the ones yielding the worse results among all. Only for the first picture one can say that there is some weakness on the results since using three regressors the identification level is under 90%. The second picture give 100% correct identifications. According to these results and since that even the worse cases yield good enough values of correct identifications, the method used seams to be accurate to perform it role.

A next natural step will be the use of other data sets from the same objects in the same positions but in different sessions of measurements, in order to validate the identification method.

Validation

Here the data used for the objects identification is different from the one used in the composition of the identity lines stored in the memory of the system.

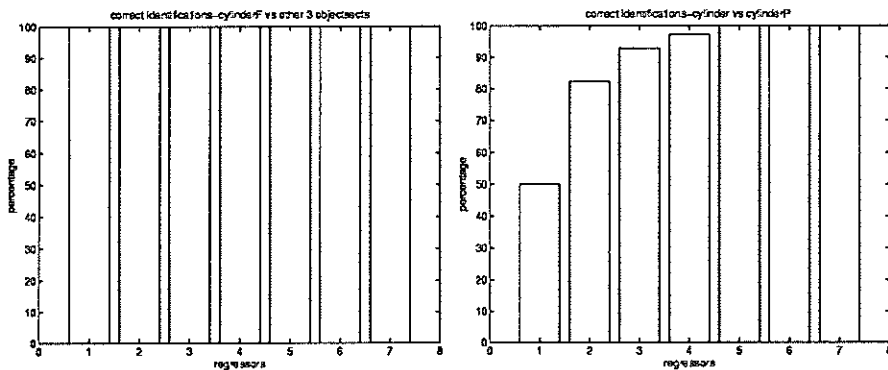


Figure 5.10 Correct identifications using validation data for the cylinder with a hole and the cylinder

Figure 5.10 give good results for the identification of the cylinder with a hole when the second identity lines are from the other three objects. Also for the cylinder the results are acceptable. On the opposite side Figure 5.11 give two cases of 100% incorrect identifications (first picture). The observations of cylinder-P are most of the time interpreted as belonging to other objects.

Concerning the cube (Figure 5.12) the cases of correct identification is higher than in the identification of the cylinder-P. Anyway, when the second identity line is from the cylinder the result is still not good enough.

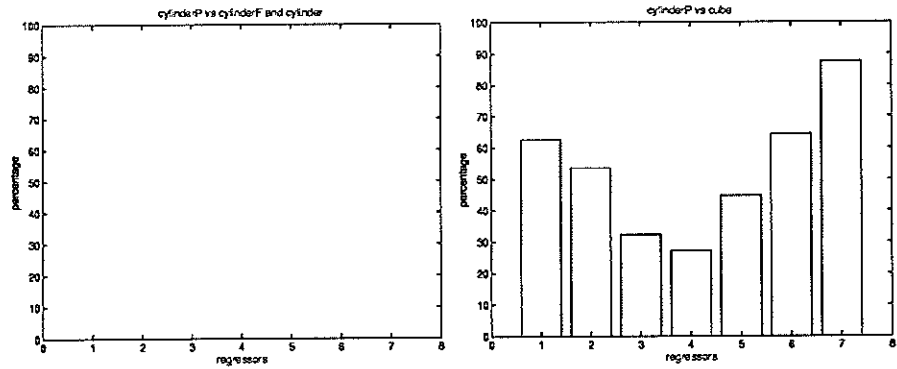


Figure 5.11 Correct identifications of the cylinder with a hole, when the second ID-lines are form the cylinder and cylinderF in the first picture, and from the cube for the second picture

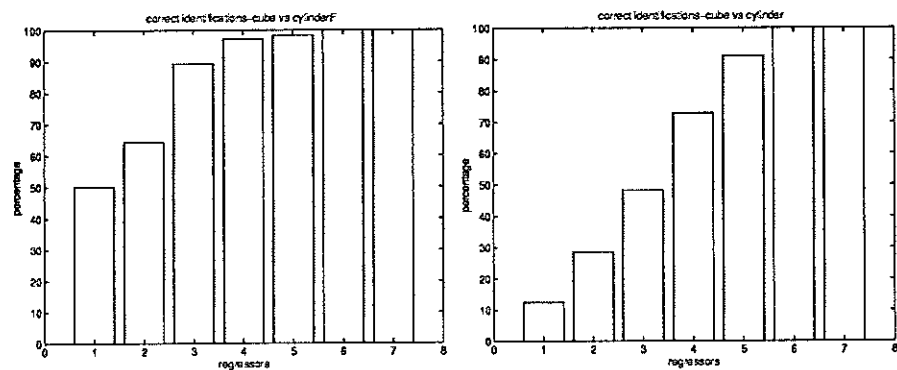


Figure 5.12 Correct identifications of the cube when the second ID-lines are from the cylinder with a hole in the first picture and from the cylinder in the second picture

Looking to these results obtained with sets of data from different sessions of measurements, it can be seen that they are not consistent, the first ones are very good while the ones using the validation data are bad. Also the identification of the cylinder with a hole does not seem to be affected by the validation data!

The reason for this can be found by observation of the echoes from different sessions of measurements used in for validation.

5.3 Variations in Data

Figure 5.13 and Figure 5.14 show the echoes of the cube and the cylinder-P, for the first set of measurements used to compose the identity lines and for the set of measurements used in the validation of the identification method respectively. These two sets were taken in two different session of measurements.

Observing Figure 5.13 and Figure 5.14, there are significant differences between them. Not only in amplitude, but also and more important are the differences in its shape. For example for the cylinder-P the transition from the first peak to the second one is quite different, introducing important variations in shape. The problem behind this is the fact that in the physical world the echo is the reflection of an ultrasonic wave by the object. The ultrasonic vibrations of the air are dependent of the environmental conditions. For example the temperature variation can introduce these kind of variations in the echos.

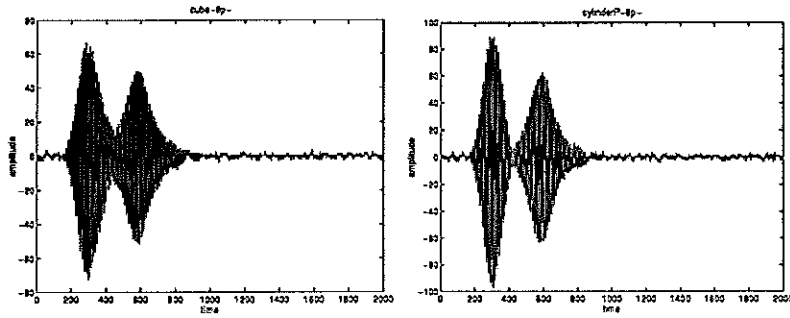


Figure 5.13 Echoes of the cube and cylinder-P from the set used to compose the ID-lines of these objects.

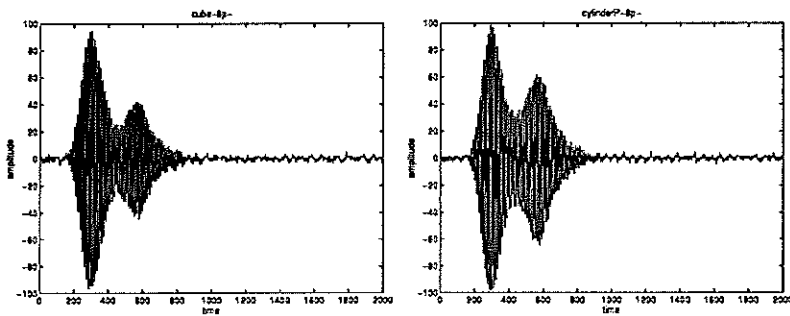


Figure 5.14 Echoes of the cube and the cylinder-P from the set used in the validation of the method.

It follows that the identity line of each object is composed using data from a certain set of measurements from that object. For future identification the method is applied to a new set of echoes that can in some way yield significant differences compared with the one used in identity line. The result will be new Bode gain curves that can be closer from the ones (also used to compose the ID-lines) of other object. Hence, when the LS-method tries to estimate the correct identity lines with this new regressors the result can easily give better estimate for any other object ID-line.

Nevertheless, the identification of the cylinder with a hole seems not to be affected by the variation of the echoes!

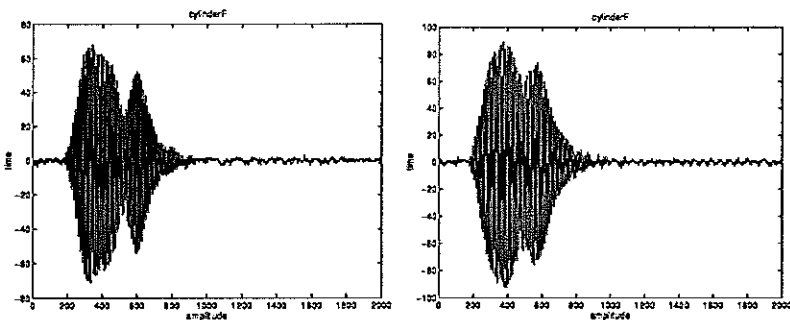


Figure 5.15 Echoes of the cylinder with a hole. The first one is from the set used in the ID-line and the second one is from the validation set.

Figure 5.15, show variations of the echoes of cylinderF. Comparing this echoes with the echoes of ether objects they are much different. Even when variations put some distortion in the data for identification that data is still to different to fit-in other objects echoes.

Considering than, object identification with this method, obviously, a condition to impose so that the method can work is to keep the objects data for identification constant or almost constant between different sessions of measurements.

5.4 Identification by Composition of Envelopes as Signals in Time

For each each object there are available a set of eight envelopes describing it and its position. On the other hand the identification method based on the LS-method presented in chapter 3, can easily be adapted and applied to other kinds of curves (data sequences), then to Bode gain diagrams. Here the use of the identification method in the envelopes as signals in time is analyzed. Figure 5.16 shows the eight envelopes of the cylinder.

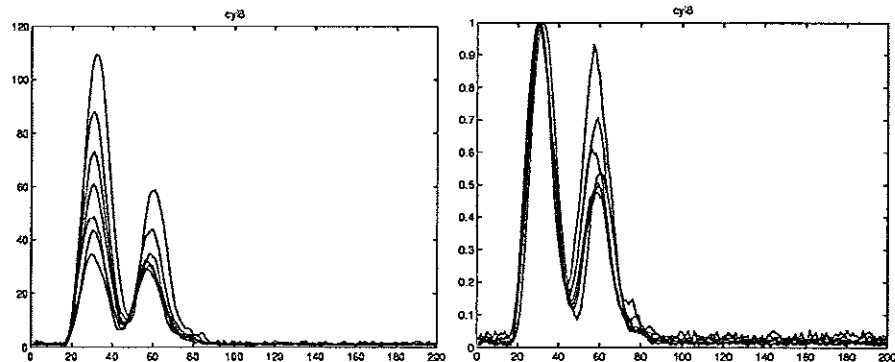


Figure 5.16 Envelopes of the cylinder echoes. In the first place the envelopes are showed with decreasing amplitude as the distance to the center increases. In the second place envelopes are normalized

The amplitude of the curve decreases with the distance from the object to the central position. In order to put together the envelopes of an object and increase the distance between groups of envelopes for different objects, the envelopes are normalized by the maximum of each one so that all first peaks can have amplitude one.

$$\frac{\text{envelope data set}}{MAX(\text{envelope data set})} \quad (5.2)$$

The first peak is the one that reflect the objet properties. The second peak is a cause not of the object but of the platform that support the objects (Figure 1.1). Once more identity lines were built with envelopes of different positions and the usual steps of the identification method were applied.

Results of the Method

The method was tested with the set of data used in the construction of the identity lines. Only in the case of the cylinder-P with second identity lines from the cube the results are not good enough for correct identification. When the second identity line is from the cylinder the results are better (Figure 5.17)

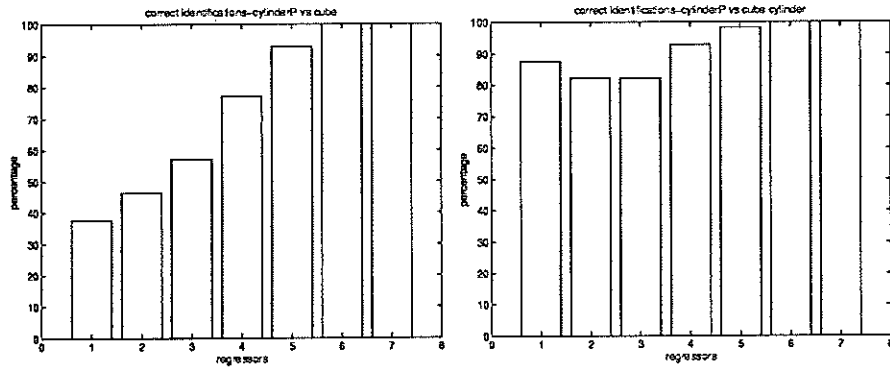


Figure 5.17 Identification of the cylinder-P when the second ID-lines are from the cube and from the cylinder respectively.

These two cases are the worse ones. For the other three objects the number of correct identifications is 100% or close showing a good accuracy for the identification method. Even with the seven and nine millimeter positions, where the envelope becomes much different compared with the others in positions close to the center (0 mm), the method seem to work.

The use of validation data would of course give unconsistent results compared with these ones due to the data and how it varys from one session of measurements to another session.

Nevertheless, this approach show encouraging results even when by observation of the normalized envelopes they seam not to be so close to each other as for example the Bode gain curves are.

6. Conclusions

A discussion about the identification method developed in this work, is presented. The approaches used with the method are stated and an interpretation for its behavior is given resulting in three rules for the method use. Later some remarks are made and a broader view for the use of the method is presented as possible points for further research.

6.1 Discussion

The aim of the present work was to develop an identification method capable of perform object identification by analysis of ultrasonic echoes. The basic idea of the method is based on the LS-method applied to the linear regression model

$$Y = \Phi \Theta \tag{6.1}$$

describing the objects for identification. Each object was defined by Y , based on the regressor matrix Φ (containing information about the objects) the LS-method gives an estimate of Y (\hat{Y}). Analyzing the prediction errors $\epsilon = |Y - \hat{Y}|$ a decision about the object identity can be made.

Two main approaches were followed. The first one was the one from which the method was developed. Based on the objects echoes and using the state-space identification algorithm as presented in chapter 2, systems whose impulse response fits the original echoes, were produced and its Bode gain curves used to built the linear regression model Y .

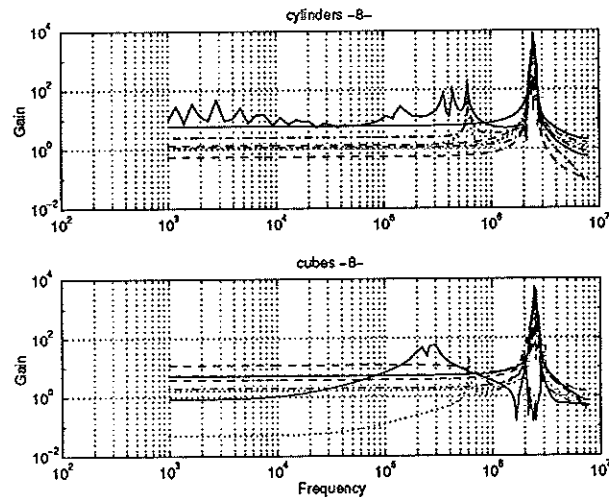


Figure 6.1 Bode gain curves for the cylinder and the cube.

As it was discussed by observation of results (chapter 4) the accuracy of the method is not sufficient using this Bode gain lines. A reason for it rely on the large resonant peak common to every line . The ultrasonic sensor used in the measurements produce a wave oscillating with a frequency of 200 KHz causing the resonant peak in the Bode gain lines for every object. This common

characteristic for every object masks the differences between them. Hence the LS-method may give an estimate closer of other object than the right one.

The second approach is based on the echoes envelopes. The fact that by simple observation of the echos shape objects could be recognized, as well as the fact that the absence of oscillations in the envelopes will not give a resonant peak in the Bode gain curves, were the reasons to investigate the functionality of the method using the envelopes.

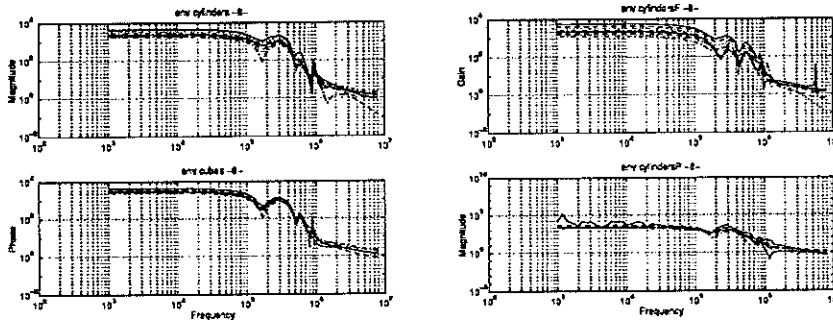


Figure 6.2 Bode gain curves for the envelopes of the cylinder, cube, cylinder with a hole and cylinderP.

With the new Bode gain curves the method gives optimal results. The resonant peak is no longer present and nice regularities happen in the curves. Based on the good accuracy of the method with this lines and observing Figure 6.2, as well as on the interpretation of the method's failure in the first approach, the following three rules can be stated as the necessary and sufficient conditions for a successful application of the method.

- Identification Conditions
 - All lines defining an object, independently of the objects position, should be as close as possible.
 - Any group of lines defining an object should be as far as possible from groups of lines defining other objects.
 - The position of each group of lines have to remain approximately constant having as a reference the group from where the ID-line for the object was composed.

A interesting point is that the idea of identity line as a composition of the important curves from the object lose its value as the first rule gets stronger. In the ideal case if all the lines defining an object regardless its position were equal, the identity line would be only this line and not a composition of several lines.

The problem originated by the variance in data from one session of measurements to another session violate clearly the third rule. The reason why the results of the method where so poor was due to changes in the groups for the new measurements, relatively to the previous positions when the objects identity lines were composed. The new objects estimates can than be closer of ID-lines from other objects than themselves.

As well as for the approach using Bode gain curves of the envelopes, the method was used in the original envelopes after normalization and the results were good. Unfortunately the envelopes would also reflect the variations of data from session to session and again the third rule would not be followed, so incorrect identifications will occur.

The solution to the problem of object identification using the identification method here presented applied to ultrasonic sensor system rely on the search of methods that can able the ultrasonic system to give data in an invariant form regardless the environmental conditions during the measurements as well as other sources of disturbances.

6.2 Further Research

Future work in the following points also refereed by Lindstedt [4] is necessary in order to satisfy the conditions for identification:

- Compensation of changes in the working environment. The temperature variation is an important perturbation.
- Compensation of disturbances during the measurements.
- separation between workspace and objects.

A remark to make is about the computation time of the identification process. The state-space identification algorithm is the responsible for the major part of computation time. As discussed in chapter 2, the singular value decomposition of the Hankel matrices is very time consuming. Anyway without having any previous knowledge of systems that are about to be determined by the algorithm and namely the systems order, the singular values for determine a balanced realization of the system have to be available. The decision to create the system is then made by ignoring the singular values associated with the irrelevant states for the system dynamics. But if the system order is known *a priori*? If so this might be used as a condition to determine a top limit for the amount of singular values necessities to determine the correct system, stopping the computation where the unnecessary singular values start to be calculated. The systems from echoes envelopes have orders between nine and thirteen. For this kind of order only a small quantity of singular values among all are needed. So if only the necessary singular values were calculated, the computation time would decrease drastically compared with the actual one. This would be an important point to be checked and implemented in the future.

Looking again to the identification rules, they do not necessarily have to be restricted to ultrasonic information. Under a more general view, the method can perform its role when applied to any descriptive curves of objects if these curves follow as close as possible the three rules of the method.

Hence, in future research, methods that can produce lines with such characteristics will give valuable contributions to the identification process in general as well as a wide range of possibilities and purposes for the method presented in this work.

7. Appendix A

In the appendix the figures that represent the results concerning the object vectors approach are presented.

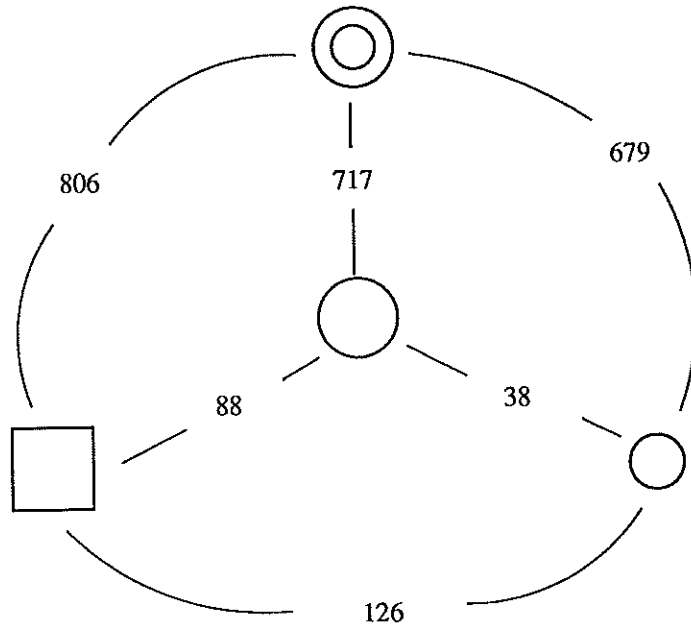


Figure 7.1 Distances between objects using method 1 for 4-pulse input signal

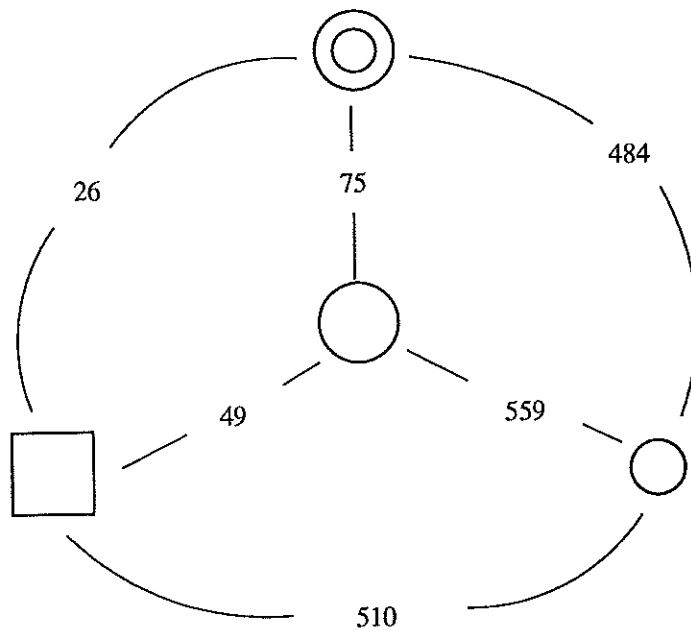


Figure 7.2 Distances between objects using method 1 for 8-pulse input signal

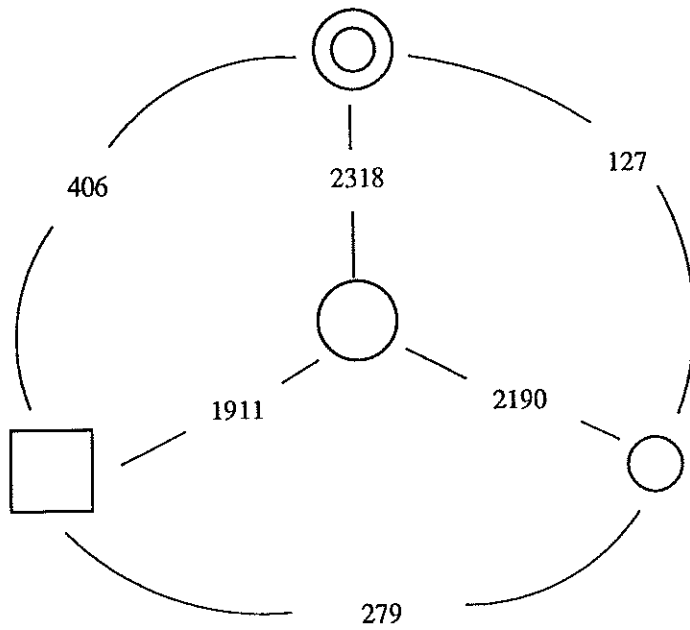


Figure 7.3 Distances between objects using method 1 for 12-pulse input signal

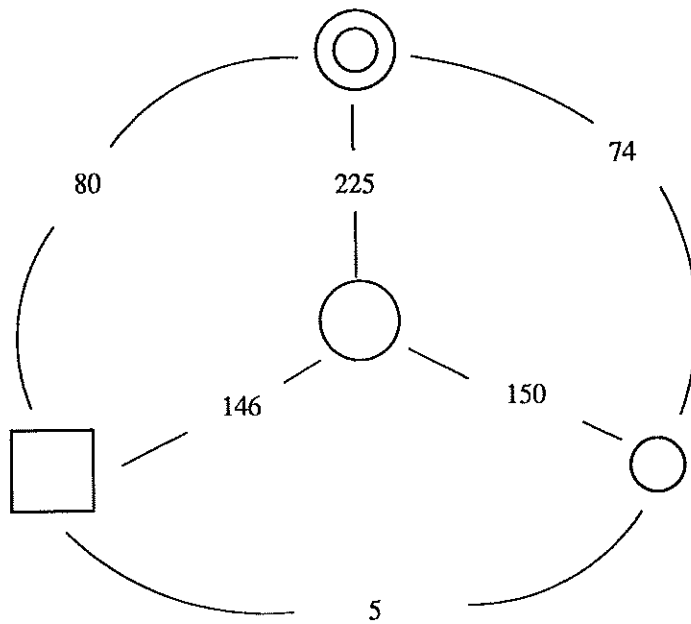


Figure 7.4 Distances between objects using method 1 for 16-pulse input signal

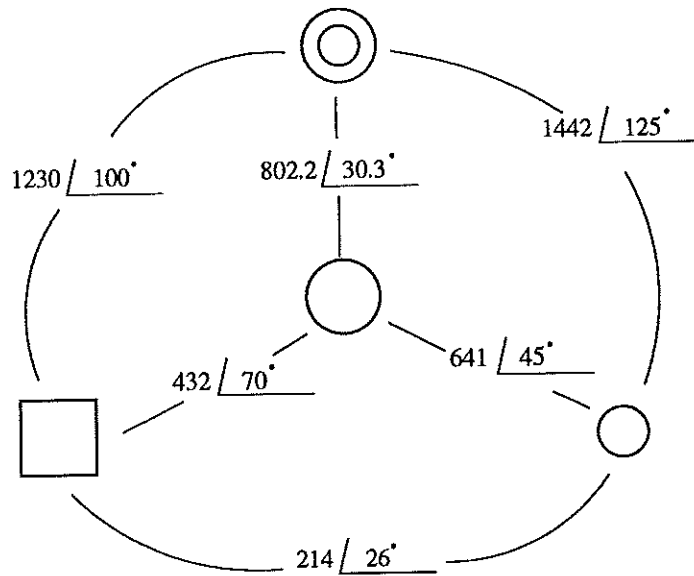


Figure 7.5 Distances between objects using method 2 for 4-pulse input signal

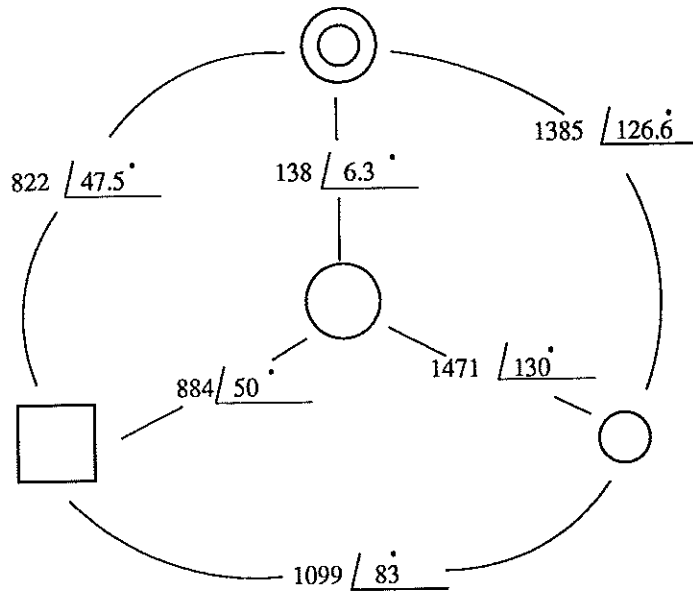


Figure 7.6 Distances between objects using method 2 for 8-pulse input signal

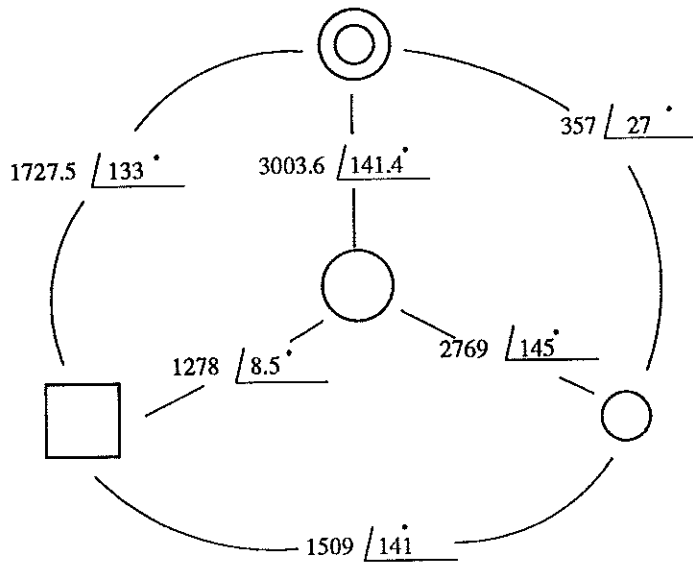


Figure 7.7 Distances between objects using method 2 for 12-pulse input signal

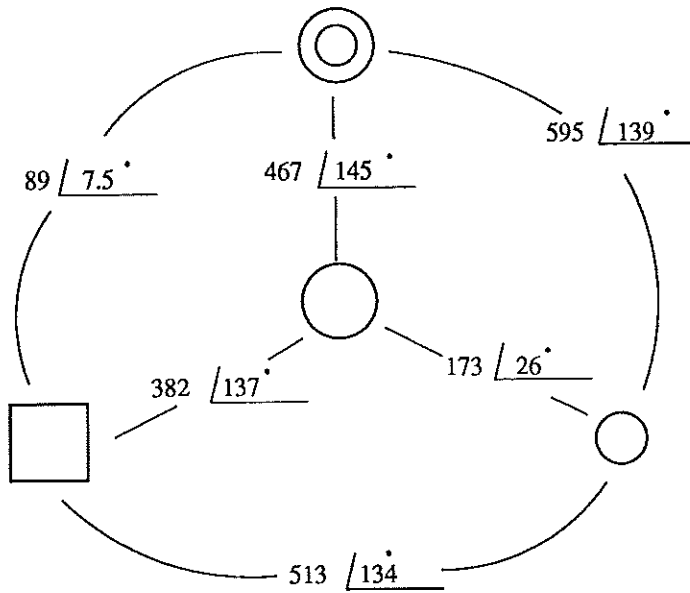


Figure 7.8 Distances between objects using method 2 for 16-pulse input signal

8. Appendix B

The implementation of the State-space Identification Algorithm is presented in Matlab code. The first one is used for the echoes simulation. The second one is used for envelopes echoes simulation. The function hil.m used to take the time envelopes echoes is also presented.

```
%
% identification of the sys generator of the echo as an
% impulse response
%
data=input('name of the file');
plot(data);disp('press any key');pause
%
w=1;while (w>0)
i=input('start:');w=input('interval:');
plot(data(i:i+w));
end;%clg;
%
i=input('start:');w=input('interval:');
w1=round(w/2)+1;w2=4*round(w1/4);w3=2*w2;
dd=decimate(data(i:i+w3),2);
ns=size(dd);
r=ns/2;s=r;
%
dd=dd-mean(dd);
%
plot(dd);disp('press any key to continue');pause;
%
H0=zeros(r,s);H1=zeros(r,s);
%
for ii=1:r, for jj=1:s,
H0(ii,jj)=dd(ii+jj-1); H1(ii,jj)=dd(ii+jj);
end;end;
%
[uu,ss,vv]=svd(H0);
%
plot(diag(ss)/sum(diag(ss)));
ylabel('singular values magnitude');
xlabel('system order');
%
nn=max(r,s);
rs=diag(ss)/sum(diag(ss));
sound(dd);

sv=1; while sv>0;
sv=input('enter the minimum singular value:');
if sv==0,break;end
k=0; for ii=1:nn, if (rs(ii)>sv); k=k+1; end ; end;q=k
```

```

sg=ss(1:q,1:q); ug=uu(:,1:q); vg=vv(:,1:q);
Ag=inv(sqrt(sg))*ug'*H1*vg*inv(sqrt(sg));
B=sqrt(sg)*vg'; Bg=B(:,1);
C=ug*sqrt(sg); Cg=C(1,:);
y=dimpulse(Ag,Bg,Cg,0,1,ns);

subplot(311);plot([y dd]);
title('superposition of simulated and real echos')
subplot(312);plot(y);title('simulated echo')
subplot(313);plot(dd);title('real echo')
end

[numg,deng]=ss2tf(Ag,Bg,Cg,0,1);

```

State-space Identification Algorithm for models simulating the envelopes echoes.

```

%*****
% identification of the sys generator of the envelope of the
% echo as an impulse response
%
%*****
%
%bus=input('name of the file with out extention:', 's');
%load(bus)
%clg;
bat=input('name of the file');
plot(bat);disp('press any key');pause
%
data=hil(bat,2);
plot(data);disp('press any key');pause
%
w=1;while (w>0)
i=input('start:');w=input('interval:');
plot(data(i:i+w));
end;%clg;
%
i=input('start:');w=input('interval:');
w1=round(w/2)+1;w2=4*round(w1/4);w3=2*w2;
dd=decimate(data(i:i+w3),2);
ns=size(dd);
r=ns/2;s=r;
%
%dd=dd-mean(dd);
%
plot(dd);disp('press any key to continue');pause;
%
H0=zeros(r,s);H1=zeros(r,s);
%
for ii=1:r, for jj=1:s,
H0(ii,jj)=dd(ii+jj-1); H1(ii,jj)=dd(ii+jj);
end;end;

```

```

%
[uu,ss,vv]=svd(H0);
%
plot(diag(ss)/sum(diag(ss)));
ylabel('singular values magnitude');
xlabel('system order');
%
nn=max(r,s);
rs=diag(ss)/sum(diag(ss));
sound(dd);

sv=1; while sv>0;
  sv=input('enter the minimum singular value:');
  if sv==0,break;end
  k=0; for ii=1:nn, if (rs(ii)>sv); k=k+1; end ; end;q=k
  sg=ss(1:q,1:q); ug=uu(:,1:q); vg=vv(:,1:q);
  Ag=inv(sqrt(sg))*ug'*H1*vg*inv(sqrt(sg));
  B=sqrt(sg)*vg';Bg=B(:,1);
  C=ug*sqrt(sg);Cg=C(1,:);
  y=dimpulse(Ag,Bg,Cg,0,1,ns);
%
dist=1-(norm(dd-y))/norm(dd)
%
subplot(311);
plot([y dd]);
title('superposition of simulated and real envelopes')
subplot(312);plot(y);title('simulated envelope')
subplot(313);plot(dd);title('real envelope')
  end
  pause;
  %pzmap(Ag,Bg,Cg,0);zgrid;axis([-1.2 1.2 -1.2 1.2]);
  %axis('square')
  %
  [numg,deng]=ss2tf(Ag,Bg,Cg,0,1);
  %
  %Ag=input('A matrix:', 's');

end

```

The function *hil(echo,d)* uses the Hilbert transform to produce the echoes envelope with a decimation of *d*.

```

%*****
% HIL(eco)
% envelope of the echo by the absolute value of the hilbert
% transform
%*****
function h=hilb(eco,n)
h=decimate(abs(hilbert(eco-mean(eco))),n);

```


9. Appendix C

The function used to produce the estimate \hat{Y} of the linear regression model $Y = \Phi\Theta$ using the LS-method is presented as well as the function used to produced all C_p^8 possible cases for identification

LS-estimates \hat{Y} of Y

```
%
% lsfit(Y,fi): the LS-method aplied to the "output-Y" &
% regressor fi.The result will be "estY"
%
function [estY,dist] = lsfit(Y,fi,W)

th=pinv(fi)*Y;
estY=fi*th;
%
loglog(W,fi,'g--',W,Y,'-.',W,estY);
title('regressors-Y-estimatedY');
%
dist=1-(comp3(Y,estY))/norm(Y)
%s=comp3(Y,estY)
```

Study of C_p^8

```
%
% [erros,ident,bad]=cob(a,p,bs1,bs2,w) give all combinations
% of p "images"
% of the 8 images of the object(s)
%
% a: all images to combine
% p: number of images by combination
% bs1: id-line of the object to be identified
% bs2: id-lines of the objects to make the comparision
% w: frequency ( try wc8d5)
%
function [erros,ident,bad] = cob(a,p,bs1,bs2,w)

[ma,na]=size(a);
%
if p==1

iii=0;k1=0;bad=0;nc=8
b=zeros(ma,p); %
erros=zeros(nc,2); % error matrix and regressor matrix are
ident=zeros(nc,1); % created

for k0=(k1+1):na; kk=[ k0] %index for each combination

for ii=1:ma,for jj=1:p
```



```

b(ii,jj)=a(ii,kk(:,jj)); %regressor matrix
end; end;

[est1,ee1]=lsfith(bs1,b,w);[est2,ee2]=lsfith(bs2,b,w);
ee=[ee1 ee2];iii=iii+1;

for jjj=1:2
erros(iii,jjj)=ee(1,jjj); % error matrix
end;

if ee1>ee2 ident(iii,1)=1;else ident(iii,1)=0;
bad=bad+1;end;ID=ident(iii,1)

end;

end;
%
if p==2

iii=0;k2=0;bad=0;nc=28;
b=zeros(ma,p); %
erros=zeros(nc,2); % error matrix and regressor matrix are
ident=zeros(nc,1); %created

for k1=(k2+1):(na-1),
for k0=(k1+1):na; kk=[k1 k0] %index for each combination

for ii=1:ma,for jj=1:p
b(ii,jj)=a(ii,kk(:,jj)); %regressor matrix
end; end;

[est1,ee1]=lsfith(bs1,b,w);[est2,ee2]=lsfith(bs2,b,w);
ee=[ee1 ee2];iii=iii+1;

for jjj=1:2
erros(iii,jjj)=ee(1,jjj); % error matrix
end;

if ee1>ee2 ident(iii,1)=1;else ident(iii,1)=0;bad=bad+1;
end;ID=ident(iii,1)

end;
end;

end;
%
if p==3

iii=0;k3=0;bad=0;nc=56;
b=zeros(ma,p); %
erros=zeros(nc,2); % error matrix and regressor matrix are
ident=zeros(nc,1); % created

```

```

for k2=(k3+1):(na-2),
for k1=(k2+1):(na-1),
for k0=(k1+1):na;   kk=[k2 k1 k0]   %index for each combination

    for ii=1:ma,for jj=1:p
    b(ii,jj)=a(ii,kk(:,jj)); %regressor matrix
    end; end;

    [est1,ee1]=lsfith(bs1,b,w);[est2,ee2]=lsfith(bs2,b,w);
    ee=[ee1 ee2];iii=iii+1;

    for jjj=1:2
    erros(iii,jjj)=ee(1,jjj); % error matrix
    end;

    if ee1>ee2 ident(iii,1)=1;else ident(iii,1)=0;
    bad=bad+1;end;ID=ident(iii,1)

end;
end;
end;

end;
%
if p==4

iii=0;k4=0;bad=0;nc=70;
b=zeros(ma,p);   %
erros=zeros(nc,2); % error matrix and regressor matrix are
ident=zeros(nc,1); % created

for k3=(k4+1):(na-3),
for k2=(k3+1):(na-2),
for k1=(k2+1):(na-1),
for k0=(k1+1):na;   kk=[k3 k2 k1 k0]   %index for each
                                                %combination

    for ii=1:ma,for jj=1:p
    b(ii,jj)=a(ii,kk(:,jj)); %regressor matrix
    end; end;

    [est1,ee1]=lsfith(bs1,b,w);[est2,ee2]=lsfith(bs2,b,w);
    ee=[ee1 ee2];iii=iii+1;

    for jjj=1:2
    erros(iii,jjj)=ee(1,jjj); % error matrix
    end;

    if ee1>ee2 ident(iii,1)=1;else ident(iii,1)=0;
    bad=bad+1;end;ID=ident(iii,1)

end;
end;

```

```

end;
end;
end;

end;
%
if p==5
iii=0;k5=0;bad=0;nc=56;
b=zeros(ma,p); %
erros=zeros(nc,2); % error matrix and regressor matrix are
ident=zeros(nc,1); % created

for k4=(k5+1):(na-4),
for k3=(k4+1):(na-3),
for k2=(k3+1):(na-2),
for k1=(k2+1):(na-1),
for k0=(k1+1):na; kk=[k4 k3 k2 k1 k0] %index for each
%combination

for ii=1:ma,for jj=1:p
b(ii,jj)=a(ii,kk(:,jj)); %regressor matrix
end; end;

[est1,ee1]=lsfith(bs1,b,w);[est2,ee2]=lsfith(bs2,b,w);
ee=[ee1 ee2];iii=iii+1;

for jjj=1:2
erros(iii,jjj)=ee(1,jjj); % error matrix
end;

if ee1>ee2 ident(iii,1)=1;else ident(iii,1)=0;
bad=bad+1;end;ID=ident(iii,1)

end;
end;
end;
end;
end;

end;
%
if p==6

iii=0;k6=0;bad=0;nc=28;
b=zeros(ma,p); %
erros=zeros(nc,2); % error matrix and regressor matrix are
ident=zeros(nc,1); % created

for k5=(k6+1):(na-5),
for k4=(k5+1):(na-4),
for k3=(k4+1):(na-3),
for k2=(k3+1):(na-2),
for k1=(k2+1):(na-1),

```

```

for k0=(k1+1):na; kk=[k5 k4 k3 k2 k1 k0] %index for each
                                %combination

    for ii=1:ma,for jj=1:p
        b(ii,jj)=a(ii,kk(:,jj)); %regressor matrix
    end; end;

    [est1,ee1]=lsfith(bs1,b,w);[est2,ee2]=lsfith(bs2,b,w);
    ee=[ee1 ee2];iii=iii+1;

    for jjj=1:2
        erros(iii,jjj)=ee(1,jjj); % error matrix
    end;

    if ee1>ee2 ident(iii,1)=1;else ident(iii,1)=0;
        bad=bad+1;end;ID=ident(iii,1)

end;
end;
end;
end;
end;
end;

end;

if p==7

iii=0;k7=0;bad=0;nc=8;
b=zeros(ma,p); %
erros=zeros(nc,2); % error matrix and regressor matrix are
ident=zeros(nc,1); % created

    for k6=(k7+1):(na-5),
        for k5=(k6+1):(na-5),
            for k4=(k5+1):(na-4),
                for k3=(k4+1):(na-3),
                    for k2=(k3+1):(na-2),
                        for k1=(k2+1):(na-1),
                            for k0=(k1+1):na; kk=[k6 k5 k4 k3 k2 k1 k0] %index for each
                                                                %combination

                                for ii=1:ma,for jj=1:p
                                    b(ii,jj)=a(ii,kk(:,jj)); %regressor matrix
                                end; end;

                                [est1,ee1]=lsfith(bs1,b,w);[est2,ee2]=lsfith(bs2,b,w);
                                ee=[ee1 ee2];iii=iii+1;

                                for jjj=1:2
                                    erros(iii,jjj)=ee(1,jjj); % error matrix
                                end;

```

```

    if ee1>ee2 ident(iii,1)=1;else ident(iii,1)=0;
    bad=bad+1;end;ID=ident(iii,1)

end;
end;
end;
end;
end;
end;
end;

end;

if p==8

iii=0;k8=0;bad=0;nc=1;
b=zeros(ma,p);      %
erros=zeros(nc,2); % error matrix and regressor matrix are
ident=zeros(nc,1); % created

    for k7=(k8+1):(na-6),
    for k6=(k7+1):(na-5),
    for k5=(k6+1):(na-5),
    for k4=(k5+1):(na-4),
    for k3=(k4+1):(na-3),
    for k2=(k3+1):(na-2),
    for k1=(k2+1):(na-1),
    for k0=(k1+1):na;   kk=[k7 k6 k5 k4 k3 k2 k1 k0]%index for each
                                %combination

        for ii=1:ma,for jj=1:p
        b(ii,jj)=a(ii,kk(:,jj)); %regressor matrix
        end; end;

        [est1,ee1]=lsfith(bs1,b,w);[est2,ee2]=lsfith(bs2,b,w);
        ee=[ee1 ee2];iii=iii+1;

        for jjj=1:2
        erros(iii,jjj)=ee(1,jjj); % error matrix
        end;

        if ee1>ee2 ident(iii,1)=1;else ident(iii,1)=0;
        bad=bad+1;end;ID=ident(iii,1)

    end;
end;
end;
end;
end;
end;
end;
end;
end;
end;

```

end;

end;

References

- [1] S. Bayard, "An Algorithm for State-Space Frequency Domain Identification Without windowing Distortions", *IEEE Transactions in Automatic Control*, Vol 39, no.9, sept 1994
- [2] R. Johansson, "State-space Methods", Dept. of Automatic Control, Lund Institute of Technology, 1995
- [3] R. Johansson, *System Modeling and Identification*, Prentice-Hall, Englewood Cliffs, N.J., 1993
- [4] G. Lindstedt, "A Versatile Ultrasonic Sensor System for Industrial Robot Applications", Industrial Electrical Engineering and Automation, Lund Institute of Technology, May 1993
- [5] L. Sobral, "The Identification Problem using an Ultrasonic Sensor System", Dept. of Automatic Control, Lund Institute of Technology, April 1995
- [6] K.J.Åström, B. Wittenmark, *Computer Controlled Systems*, Prentice-Hall, Englewood Cliffs, N.J., 1990
- [7] V. Oppenheim, S. Willsky and Ian T. Young, *Signals and Systems*, Prentice-Hall International Editions, 1983

