Automatic Discrimimation of the Modes of Permanent Flow of a Liquid Simulating Blood

Malika.D Kedir-Talha, and Mohamed Mehenni

***Abstract*—**In order to be able to automatically differentiate between two modes of permanent flow of a liquid simulating blood, it was imperative to put together a data bank. Thus, the acquisition of the various amplitude spectra of the Doppler signal of this liquid in laminar flow and other spectra in turbulent flow enabled us to establish an automatic difference between the two modes. According to the number of parameters and their nature, a comparative study allowed us to choose the best classifier.

***Keywords*—**Doppler spectrum, flow mode, pattern recognition, permanent flow.

I. Introduction

THE purpose of this study is to obtain an automatic classifier of the flow mode. Such a system would be used to allot an unspecified Doppler signal of a liquid simulating blood to the class of the mode which corresponds to it. Whatever the field, the amount of data to be treated is often very important. In order to obtain a relatively fast classification of these data, it will be necessary to reduce their number. In order to do that, it will be enough to reduce the number of parameters representing the Doppler signal of the studied liquid, by removing those which do not influence the results in a notable way. Thus, we will preserve only the most relevant parameters, in order to obtain a correct classification of the acquired signals.

Two methods of pretreatment will be applied, in order to extract the parameters characterizing the Doppler signal. The training will determine the best classifier and it is the error of classification which will influence the choice of the method to adopt. The first method of pretreatment, based on the concept of a tree, is the Branch and Bound (B &B) method. It allows the extraction of the most relevant parameters.

The second method is based on the amplitude of the Doppler signal spectrum shape in laminar or turbulent flow. The Gaussian shape of the spectrum makes it possible to extract the parameters according to the spectral distribution of the signal.

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II. Experiment and Method

A. The Model of the Doppler Signal

The Doppler signal is the sum of the contribution of all the diffusers passing by the volume of measurement [1]; the exact movement of each particle of the fluid is unknown and non measurable; it is impossible to simulate the Doppler signal without simplifying the problem.

To reduce the complexity of the problem, we make the following assumptions [2]:

- the speed vector of each retro
- diffuser is parallel to the walls of the blood vessels.
- the blood vessel is a rigid cylindrical tube, an assumption which eliminates the vibrations of the walls
- the flow is permanent, which involves that the amplitude of the Doppler signal as well as the speed are constant while the particle passes through the volume of measurement

The designed model simulates blood circulation by means of latex pipes of different diameters (4,6,8)mm, the circulating fluid is an aqueous solution containing micro - spheres with a diameter of 10 μm, which is close to the size of the blood cells. The density of the solution is 1 g/cm3 and is measured at ambient temperature. A flow meter was used to measure the flow and to check the states of steady flow (regular). An adapted positioning system was used to fix the probe plunged in water and to change with precision the θ angle [3].

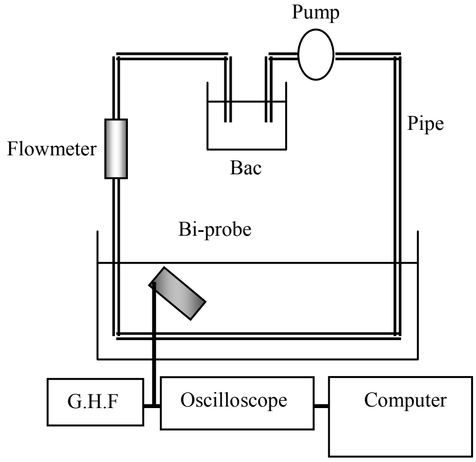

Fig. 1 Diagram of the simulation experiment

This bi-probe has a Z=38 impedance for a frequency of emission $Fe=6.5MHz$. The digital oscilloscope makes it possible to visualize the reflected signal and to sample it; the spectra of amplitude are calculated by means of the FFT (Fast Fourier Transform).

B. Characterization of the Modes of Flow

The dispersion of the fluid is directly related to its hydrodynamic properties like viscosity, the density and the nature of the flow [4]-[5]. This last characteristic is very important: our study is based on the knowledge of the nature of the flow which enables us to determine the circulatory speed of blood. The modes of flow are clearly distinguished according to the Reynolds number, Re, which makes it possible to define the laminar or turbulent character of a flow. For our application, we supposed that blood is incompressible and viscous; thus the blood flow is considered to be laminar for values of de Re < 2500 and turbulent for Re > 2500.

III. Pretreatment

After having put together the data bank of the whole set of the Doppler signal amplitude spectra of the liquid simulating blood, it is essential to make a treatment device which will be used to extract the most representative parameters of the Doppler signal. Thus we have applied two methods, the B&B method and another one based on the Gaussian shape of the signal.

A. Method of Branch and Bound (B&B) [6]

The method consists in finding the whole set of the parameters to be removed and keeping the most relevant ones. In order to do that, the method uses a tree with as many branches as possible combinations. Each branch, in its turn, consists of nm nodes (nm = number of parameters to be removed = a number of tree levels). The node represents the number of the parameter to be removed. A node on a K level will be associated to the whole set of the nodes connecting it to the root. A criterion J_k $(P_1,P_2,\ldots P_k)$ will make it possible to measure the quality of the subset of the k parameters $P_1,P_2,\ldots P_k$

The selected criterion is that of Mahanalobis which minimizes the interclass distance and maximizes the intraclass distance.

$$J = M^T S^{-1} M$$

$$M = M_2 - M_1$$

$$S = (S_1 + S_2) / 2$$

where

M_i average vector of class i.

S_i covariance matrix of class i.

i = 1,2.

B. The Gaussian Shape of the Spectrum Signal

Considering the shape of the spectra of the acquired signals, Fig. 2 and Fig. 3, the amplitude spectrum of the signal is modelled by a Gaussian shape [7]. Thus it becomes obvious that we have to represent this signal by its moment of first order and that of second order. The F_m frequency will correspond to the maximum Am, F_1 and F_2 corresponding to $A_m/2$, make it possible to define the relative variation $\Delta F = F_2 - F_1$. We can obtain thus the characteristic parameters of this Gaussian shape which are specific for each spectrum and consequently characterize the flow modes [8].

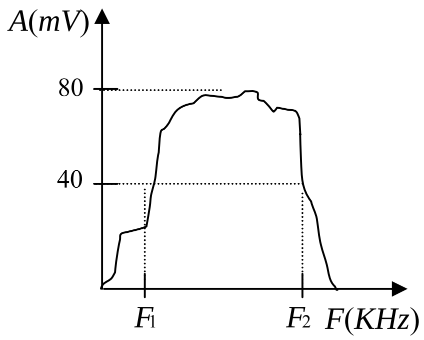

Fig. 2 Spectrum of Doppler amplitude in laminar mode

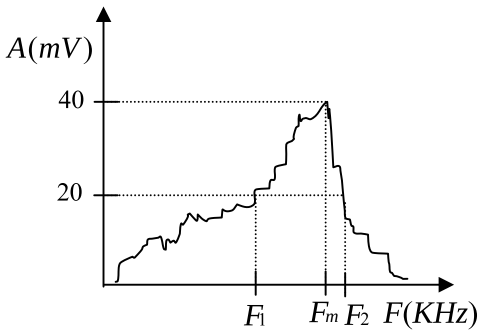

Fig. 3 Spectrum of Doppler amplitude in turbulent mode

IV. Automatic Classification

In the case of the B&B method, the amplitude spectrum of the Doppler signal is presented under the form of a set of parameters, I.e. by an X vector of the space of measurement IR^n . A shape will be thus defined by a point of this space. For the other pretreatment method, which takes into consideration the Gaussian shape of the spectrum, the parameters representing the form are four frequency parameters

$(F_1 , F_2 , \Delta F, F_m)$.

The problem of the recognition of the form amounts to locating and separating the various groups in this space, which will in fact represent the whole set of the classes. Thus defined, a class will regroup the whole set of similar forms, and the recognition of an unspecified Doppler spectrum will consist in determining the class to which it belongs I.e. its flow mode. We have thus to find a family of discriminating functions which will make the best discrimination of the space of measurements. According to whether the data were linearly separable or not, we have used the following classifiers:

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A. Linear Classifier

In the case when the shape categories (Doppler Spectrum or frequencies) are represented by quite distinct spaces of measurements, a linear hyperplane could be determined by an algorithm such as the perceptron or the gradient algorithms in order to make a distinction: we can thus say whether the classes are linearly separable. In our case we have two flow modes, therefore two classes C_1 and C_2:

C_1 : class of the laminar flow.

C_2: class of the turbulent flow.

- Method of the PERCEPTRON

the linear hyperplane equation is: $w^T.(x,1) = 0$

In the case of the two classes C_1 and **C2** of the space of measurement IR^2, we're looking for a vector W such as to make the fewer errors possible [9].

$$w^T .(x, 1) > 0 \Rightarrow x \in C_1$$
$$w^T .(x, 1) < 0 \Rightarrow x \in C_2$$

The w vector a n +1 components. The principle of the algorithm is based on the fact that if a point is not well classified, we must move the hyperplane in order to bring it closer to the optimum value. This algorithm converges only if the classes are linearly separable. Its importance lies in its speed of convergence, in the space allocated for its execution and in the fact that it is easy to use.

- Method of HO-KASHAP

The HO-KASHAP algorithm is based on the minimal quadratic error methods by using the gradient technique [10] . This algorithm gives an indication on the separability of the classes. If some components of the vector ″e″ are negative whereas the others are null, we can conclude that the classes are not linearly separable and that a non-linear algorithm of classification is then necessary.

For the whole set of the data bank, it is obvious that we have to start by determining a linear classifier. By applying the perceptron algorithm we obtain the classifier in a simple and direct way if the classes are linearly separable. If that diverges, we shall use the algorithm of HO-KASHAP which will allow us to justify the non linearity of the classifier, by examining the error vector. This way, we will be able to design a non-linear classifier.

B. Non-Linear Classifier

- Method of Sklansky-Michelotti

This method is based on the separation of each class in a certain number of subclasses, each one represented by its center called a ″ prototype″. We adopted the linearization per pieces approach [10]. Thus the linear algorithms mentioned above will contribute to determining the non-linear borders. In our case we have two classes C_1 and C_2 whose prototypes are U_i et V_j , i, j =1,2 respectively... (the prototypes are found by applying the algorithm of K averages).

$$L_{12} = [(U_i , V_i), d (U_i ,V_i) < d(U_i ,V_k)] \; \forall \; K$$
$$L_{21} = [(U_i ,V_i), d (U_i ,V_i) < d(U_p ,V_k)] \; \forall \; p$$

$$\Pi = [L_{12} \cap L_{21}]$$

V. Experimental Study

A. Pretreatment:

The classification consists in assigning each form to a class, starting from the values of the various parameters obtained at the pretreatment stage. It is obvious that whichever method we may use, the classification can be correctly carried out only if the parameters extracted during the description phase are representative for the form.

- Method of B&B During the classification of the forms, the number of data to be treated is often important for two main reasons: because the number of the forms to be treated is large, but also because the number of parameters used for the representation of each form is very large too. This involves a large number of treatments, therefore a long computing time, but also an important memory effort, which can be, at times, experimentally impossible. Thus the B&B method reduces the number of data to be treated, by removing the least relevant parameters. For the whole set of the data bank of the Doppler signals, in laminar and turbulent flows, we have applied, at the beginning, the linear classification. We obtain the following curve:

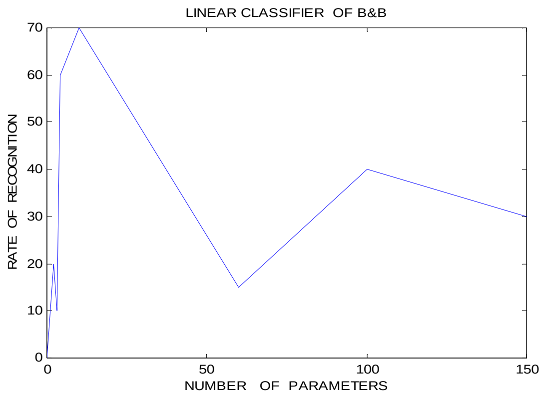

Fig. 4 Linear classifier of B&B

The Fig. 4 shows the evolution of recognition rate according to the number of parameters chosen by the method of B&B. Thus the best rate of recognition (70%) is obtained for a parameters number of 10.

- Method of the Gaussian

For the four frequency parameters (F_1 , F_2 , ΔF, F_m), the linear classifier carries out a TR of 60%; on the other hand if the two methods are combined, I.e. selecting among the four frequential parameters, the most relevant ones by the B&B method, we obtain the following figure:

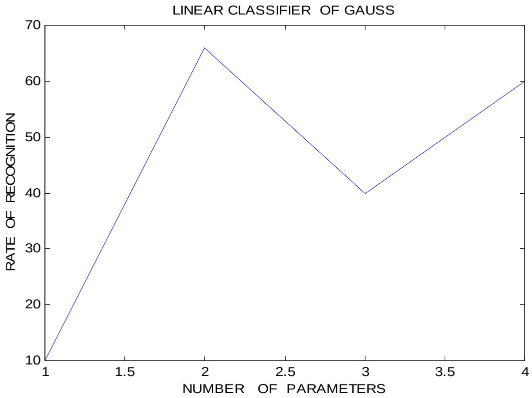

Fig. 5 Linear classifier of Gauss

The best recognition rate (TR = 66%), is obtained for a number of parameters of two, namely (ΔF, F_m). We improve, thus, the TR and the time of decision since the number of parameters was reduced to two. On the comparative level, if we consider the best linear classifier as being that which gives us the best TR, our choice will be TR = 70%. This one is obtained for a number of parameters (spectral amplitudes) of ten (10). But, on the other hand, we obtain a TR = 66% for a number of frequency parameters of two (02), which is close to the precedent but with an advantage of time of decision. This kind of classifier could be used in the case of an application in real time, where the time factor plays an important part, for instance in the monitoring of a patient.

It is obvious that for the same number of parameters, the recognition time (known also as the time of decision) for each linear classifier is shorter than that for the non-linear classifier. Thus for the same parameters, selected by the B&B method, we apply, at this phase, the non-linear classifier. We obtain the following results:

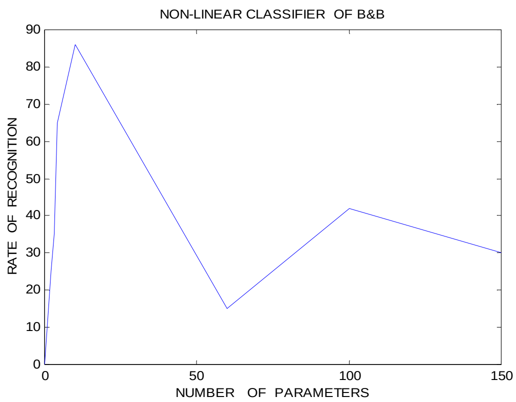

Fig. 6 Non-linear classifier of B&B

The chosen classifier is that which corresponds to the 16 most relevant parameters chosen by the B&B method with a TR = 86%.

As we have done previously, we apply the same algorithm of the non-linear classifier in the case where the selected parameters are frequential and are selected by the B&B method. We obtain the following curve.

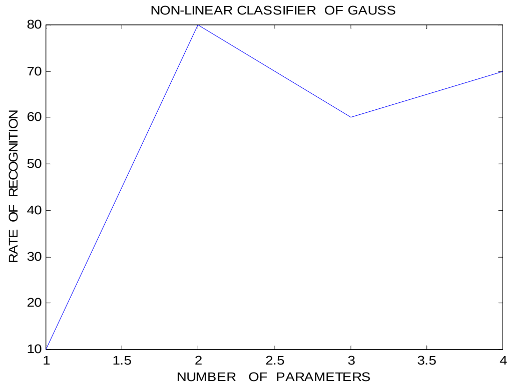

Fig. 7 Non-linear classifier of Gauss

The best TR for one of the two (02) frequential parameters of the Gaussian form, is of 80%. In this case the best classifier is that of the B& B method if the factor time is not important. It is logical to choose the latter, but only to the detriment of the time of decision. Such a classifier will be appropriate for an application in differed time, such as screening, where the real time factor is no longer essential.

VI. Conclusion

The B&B method, has allowed us to confirm that a subset of parameters does not inevitably give a better classification than a subset with fewer elements than the first one. Indeed, certain parameters are not essential for the classification, their presence, on the contrary could complicate the process of recognition.

The simplicity of the pretreatment method based on the Gaussian shape of the spectrum of the Doppler signal, represents a major advantage, all the more since the margin between the classifiers of the two methods is not too important, and since the reduced number of parameters of this method allows us to improve the time of decision.

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