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# Imagery: Virtual Lab for Computer-Aided Training on Digital Image Processing

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**Resumen** Imagery es un laboratorio virtual, intuitivamente fácil de usar, creado para ser utilizado como un laboratorio de Procesamiento Digital de Imágenes (PDI), el cual permite al usuario experimentar con algoritmos de PDI. Imagery opera sobre imágenes proporcionadas por el autor y también por el usuario.

Reflejando el área de especialidad de su autor, Imagery incluye algunos módulos que tratan con algoritmos de Reconocimiento Invariante de Patrones.

Los reportes de investigación y los libros de PDI tratan con algoritmos para operar digitalmente sobre imágenes y, generalmente incluyen algunas imágenes para mostrar los efectos de esos algoritmos, sin embargo, la mayoría de las veces aquellas imágenes no son suficientes para evidenciar todo el potencial de los algoritmos.

En este reporte se da cuenta de la creación de Imagery, un Laboratorio Virtual para Educación Asistida por Computadora (enseñaza y aprendizaje) de PDI. Imagery puede ser usado en el aula, en el laboratorio y en casa.

La ventaja de usar software para enseñar (aprender) una operación sobre imágenes como aquellas que se llevan a cabo en PDI, es que con la ayuda del software, las transformaciones pueden ser apreciadas en tiempo real, pueden variarse algunos parámetros de control, y apreciar su efecto. Aun cuando el autor de Imagery ha incluido alguna teoría, el software es un complemento muy útil a las clases y libros especializados.

**Palabras clave:** procesamiento digital de imágenes, algoritmos, enseñaza, aprendizaje, reconocimiento de patrones, visión computacional, visión cibernética.

**Abstract** Imagery is an intuitively-easy-to-use Virtual Lab to be used as a Digital Image Processing (DIP) laboratory, allowing the user to experiment with DIP algorithms, enabling him to see their effects on images included by its author and also on those of the user.

Reflecting the specialization field if its author, Imagery includes some modules dealing with algorithms used in Invariant Pattern Recognition.

Research papers and books on DIP deal with algorithms to digitally operate on images, and generally some images to show the effects of those algorithms are included, however most times those images are not enough to make evident all the potential of the algorithms.

In this paper the creation of Imagery, a Virtual Lab for Computer Assisted Education (teaching and learning) of DIP is reported. Imagery may be used in the classroom, in the lab and at home.

The advantage of using software to teach (learn) a given image transformation like those performed in DIP, is that with the help of the software the transformations can be appreciated in real time, control parameters can be varied and the corresponding effects appreciated. Even though the author has included some supporting theory in the software, Imagery is a very useful complement to a specialized textbooks and classes.

**Key words:** digital image processing, algorithms, teaching, learning, pattern recognition, computer vision, cybernetic vision.

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## 1. Introduction

Most books on Digital Image Processing (DIP) 1-5, expose the theory and Mathematics of this relatively new field including one example (maybe two) and from this the student has to appeal to his/her imagination in order to assess the power of the algorithm he/she is studying, the teacher has to make use not only of chalk and blackboard but also he must use images in order to show the original image and the final one after the image transformation with a given algorithm.

If a student feels curiosity or interest for a given topic, he has to make the computer program to visualize the results, thus wasting time and effort. In these cases it would be much better if the instructor had a software with which he can dynamically show the students what he is talking about. The class would be not only much more dynamical but also interesting and easy to follow by the students.

Some books and research papers report having used and algorithm to perform a given task, which may not be assessed unless the corresponding computer program is made, this is the case with some Convolution Filters, it is then when Imagery can be used to very rapidly visualize the mentioned results.

A meticulous understanding of DIP is important when developing software for automatic (unsupervised) Pattern Recognition, because in these cases it is necessary to develop algorithms capable of deciding autonomously the operations to be done over an image before extracting information from it, not all images in a given set might need exactly the same operations, this is the case of the computerized detection of flaws in pieces being transported over a conveyor band, this is, automatic quality control.

The author of this paper had to teach DIP at the graduate level to a group of students with different backgrounds, seeing that the experience resulted extremely hard, he decided to create Imagery, a software for Computer Assisted Education of DIP.

Imagery is based on several books and research papers used by its author while teaching DIP, it is also based on the research the author carried out on pattern recognition.

The advantage of using a software to teach image transformations like those performed in DIP, is that with the help of the software the transformations can be appreciated in real time, the exposition is not limited to original and final image, because even intermedial steps on an image transformation may be shown, and very many examples can be appreciated.

Imagery includes some images supplied by the author, however the users may experiment with images of their own, the only restriction being the size. Every module of Imagery contains some pertinent theory but it is important to mention that this software is a complement to a specialized textbook or classes, it is not self sufficient, however it is a great help for both teacher and student.

Imagery is a software that can be used in the classroom, in the Laboratory or at home. In the classroom this software helps the teacher in the exposition of the DIP topics he/she is covering; in the laboratory, Imagery can be used to carry out experiments supporting the topics covered in class; at home, this software can be used by the student to practice and thus reinforce the knowledge acquired in class. This virtual lab may also be used by the independent student or by that in a Distant Learning program.

## 2. Images from the standpoint of DIP

In the field of DIP an image, may be a photograph, is discretized as a two-dimensional light intensity function f(x,y), where (x,y) are the coordinates of every point and the value of the function f at point (x,y) is the light intensity at that point. A digital image is a matrix with rows and columns indicated by x and y, and the matrix element indicates the colour (light intensity) at that point. Digital image researchers have developed mathematical operations over functions like f(x,y) so as to carry out transformations of them. A software for DIP like Imagery makes use of those mathematical transformations, to carry out the operations on the images. Some examples of these transformations include (1) the cleaning of a noisy image, (2) The detection of straight lines (illegal airports) in aerial photographs through a cloudy day, (3) the detection of contours in poor quality images, etc.

The field of DIP deals with the transformations that can be done on images, to extract some information from them. The images are treated as bidimensional functions in x and y and the transformations are mathematical operations carried out over this functions so as to transform them.

## 3. Topics Included in the Imagery Virtual Lab

Imagery currently includes 29 modules dealing with:

| | |
|---|---|
| 1 | **Analysis of Colors: Color Synthesis** |
| 2 | **RGB Color Mixing** |
| 3 | **Straight line representation** |
| 4 | **Geometrical Transformations: Translation** |
| 5 | **Rotation** |
| 6 | **Size Scaling** |
| 7 | **Shearing** |
| 8 | **Image Transformations** |
| 9 | **Point detection mask** |
| 10 | Line detection masks: Vertical, horizontal, slash, back slash |
| 11 | **Binary image boundary detector** |
| 12 | **Image Subtraction** |
| 13 | **Pattern Centroidal Profile Representation** |
| 14 | **Histograms** |
| 15 | Binarizer: Conversion of Grey-Level To Binary Images, Thresholding |
| 16 | **Erosion of binary images** |
| 17 | **Dilation of binary images** |
| 18 | BorderLiner: Histogram-Assisted Edge Detection of Grey-Scaled Images |
| 19 | **Surrounder: Segmentation** |
| 20 | Edge enhancement by Gradient. (The Sobel Operator) |
| 21 | Edge enhancement via the Laplacian operator |
| 22 | **Spatial Operators (Convolution Filters)** |
| 23 | **High boost filter** |
| 24 | **User-Defined Convolution Filters** |
| 25 | **Noise-Reduction Median Filter** |
| 26 | **Massive RTS Invariant Moments** |
| 27 | **Boundary RTS invariant moments** |
| 28 | **The Polar Hough Transform** |
| 29 | **Hough-Transform-based Line Detector** |

Javier Montenegro

## 4. Description of some modules

Due to lack of space only the screen shots of some modules are included in this report.
All modules are fully interactive, they operate on some images supplied by the author and also on images supplied by the user. Every module also includes the pertinent but very succinct theory. Imagery operates all types of images (medical, mechanical, biological, etc)

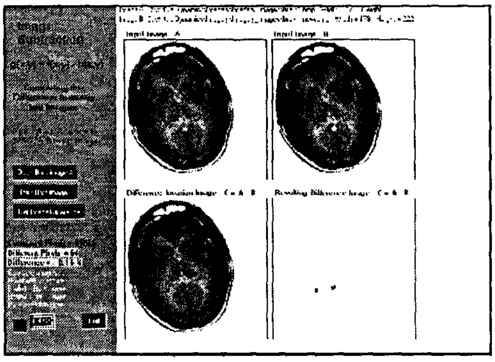
**Color Synthesis and RGB Color Mixing:** these deal both with the analysis of colour from the standpoint of the RGB representation. The Red, Green and Blue components of every colour are be detected also the combinations of R, G and B are dealt with.

**The straight line representation:** deals with the difficulties encountered when making a line, due to the discretization of image space, in order to make a line the researcher must develop the line either by x or y, depending on its orientation.

**Geometrical Transformations (Translation, Rotations, Size Scaling and Shearing):** In these modules the user designs his/her own objects (polygons) with the mouse over the screen and then sets the parameters for the corresponding transformations and the software produces the corresponding geometrical transformations.

**Image Transformations:** This module deals with Color Inversion, Horizontal mirror effect, Turn Image Upside Down, 90° Rotation, 180° rotation, and Vertical Flip, 270° Rotation and Vertical Flip.

**Image Subtraction:** This module allows the user to visualize the difference between two apparently equal images, shows how to detect the differences between two images: $g(x,y) = f(x,y) - h(x,y)$



**Detection of dots and lines on images:** these modules show the corresponding effects, in the case of line detectors, these may be horizontal, vertical and diagonal (45° and 135°). Lines may also be detected through the Polar Hough transform, and Imagery allows the user to analyse and compare both algorithms.

Dot (point)
Detection Mask

| | | |
|---|---|---|
| -1 | -1 | -1 |
| -1 | 8 | -1 |
| -1 | -1 | -1 |

Detects isolated points different from a constant background

Lines at 135°
Detection Mask

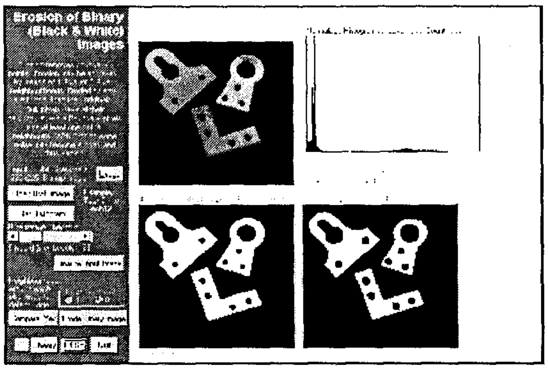
| | | |
|---|---|---|
| 2 | -1 | -1 |
| -1 | 2 | -1 |
| -1 | -1 | 2 |

**Erosion and Dilation:** These two modules may be used to show the use of these algorithms to get rid of some minute imperfections on images.

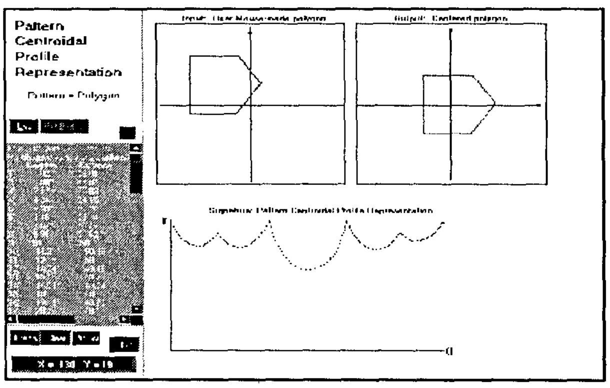
Erosion removes boundary points. Erosion may be achieved by means of 4-Pixel or 8-Pixel neighbourhoods. Eroded objects are thinner than their originals.
Bulk pixels have all their neighbours, while Boundary pixels miss at least one of their neighbours. With Erosion some noise may become eroded and thus vanish.

With Dilation, small holes or cracks become filled and the contour line becomes smoother. In Dilation, pixels having at least one neighbour within the mask, survive.

Dilation expands an image, whereas Erosion shrinks it. Objects dilated with an 8-pixel mask result much more dilated than those dilated with a 4-pixel mask.




Pattern Centroidal Profile Representation: In this module the user must design a polygon with the help of the mouse. Only one polygon at a time. The input polygon (pattern) does not need to be centered on input region.




Given a pattern (polygon) in input image, this software detects its Centroid (geometric center), then displaces the whole pattern in such a way as to place its centroid in the origin of coordinates (0,0),

Since no rotation is carried out, the orientation of the translated pattern is the same it has originally. Next the angle and distance of every border point (x,y) with respect to (0,0) is computed, this constitutes the Centroidal Profile Representation of the pattern.

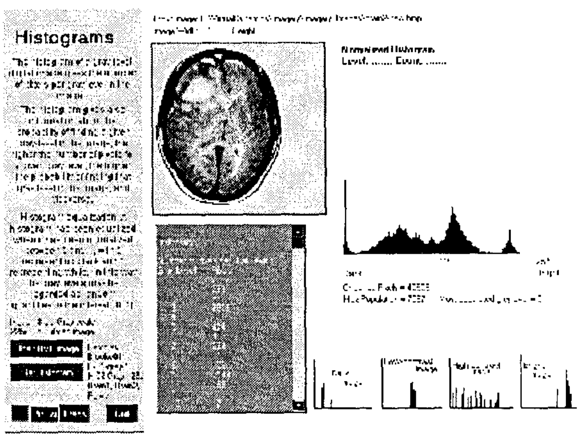
The Centroidal profile representation seems to be possible only as long as the object is not solid but edged, has no holes, the image is clean.

**Histograms:** The histogram of a grey-level digital image gives the number of pixels per grey level in the image.

The histogram gives also information about the probability of finding a given grey-level in the image, the higher the number of pixels for a given grey level, the higher the probability of finding that grey level in the image, and viceversa.

**Histogram equalization:** A histogram has been equalized when it has been normalized between 0 and 1, with 0 representing black and 1 representing white. In this way the grey levels may be regarded as random quantities in the interval from 0 to 1.

When the user strolls the mouse over an obtained Histogram, the numerical values of the population for every visited point is displayed. A list of color intensity and population is shown.




**Edge enhancement by Gradient. (First Derivative via The Sobel Operator)**

Sobel (first derivative, Gradient) Operators are used to detect edges, these operators provide both differencing and smoothing effects. Sobel operators are used to compute the magnitude of the Gradient, which consists in obtaining the partial derivatives with respect to x and y at every pixel location. First Derivatives (Sobel Operators) enhance noise.

Gradient Operator :

| | | |
|---|---|---|
| NW | N | NE |
| W | ● | E |
| SW | S | SE |

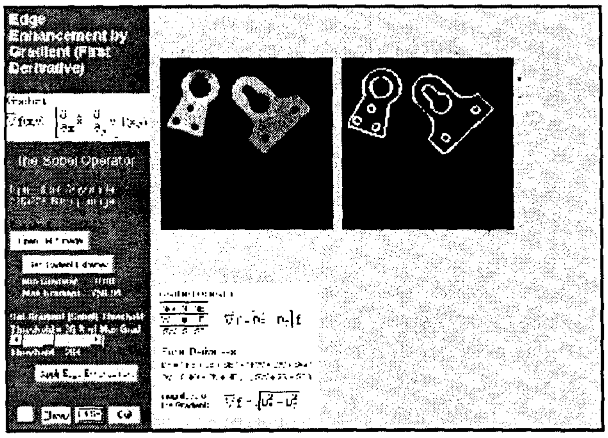
$$\vec{\nabla} f = \left[\vec{Dx} + \vec{Dy}\right] f$$

Sobel Derivatives:

$Dx = ( NE + 2E + SE ) - ( NW + 2W + SW )$

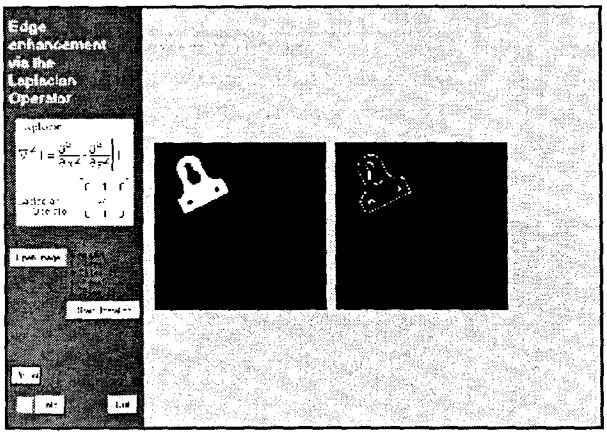
$Dy = ( NW + 2N + NE ) - ( SW + 2S + SE )$

magnitude of the Gradient: $\left|\vec{\nabla} f\right| = \sqrt{D_x^2 + D_y^2}$




## Edge enhancement via the Laplacian operator

The sign of the 2nd derivative determines whether an edge pixel lies on the dark (positive sign) or light (negative sign) of an edge.
The result of the operations on the neighbourhood of pixel at position (x,y) is the new value of the pixel at (x,y).




## High boost filter

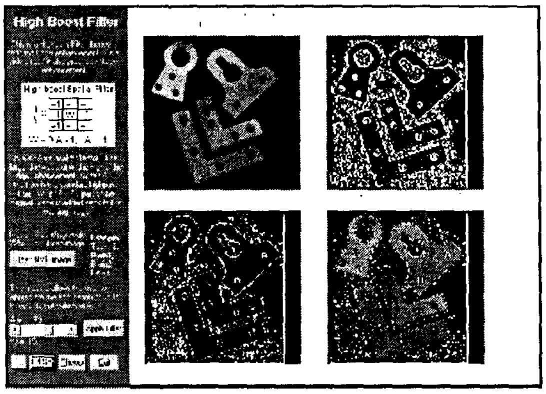
This is a Highpass Filter, hence it performs Edge enhancement. As a side effect, it also produces Noise enhancement. Highpass filters carry out sharpening, which means that noise and other sharp intensity transitions are enhanced.

High-boost Spatial Filter

$$\frac{1}{9} \times \begin{bmatrix} -1 & -1 & -1 \\ -1 & W & -1 \\ -1 & -1 & -1 \end{bmatrix}$$

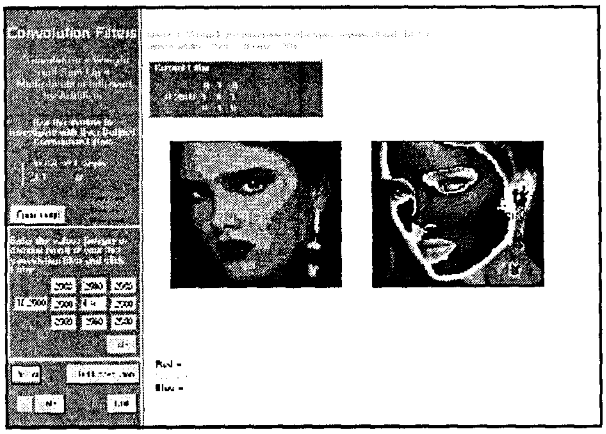
$$W = 9A - 1, \quad A \geqslant 1$$

In the High boost spatial filter, A is an Amplification factor. The larger the value of A, the higher the Edge Enhancement. When A = 1 the filter is the standard highpass filter. When A > 1, part of the original image is added back to the resulting image.

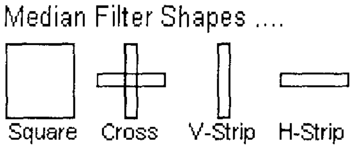



**User-Defined Convolution Filters:** This module is for the user to investigate the result of operating an image with his/her own 3x3-filters. The user loads a test input image and enters the 3x3-filter factors in the nine 3x3-entries and in the coefficient of the filter mask. Some pre-defined convolution filters have been included so that the first-time user can easily see how this module operates.

Many of the filters used in Texture Analysis 9 may be quickly tested with the convolution module included in Imagery.



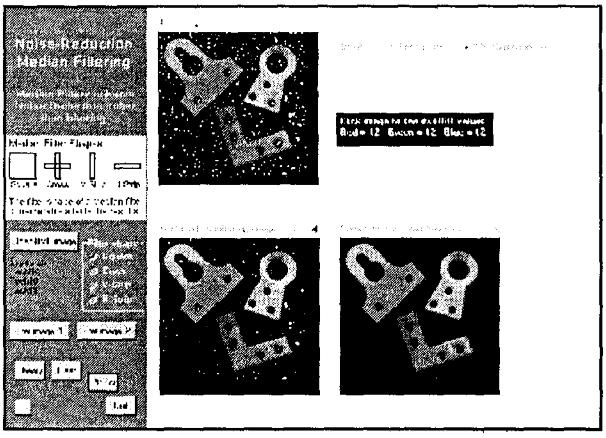
**Noise-Reduction Median Filters:** In a Noise-Reduction Median Filter, the grey-level of each pixel in the image is replaced by the value of the Median of the grey levels in the neighbourhood of the pixel, not by the neighbourhood average as Smoothing filters do. Median filters are classified as non-linear filters, their size depends on the application.




The filter shape of a Median filter considerably affects the results.

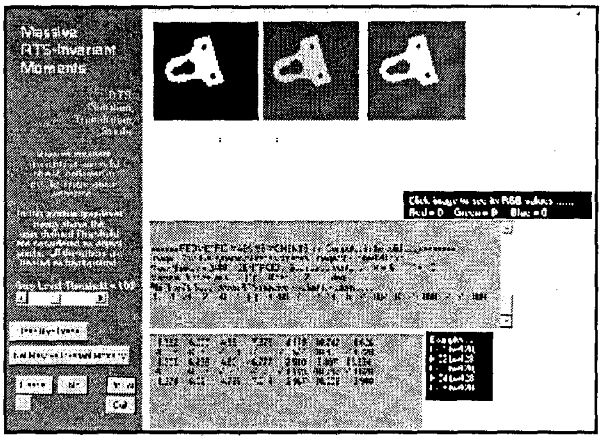
To set up a median filter order from min to max the values of the grey levels of the pixels in the neighbourhood of each pixel p, take the Median of this set (including p) and replace the grey level of pixel p with the Median.

In this module a 3x3 Median filter is being used. The filter may be applied to an image in any of its four versions: Square, Cross, Vertical and Horizontal Strip.
Two successive filter applications are possible, not necessarily with the same filter:
Filter image (A): Operates on input image (1), and generates image (2).
Filter image (B): Operates on image (2), generating image (3).




**Massive RTS Invariant Moments:** RTS stands for Rotation, Translation and Scale. These are Massive Moments 6-7 because these operate on all the pixels of an image, this in contrast with the Boundary Moments 8, which operate only on the border pixels of an image.

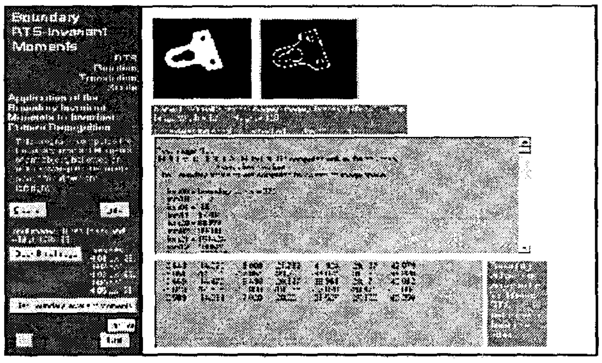
This module operates on either binary (black and white) or grey level images.




Binary images are straightforwardly submitted to the RTS invariant moments computations.
When operating on Grey-level input images, these are binarized (converted to black and white images) before being submitted to the invariant moments computations. Binarization is achieved with the user-defined Grey-Level-Threshold deciding which grey levels must be considered background and which as the object pixels.

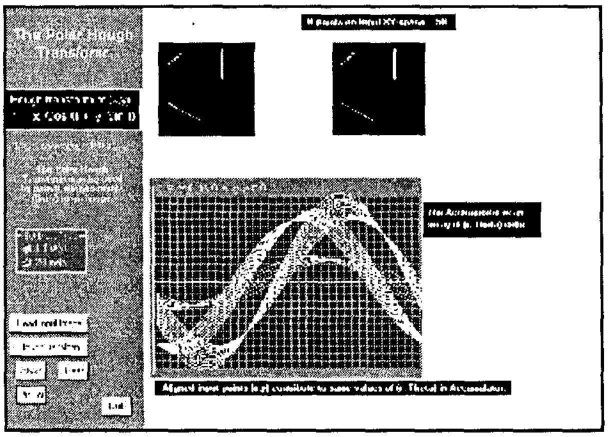
Grey levels of the image pixels above the user-defined Grey Level Threshold are treated as being part of the object in the input image, all the other grey levels are regarded as background.
In a pattern recognition session all images must have been obtained under the same conditions (light, etc) and the grey level threshold must be kept the same for all of them.

**Boundary RTS Invariant Moments:** This module together with that dealing with the Massive RTS Invariant Moments, allow the user to compare the power of the Massive and Boundary Invariant Moments 8, for invariant pattern recognition applications to cybernetic vision (computer vision), an area of the Artificial Intelligence. By making some applications to images 12,14, the user can convince himself that the boundary moments are much more powerful and convenient to use than the massive moments.



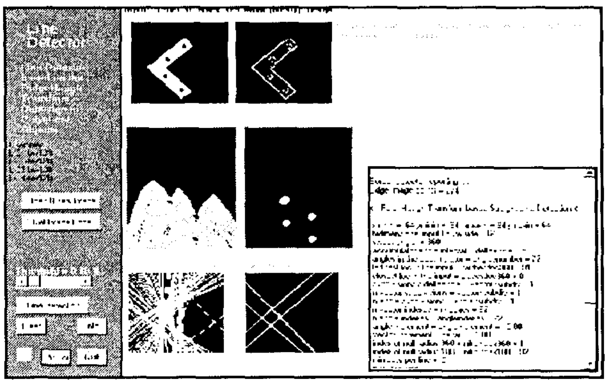
**The Polar Hough Transform:** this is a distortion tolerant technique that maps image-space points into curves in a parameter space. The Polar Hough Transform may be used to detect aligned points (lines) in an image, it maps image-space points of coordinates (x,y) into a parametric accumulator space (,). by means of

$$p = x \ \text{Cos} \quad + y \ \text{Sin}$$



In this module, the user uses the mouse to place single dots and/or lines on an input region on screen, then the software reads this input and makes the corresponding Polar Hough Transform, point by point, in this way the user can clearly see how every point (x,y) is mapped as a sinusoid in the Accumulator space. It can also be seen that those sinusoids corresponding to aligned points (lines), meet all in a single point in (,) space. Hence the representation of aligned points as (,) pairs results evident.

**Hough-Transform-based Line Detector:** This is a powerful algorithm created by the author10,13 of this report, it deals with the invariant pattern recognition of polygonal objects, it has been successfully applied to detect flaws in chocolates and biscuits11 and also in L-shaped mechanical pieces. This module is a description of the invariant pattern recognition algorithm developed by this author.



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