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Virtual Holographic Recognition and Its Applications in Medicine and Other Fields

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ABSTRACT

Novel digital applications developed from analog holographic recognition techniques are presented. Virtual Holographic Recognition (VHR) substitutes physical processes in matched filtering by digital equations and calculates light distribution on the observation plane. If a certain image is defined as a reference, bright light spots corresponding to coincidences between the searched element and the image under study can be numerically calculated with a high degree of accuracy. Since peak values and radial symmetry of values define the degree of coincidence with the reference, this method can be used to find elements similar –up to any degree- to a given reference in a complex image. Current applications include detection and location of malignant masses and nodules in mammograms, computed-tomography (CT) chest scans and conventional digitized radiographs. If the image taken by a digital video camera is continuously processed and the position of the peak corresponding to a reference is tracked on a screen, it allows for guiding of persons in complex environments. Application to guiding of disabled in sport courts is also described.

Keywords: Digital Holography, Holographic Recognition, Computer-aided diagnosis, Disabilities

1. INTRODUCTION

In recent years and within the broad field of image processing, methods for object recognition and image interpretation are undergoing a striking development. Main fields of interest include that of medical diagnosis, as useful aids helpful to reduce and avoid errors in radiological diagnosis. Broadening of its applicability in a cost-effective manner is also a desirable goal for complete or partial automation of periodical screening programs in areas of deep social interest such as breast and lung cancer detection.

Method described in this work, "virtual holographic recognition" (VHR) is based upon a digitally implemented combination of histogram filtering techniques with a holographic image recognition process. Proposed connection of holography and medical image element identification yields a completely digital procedure useful in computer-aided diagnosis systems, which can also be integrated in automated processes or systems and used in personal computers by individual radiologists.

Within this specific field of holographic filtering, currently available results are centered in complex optoelectronic devices for analog signal processing, mainly applied to military synthetic-aperture-radar (SAR) image processing[1-2]. Other applications also include target tracking systems[3-4], astronomical and weather satellite image interpretation, and binary characters identification devices applied to dactilographs and writing analyzers[5]. Research on computer-generated holograms and interferograms is, on the other hand, mainly devoted to three-dimensional visualization systems and industrial quality control. Applications of holography in medicine, a very recent field of interest, are being oriented to generation and visualization of three-dimensional displays[6-8], superposition of holographic images in surgery[9] and holographic medical image archive management[10].

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2. VIRTUAL HOLOGRAPHIC RECOGNITION

Proposed method is based in quantifying, by numerical evaluation, the degree of coincidence in shape, size, orientation, optical density and color of a reference image with the image under study. Reference images are those of elements of known interpretation with which images to be studied are compared. In radiological examples depicted in this work, these known elements are malignant breast masses and lung nodules extracted from mammograms, CT scans and conventional thoracic radiographs whose diagnosis had been confirmed with surgery or after biopsy.

For the purpose of calculation, each image -black and white or colored- is transformed into a numerical matrix of values in which its minimum and maximum values correspond, respectively, to the lowest and highest color tones. The difference between these values is therefore the *scale range* of the original image. Values of these matrices are further transformed into a graphical scale defined from 0 (black) to 100 (white) so that filtering parameters and processes can be described in these new *graphic units* (GU) irrespectively of the values or scales of the original images. If images are obtained from a device already in digital format, such as computed tomography scans, its corresponding numerical values in the appropriate scales, such as Hounsfield units, are apparently maintained throughout the process, being all calculations performed in the new GU scale. If images are conventional X-ray images, such as radiographs or mammograms, when digitized they are also directly converted to the new numerical scale.

Application of the method is accomplished in a multi-stage analysis scheme, in which user can interactively control all steps. Process begins with selection and classification of images, assuring that they belong to the same type. Then, as described in next paragraphs, a certain combination of histogram filtering techniques is applied and a digital holographic image recognition procedure is implemented. Finally, resulting image of coincidence is evaluated and visualized in a user-friendly interface to facilitate its interpretation. Described procedure also yields the possibility of performing an automated evaluation of the coincidence of the studied image with all elements filed in a database.

Filtering of the reference image

Histogram of the reference image is obtained and represented. Its maximum and minimum values define a subset of the GU scale, the *fringe of interest* (FI), which contains the values of all points of the searched reference element. Upon visualization of histogram, a *window filtering of the reference image* (WFR) may be applied such that values within a certain interval of the FI remain unaltered and those above or below are transformed to the black file background (zero numerical value). Interactive modification of this filter permits the user to select intervals of the histogram and observe the contribution of different densities to the complete image, in a similar way as window-width and window-level changes do in CT images. This process also allows for a certain *segmentation* of the image of the searched reference element since points out of the selected interval are retained for visualization purposes though excluded from coincidence calculations. It may be used, for example, to eliminate higher -white- values corresponding to bone or vascular structures thus yielding a *filtered fringe of interest* (FFI) within which only values really belonging to reference element are retained (Figure 1).

Filtering of the image to be studied

Histogram of the image to be studied is also obtained and different filters may be applied. A *window filter of the studied image* (WFS), completely equivalent to the described window filter of the reference element (WFR) can also be applied. Another possible filter is the *fringe-of-interest filter* (FIF). If selected, only points whose values lay within the filtered fringe of interest of the reference image are retained in the image under study, while all densities different from those contained in the searched reference element are excluded from calculations.

Finally, an *enhancement filter* (EF) is also available. This filter transforms certain ranges of values of the previously filtered images to a given percentage of the original scale range. This way, organs or structures corresponding to these values, which have no similarity to reference element and would therefore be lost in the resulting coincidence image, can be observed to facilitate location or interpretation of other elements.

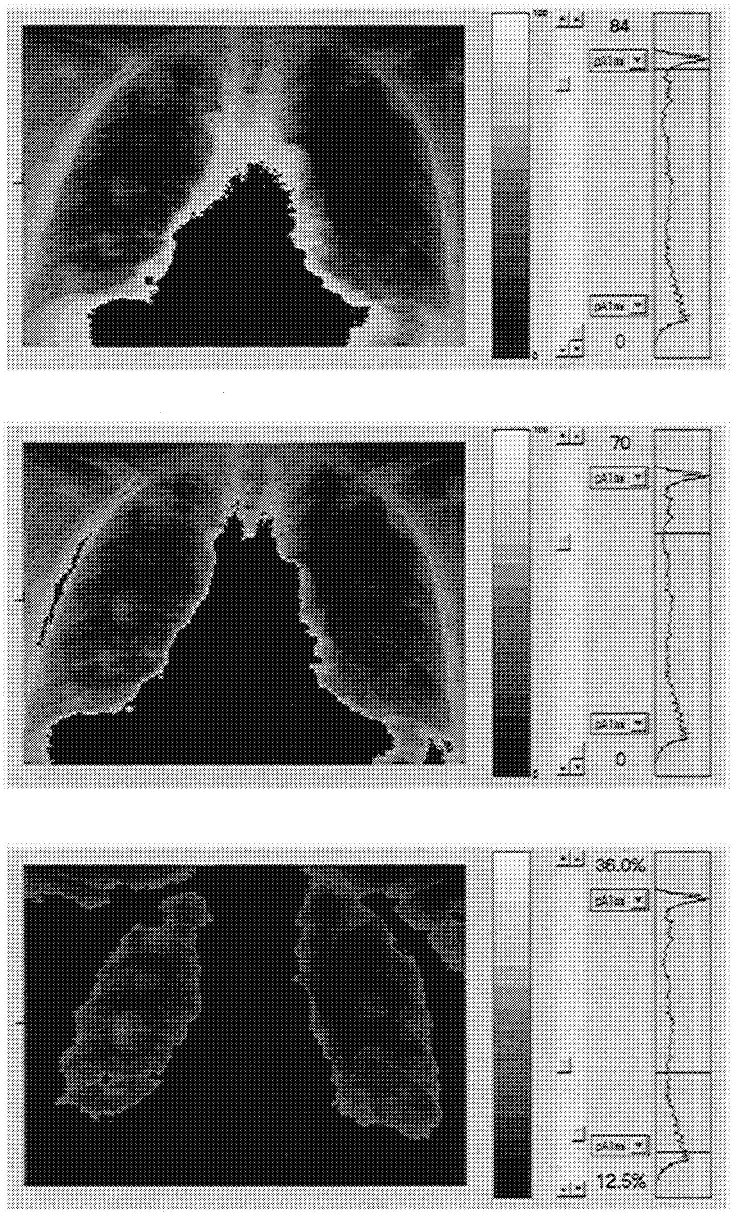

Figure 1. Window filter of a complex image (digitized chest radiograph) showing histogram visualization and segmentation to retain only lung fields of interest for analysis of malignant pulmonary nodules.

Holographic filtering and recognition

Once images have been filtered as described, a virtual holographic image recognition procedure is implemented. Within this stage, a Fourier hologram (VanderLugt filter) of the filtered reference element is numerically generated and, if desired, also filtered by any of the available procedures. Then, a bidimensional Fourier transform of the image to be studied is obtained and its product with the intensity -transmittance- of the previous holographic filter is evaluated. Finally an inverse bidimensional Fourier transform of the product is also performed. It has been shown[11-12] that intensity of resulting image is made up to two terms, namely the self-correlation of the searched reference image and its cross-correlation with the rest (``noise") of the image to be studied.

In proposed VHR[13-14], absolute coincidence occurs when searched reference element is contained, in the same color, scale and orientation, in the image under study. In this case, self-correlation term yields a radially symmetric coincidence point-like peak whose numerical value is many orders of magnitude higher than those of surrounding points while values of adjacent pixels decrease from that of the peak to zero background, where no coincidence exists. A positive *occurrence* of search is then defined, precisely centered at the position of the maximum of the peak. If visualized in the form of a two-dimensional map with a color scale ranging from dark blue -zero value- to bright red -maximum value-, correct identifications -given by positives occurrences- are identified by radially symmetric colored regions whose values decrease from the high peak to blue surrounding area (Figure 2).

Differences between searched element and those found in the image under study decrease the maximum value of the coincidence peak, reduce its symmetry and broaden its surrounding area. However, as long as these features exist -centered relative maximum and symmetrically decreasing surrounding values- a coincidence between searched reference element and that present in the studied image is positively defined by this method as occurring in that point.

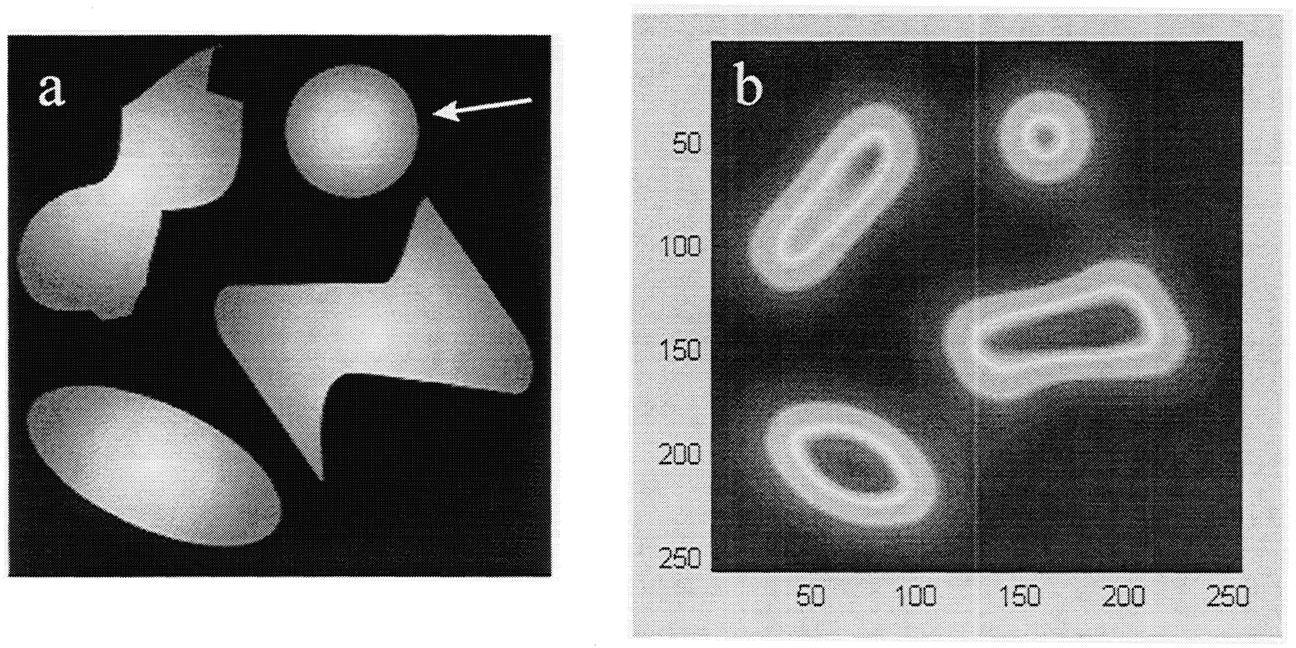

Figure 2. a) Arrow indicates element selected as search reference among different objects of the same optical density. b) Color-map showing result of evaluation and correct location of searched element.

High values of the crossed correlation term -noise- are also possible due to calculations performed in regions of high numerical values -for example, white tones- of the original images. They would also appear in upper tones of the deployed color scale but should not be identified as positive occurrences of searched element as long as they do not possess required symmetry (Figure 3).

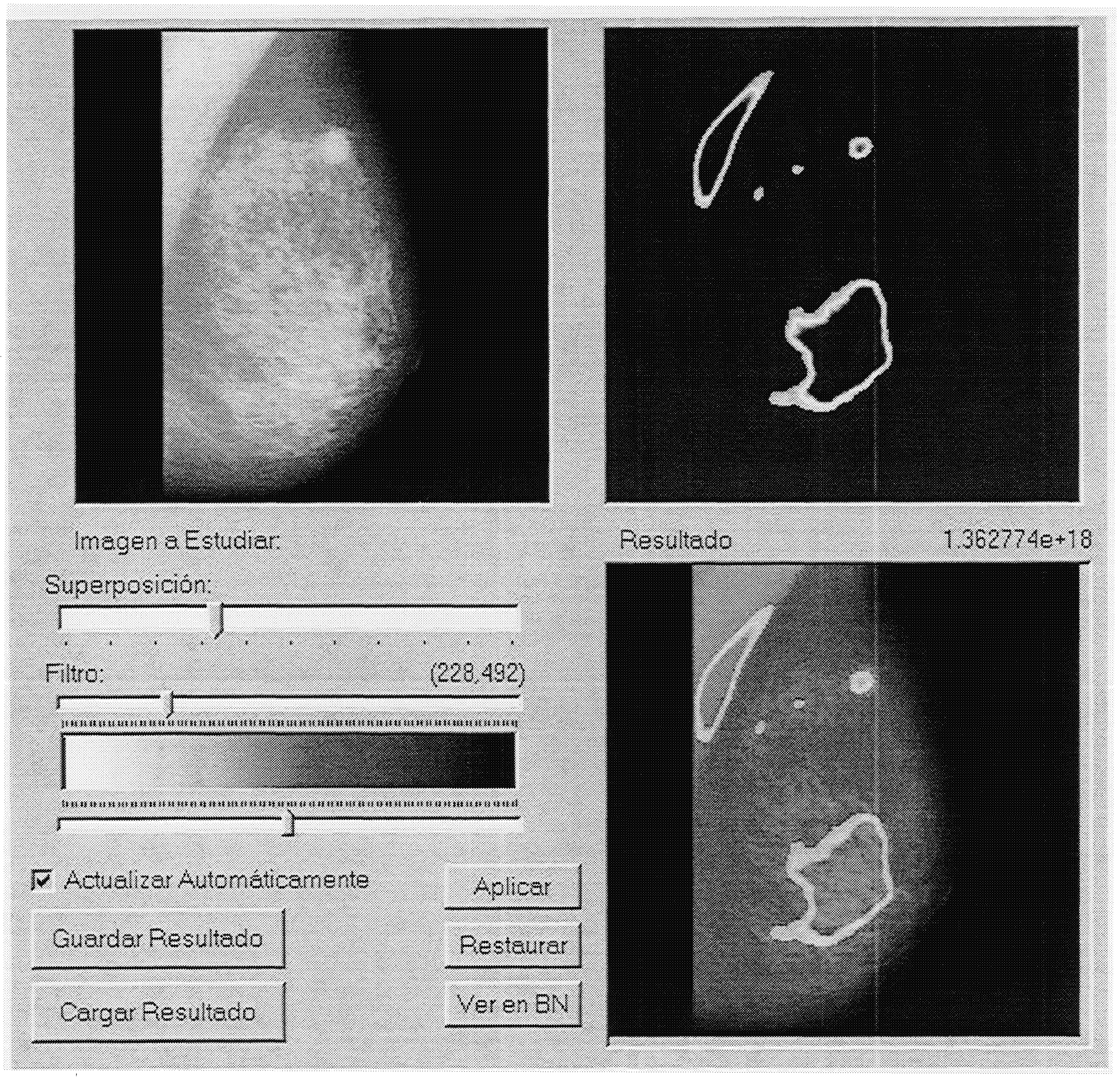

Imagen a Estudiar:

Resultado 1.362774e+18

Superposición:

Filtro: (228,492)

☑ Actualizar Automáticamente

Figure 3. Application of VHR to location of malignant nodule (rounded) in mammogram analysis. Local maximum with radial symmetry occurs at location of lesion. Lower image shows overlapping of original image under study and the resulting (calculated) image of coincidences.

On the other hand, false positives may occur if searched reference element is not exactly defined or if it is such that it may be considered as partially included within some region of the image under study. In this case a coincidence peak of irregular surrounding area may also appear. A careful balance between approximate symmetry and value of the peak compared to that of its neighborhood must therefore be evaluated to decide whether a coincidence is to be considered a positive finding or not. In this work, true-positives are defined when peaks with at least 50% of its radially symmetric surrounding area overlap at least 50% of a true lesion, as defined by an expert radiologist. Negatives occurrences are defined if surrounding area around the peak lacks of symmetry in more than a 50% or if there exists no peak value in that area.

Best results of search are obtained when proper filtering previous to holographic recognition has been performed. In this sense, proposed filtering steps (WFR, WFS and FIF) may be used to eliminate densities and regions of well-known interpretation, such as bone or vascular structures, from studied images. If such ``noisy regions" of high numerical values are excluded from search, subtle differences among point values may be more clearly observed in different color tones, thus allowing for intuitive -or automated- location of peaks corresponding to correct positive identifications. Further filtering of the coincidence image is also possible with the *coincidence filter* (CF). If values above a certain upper limit are made equal to this limit, it becomes the new maximum of the coincidence matrix. The rest (a reduced part) of the values are spanned over the whole color scale and, thus, sensitivity is increased. This increase in sensitivity does not imply a decrease in specificity since more colored regions lacking of symmetry should not be confused with true positives. Previously obtained positives may be overlapped (Figure 4) and to avoid it, their locations prior to filtering should be recorded in the system. A similar filtering may be applied to values below a certain lower limit of the coincidence image to reduce the sensitivity and, thus, the number of false-positives though weak true-positives should also be previously recorded.

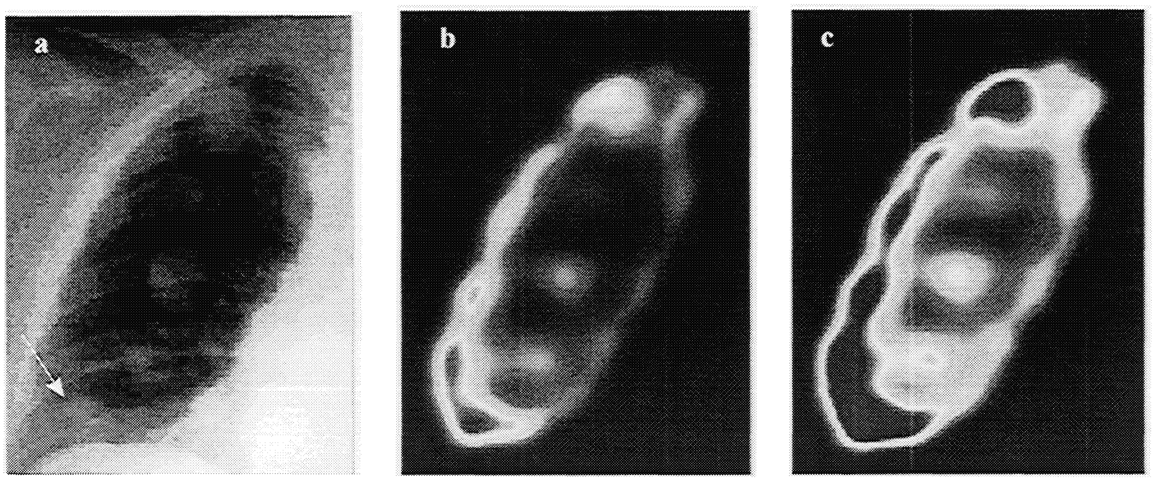

Figure 4. Application of VHR to analysis of a low-resolution digitized chest radiograph. Arrow in a) indicates malignant nodule selected as reference. Other nodules are correctly located in b) and, after application of CF, in c). Last image also includes a hardly-visible nodule due to metastasis in upper region. Visualization with a "zoom" tool allows for thorough evaluation of required radial symmetry. Highly valued regions have not been excluded to show its effect.

3. APPLICATION TO COMPUTER-AIDED DIAGNOSIS

Described method[13-20] has been applied to three different types of medical images: conventional chest radiographs, thoracic computed tomography (CT) scans and mammograms. Within each type, reference elements have been searched in databases of images, including the ones where the references were taken from. References elements have been extracted from digitized images using a cut-paste tool implemented in authors' computer program. Computing time required for each search was in the order of 30-45 seconds, depending on the relative sizes of the image (512 x 512 pixels). In all cases, diagnoses of these elements had been previously confirmed with surgery or after biopsy, and location of lesions in the different techniques was determined by 2 expert radiologists.

In mammogram analysis[21-23], proposed method has proven its usefulness to detect both malign and benign masses of different radiological characteristics, including well and badly defined contours, and different sizes and densities of adjacent parenchyma. Results obtained in analysis of thoracic CT scans are also promising[24-26] though not as clear and intuitive as those of mammograms. The number of false positives is raised by presence in images of residual lesions, granulomas, vascular structures and other elements which may have some degree of similarity to searched reference nodules. The possibility of automated studying of different consecutive scans, currently under development, is expected to improve correct discernment of vascular structures transversally sectioned. In conventional thoracic radiographs, quite promising results are also obtained in spite of overlapping of anatomical structures and substantial differences in optical densities of images. Areas of high numerical noise due to these factors are its main source of false positives and require careful analysis of the symmetry around the coincidence peaks.

In all described types of images, use of wider databases containing a large number of cases with diverse types of nodules would allow for a more precise determination of the filtering parameters appropriate for each image type, thus improving sensitivity and specificity. Digitized images of higher resolution will also substantially improve results and allow for location and interpretation of smaller elements, such as clustered microcalcifications in mammograms. Promising results obtained in the different types of images under study strongly support the interest of further testing of this method in an standard clinical trial.

4. GUIDING OF DISABLED AND OTHER POSSIBILITIES

A number of different applications of this method arise, as a consequence of the possibility of evaluating the degree of coincidence between arbitrary digital images. If the peak value of coincidence is tracked as the computer processes -in real time- the image taken by a digital video camera, the system can be used to automate different tasks and systems. If the image under study corresponds to a microscope connected to a computer, VHR can be used to identify and count the different elements present at the image. This is the basis of a system for analysis of microscopy images developed by author's team[27], recreated in Figure 5.

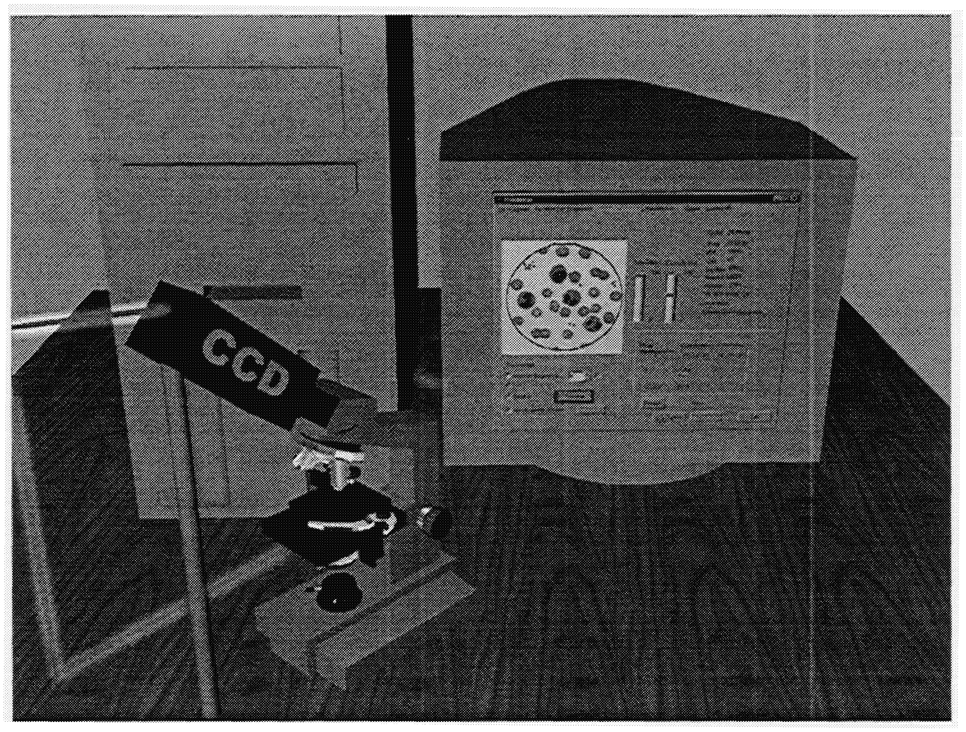

Figure 5. Scheme of the "HoloMicro: Holographic Optical System for Analysis of Microscopy Images".

On the other hand, if a camera is fixed and all permanent objects in its field of view are identified and assigned a *coefficient of danger* -or any other type of descriptive information- VHR can be used to detect and track another element –the *searched* image- present in the image under study. If this element is the image of a person, the system can automatically evaluate its position and trajectory with respect to the objects and generate messages informing the person of his/her surrounding environment. This idea has been applied to guide persons with disabilities in sport practice, by programming the computer to generate and send voice messages according to the sport and person playing. Messages can be transmitted to user by a wireless headphone (Figure 6) or by any other mean adapted to specific disabilities. Especially useful for blind people, this system can be used whenever repetitive training under supervision is required, it can be extended to home or office environments and it has been awarded the 1999 Research Prize of the Spanish Federation for Sports of the Physical Disabled[28]. Key point is that holographic recognition, in the digital procedure of VHR, allows the computer to track a non-binary figure (image) in a complex environment (conventional video image). In a similar sense as used in military applications recently disclosed –in analog devices- it opens the door to promising novel applications in fields of deep social interest.

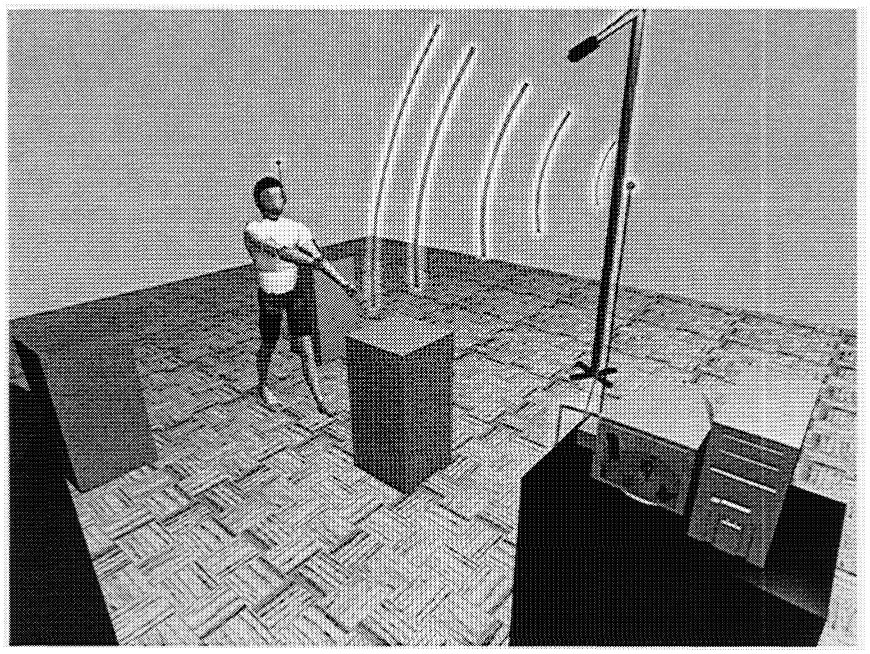

Figure 6. Recreation of the "SIGO: Interactive Optical Guidance System" in operation.

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