WWW Based Service for Automated Interpretation of Diagnostic Images: The AIDI-Heart Project

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Abstract. This paper presents AIDI-Heart, a computer-based decision support tool for automated interpretation of diagnostic heart images, which is made available via the web. The tool is based on image processing techniques, artificial neural networks, and large and well validated medical databases. The performance of the tool has been evaluated in several recent papers and the results show the high potential for the tool as a clinical decision support system. The tool has now been integrated into a WWW environment for easy access and operation using your favourite web-browser. This first version of AIDI-Heart is evaluated by three hospitals, two in Denmark and one in Sweden.

1 Introduction

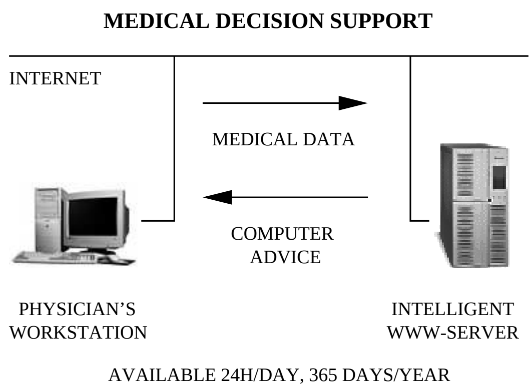

Fig. 1. The information flow between the physician and the server.

The practice of medicine is to a great extent an information-management task. A physicians decision making is based upon expert knowledge, information from the individual patient, and information from many previous patients, the latter known as experience. Decision making is often very difficult due to the fact that not only is the required expert knowledge in each, of many different, medical fields enormous, and growing daily, but also, the information available for the individual patient is multi-disciplinary, imprecise and very often incomplete. The interpretation of all data available from a patient is made by a physician, who may have a limited knowledge, and experience, in analysis of some of the data. In this situation physicians can consult a more experienced colleague at the clinic.

With the aid of modern information technology, it is also possible for a physician to contact an experienced colleague at another hospital and transfer data to him or her. For example, a physician at a remote hospital can send a diagnostic image to an experienced physician at a university hospital. Thereafter they can discuss the image over the phone. A problem with this technique is that experienced physicians are not always available when the advice is needed. Therefore computer-based decision support systems available via the web is an interesting alternative. With this technique decision support is available 24 hours per day, 365 days per year.

2 Automated Interpretation of Heart Images

2.1 Heart Images

The blood flow to the heart can be examined by injecting a radioactive tracer (technetium-99m sestamibi) and thereafter acquiring scintigraphic images with a gamma camera. The patient is examined both at rest and after exercise and the results are presented as two so called bull's-eye images, see fig. 2. Dark areas

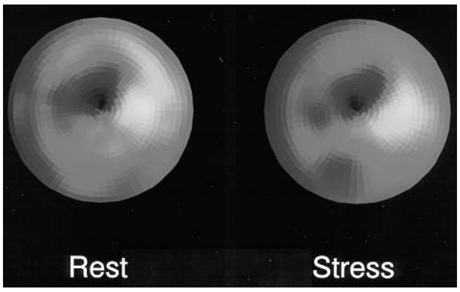

Fig. 2. Heart images in the form of so called bull's-eye images, one obtained at rest and the other after exercise.

in these images represent parts of the heart with reduced blood flow, generally caused by coronary artery disease (CAD). The interpretation of these images is a pattern recognition task. The physician must rely on his or her experience rather than on simple rules of how to interpret the image. A less experienced physician can benefit from a computer-based decision support system when a more experienced colleague is not present. Also a very experienced physician can use such a system for a second opinion.

2.2 Automated Interpretation

Automated interpretation of heart images using artificial neural networks was introduced a few years ago [1–4]. It was shown that the best neural networks detected CAD as good as or even better than experienced observers [4]. In clinical practice this type of intelligent computers will not replace, but assist the physicians by proposing an interpretation of the studies. It was therefore of interest to find that physicians interpreting heart images benefit from the advice of neural networks measured both as an improved performance and a decreased intra- and inter-observer variability [5]. It has also been shown that these neural networks can maintain a high accuracy in a hospital separate from that in which they were developed [6].

2.3 Databases

The performance of decision support tools such as artificial neural networks depends largely on the size and the composition of the training databases. Therefore, four different sets of data were pooled to a training database consisting of heart images obtained from 441 subjects. The true diagnosis (CAD or not) for each of the patients, was obtained by performing an invasive and more expensive examination, coronary angiography. The healthy subjects all had a $< 5\%$ likelihood of CAD. A total of 221 patients had signs of CAD while the remaining 220 patients and healthy subjects were defined as normal.

The following four data sets were used in the first version of AIDI-Heart:

- 135 patients examined at the University Hospital in Lund, Sweden during the period from November 1992 to October 1994 [4–6].
- 110 patients examined at the University Hospital in Lund, Sweden during the period from June 1995 to May 1997.
- 68 patients examined at Rigshospitalet, Copenhagen, Denmark during the period from December 1991 to March 1994 [6].
- 128 healthy subjects in the Copenhagen City Heart Study Denmark [7].

2.4 Image Processing

Artificial neural networks are used as the computer-based classification tools for the heart images. The size of the images are $17x64$ pixels and an image reduction method is needed in order to limit the complexity of the neural network. A Fourier transform technique was used as follows: Each of the two $17x64$ images was expanded by mirroring about row 17, and then discarding the last row (i.e. the first row of the succeeding Fourier period), to produce $32x64$ matrices.

The two $32x64$ matrices were input as the real and imaginary parts of a complex $32x64$ matrix in a fast Fourier transform [8]. A selection of 30 values constituting the real and imaginary part of the coefficients for 15 of the lowest frequencies were used as inputs to the neural networks. For more details see [4].

2.5 Artificial Neural Networks

A 3-layer perceptron neural network architecture [9] was used. The input consisted of 30 Fourier frequency components and it was found that 4 hidden neurons was enough for this application. The single output neuron encoded a possible CAD (1) or normal (0) subject. A weight decay term was used during the training to further regularize the network in order to optimize the generalization performance.

The performance of the artificial neural networks was evaluated using a cross-validation procedure. The output values for the test cases were in the range from 0 to 1. A threshold in this interval was used above which all values were regarded as consistent with CAD. By varying this threshold a receiver operating characteristic curve was obtained. Areas under these curves were calculated as measures of performance. Figure 3 shows the ROC-curves for the territories LAD and RCA/LCX (see below for an explanation). Both territories had an area under the ROC-curve of 0.81.

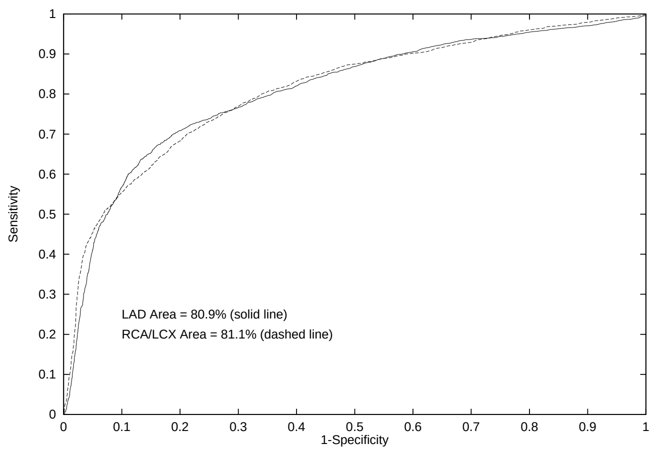

Fig. 3. Receiver operating characteristic curves for the LAD and RCA/LCX territories.

2.6 Presentation of Computer Advice

The AIDI-Heart interprets all images regarding the presence/absence of CAD in two vascular territories of the heart, the LAD and the RCA/LCX territories.

Therefore two different sets of neural networks were trained to detect CAD, one in the LAD territory and one in the RCA/LCX territory. The output values of the networks were in the range from 0 to 1. Three thresholds were used to transform the output values into four different statements. For example, output values below the lowest threshold were regarded as "definitely not CAD". The advice of AIDI-Heart was presented to the physicians as two statements, one for each of the two territories, together with the corresponding output values. The output value can be regarded as an estimate of the probability for CAD.

3 The WWW Service

The functionality of AIDI-Heart is based on a client-server paradigm via Internet and integrated into a WWW environment. The server is able to accept queries from clients and return an advice based on a computer-based decision support tool. The client can, besides sending images, also return feedback concerning the computer advice. Collecting and storing this feedback on the server will enable us to further enhance the decision support tool and thereby decrease the number of misinterpretations.

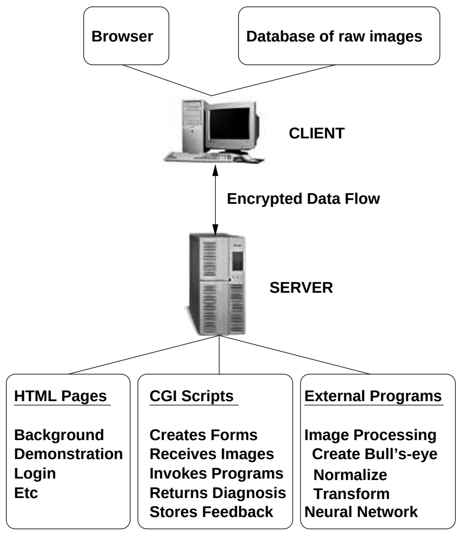

Fig. 4. Overview of the AIDI-Heart server for automated interpretation of heart images.

Figure 4 shows an overview of the functionality of the server. A typical session can be described as follows: The client, i.e. a physician with a workstation connected to Internet, starts his favourite browser and opens the home-page of

AIDI-Heart. This page is maintained by the server, physically located in Lund, Sweden. When the client requests the page containing the actual user interface for the service, the server demands a correct user name and password from the client. If the login succeeds a CGI-script is launched at the server. This script presents a form to the client to fill out with the path and filename of the raw image residing on the client computer. The heart image is then sent over the Internet in an encrypted state (40 bits) to avoid patient data to be read by a third party. The script, still running on the server, receives the image and starts manipulate it with the help of several external programs. When all programs are executed, a diagnostic advice will appear in the clients browser. This answer contains the evaluation result from the decision support tool (i.e. the artificial neural network) along with bull's-eye images for a visual feedback. The client can also return feedback which can be used for evaluation of the system.

3.1 Demonstration

This demonstration will show how the AIDI-Heart service works. There are three steps to complete in order to obtain an interpretation of the heart images.

Login Start your favorite browser and point to the WWW-address for the AIDI-Heart service. You will be presented with a "LOGIN" button. After clicking it you have to enter your personal username and password (assigned by ISM) in order to access the actual send and answer page (figure 5).

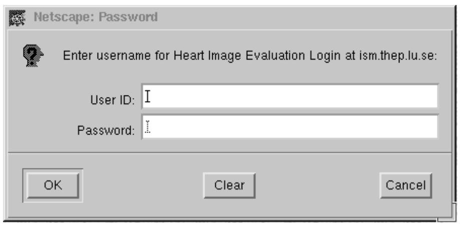

Fig. 5. Username and password form that has to be completed in order to access the full service.

Locate Data You must locate the file(s) containing your data. The supported file format is currently the Interfile Version 3.3 format. There are two possibilities here:

1. One file contains both the header and the data. The filename usually end with .ifl. This is a safe way since the patient name and patient data cannot be mixed up.

2. Two separate files, one usually ending with .ihd (or .hdr) contains the header and one ending with .img (or .dat) which contains the raw image data. It is important here to make sure that the header and data belong to the same patient.

In order to send the data file(s) you will be presented with a filebrowser interface, figure 6.

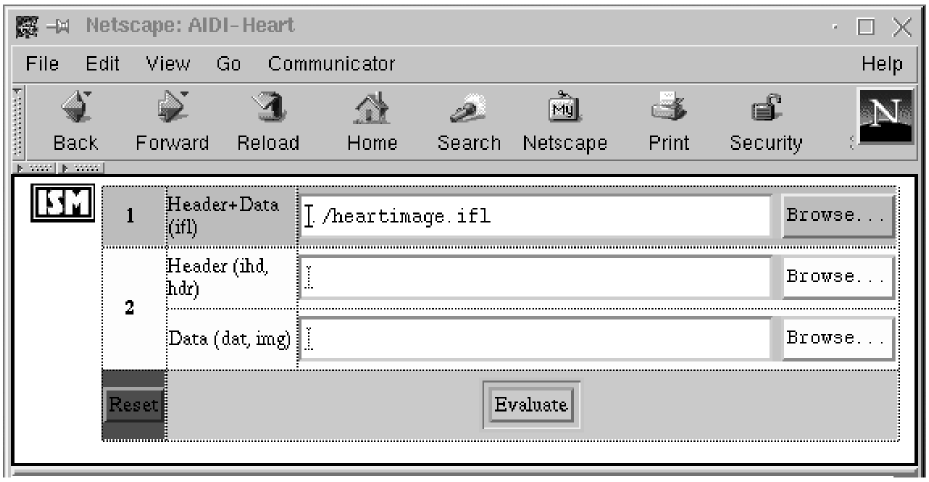

Fig. 6. The interface used to send the data file(s).

Send Data Simply click the "Evaluate" button and the chosen file(s) will be sent to the server. Note! that the files being sent to the server will be encrypted because of the nature of the information sent.

The interpretation, figure 7, will be presented as one out of four different statements for each of the two vascular territories (LAD and LCX/RCA) together with the corresponding network output values. The bull's-eye images and some patient data are shown at the lower part of the figure. There are also the possibility to send feedback to the server regarding the diagnostic interpretation.

3.2 System Evaluation

During the winter 1998/1999 the system is evaluated by three university hospitals, two located in Denmark and one in Sweden. The evaluation process is primarily focused on the user interface and the security issues. The accessibility of a decision support system is very important. Most physicians are non-IT

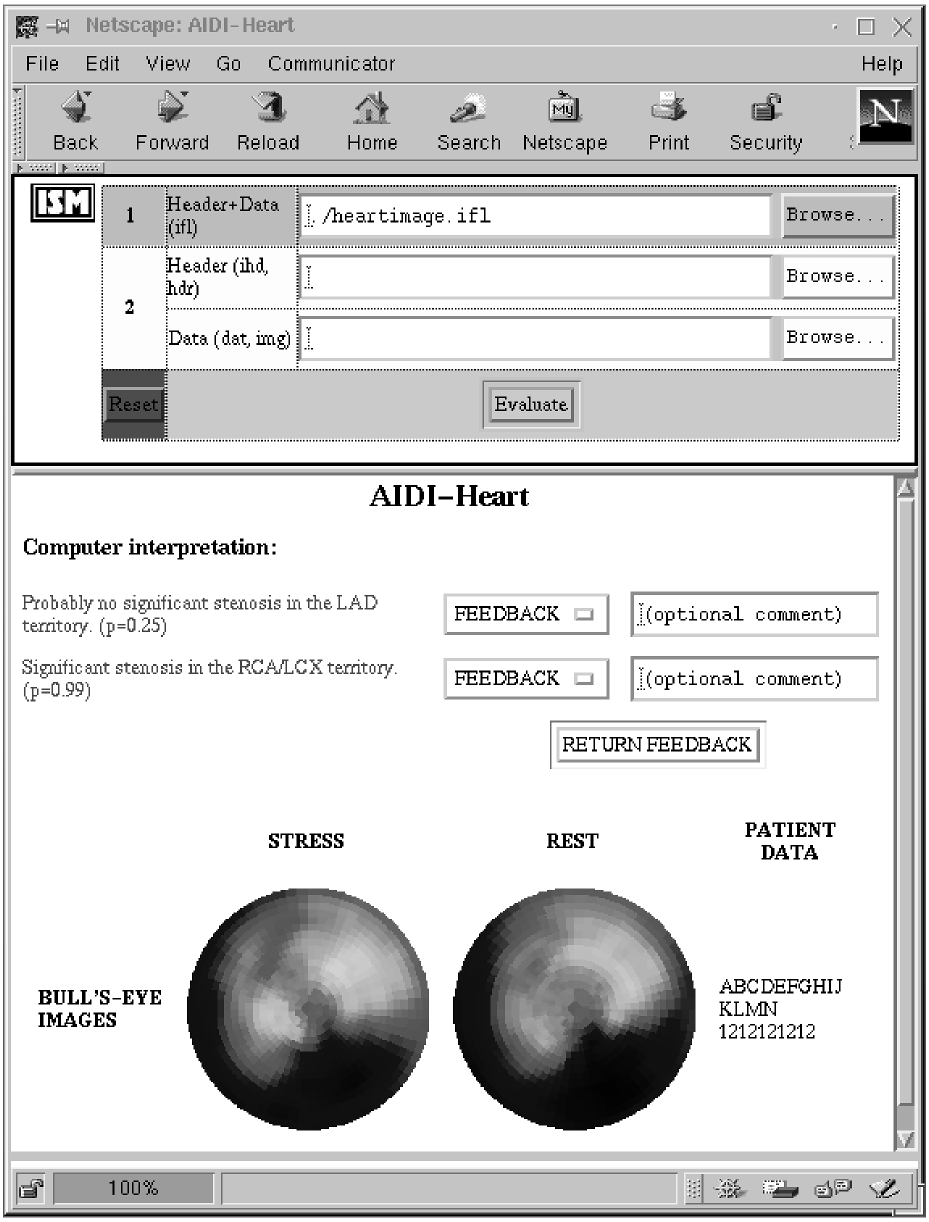

Fig. 7. The output from the AIDI-Heart. For these heart images the neural network detected a significant stenosis (CAD) in the RCA/LCX territory, while the upper region (LAD) appeared to be normal. The client can return feedback and some additional comments using the FEEDBACK-buttons. The lower part of the figure shows the bull's-eye images.

specialist who only will adopt a system which is perceived as being easy, and not time consuming, to use. Another important issue that is evaluated is security. The data transferred from the client (physician) to the server includes data which is attributable to an individual patient. Therefore, techniques were developed to ensure data security at all times. These techniques include encryptation of the data transferred.

4 Discussion

The are four main reasons to believe that the use of computer-based decision support systems in the medical field have the potential for rapid expansion within the immediate future.

1. The development of interfaces can make computer-based decision support systems easily available to non-IT specialists such as the physicians, by employing state of the art information transfer, and assimilation techniques via web-browsers and java-scripts. These techniques make it possible to reach many physicians world-wide, as well as facilitating distribution of the latest version of the software.
2. Emerging techniques such as Data Mining and Artificial Intelligence make it possible to develop more accurate decision support systems than would have been possible some years ago. It is crucial that different methods of data analysis and decision support system designs are studied in order to find optimal solutions for different diagnostic problems in various medical domains.
3. Vast medical databases in digital form can now be developed. These large information resources are important in order to create and control high quality decision support systems.
4. The infrastructure required for a widespread introduction of intelligent information systems, i.e. physicians workstations, networking, common standards for data-exchange, data storage, has been put in place in many hospitals, clinics, and surgeries, even in remote areas. Thereby, patient data, history, findings from physical examination as well as data from laboratory tests, and diagnostic imaging and so on can easily by used as input to an intelligent system.

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