Collaborative Tool for Annotation of Synovitis and Assessment in Ultrasound Images

Marek Kulbacki[1], Jakub Segen[1], Piotr Habela[1], Mateusz Janiak[1], Wojciech Knieć[1], Marcin Fojcik[2], Paweł Mielnik[3], and Konrad Wojciechowski[1]

[1] Polish-Japanese Institute of Information Technology
Koszykowa 86, 02-008 Warsaw, Poland
[2] Sogn og Fjordane University College
Vievegen 2, 6812 Førde, Norway
[3] Revmatologisk Avdeling, Førde sentralsjukehus
Svanehaugvegen 2, 6812 Førde, Norway
mk@pjwstk.edu.pl

Abstract. We present a cloud based collaborative tool intended for organization and unification of USG data and annotation of features useful for discovery of synovitis. The Annotation Editor can be used to outline anatomical features in an ultrasound images such as joint and bones, and identify regions of synovitis and level of synovitis activity. The software will be used by medical personnel for building reference database of annotated ultrasound images. This database will be the source of training and testing data in a system of automated assessment of synovitis activity. System supports collaborative use and management of the database from multiple locations. Semiquantitative ultrasound is a reliable and widely used method of assessing synovitis. Presently used manual assessment needs trained medical personnel and the result can be affected by a human error. A proposed system that can automatically assess the activity of synovitis would eliminate human dependent discrepancies and reduce time and the cost of evaluation.

Keywords: Synovitis, Medical Image Annotation, Ultrasonography, Medical Databases, Modern Diagnostics

1 Introduction

Chronic arthritis is a heterogeneous group of diseases characterized by longlasting inflammation of joints. They can influence the patients general condition and involve other organs besides joints. Prevalence of chronic arthritis can be estimated up to 1.5% of population. The most frequent is rheumatoid arthritis with estimated prevalence from 0.5 to 1.0% of population. Accurate measurement of disease activity is crucial to provide an adequate treatment and care to the patients, and medical ultrasound examination provides useful information regarding this activity. Medical ultrasound examination is a method of visualization of the human body structures with high frequency acoustic waves. Power Doppler method uses Doppler effect to measure and visualize blood circulation in tissues. Ultrasound examination with power Doppler is a validated method of assessing joint inflammation [1]. The procedure is standardized and different projections can be used to visualize joints and joint inflammation, but most frequently dorsal medial line is used in joints of the hand. Both quantitative and semiquantitative methods of activity measurement were evaluated in clinical praxis [2, 3]. Both were considered reliable and repeatable. When quantitative methods measure directly different parameters such as intensity of Doppler signal, semiquantitative method evaluates ultrasound image. The second one is performed by a human examiner. The examiner estimates the synovitis activity based on experience or standardized atlases. The result is registered as a number from 0 to 3, where 0 means no inflammation and 3 the highest possible inflammation activity. Level of arthritis in USG without PD is achieved with estimation of dark grey/black area (hypoechoic) over the joint. Measured area corresponds to area of synovitis (Fig. 1 top). In USG with PD the this level is estimated according to intensity and area with a visible flow in small blood around the field of synovitis (Fig. 1 bottom).

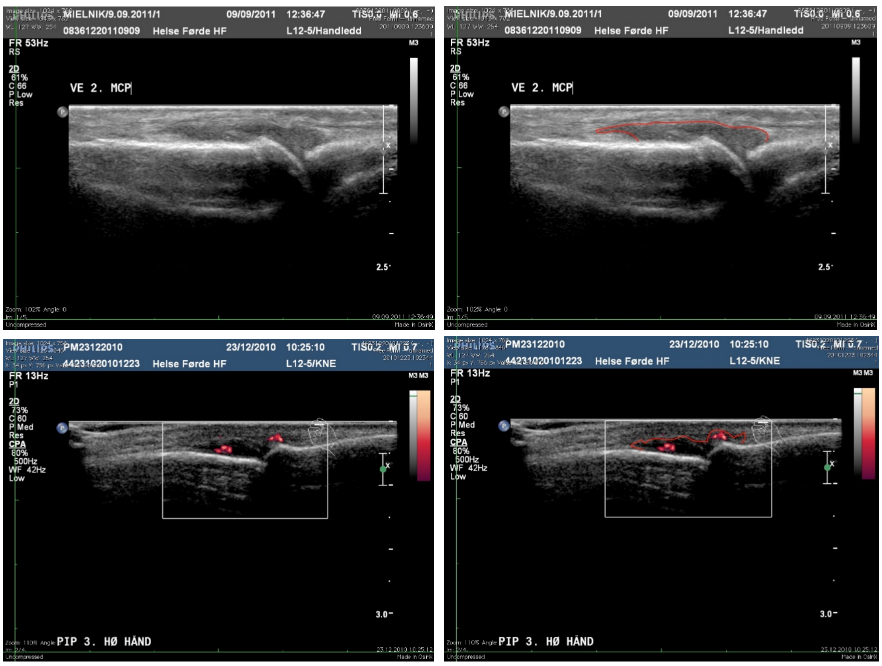

Fig. 1. Images of selected joint without and with outlined synovitis region: classic USG (top), USG with PD (bottom).

Semiquantitative method is more often used in clinical praxis and scientific studies [2]. Possible discrepancies between different examiners and different examinations can influence results in this method [4]. A software system with automated synovitis assessments would reduce human dependent discrepancies in synovitis evaluation, which would improve the quality of results from large multicenter studies, where comparability of assessments from different sources is essential. It would also reduce the time and cost of large scale medical trials and help in everyday clinical practice. A project MEDUSA, summarized in Section 1.1, has been undertaken towards the development of such a system. A tool for ultrasound image data organization and annotation, which is a critical part of MEDUSA, is described in the reminder of this paper.

1.1 The goal - synovitis estimator

Manually prepared annotations are necessary to construct a synovitis estimator - an adaptable function, that will be trained to assess a degree of synovitis activity from an ultrasound image of a joint using machine learning methods. The estimator will be trained using ultrasound images of joints along with their synovitis assessment activity scores provided by expert examiners, with the aim for the estimator to approximate the average expert score. The estimator will be built with the help of features extracted from an image, using image processing methods. While many common techniques of image based recognition use global features that preserve only a small part of image information, a goal of the proposed approach is to use as much as possible of the relevant information from images in a form that is invariant to transformations resulting from different probe placements, joint articulations, and interpatient differences. To achieve this goal we use an articulated model containing the image features that are related to parts of the skeleton, such as the bone edges and joints. A method of registration appropriate for articulated models, such as the Constellation method, graphcuts optimization [5], Laplacian eigenfunctions [6], or stochastic graphs [7], are the basis of a learning algorithm that will be used for the final inference of a class model for each joint. This inference process will use a supervised learning approach that relies on annotations identifying the desired features, added to the test images by trained examiners. Registration of an image of a joint with a class model will, in effect, bring the image into a common frame of reference. The measurements performed on the image relative to the class model will have reduced variability with respect to different probe placements and joint articulations, and after intensity normalization, with respect to interpatient differences. The synovitis estimator will be constructed using methods of learning multivariate functions, such as the multivariate regression. For a greater reliability, multiple partial estimators will be used, each based on a different type of image measurement. The final, integrated synovitis estimator will combine the outputs of partial estimators into the final assessment score using a method such as boosting [8]. To collect representative training sets required for analyses of USG images and assessment of synovitis activity stage and gather rheumatologists, annotators and researchers distributed geographically we developed collaborative environment for organization and processing of USG data.

1.2 Medical data collection and feature selection

Ultrasound images are collected in standard measurement procedure from the patients with chronic arthritis during routine visits at the rheumatology department of Helse Førde. Preliminary analyses are conducted by trained, experienced medical personnel. In the next step group of trained medical students adds manually annotations representing joint structure and inflammatory level. Annotations added to the images by a trained examiner will identify and mark in each image selected anatomical features such as bones and joints, outline the regions that show inflammation and add to the image the human scores of the degree of synovitis (Fig. 2). These annotations verified by experts are training sets necessary for analyses of USG images and assessment of synovitis activity stage. To reduce bias associated with different joint anatomy we limited measurements and assessments to metacarpo-phalangeal joints (MCP) and proximal intra-phalangeal joints (PIP), what results in the occurrence of 20 different joints.

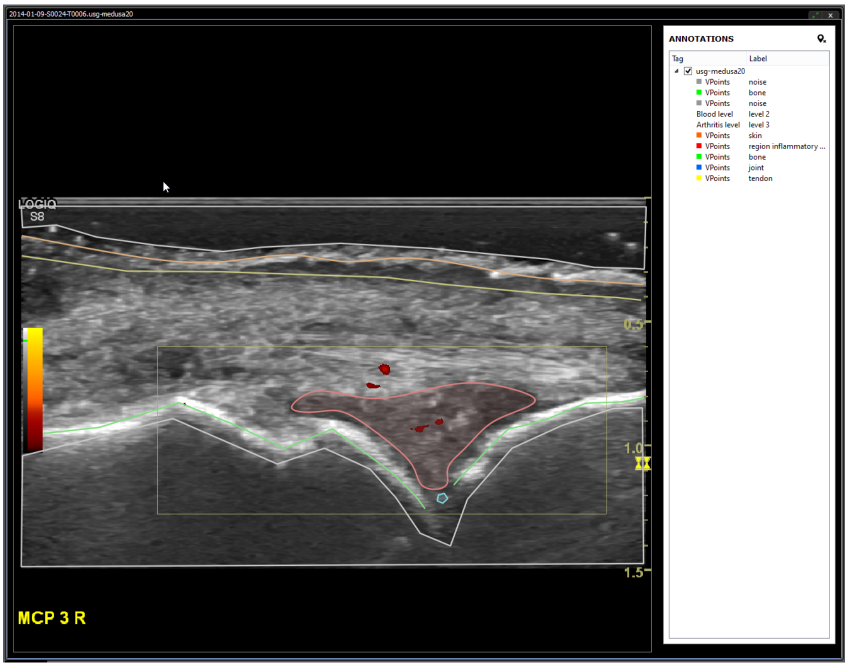

Fig. 2. Annotations of anatomical features and synovitis region and level.

2 System Architecture

According to given requirements, the proposed solution is based on client-server model. For performance reasons and flexibility C++ programming language was chosen. Software is able to run in multiplatform environment in particular Linux and Windows platforms with possible extensions to mobile platforms (tablets and smartphones data browsing and inter-user communication). Client application has modular structure, that enables a simple extension of its capabilities with dedicated plugin system. Main requirements of hand ultrasonography image server and its remote access and annotation by a client were motivated by the following considerations:

- The resources on the cloud available to search and download by remote clients;
- Consistent data set in the face of multiple distributed data providers and annotators;
- Consistent authorization mechanism for the data access and updating;
- Uniform data, identifiable and easily transformable for the purpose of prospective integration with another kinds of medical data.

To simplify the design and to allow for partially offline use of the tools, the system interface has been designed as a set of stateless Web services. For syncing the local databases of the client applications with the system, incremental bundles of session, trial and file metadata are served accordingly to a last sync timestamp. Metadata are synchronized separately and data files are downloaded on demand only (Fig. 3). Online collaboration on the trial annotation process is also realized that way. Data is kept under the control of a database management system to ease the load balancing and backups. Raw USG data is not the subject of editing: we only add, edit and delete metadata and annotations.

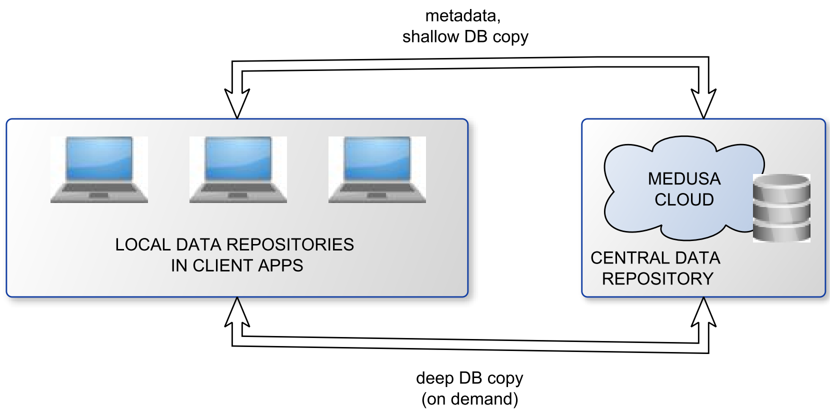

Fig. 3. Data Synchronization between Central Data Repository and Local Data Repository.

The developed prototype demonstrates features that benefit medical informatics systems. It provides centralized storage for medical data and their descriptions and exchange of data between users, giving them possibility to consult specific cases. Local repository is ciphered and the access to remote storage is limited only to verified/registered users. Users are able to filter the data according to given criteria and manage filters themselves. This stage supports browsing, viewing, processing and comparing data records. Client application is modular and use intuitive data flow from sources to sinks to easily swap and extend data processing modules [9]. Data processors can perform appropriate data manipulations such as filtering and transforming images or feature detection. Finally data sinks are placed where data flow results would be permanently stored allowing to browse such data and use it in further work. Such data flow allows grouping of elements, performing some more general steps and use that structures separately as templates. It is also possible to save and restore the structure of the processed objects. Such structure could be also exchanged between platform users for discussion of particular data flow application and testing.

2.1 Annotation editor

The architecture of Annotation Editor is based on previously developed Motion Data Editor [10], that was originally designed to support physicians in viewing medical data for diagnosis of various human movement disorders. The Annotation Editor is an application dedicated to medical and technical staff working with USG images. It‘s main goal is to support medical teams in collecting USG images, annotating them in the direction of inflammatory level with well-defined image areas and verification of proposed annotations and other attributes. These goals were achieved by a composition of a standalone application (supplied with medical data browser and editor) and dedicated medical images database. Annotation Editor introduces simple, yet complete procedure for annotations state

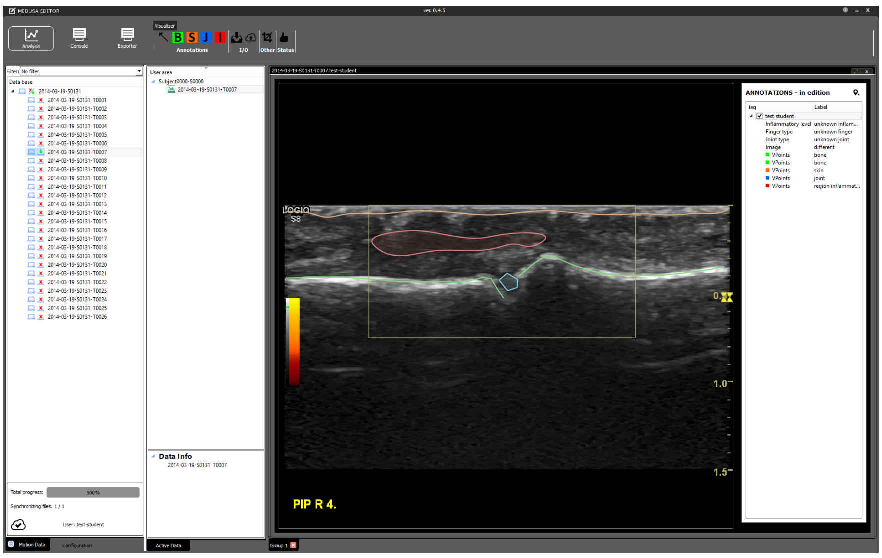

Fig. 4. Annotation Editor User Interface.

change based on a simple state machine mechanism. Current USG systems in hospitals provides data in DICOM format. Although it is a standard its very inconvenient for the use in distributed environment, where each operation involving raw image data is a time consuming process. Annotation Editor supports and can import DICOM files but uses PNG format for image processing. PNG format thanks to lossless compression is about 20 times more efficient than original DICOM data. For metadata such as annotations and other descriptive data we chosen XML format. Client application has also custom User Interface with access to different spaces: Data Providers, Viewers, Annotators, Validators (Fig. 4). It organizes data according to the hierarchy Lab $>$ Session $>$ Trial $>$ File. That structure represents the core content of the system (session and trial is only required and visible to the client). But this is the whole structure necessary when we gather data from hospital and process multiple trials. The annotation dictionary provides the building blocks for creating trial annotations. Session groups and User groups are introduced to ease the management of the larger number of users with their various roles and possibly, also a varying access of the data made available to them.

2.2 Database

The database component of the system (Fig. 5) depends on rather conventional technological solutions involving common protocols and data formats used by a stateless service oriented interface layer [11]. This allows for integration with various client platforms while maintaining a uniform mechanism for user identification and authorization. Although the primary role of the component is to provide the repository functionality for publishing, updating, browsing and retrieving of digital imaging data, the usage pattern of the system also poses some workflow management challenges. Those two characteristics, data and workflow management, are interrelated. Even the simplest data access scenario requires determining the user role and their privileges, resource being in an appropriate state of its lifecycle, and, on the other hand, may involve the update of the persistent data. Two conceptual layers of the system's functionality can be distinguished: data collection, unification, storage and retrieval, and online collaboration over the stored data.

The first of the aforementioned layers requires agreeing on and applying standards on the data formats, image properties and naming conventions and providing selected users with the privilege of submitting data. The resources are organized into a generic hierarchy that distinguishes Sessions and Trials. Subjects can be defined on per-session basis, though are not used for the synovitis related images described here. Each Trial represents a single image and the associated data containing its description. Both the publishing and retrieval of image data are supported by the set of services that effectively provide the respective data cloud functionality. However, to assure the capability of autonomous (offline) work of an application, the operations for bulk download of a lightweight snapshot of the database (called a shallow copy) and its subsequent timestamp-driven updates have been provided. Multiple provider users are allowed and, based on

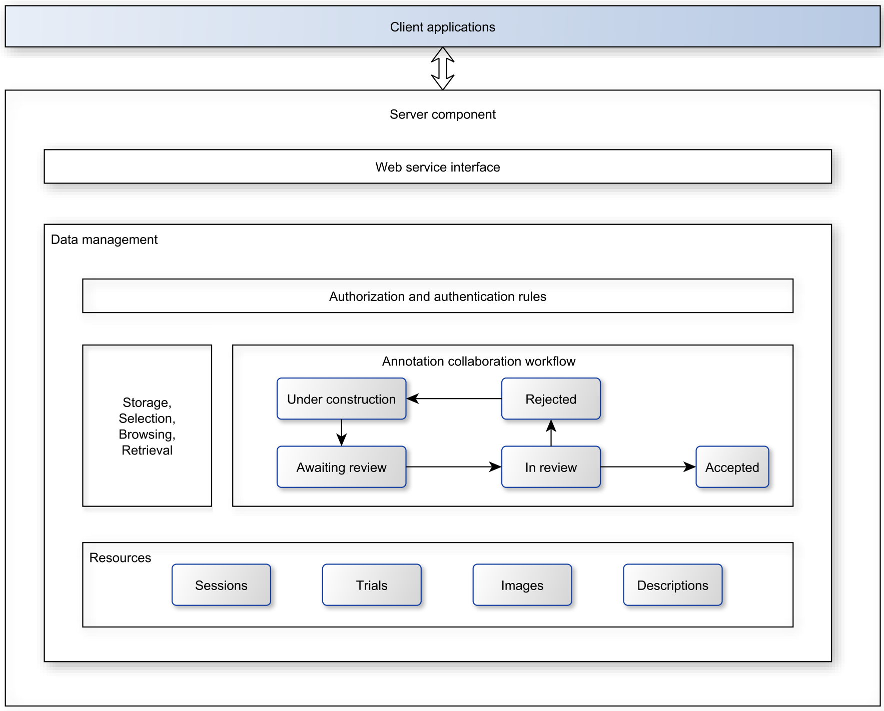

Fig. 5. Main Server Components.

the origin and purpose of the data and assignment of a session to particular session groups (as well as users to user groups) the access control is maintained. The second layer can be described as online collaboration over the imaging data. Here, although each particular step is performed through a stateless service operation call, a coordination of the work and the consistency of parallel access needs to be assured. Hence the necessary data is stored together with resources being processed that indicate their current state of processing and its performers. The current status of work, on annotating a USG image, can be described as a simple state machine that describes a particular annotation and consists of the following states: 1 under construction, 2 awaiting review, 3 under review, 4 approved, 0 rejected, where the rejected annotation can be restored to the state 1 again by its original author (annotator). The roles involved in the process are Student retrieves and analyzes image; provides an annotation, and Doctor reviews the annotation. The annotations that have been approved become visible to all the users having the read privileges of the respective sessions. The need of providing the aforementioned functionality requires going beyond the existing publish-assign privileges-browse-retrieve scenario. The aforementioned use case illustrates the fact that the generic repositories of imaging data like the one described here can potentially be a subject of many types of similar collaboration processes and hence, in addition of generic structure for resource repository and description, also the generic, dynamically definable workflow patterns for privilege definition and user collaboration are being considered for the future design and implementation of this component.

3 Conclusion

The Annotation Editor with cloud based environment for communication, data gathering and management is a next step that simplifies the process of ultrasonography data acquisition and processing. The platform is scalable, it has the functionality for information exchange between medical experts and students and offers the opportunity of mutual cooperation in the form of social network. Collected data are anonymous, lightweight, with annotations created manually by students and assessed by experts. It gives a great number of synovitis examples in the form of reference database for physicians as well as researchers. We are working on metadata uniformisation towards the possibility of replacement annotations prepared by different selection methods.

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