Interactive Annotations to Support Collaborative Analysis of Streaming Physiological Data

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Abstract—The processing of a patient in a medical facility encompasses data acquisition, data analysis, diagnosis and medical reporting. The result is a program of treatment for the patient. It is postulated that the latter two stages can be facilitated by allowing acquisition locations to avail of data interpretation by multiple off-site analysts who interactively annotate patient data in a collaborative fashion.

The concept of “meta annotations” is also introduced, whereby users can comment on an annotation or supply a confidence rating that indicates their assessment of the accuracy of an annotation. This concept enhances the utility of annotations by transforming them from simple textual labels to focal points for discussion and consensus building.

I. INTRODUCTION

The prompt analysis of Electroencephalogram (EEG) and other physiological data streams captured in the intensive care unit (ICU) is essential as only a limited window of opportunity for treatment may be available. Ideally, an experienced on-site analyst will be available to study the ongoing recording and issue a clinical report. In many locations, however, such expert analysis is not available locally [1], while the rate of neurological disorders is expected to increase globally in the coming years [2].

A web-based remote monitoring system titled, ‘Physiological Data Server (PDS)’, was presented in [3] that allows physiological data streams to be viewed in near-real-time, while acquisition is ongoing, via a web interface. Users are presented with a continually updating view of the entire data stream, allowing them to view new data as they arrive or review data transferred earlier. Although developed specifically for EEG data, the system is generally-applicable and can be used to remotely monitor any type of biosignal. The system has since been extended through the addition of an agent framework that allows data to be processed as it passes through the system.

It is envisioned that the provision of this rich medium of communication will facilitate collaborative diagnosis and provide a co-operative environment for data interpretation. The introduction of functionality for human-to-human collaboration will allow for improved patient care by facilitating more accurate and timely diagnosis. Furthermore, the annotations added by humans will provide a valuable resource for the training and evaluation of software agents [4].

The remainder of this paper is organised as follows: Section II provides an overview of related work focusing on health orientated systems, the annotation of data and collaborative diagnosis. Section III describes the functionality of annotations and discusses the differences between simple paper-based schemes and the more modern digital equivalents. The design and operation of annotations within the system is discussed in Section IV. The different types of annotation are detailed in Section V and two envisaged use cases are presented. Our conclusions and future work are discussed in Section VI.

II. RELATED WORK

The agent framework presented in [4] enhances the remote monitoring system described previously allowing a user-configurable set of agents to perform analysis on physiological signals as they are streamed through the system. The output of the agents assists with the analysts’ interpretation of the data being streamed and hence can reduce time to diagnosis. Two agent types were considered: agents that highlight recording segments of interest and agents that derive one signal type from another (e.g. aEEG from EEG).

The BRIAN remote monitoring system for EEG presented in [5] supports the display of annotations created during data acquisition (prior to data upload).

A decision support system for clinicians is presented in [6]. The system facilitates the organised acquisition of patient and clinical information, which, when combined with expert knowledge, provides a test-bed for the development and evaluation of knowledge-based decision support functions.

A taxonomy of different models for human machine cooperation is presented in [7]. The concepts behind co-operative problem solving are defined, the requirements for modelling
the interaction between humans and machines are discussed. A number of existing systems are also reviewed with concluding remarks on the implementation of multi-human, multi-machine cooperative systems.

The reasoning behind paper annotations is examined in [8]. The motivations for the different type of annotative marks made on paper as well as the perceived benefits for each kind are discussed. A comparison is then made to Web 2.0 technologies and a prototype for annotating web pages in a paper-like fashion is presented.

The collaboration between different disciplines in health care and the complexities involved in implementing efficient information exchange is discussed in [9]. Difficulties with written and electronic medical forms, the rigid structure imposed by forms, and how this constrains conversational and narrative practices is outlined. A model for communication via forms that supports collaboration by accommodating different levels of interpretation is presented.

The addition of annotations to electronic health records (EHR) as a means to promote collaboration, coordination and awareness is presented in [10]. The loss of created knowledge due to the strict structure of the EHR is discussed, along with a proposed solution: the use of annotations to allow documents overcome this rigidity and provide support for non-envisioned functionality.

A Tablet-PC based software tool for collaborating on time series data is presented in [11]. It provides functionality to allow the researcher to browse data sets, create, view and edit annotations (both their own and those created by others). The use of annotated data to create feature-specific datasets for the training of diagnostic algorithms is proposed.

III. ANNOTATING DATA

The annotation of data, be it paper-based written material or digital data, is representative of an engagement with the material [12]. This engagement results in the creation of metadata that serves a purpose desired by the individual creating the annotation. The defining characteristic of an annotation is its intended purpose. For example, the act of highlighting a sentence might serve as a signal for future attention or as a memory aid.

Paper-based annotations can take many forms, such as highlighting, underlining, comments, color coding, short notation, calculations, references to other material, writing at top/bottom of documents and keeping pages of separate notes for a document. For studies on the different forms of paper-based annotations and their relationship with their intended purpose, see [12], [8], and [13]. The design and implementation of digital annotation systems that mimic the functionality of their paper-based counterparts in medical and technical fields are presented in [10], [9], [14].

A survey of the most desired functionality in the digital annotation of data, in [13], found that functionality available in traditional paper-based annotation schemes, such as marking up documents, writing between margins and writing at the top of documents is not as desired as more advanced features such as the ability to annotate images, insensitivity to document format and the ability to search annotations. This is an indication of the high expectations users have of digital annotations; functionality already available to them on paper is taken for granted. As a result, when designing the annotation system for PDS it was considered a priority to support the functions already provided by paper-based systems, as these would be expected by users, as well as identifying advanced features which would be of value.

An advantage of digital annotations is their ability to implement functionality that paper-based schemes cannot support. Examples include:

1) Support for comment sharing in documents.
2) Compact display of indexed annotations and relationship discovery.
3) Collaborative sharing of comments with selective viewing permissions [13].
4) Support for editing of own and other users’ annotations [11].
5) The ability to search a collection of documents based on keywords within annotations.
6) Annotation of time series data and searching based on similarity to annotated segments.
7) Extraction of metadata that, combined with further processing, allow for the creation of further valuable data, such as training sets for machine learning algorithms.
8) The ability to circumvent the rigidity of electronic health records by allowing the creation of data not envisaged and accommodated by the original document schema architects.

The functionality chosen for the PDS annotation system is a combination of the features provided by traditional paper-based systems with the collaborative and knowledge-sharing capabilities facilitated by digital annotations. The collaborative functionality facilitated by digital annotations was then extended to include meta-annotations in the form of comments and confidence measures.

IV. ANNOTATIONS IN PDS

Paper-based EEG monitors allowed for manual annotation through the addition of handwritten notes indicating acquisition events and features of interest in signals. More modern, software-based systems support the addition of simple textual annotations both during acquisition and subsequent analysis. Some systems, such as the Natus Olympic Brainz Monitor [15], allow for annotations to be viewed and added from a remote review station. The goal of the annotation system in PDS is to extend this functionality to create a common medium for the interchange of signal metadata between all actors (human and software) in the system.

Humans use the annotation system as an aid for analysis, collaboration with colleagues, identification of features of interest (FOI) and for training purposes. Software agents provide annotations that can assist humans with their analysis. Furthermore, software agents can make use of annotations provided by humans both as a resource to be searched and as
a source of training data. The resulting metadata is therefore of benefit to all actors in the system (see Figure 1), including the patient whose data is being streamed through the system (through reduced time to diagnosis).

The most simple use case for the annotation is as a system for humans to leave notes for themselves. This is useful for memory aiding, indications for further analysis, etc. The system supports private annotations for this purpose. A new annotation is created by selecting an option from the drop-down menu at the top of the application window. A mouse click is then used to indicate the annotation starting point. Once the starting point has been selected, a new, empty annotation appears. The on-screen representation consists of an annotation summary component and two arrows indicating the start and end recording offsets. The start and end arrows can be dragged to change the recording segment referred to by the annotation. The annotation summary consists of four sub-components indicating the annotation type, description, visibility (public/private) and affected channels. These can be specified by clicking on the respective subcomponents. The annotation summary also contains a button that saves the newly-created annotation to the server. Alternatively, a drop-down menu option is available to save all newly-created annotations.

A more advanced use case arises when a human analyst makes some of his/her annotations public. When a public annotation is added, all other reviewers viewing the recording in question are notified as soon as the annotation is saved via a server-push messaging system. The other reviewers can then add meta-annotations by rating or commenting on the annotation. The rating system allows the other reviewers to provide a measure of their confidence in the accuracy of the annotations; the available options are “strongly disagree”, “disagree”, “neutral”, “agree” and “strongly agree”. Reviewers may also comment on the annotation. The result is a thread of ratings and discussion pertaining to the annotation, facilitating consensus diagnosis or training instruction. The annotation summary components for public annotations contain a label indicating the number of associated ratings and comments. If any of these items have not yet been viewed, then the label text is rendered in a different colour to draw the user’s attention to the new content. Hovering the mouse pointer over an annotation summary component causes it to expand to display the ratings and comments below. Clicking on an annotation summary component brings up a more detailed user interface that allows new comments and ratings to be added. Any comments or ratings added to an annotation are immediately saved to the server automatically.

Users can navigate quickly from one annotation to the next using a pane at the bottom of the viewing window that displays the annotations in the vicinity of the currently-visible recording segment. Annotations currently visible on-screen are displayed in the center, with those preceding and following shown on the left and right, respectively. A complete list of all annotations attached to the data stream can be viewed via a drop-down menu option. This view contains visibility settings for the various annotation categories and allows annotations to be grouped.

The creation of a large body of data that has been annotated by experts is also of benefit to humans. Users can identify human experts whose work is relevant to them and view all of that user’s annotations by visiting the user’s profile page on the system. This feature encourages knowledge sharing and collaboration and provides a a learning platform for junior staff to learn from more experienced analysts, and for senior analysts to monitor the progress of junior staff.

V. Annotation Types and Sources

Top-level annotations annotations fall into three categories: events, comments and waveform classifications. Events indicate occurrences at the acquisition location that are of interest to analysts, such as impedance tests and patient movement. Comments are general, free-form text markup of the signal data. Waveform classifications represent a categorisation of a recording segment by a human analyst or software agent. Meta-annotations in the form of comments can be added to any top-level annotation. However, confidence measures can only be applied to waveform classifications.

Annotations can originate from a number of sources:

1) Acquisition Location Modern EEG acquisition software typically annotates the output file being produced with annotations indicating events of interest during acquisition, such as when an impedance test is performed or a loose lead is detected. These can be supplemented by notes entered manually by staff either at the bedside or at a review station. Examples includes notes indicating that the patient has been moved or highlighting features of interest such as suspected seizures or signal artifacts.
She views the recording in question and distinguishes the type two different waveform types.

The user identifies a “feature of interest”, e.g. a neonatal seizure. The user creates a public annotation of the seizure as described in Section IV. The user continues reviewing other recordings on the system. When the user saves the annotation, the information entered such as the waveform type, duration, start-time, end-time, and affected channels are stored in PDS’s relational database.

This result is a collection of seizures that can be independently verified by another reviewer. If the reviewers do not agree on a waveform classification, then a discussion takes place via the addition of comments. The reviewer and his/her peers can also express the level of confidence that they have in the classification. Eventually, a consensus is reached on whether or not the waveform fits the classification assigned to it.

B. Analyst training

A trainee analyst is reviewing a recording in the viewer. The trainee is uncertain about whether a particular waveform should be classified as a seizure or recording artefact. The user annotates the seizure with a question, stating their own views and asking for guidance on how to distinguish between the two different waveform types.

A more experienced analyst logs in and notices the question. She views the recording in question and distinguishes the type of seizure due to a number of characteristic features the first user hadn’t been aware of/had experience with.

The question evolves into a thread based discussion on distinguishing between the two different types of seizure. The original user annotates the seizure as the correct type and it is persisted to the database.

VI. Conclusions and Future Work

The work presented introduced interactive annotations as a means for collaborative analysis of data and a means to reduce time to diagnosis. Collaboration is supported by the ability to annotate data as it streams through the system, supporting querying, feature detection and commenting. The idea of “meta-annotations” has been introduced to further knowledge creation and sharing, allowing users to benefit from the identification of important data by consensus and discussion.

The primary benefits of the proposed system are collaborative diagnosis, reduction in time to diagnosis and reduction in specialists’ workload. Secondary benefits include increased knowledge sharing, identification of features of interest within the data, and the provision of a training platform for software agents and human analysts.

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References


