Voice-supported Electronic Health Record for Temporomandibular Joint Disorders

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Keywords

Electronic health record, structured data entry, dentistry, temporomandibular joint disorder

Summary

Objectives: To identify support of structured data entry for an electronic health record application in temporomandibular joint disorders.
Methods: The methods of structuring information in dentistry are described and the interactive DentCross component is introduced. A system of structured voice-supported data entry in electronic health record on several real cases in the field of dentistry is performed. The connection of this component to the MUDRLite electronic health record is described.
Results: The use of DentVoice, an application which consists of the electronic health record MUDRLite and the voice-controlled interactive component DentCross, to collect dental information required by temporomandibular joint disorders is shown.
Conclusions: The DentVoice application with the DentCross component showed the practical ability of the temporomandibular joint disorder treatment support.

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1. Introduction

The electronic health record (EHR) is defined as a repository of information regarding to the health of a subject of care in computer-processable form, stored and transmitted securely and accessible by multiple authorized users [1]. Its main goal is to support continuous, efficient and high-quality integrated healthcare by using structured data entries [2, 3], interoperability [4] and standards [5], real-time and point-of-care usage [6], privacy enhancing techniques improving security aspects [7, 8], semantic interoperability by ontology-based approaches [9] or decision support systems [10]. A comprehensive and suitable EHR system has not been internationally implemented by any software company or other vendor till now, that is why the evaluation of different EHR systems is important [11]. One improving possibility of EHR is implementation of a voice control system, which would simplify the whole process of data gathering.

Voice commands usage has been experimented with since the 1990s [12] as a convenient replacement of computer control using keyboard and mouse. The necessity of using human voice to control a computer or other device arises in typical hands-busy environments such as surgery or dentistry [13].

Voice-controlled electronic health records possess qualifications in supporting continuing, efficient and high-quality integrated healthcare by providing comprehensive information about the individual. They keep the data on the individual's current and historical health, medical conditions, tests, treatments or medication as essential EHR systems. In addition they can also provide more advanced processing of these data and decision support functionality not just in the basic dental documentation, but also in specialized subgroups, i.e. for temporomandibular joint disorders. Especially groups of diseases like a temporomandibular joint disorder can be involved in the whole process of masticatory system analysis [14].

The unclear etiology of TMD, the same clinical findings resulted from various causes, and the proven relation between TMD and psychological factors are the main reasons why there is still no consensus in classification of TMD [15, 16]. All these mentioned facts make from TMD a very complicated group of diseases for creating a suitable and compact EHR system. One of the most commonly used diagnostic schemes intended for research purposes is the Research Diagnostic Criteria for TMD (RDC/TMD). RDC/TMD standardizes the clinical examination of patients with TMD, improves reproducibility among clinicians and facilitates comparison of results among researchers [15].

Temporomandibular joint disorders (TMD) and their most common signs and symptoms such as pain, limited mouth opening and joint sounds could be caused by muscle disorders, intracapsular derangement of the components of the temporomandibular joint (TMJ), and degenerative changes in the bony components of the joint itself [15]. TMD are considered to be a subgroup of musculoskeletal disorders [15–17]. This may explain reports of successful use of physical therapy in the treatment of TMD.

Our application was prepared to produce a user-friendly program, which will unify the whole masticatory system and its problematics, because all its parts are directly connected. The system was enhanced with the automatic speech recognition module.

2. Multimedia-distributed Electronic Health Record

The development of an electronic health record at the EuroMISE Centre started in the year 2000 based on inspirations and experiences from existing CEN/TC251 standards and several European projects, mostly the I4C and TripleC projects [18]. The main requirement for the proposed system was the storage of structured data combined with free text with the possibility of dynamic extension and modification of the set of collected attributes without any change of the database structure. The research resulted in a pilot EHR application called MUDR (multimedia-distributed EHR). Another related electronic health record called MUDRLite [21] has been developed in 2003 with emphasis put on the small-scaled environment's needs. MUDRLite operates as a command interpreter; it processes the instructions encoded in the so-called MLL (MUDRLite Language) [22] based on XML and manipulates the database layer as well as the visual aspects and behavior of the MUDRLite user interface. The pilot application was prepared for dentistry [13].

The main architecture of MUDR EHR was based on a 3-tier architecture, consisting of database layer, application layer and user interface layer. The set of collected attributes and relations between them is stored in a directed graph structure called "knowledge base". The vertices of the graph describe the collected attributes by their unique id, internal name, physical data type and other auxiliary information; the graph edges describe the relations among attributes. The dominant edge of type "inferior" defines the hierarchical tree structure of the knowledge base, so that the knowledge base can be described by a directed forest with a few trees. These trees are also called "knowledge base domains". Each tree in the graph describes the data of one patient. Each vertex in the tree describes one instance of the medical concept from the knowledge base. The application layer consists of four basic components – the HTTP server used for communication with client applications, EHR-AppL service implementing the main application logic, CGI-script (potentially more of them) serving as an interface between HTTP server and EHR-AppL service and possibly medical guideline modules.

The MUDRLite architecture is based on two tiers. The first one is a relational database (e.g. MS SQL) and the second one is a MUDRLite user interface layer (MUDRLite UI). The database schema corresponds to the particular needs of the target domain and therefore varies significantly in different environments, as opposed to the fixed database schema in the MUDR data layer. The core of MUDRLite – MUDRLite Interpreter – is able to handle various database schemas. This feature often simplifies the way of importing old data stored in other databases or files. The visual aspects as well as the behavior of the MUDRLite UI are completely described by an XML configuration file. The end-user can see a set of forms with various controls placed on them by appropriate XML elements.

3. Interactive DentCross Component with Automatic Speech Recognition (ASR) Engine

To gain MUDRLite's user acceptance in the field of dentistry, a highly advanced component – the interactive dental cross, which is a graphic part of dental documentation [13] – has been developed. The DentCross component is implemented as a standalone library DentCross.dll, completely developed for the .NET Framework platform using the Microsoft Visual Studio.NET 2003 development tool.

A user-defined component is inserted by the custom element of the MLL with the following mandatory attributes: "dll" specifying the name of the assembly where the component is implemented and "class" specifying the name of the main class of the included component. This component is fully interactive. The dentist can choose among about 60 different actions, treatment procedures or tooth parameters that are displayed graphically and in a well-organized manner (►Fig. 1).

The schema of the underlying database of the electronic health record reflects the structure of the subset of a large hierarchical knowledge base, created for the domain of dentistry both in Czech and English languages. The database contains characteristics of each individual tooth – localization (mesial, incisal, incisal-distal, incisal-mesial, distal, cervical-vestibular, cervical-oral, vestibular and oral, mounts 1, 2, 3 and 4) and type (primary, secondary) of caries, agenesis, periodontitis, necrosis, gangrene, characteristics of treatment procedures – localization and material of filling(amalgam, composite, compomer, glassionomer, temporary filling), different type of implants, crowns, inlays, localization and material of bridges, extractions, and the additional characteristics like bleeding indexes, tartar and attributes of periodontium. The large knowledge base uses different well-known classifications like Baume classification of pulpitis, Black classification of cavities, Angle classification of malocclusion, Voldrich classification of missing teeth, Kennedy classification of partially edentulous conditions and partial dentures, gingiva and periodontium disease classification according to WHO, etc. The technology of the knowledge base representation was applied for a Czech national patent under the No. PV 2005–229.

The automatic speech recognition (ASR) engine was implemented as a standalone application, running in the server mode in the background. The server communication protocol is proprietary, running at the top of TCP/IP stack. The communication protocol enables the startup and shutdown of the recognition process,

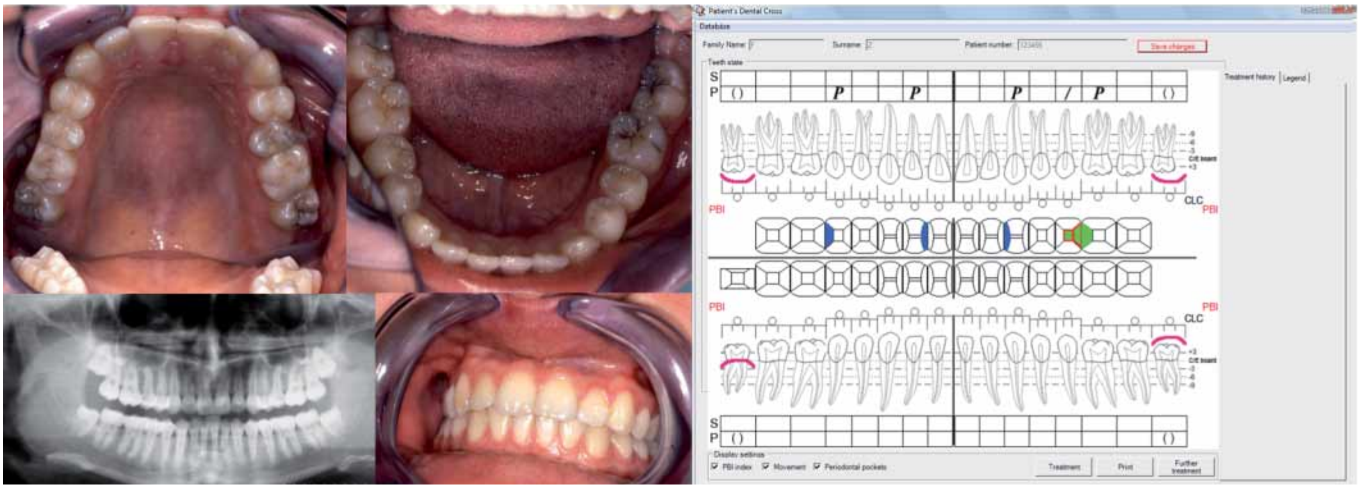

Fig. 1 Interactive DentCross

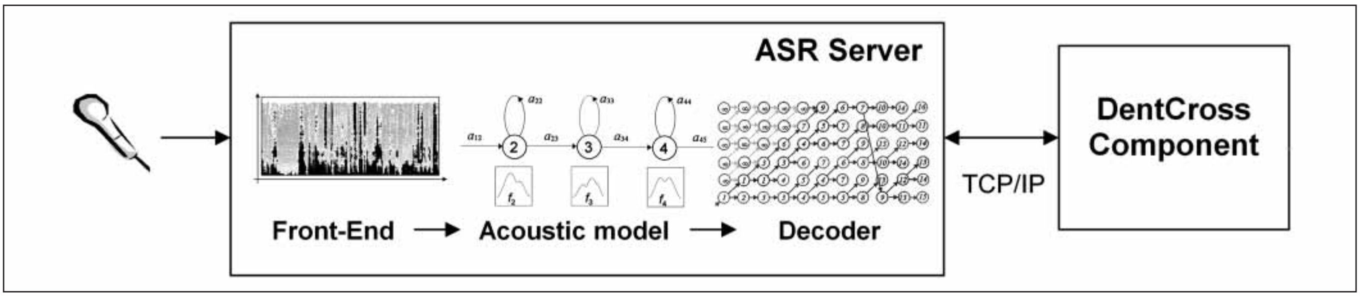

Fig. 2 Automatic speech recognition functionality

the run-time configuration of the recognition task as well as receiving the recognized phrases by a client.

The ASR system is speaker-independent and uses statistical techniques. The ASR module scheme can be seen in ▶Figure 2. The speech signal is digitized at 8 kHz sample rate. Then, the pre-emphasized acoustic waveform is segmented into 25-millisecond frames with 15 ms overlap. The acoustic model is based on modelling of triphones. Each individual triphone is represented by a three-state left-right HMM (Hidden Markov Model) with a continuous output probability density function assigned to each state. The decoder uses a Viterbi search technique combined with an efficient beam pruning algorithm [23].

The DentVoice application prototype binds the DentCross component and the TCP/IP client of the ASR server with a voice commands definition file. The ASR client uses a DentCrossHandler class that implements all the functionality of the DentCross component.

The speech recognition is activated immediately at the DentCross component's start-up. The recognition process can be paused or stopped by special voice commands or via the user interface. Voice commands can be divided in two groups: global commands and context-dependent commands.

Global commands are designed to manipulate the recognition process, e.g. to pause, resume, stop etc. and to close message boxes opened by the application to alert the user.

Context-dependent commands rely on the current state of the DentCross component and can be further divided into 33 command groups corresponding to the 33

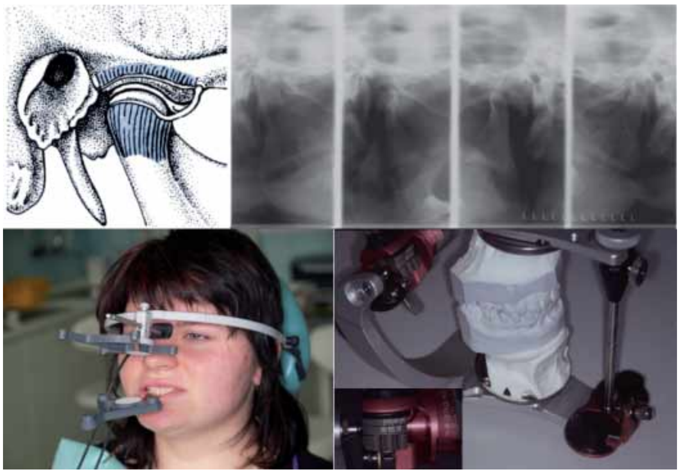

Fig. 3 Computer-supported TMJ analysis

states (e.g. tooth treatment status, caries placement, caries type, the type of root canal treatment material).

4. Voice and Computer-supported Treatment of Patients with the TMJ Parafunction

The basis for a successful treatment is a determination of the patient´s causal problems [24]. New findings concerning the etiology of TMD have led to changes in therapeutic procedures. For the promotion of musculoskeletal system's natural healing capacity a complex conservative treatment is currently preferred to the irreversible surgical or prosthetic therapy.

4.1 Case Report

This case report shows integration of the automatic speech recognition and DentCross component in the TMD treatment.

Based on a referral from dental surgeon the patient was examined for frequent joint sounds and a long-lasting pain in the area of the temporomandibular joints, likely caused by an impairment of the interarch tooth relationship. The patient did not suffer from bruxism or other parafunction habits. The methods of structuring information in dentistry can be illustrated by utilizing voice-supported interactive DentCross component. The interactive DentCross component helps in collecting the dental information, preparing the treatment plan and monitoring the progress of the therapy. Everything is connected with the anamnestic data gathering in the special form, which is a part of the DentCross.

4.2 Treatment Plan

1. Implementation to the interactive DentCross component – dental examination and anamnestic data
2. Training of opening of the mouth in the axis, without deviation
3. Stabilization splint
4. Computer-aided face bow analysis
5. Prosthetic treatment
6. Finalization of the treatment and soft splint
7. Recall and treatment evaluation by the patient

4.3 Pre-treatment

During the pre-treatment process, the Interactive DentCross component has been used to support the graphical analysis of upper and lower dental arch. All the examination and anamnestic data have been implemented to enable general status analysis and complex overview, which is crucial for TMD treatment (▶Fig. 1).

4.4 Treatment

The patient was recommended not to open the mouth maximally, to avoid biting hard food and not to chew a chewing gum. With the help of hard acrylic splint stabilization was performed to cover all the teeth of the upper jaw, so making their surface smooth. This ensured centric occlusion, elimination of posterior interferences, providing anterior guidance on anterior teeth and reduction of neuromuscular activity. Putting the patient for two months of this regime resulted in substantial reduction of pain and/or frequency of joint sounds in the left TMJ.

Then prosthetic treatment of the incorrect jaws relations was initiated. A gradual analysis of study casts was generated in the fully adjustable articulator Protar Evo 7 (KAVO, Germany) and by a computer face bow transfer Arcus Digma (KAVO, Germany) (▶Fig. 3). After the prosthetic treatment a soft splint was fabricated on the lower jaw cast and the patient wore it nightly. The soft biting splint and prosthetic treatment contributed to a decrease loading of the TMJ that resulted in a reduction of pain in the area of the TMJ. Abrasion was virtually eliminated.

5. Discussion

Accomplished analyses of the current state of commercially available software products and patent technologies suggest that the software support for storing the dental health documentation is slowly developing [18]. The new trends are designing an object-relational model based on structured knowledge elements that are dynamically reusable by different multimedia-based tools for case-based documentation, disease course simulation, and decision support [19] and focusing on the explicit user requirements [20]. The presented interactive DentCross component also increases the quality of electronic health record. The graphical design of the DentCross UI is specifically designed to look like a dental arch photo combined with an X-ray image (i.e. root canal or implant picture). Papilla bleeding index, tooth movement, calculus, bone resorption, periodontal pocket and TMJ data can be also documented.

The TMJ arthralgia was, namely in the presented case, probably caused by a repeated traumatization of the TMJ due to an incorrect stereotype of the mouth opening, chronic overloading of TMJ as a consequence of an unstable occlusion and displacement of the disc associated with an irritation of retrodiscal tissue [12, 16].

Our experience with the voice-controlled input suggests that this control modality is highly suitable for application in the medical environment and its usefulness is not limited to dental praxis alone. The voice-controlled input is useful whenever the use of other input modalities would impact negatively the user's performance in terms of increased time required to accomplish a given task or by increasing the user's feel of discomfort. These situations frequently occur, for example (but not exclusively), during the patient's examination, surgery or during the manual microscopical analysis of blood/tissue samples. In these areas, high volume vocabulary speech recognition system (HVV-SRS) would be a great benefit, eliminating the need for requiring special UI adapted for the phrase-recognition voice control. However, the call for domain-specific language model for HVV-SRS is the main challenge in applying the HVV-SRS in praxis.

Forthcoming development will address the usage of a computer-synthesized speech. DentCross will read aloud the actual status of patient's teeth as stored in the database and the dentist will only need to check whether the recorded information is correct.

6. Conclusion

The MUDRLite EHR with interactive DentCross component allows transparent health record on the whole dentition and accomplished examinations of a patient in a concentrated form. The dental information recorded in a common graphical structure accelerates the dentist's decision-making and brings a more complex view on gathered information. DentVoice (a voice-controlled version of the DentCross) application is currently being tested in the process of dental data capture and evaluation. This approach can not only ease the recording of structured data in dental practice but it also can support TMJ disorder therapy. The described application of MUDR EHR with DentCross component thus opened new possibilities of storage and classification of data in dental medicine.

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