Designing A Patient Monitoring System for Bipolar Disorder Using Semantic Web Technologies*

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Abstract—The new movement to personalize treatment plans and improve prediction capabilities is greatly facilitated by intelligent remote patient monitoring and risk prevention. This paper focuses on patients suffering from bipolar disorder, a mental illness characterized by severe mood swings. We exploit the advantages of Semantic Web and Electronic Health Record Technologies to develop a patient monitoring platform to support clinicians. Relying on intelligently filtering of clinical evidence-based information and individual-specific knowledge, we aim to provide recommendations for treatment and monitoring at appropriate time or concluding into alerts for serious shifts in mood and patients’ non response to treatment.

I. INTRODUCTION

A MELIORATE the quality of healthcare services is a main and constant need in health community. As the technology evolves to provide assistance to health care services more effectively, intelligent and repository medical systems emerge to meet these needs [1].

Procedures of early diagnosis, optimal treatment strategies and disease prevention, as well as analysis, management and communication of medical information increase the necessity of developing patient monitoring systems and integrating them in healthcare domain [2], [3]. In this regard, it is necessary to consider integration of medical information from various sources, as well as constant, on-time briefing of patient’s health state and behavior. Multi-source patient monitoring evolves into an important service in this domain.

Mental illnesses are associated with impairments in mood, behavior, thinking, as well as in interpersonal communication and social relations. Bipolar disorder (BD) is a severe mental illness that influenced by both genetic and environmental factors. The course of illness is primarily characterized by great mood swings, recurrence and risks of suicidal attempts. BD is accompanied with high prevalence (1-2%) and incidence, and is linked to significant chronicity [4]. As a result, the quality of life in patients suffering from BD decreases, along with the negative impact on themselves, their families and on society. Because of the dynamic and devastating nature of BD there is a necessity for patient monitoring systems that can understand it and subsequently support longitudinal monitoring of bipolar disorder. Therefore, we must consider different issues of patient’s physical, emotional and social status, in order to manage and treat efficiently BD. Nowadays, advanced systems are generated to monitor patients with BD by exploiting the daily mood charting, or by analyzing data from wearable, environmental sensors and Smartphone applications [5], [6].

Longitudinal monitoring is important in patients with BD; we aim to approximate the problem of long-term follow-up by generating a time-determined ontology relying on semantic Web technologies being able to provide specific reasoning over various aspects of BD and on their evolution over time. Based on well-established clinical guidelines [7] we developed personalized models that can better follow mood shifts, recognize early warning signs and facilitate their timely intervention by clinicians. In this work we provide an intelligent patient monitoring system, which is perceived as the back-end part of a novel service platform for bipolar patients, as well as data integration methods for Electronic Health Records (EHRs) that have more or less become part of modern e-health care systems. We derive new knowledge by applying reasoning in the instance semantic data of the ontology.

Aiming at developing an intelligent patient monitoring system, in Section II, we present the integrated platform, that consist of an EHR system based on the Health Level Seven Reference Information Model (HL7-RIM) [8] and the utilization of Semantic Web technologies. Both components of the platform have already been implemented and are currently under testing using real patient data.

II. INTELLIGENT PATIENT MONITORING SYSTEM APPROACH

We present an intelligent patient monitoring system architecture using Semantic Web and an EHR for bipolar patients. We aim at supporting clinical professionals in the initial evaluation and diagnosis of adults with suspected BD, as well as to provide evidence-based treatment options for a personalized therapeutic approach, notifications for early warning signs and alerts for crucial mood swings leading to

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their timely intervention in order to prevent relapse and suicide. It is essential to mention that security is of great importance and that all sensitive data collected through the EHR, are stored in a secured manner. The whole platform consists of four main tiers (Fig. 1) namely, a) Presentation tier, b) Application tier, c) Intelligence tier, and d) Data tier.

![Platform Architecture - Tiers](image)

**A. Presentation Tier**

The presentation tier comprises the top level layer and is responsible for the human computer interaction and for the data presentation. That tier provides advanced usability, and visualization functionality along with a simple and rich graphical user interface (GUI), which can be accessed on the Web. Moreover, this tier provides statistical graphs for intuitive visualization of the current status of patients in terms of episodes and drug administration over time (Fig. 2).

![Graph presenting patient’s episodes (depressive, manic) with respect to the treatment during a 12-month period](image)

**B. Application Tier**

The application tier is the middle tier of the platform. This tier controls all the system operations by performing detailed processes. It consists of three sub-tiers: 1) Business logic, 2) Security and 3) Data access.

The main functionalities of the business logic tier are related to patients’ and users’ data management, management of patients’ informed consent documents, generating dynamic clinical forms, collecting data for the visualization diagrams, comparing patient’s re-examinations, printing capabilities, robustness and fault tolerance, interoperability standards and system integration.

The security framework consists of the role based access control mechanism (RBAC) [9] and the encryption/decryption mechanism for user’s passwords and patient’s sensitive data. Users in the system have roles that regulate their actions. These roles can guarantee that no user can perform ineligible acts. Furthermore, all users’ passwords and patients’ sensitive data are stored in an encrypted way, ensuring the confidentiality in case that the database access is breached by a third party. Finally the Secure Socket Layer (SSL) [10] protocol is utilized in order to preserve the secure data exchanged.

The data access sub-tier handles all the logic regarding data management by utilizing the usage of Data Access Objects (DAO) and the Object Relational Mapping (ORM), which solves object-relational impedance mismatch problems by replacing direct persistence-related database accesses with high-level object handling functions.

**C. Intelligence Tier**

This tier (ontology) aims at identifying the key components of bipolar disorder, while emphasis is placed on modeling temporal concepts and relationships. The time-determined ontology is based on well documented clinical guidelines and algorithms and its purpose is to develop electronic support to clinicians and health care professionals in BD issues through a suggested sequence, while taking into account patient-specific information (demographic, medical, behavioral) from heterogeneous sources of the input repository. Both, clinical guidelines and user scenarios for individualized bipolar patients’ are used to develop the ontology.

1) **Guidelines:** The intelligent tier reclaims different aspects of the treatment and management of bipolar disorder, operating in five selected evidence-based clinical practice guidelines: WFSBP [11], CANMAT [12], NICE [13], Australian and New Zealand [14], British Association for Psychopharmacology [15], and other systematic reviews for BD [7].

2) **User Scenarios for Bipolar I Disorder:** Bipolar I disorder (at least one manic or mixed episode) is one of the four basic types of BD, in accordance with the Diagnostic and Statistical Manual of Mental Disorders (DSM). Presently, we provide user diagnostic and treatment scenarios for bipolar I disorder (BDI). Diagnostic scenarios consider specific information of screening and assessment tools and persons' history. Diagnosis of bipolar I disorder follows the established criteria of the DSM-IV for a manic or depressive episode along with their severity, takes into consideration the mental or/and medical comorbidities and impedes misdiagnosis, especially with major depressive disorder (unipolar disorder).
The diagnostic scenarios are designed to aid the clinicians with a procedure of sequential steps: the initial evaluation considering the differential diagnosis; the assiduous psychiatric examination addressing the different patterns of BD emergence, the possible phase transitions (mania to depression and vice versa, with or without symptom free intervals), comorbidities (primary or secondary BD) [4]; and the diagnostic accuracy when patients fail to respond to treatment [7], [11]-[15].

Relying on the aforementioned evidence-based management and treatment guidelines, we developed the user scenarios for BD treatment, following the dynamic disease course, and considering treatment issues specific to the shifting in mood connected to the acute treatment (mania, depression, mixed states, psychotic features, rapid cycling, and electroconvulsive therapy), or to symptom-free intervals (euthymia) associated with the maintenance treatment (rapid cycling, relapse prevention, treatment discontinuation). Patient longitudinal monitoring is performed by the system to evaluate the presence or absence of symptoms, psychiatric and medical comorbidities, medication adherence, medical morbidity and mortality, and to identify therapeutic drug safety and tolerance. The monitoring functionality is implemented by means of inputs received from sensors (i.e. biosignals) and smartphone applications (e.g. voice analysis) accompanied by inputs (paper-based and electronic-based data like mood diaries and medication monitoring) from the user's environment (family, carers) or the user himself. Warnings have been placed in decision nodes with relevant annotation from the literature in order to yield the appropriate hints and alerts to the clinicians on real-time.

3) **BD Ontology:** Formal ontologies such as SNOMED CT [16] or other formal approaches, formalize domain terminology and categorization, offering great advantages in formal rigor and inference power. Despite the advantages, formal ontologies limit the expressiveness of the domain representation and design to an upper level description [17], [18]. Considering this limitation, formal ontologies can be regarded as upper level ontologies, offering a vocabulary of terms along with concept definition and their inner-relationships and as such they are integrated to our developed ontology which, however, is more specialized and geared around concepts related to the monitoring of patient condition and its evolution in time.

The representation of the domain of bipolar disorder occurs through the description of the corresponding concepts, their characteristics and the correlations between them. The designed ontology includes all these aspects which are presented in figure 3.

Dynamic entities (entities which evolve in time):

- **EHR:** the electronic medical record of patient.
- **PatientState:** patient’s current state (in euthymia or in an episode).
- **Symptom:** the symptom (type, severity).
- **Therapy:** the therapeutic approaches a patient may receive (medication, hospitalization, psychotherapy).
- **Medicine:** the substance administration of the patient.
- **Monitoring:** is superclass of classes (i) FunctionTest which are the tests a patient is submitted to (imaging tests, laboratory tests etc.). Function tests are based on guidelines that provide the recommendations for the initial baseline assessments and the follow-up laboratory investigations and monitoring strategies for bipolar patients [7], [11]-[15]. (ii) Biosensor which keep the information of biosignals recorded from sensors applied on patient. Class Monitoring is related with class Standard, which holds its general attributes (unit of measurement, normal values).

Static entities (entities which do not evolve in time):

- **Patient:** patient’s personal and demographic information
- **Episode:** the type (manic or depressive) and severity of an episode.
- **Diagnosis:** the type of the disorder (Type I or Type II) and whether the patient suffers from rapid cycling.
- **PatientHistory:** patient’s medical history. Age of onset, heredity, number of manic or depressive episodes, previous medication.
- **Standard Test:** highest and lowest optimal values of each functional test and unit of measurement.
- **SideEffect:** possible side effects of a medicine.
- **InitialEvaluation:** initial evaluation for the diagnosis procedure. The initial evaluation is a combination of a) mood questionnaires for symptoms evaluation (MDQ, B SDS, CIDI); b) patient’s history record collected by the clinician; an c) various functional tests that the patient is submitted into, in order to ensure the psychiatric disorder and reject other medical causes.
- **Medical Cause:** whether the clinical evaluation suggests other medical cause than bipolar disorder.

![Figure 3. Class Diagram of the developed temporal ontology](image)
Relationships Dynamic classes are related with each other during specific intervals. The main concept in the ontology is the class EHR.

The initial design was based on a static ontology that describes the main concepts of the BD disease scenario and was developed by using a common ontology editor. Then, the CHRONOS plugin of Protégé [19] was utilized in order to convert it to temporal. A reasoning system was implemented by means of Semantic Web Rule Language (SWRL) rules [20] in order to issue alerts and recommendations. Ontologies populated with real data collected from 10 patients whose condition is monitored over a period of a few days to a year.

D. Data Tier

The data tier constitutes the database server and is used by the integrated platform to hold the rest of the data. In that way, data is kept neutral and independent from the rest of the tiers offering improved scalability and performance. The design of the database was based on HL7-RIM, which is the cornerstone of the HL7 Version 3 development process.

III. CONCLUSIONS

We indicate that Semantic Web allows systematic knowledge extraction and ontology creation by analyzing patient records and filtering evidence-based guidelines resulting in recommendations and notifications for individualized diagnosis and treatment approaches. In addition, we illustrate an EHR as a perspective for an advanced environment that assists in monitoring of multifactorial diseases such as mental illnesses including BD.

Tests and validation were performed progressively on the implemented pilot applications to a sample of ten real clinical cases of bipolar disorder. A favorable outcome of long-term follow-up of BD patients would also serve to adopt this intelligent system useful for knowledge representation and inference to increase healthcare services in other mental or neurological disorders. In the future, we aim to test this architecture on a real setting performing data acquisition from biosensors and devices, that could be forwarded to the platform for data analysis and patient monitoring based on well-defined standards for exchanging EHR information such as the FHIR standard [21].

REFERENCES