A Multi-agent Architecture for Ontology-based Diagnosis of Mental Disorders

Todor Ivașcu*, Bogdan Manațe* and Viorel Negru*§
* *Department of Computer Science*
Faculty of Mathematics and Informatics
West University of Timisoara
bvd. V. Pârvan 4, Timișoara, Romania
§ *Institute e-Austria Timisoara*
bvd. V. Pârvan 4, Timișoara, Romania
Email:{*t.ivascu, bogdan.manate, vnegru*}*@info.uvt.ro*

***Abstract*—This paper presents a Multi-agent system that facilitates the remote monitoring of the elderly patients which are susceptible to mental disorder diseases. In order to find early signs of health condition depreciation we have assessed four of the most common mental disorder diseases to find which kind of sensors can detect specific symptoms with the main purpose of creating an early warning system. The diagnosis component is based on an ontology that defines the relations between sensors, symptoms and diseases. Based on these relationships a specialized agent can inform the medical personnel about the detected symptoms.**

***Keywords*-Cloud Computing; Multi-agent architecture; e-Health; Ontology-based diagnosis; Internet of Things;**

I. Introduction

In this paper we propose a multi-agent system for real-time healthcare monitoring. The proposed system is targeted on cognitively impaired people, and its main task is to aggregate the information collected from sensors in order to alert the medical personnel when a patient exhibits particular symptoms for a specific disease. Lack of processing power on these sensors, to perform data-aggregation tasks, require to transmit collected data to the cloud, from where diagnosis can be determined and patient's data can be accessed by the physician from everywhere.

Globally, more than a third of the population suffer from mental disorders, including 35.6 million with Alzheimer's disease and other types of dementia, a figure which is expected to double by 2030, 7 to 10 million suffering from Parkinson's disease, 400 million people of all ages suffering from depression and about 21 million suffering from Schizophrenia and other psychoses. These pathologies can have a major impact on everyday life, social and economical status, and on the quality of life of the patients [1]. With advancements in Information and Communications Technology (ICT), new methods for monitoring health conditions of the patient, in order to detect symptoms of diseases, to monitor disease progress, and to assist doctors in managing medical treatment were developed. Early diagnosis of mental disorders can help patients to live a better life.

The rest of the paper is organized as follows: Section II presents similar projects and literature review, Section III presents some of the diseases that pose a real threat for elderly people and how symptoms exhibited by these diseases can be monitored using existing sensors, in Section IV is presented the ontology used by the multi-agent system to map the symptoms to a specific disease, in Section V is presented an overview of the multi-agent system. In Section VI is described internal and external behaviors of each agent, and in Section VII are presented the conclusions of this research work.

II. Background and related work

In [2] is presented an approach for creating a disease information system that links the diseases and symptoms using an ontology. Additionally, this paper adds new concepts about the sensors that are used to gather information about specific symptoms.

Ontologies are used to describe various abstract concepts like context, weather, measurements, data provenance or concrete concepts like sensors, devices, hierarchical structure of an organization and services. Multiple researchers activating in the e-health domain have used ontologies to model disparate concepts as presented in [3], [4], [5].

A similar ontology based multi-agent system is presented in [6] where the concepts related to Internet of Things (IoT) are described using an ontology to facilitate the discovery and identification of various devices. In [7] is presented an ubiquitous sensing system based on Wireless sensor networks, which is capable to collect data from multiple monitored environments. The multi-agent system UBIWARE [8] was designed to be a self-managed complex system capable of handling distributed heterogeneous devices covered by the IoT framework. Other multi-agent systems cover various challenges posed by an e-health platform like medical education [9], remote monitoring in Ambient Assisted Living (AAL) [10], patient scheduling

978-1-5090-0461-4/16 $31.00 © 2016 IEEE
DOI 10.1109/SYNASC.2015.69

Authorized licensed use limited to: University of Cape Town. Downloaded on September 29,2022 at 09:32:43 UTC from IEEE Xplore. Restrictions apply.

based on ant colony optimization [11] and decision support for public health [12].

III. Remote diagnosis and prevention

In this section the signs and symptoms for the diagnosis of medical conditions like Psychosis and Depression, and degenerative disorders like Parkinson's Disease and Alzheimer's Disease are presented.

A. Parkinson's disease

Parkinson's disease is a degenerative disorder of the central nervous system, which progresses slowly and occurs due to the loss of dopamine-generating cells. Early diagnosis of Parkinson's disease (PD) is important to slowdown disease progression in the early stages [13]. Traditionally, the diagnosis requires a physician to observe the patient over time and recognize the basic signs of disease [14].

PD signs and symptoms can vary greatly from person to person. The basic signs which define PD diagnosis are: tremor, usually beginning in a limb at rest, and become less prominent with voluntary movement [13]; rigidity, muscle stiffness may occur in any part of the body, and can limit patients range of motion and may cause pain; and bradykinesia (slowness of movement) [14], the disease may reduce the ability to move and slows the movement, steps become shorter when walking [15], and patients may find it difficult to get up from a chair. The postural instability and freezing of gait (FoG) [16][17], which is one of main causes of falls in PD, occurs later as the disease progresses. Other symptoms like dysphagia (swallowing disturbance) or handwriting impairment are common motor problems which can appear.

In recent years several telemonitoring applications for diagnosis and monitoring of patients with PD have emerged. In [14] a method for continuously monitoring and recording patients gait characteristics using accelerometer sensor in a mobile phone is proposed. The proposed approach from [15] is based on a single wireless inertial sensor placed on the patients lower limbs for automatic FoG episode detection. In [18] a motor function test for detecting dyskinesia (spiral drawing) and bradykinesia (taping test) on upper extremity is presented.

Dysphonic problems like impairment of voice and speech are the most common signs of PD, which affect more than 90% of patients [19], and emerge in early stage of the disease. In [20] software tools for automatic acoustic analysis to detect impairment in PD patients speech is presented. In [19] an robust inference system that uses machine learning methods and algorithms, for early recognition of patients with PD and classification of the severity of the disease from the voice dataset is presented.

B. Alzheimer's disease and Dementia

Alzheimer's disease is a neurodegenerative disease, affecting memory and other important mental functions. Diagnosing Alzheimer's disease requires medical evaluation through patients' medical history, physical and neurological exam, standard medical tests and performing brain scans with magnetic resonance imaging (MRI) and computed tomography (CT). The first symptoms of patients behavioral changes are most often observed by family members or friends. Signs of Alzheimer's disease are: memory loss, such as forgetting important dates or events, especially forgetting recently learned information; asking for the same information multiple times; challenges in planning or solving problems, having trouble in following familiar recipes or difficulties in doing simple math, taking more time to do things than before; difficulty in completing familiar tasks, having trouble remembering the rules of a favorite game; having trouble understanding visual images, recognizing objects, difficulty in reading, judging distance and determining color or contrast; loss of interest in social activities [21].

In [22] a tele-monitoring system for detecting behavioral changes of elderly people in smart house settings is presented. The system employs passive infrared sensors placed in every room for detecting activities of daily living. This approach can detect if changes occur in the daily routines of the patient. A similar approach presented in [23], uses video cameras for real-time, automatic video monitoring and analysis of motor, cognitive and behavioral symptoms in AD.

Speech processing technology could be a valuable tool for assessment and early diagnosis of Alzheimer's Disease and other types of dementia. In [24] speech processing method for classifying and analysing the differences in vocal features of patients with AD and mild cognitive impairments (MCI) is presented.

C. Psychosis

Psychosis is a mental disorder associated with a range of symptoms [25] : false ideas or beliefs which can not be refuted even by logical arguments (for example, the idea that the person is being followed on the street, is being monitored, that someone is trying to poison him/her, the belief of having special powers, etc.); hallucinations (hearing different noises or voices, voices may comment on individual actions, or can command person to do certain things); seeing different colorful images with people, religious figures, and animals [26].

With these changes in thinking and perception, behavioral changes occur, the person becomes more withdrawn or isolated, has strange concerns which they did not have before, doing things which seem unusual to others, there are changes in sleep (insomnia), agitation, inner tension, emotional mood swings (sadness, euphoria or irritability) emerge, significantly decreased activity, staring without

Authorized licensed use limited to: University of Cape Town. Downloaded on September 29,2022 at 09:32:43 UTC from IEEE Xplore. Restrictions apply.

Table I
POSSIBLE SENSORS FOR MENTAL DISEASES' SIGNS AND SYMPTOMS

Sensors	Signs/Symptoms
Accelerometer	FoG, Resting tremor, Postural instability
EEG	Sleeping disorder, Early awakening, Insomnia
Video Camera	Sadness, Eye blinking, Agitation
Microphone	Impaired voice, Soft voice
Motion Sensor	Disorientation, Social isolation
Touch Screen	Dyskinesia, Bradykinesia
Bed Sensor	Sleeping disturbance, Restless sleep

blinking or blinking incessantly [25]. Behavioral changes are warning signs often seen by family members, friends and colleagues.

In [27] an intelligent system for facial expressions (mood) classification from facial images using committee neural networks is presented. The system can identify different facial expressions types such as neutral, sadness, fear, anger, happiness, etc. A non-invasive solution from [28] proposes a novel wearable system which consists of e-textile technology and biosignal processing which is able to recognize mood changes of a patients with bipolar disorder. In [29] a method for a vision system which is able to detect user's eye-blinks and can measure their duration in real-time is presented. Although this or similar systems are mainly addressed to the persons with severe disabilities to access a computer, it can be used to detect the blinking rate of a person, which is one of the symptoms associated with psychotic disorders.

D. Depression

Depression or a depressive episode is a combination of many emotional, physical, behavioral and cognitive symptoms, present for the most part of the day, almost every day, for at least two weeks, which appeared recently, or are obviously worse compared with the person's previous status.

The main element is the depressed mood, being sad for no apparent reason, present most of the time. The person suffering from depression feels sad, hopeless, discouraged, powerless, reluctant; decrease of interest or pleasure in all or almost all activities, some individuals reports that are no longer interested in hobbies, previous activities which they considered pleasurable; Other emotional and physical symptoms that occur are: Social withdrawal; Change in body weight by more than 5% in one month; Sleep disorders, insomnia is most commonly encountered; Changes in motor behaviour: agitation or psychomotor retardation; Fatigue or lack of energy, even the smallest tasks seems to require considerable effort [30].

In [31] an approach for automatic assessment of psychological conditions like depression and post-traumatic stress disorder (PTSD) is presented. This system can analyse and identify non-verbal behaviors such as affect, expression variability and motor variability from a virtual human interview dataset of video recorded interactions, and can automatically classify psychological conditions. In [32] a system for automatic sleep stages classification using a single channel EEG (ElectroEncephaloGram) signal is presented. Using pattern recognition techniques, the system can automatically identify and classify various sleep stages like sleep stages 1, 2, 3, 4, REM sleep and wakefulness. System based on Wireless Body Area Network (WBAN) presented in [33] can detect sleeping disorders using measurement from various body sensors. Sensors' data is transmitted to a central unit from where is analyzed and can classify various sleep stages and disorders.

In Table I some possible sensors for capturing or detecting signs and symptoms associated with cognitive impairments are presented.

IV. ONTOLOGY-BASED DIAGNOSIS

In this section we describe the ontology for some mental diseases and conditions, associated signs and symptoms for a specific disease, sensors for capturing corresponding symptoms and how these entities are related to each other.

Diagnosis constitutes a difficult decision-making process made by doctors in order to identify diseases based on exhibited signs and/or symptoms by the patient [34]. Using ontology, as a knowledge representation, to annotate key signs and symptoms for a specific disease, can facilitate and provide support to physicians in the diagnosis process.

We developed the Disease-Symptom-Sensor (DSS) ontology using the open-source ontology editor framework Protégé [35]. The ontology has three main classes (see Figure 1): ***Diseases/Conditions class*** which represents the mental disorders such as Alzheimer's Disease, Parkinson's Disease, Psychosis and Depression; ***Symptoms class*** which represents behavioural, motor, cognitive, facial, mood, sleep, weight and speech symptoms and/or signs associated with corresponding diseases; and ***Sensors class*** which represents some body and ambient sensors capable to capture specific signs and symptoms.

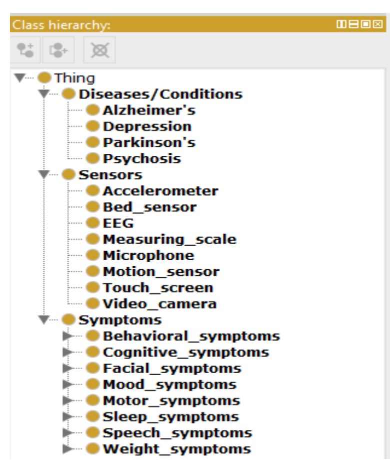

Figure 1. DSS (Disease-Symptom-Sensor) ontology structure.

Authorized licensed use limited to: University of Cape Town. Downloaded on September 29,2022 at 09:32:43 UTC from IEEE Xplore. Restrictions apply.

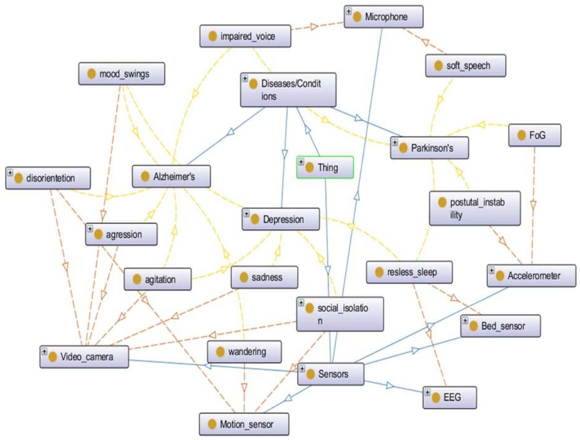

Figure 2. DSS (Disease-Symptom-Sensor) ontology model.

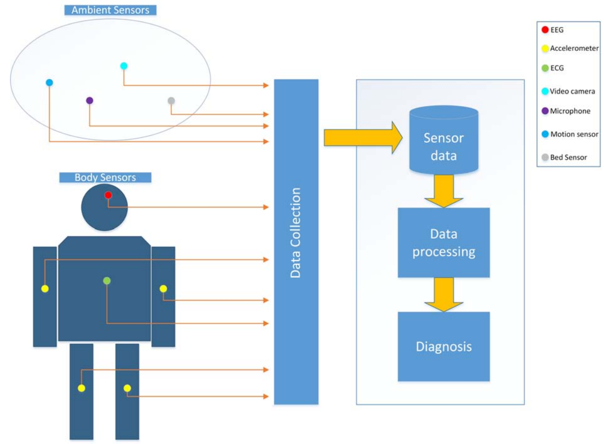

Figure 3. Remote diagnosis workflow.

Ontology is used by the multi-agent system as active knowledge to map the signs and symptoms to a specific mental disorder in order to establish diagnosis if the patient presents one of these medical conditions, but also to establish from which type of sensors these signs and symptoms originate. The system uses abductive inference method based on a generalized set covering (GSC) model [36][37] in order to compute diagnosis. The knowledge base includes a set of all diseases for each symptom and a set of all possible symptoms for each cognitive disorder. If the system discover a few symptoms to be present, it generate all possible disorders caused by those symptoms. Also it can request further data from other sensors, which are capable of capturing other symptoms for the recognized diseases, in order to eliminate some of the diseases and to establish a correct diagnosis. In Figure 2 a relation between diseases, signs/symptoms and sensors is presented. The relation between symptoms and diseases is represented by "*isSymptomOf*" property. For example *Freezing of Gait (FoG) is symptom of Parkinson's Disease*, or *Impaired voice is symptom of Parkinon's Disease and Alzheimer's Disease*. The symptoms' relation with sensors is represented by "*isSensedBy*" property. For example *FoG is sensed by accelerometer*.

V. Multi-agent architecture description

Considering the complexity, but also the necessity of real-time response, of the e-Health applications for remote patient monitoring, especially those with diagnosis mechanism, it is of great importance to utilize intelligent agents. Based on a Multi-agent system, these agents can cooperate in order to accomplish common goals.

As shown in Figure 3, the proposed architecture has three major components:

Data Collecting - Heterogeneous raw data sensed from the multiple body and/or ambient sensor nodes are transmitted to the cloud for further processing. Each category of data is stored separately (e.g. video data, audio data, accelerometer data, motion sensor data, EEG data, bed sensors data, etc.), along with the timestamp and the semantic description of the device/sensor from witch originate.

Although Cloud-based solutions address the scalability demands of the large scale e-health applications, and can also provide necessary storage for medical data, security and privacy aspects of the sensitive medical data must be taken into consideration. However this is situated outside the scope of the present paper.

Data processing - Each category of data is further processed with corresponding machine learning [19] [38] or data mining [39] [40] algorithms. If some abnormalities are recognized from the data sequence, then a proper semantic notation from the Ontology Store is assigned and the data containing known sign or symptom is stored in Symptoms Data Store. For example, from the accelerometer data, recorded when patient is walking, a high frequency oscillation in the 3-8Hz band represents freezing episode [41]. To such event, semantic notation '`FoG`' is assigned, and it's stored in the Symptoms Data Store together with the time of occurrence and duration of the event.

Diagnosis - This component analyses and reasons over processed data. For example, if patient has some symptom associated to a specific disease, medical personnel can be alerted. Using inference method, detected symptoms are combined in order to determine if the patient is suffering from a specific disease. For example, if the following symptoms are presented: '`FoG`' AND '`bradykinesia`' AND '`postural_instability`' AND '`resting_tremor`', a notification message is sent to the physician that patient exhibits symptoms of '`Parkinson disease`'. If some symptoms are missing or have not been detected related to this disease, the physician can initiate further investigations.

Authorized licensed use limited to: University of Cape Town. Downloaded on September 29,2022 at 09:32:43 UTC from IEEE Xplore. Restrictions apply.

A large volume of continuously produced raw data, collected from multiple devices and sensors, needs to be stored and processed in order to support the medical diagnosis process. Cloud computing can provide the necessary computational resources for storing, processing and extracting knowledge from this data, which would be almost impossible, or would require more time, to be done locally.

The proposed Multi-agent architecture (see Figure 4) for monitoring and diagnosis of some mental illnesses and/or conditions uses several types of agents running on cloud and locally on a personal server: Monitoring Agent (MA), Data Collector Agent (DCA), Data Manager Agent (DMA), Data Processing Agent (DPA), Diagnostic Agent (DGA) and Notification Agent (NA).

Monitoring Agent. This is the only type of agent which runs locally on the patient's personal server (e.g. smartphone, PDA or personal computer). Its job is to monitor, collect and transmit sensors' data to the Data Collector Agent. This agent establishes and maintains the direct connection of the local system with the cloud.

Data Collector Agent. This agent receives information originating from patient's bio-sensors (such as EEG, ECG, accelerometer) and from other environmental sensor (such as motion sensor, bed sensor, video camera, touch input device), and store that data in corresponding databases. His job is to store each type of data from each type of sensors separately.

Data Manager Agent. This type of agent creates instances of Data Processing Agents depending on the volume and the type of newly stored data, and it is responsible for assigning tasks to these agents. When there's no more data that needs to be processed it stops these agents.

Data Processing Agent. There is one agent for each type of data (e.g. video, audio, accelerometer data). Using corresponding machine learning or data mining technology, this agent extracts knowledge from the stored data (i.e. assigns semantic meaning to each abnormality that is detected). Interaction with the ontology is done using Apache Jena framework. Processed data is stored in Symptoms Data Store.

Diagnostic Agent. This agent verifies each symptom and/or sign which is detected and stored in the Symptoms Data Store, and tries to associate it to a specific disease, using a reasoning mechanism. If the patient exhibits some symptoms of a disease, Diagnostic Agent sends that information to the Notification Agent. In Figure 5 an example of Diagnostic Agent's methodology for combining multiple symptoms associated to a specific disease is presented. For example, if patient exhibits up to three symptoms, none of the four major mental diseases or conditions is linked to the patient. Mental diseases could have many common symptoms, so if 4-5 symptoms are noticed, this agent informs the physician about the all possible diseases caused by these symptoms. When more than six symptoms/signs are present some of the possible diseases are eliminated and an alarm is sent to the physician with the diagnosed disease.

Notification Agent. Provides information or real-time warning notifications to a physician about the patient. The doctor can see the patient's health status on a graphical user interface, if the diagnosed disease progresses or improves.

Considering that this e-Health application can be used by a large number of patients and over a long period of time,

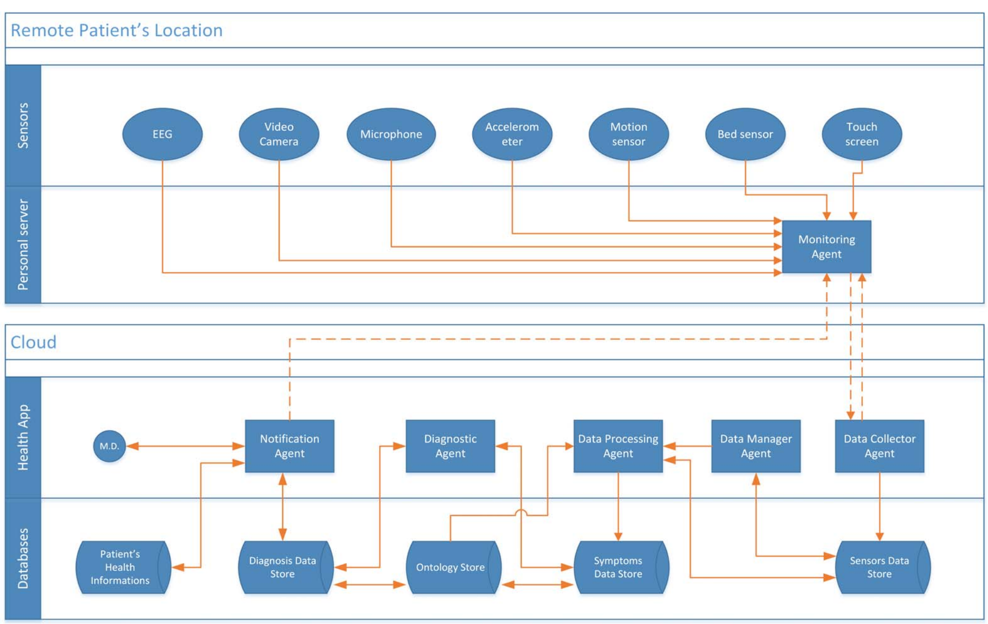

Figure 4. The multi-agent system overview.

Authorized licensed use limited to: University of Cape Town. Downloaded on September 29,2022 at 09:32:43 UTC from IEEE Xplore. Restrictions apply.

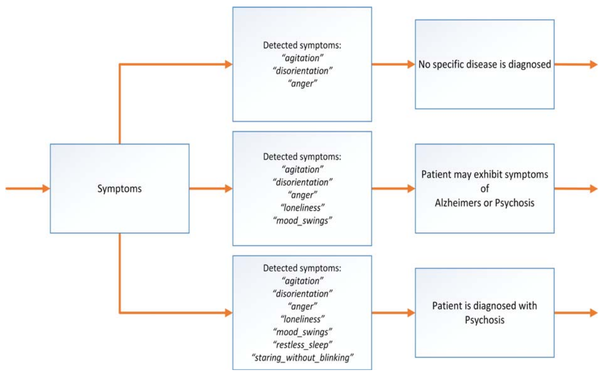

Figure 5. Diagnostic agent methodology for disease diagnosis.

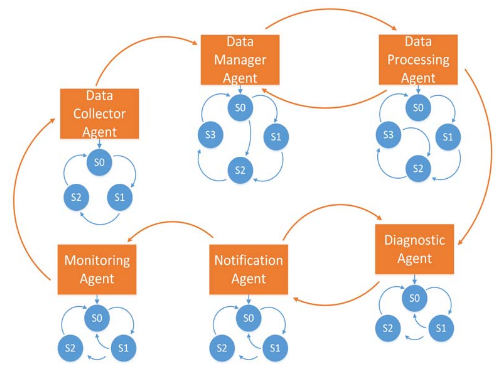

Figure 6. Multi-agent system and finite states of each agent.

scalability issues may occur. To address these issues of the proposed Multi-agent architecture, a large number of virtual machine instances must be launched in the cloud, in order to provide the needed computational resources for storing sensors' data, processing and diagnosis services. Using a BrokerAgent [42] a new virtual machine instance is created automatically when the application need more resources for storing or processing sensed data. The open-source platform mOSAIC [43] based on dynamic negotiation with multiple cloud providers, offers support for large scale applications, which uses resources rented from multiple clouds.

VI. Agents' Behaviors

Multi-agent system is situated in a rapidly changing environment, so each agent needs to have an appropriate behavior, to execute corresponding actions in response to the events. Using FIPA (Foundation for Intelligent Physical Agents) standards for agents' communication protocol, can facilitate interoperability and interactions between these heterogeneous entities. Both internal and external behaviors of a software agent can be modeled as finite-state machine (FSM), which contains a set of states and a set of transitions between them which are activated by the external events.

In Figure 6, architecture of the Multi-agent system and finite states that represents internal and external behaviors of each agent is presented.

A. Monitoring Agent

State0: In this state the agent waits for sensed data from the body and environment sensors, and receives messages with requirements, from the Notification agent, about the actions or tasks that needs to be accomplished.

State1: The agent performs requested actions; it can collect requested data from a specific sensor or can terminate the transmission from that specific sensor, to not receive further data until new requirements emerge.

State2: The agent transmits collected data to the cloud and informs Data Collector Agent.

B. Data Collector Agent

State0: In this state the agent receives information from Monitoring Agent about the transmitted data.

State1: Received data is organized by type and stored in corresponding databases.

State2: In this state this agent informs Data Manager Agent about the newly stored data.

C. Data Manager Agent

State0: Waits for messages from the Data Collector Agent, about the type and volume of the newly stored data and from Data Processing Agents about the job status.

State1: Creates necessary instances of Data Processing Agents according to the type of the data.

State2: Assigns tasks to each active instance.

State3: Stops unnecessary instances when their job is done, when there is no data that needs to be processed.

D. Data Processing Agent

State0: Waits for messages from Data Manager Agent.

State1: Selects corresponding algorithms in order to perform data processing.

State2: Performs processing in order to detect abnormalities in data sequence.

State3: Assigns semantic meaning to the detected abnormalities from Ontology Store, transmits the processed data to Symptom Data Store and informs Diagnostic Agent. When all tasks are completed it informs the Data Manager Agent.

E. Diagnostic Agent

State0: In this state the agent waits for information from Data Processing Agent about the detected symptoms and from Notification agent about the future tasks.

State1: Reads Symptoms Data Store and combines stored symptoms or signs using an inference method in order to perform a diagnosis task.

State2: If a disease is detected it sends alarms to the Notification Agent.

Authorized licensed use limited to: University of Cape Town. Downloaded on September 29,2022 at 09:32:43 UTC from IEEE Xplore. Restrictions apply.

F. Notification Agent

State0: In this state the agent waits for a message from Diagnostic agent or inputs from the physician.

State1: Displays in real-time alerts received from Diagnostic Agent or requested information, about the patient health status.

State2: In this state the agent retrieves information about the patient from the Patient Health Information database, sends messages to Monitoring Agent and Diagnostic Agent.

VII. Conclusion and Future Work

Considering the current advances of the technologies included in the Internet of Things paradigm, it is expected to enable the expansion of reliable home monitoring solutions, which will offer real-time information about the patients to the medical personnel and will also allow the patients to live a normal life by staying in the comfort of their own home.

The proposed multi-agent system was designed to be robust and scalable by using cloud computing resources to adjust to the data traffic volume. On the other hand, a lightweight component of the multi-agent system, which handles the data collection, is able to run on commodity hardware like Raspberry PI, smart phones or Arduino.

The DSS ontology developed for this particular case improves the diagnosis accuracy by mapping every sensor to a specific symptom. In this way, the system is able to predict which disease is likely to occur by matching a couple of disease specific symptoms.

This paper addresses a number of challenges regarding the real-time remote patient monitoring for detecting early mental disorder symptoms, however, we have identified a number of issues that need to be developed in the future like data privacy improvements, automated devices/sensors discovery, context sensitive information aggregation and activities correlations for users that match the same profile.

Acknowledgment

This work was partially supported by the Romanian national grant PN-II-ID-PCE-2011-3-0260 (AMICAS). The views expressed in this paper do not necessarily reflect those of the corresponding project's consortium members.

References

[1] "World Health Organization: 2014 NCD Status Report," URL: http://www.who.int/nmh/publications/ncd-status-report-2014/en/ [accessed: 2015-08-28].

[2] M. Thirugnanam, "An Ontology Based System for Predicting Disease Using SWRL Rules," *International Journal of Computer Science and Business Informatics*, vol. 7, no. 1, 2013.

[3] M. Ulieru, M. Hadzic, and E. Chang, "Soft computing agents for e-Health in application to the research and control of unknown diseases," *Information Sciences*, vol. 176, no. 9, pp. 1190–1214, 2006.

[4] J. Puustjarvi and L. Puustjarvi, "Personal Health Ontology: towards the interoperation of e-health tools," *International journal of electronic healthcare*, vol. 6, no. 1, 2011.

[5] T. Kato, N. Maneerat, R. Varakulsiripunth, Y. Kato, and K. Takahashi, "Ontology-based E-health system with Thai herb recommendation," in *Proceeding of the 6th International Joint Conference on Computer Science and Software Engineering (JCSSE2009)*, 2009, pp. 172–177.

[6] B. Manaţe, F. Fortis, and P. Moore, "Applying the prometheus methodology for an internet of things architecture," in *Utility and Cloud Computing (UCC), 2014 IEEE/ACM 7th International Conference on*. IEEE, 2014, pp. 435–442.

[7] J. Gubbi, R. Buyya, S. Marusic, and M. Palaniswami, "Internet of Things (IoT): A Vision, Architectural Elements, and Future Directions," *Future Gener. Comput. Syst.*, vol. 29, no. 7, pp. 1645–1660, Sep. 2013.

[8] A. Katasonov, O. Kaykova, O. Khriyenko, S. Nikitin, and V. Y. Terziyan, "Smart Semantic Middleware for the Internet of Things." *ICINCO-ICSO*, vol. 8, pp. 169–178, 2008.

[9] V. M. F. Ferreira, J. C. C. Carvalho, R. M. E. Costa, and V. M. B. Werneck, "Developing an Educational Medical Game Using AgilePASSI Multi-agent Methodology," in *Computer-Based Medical Systems (CBMS), 2015 IEEE 28th International Symposium on*. IEEE, 2015, pp. 298–303.

[10] P. Sernani, A. Claudi, and A. F. Dragoni, "Combining Artificial Intelligence and NetMedicine for Ambient Assisted Living: A Distributed BDI-based Expert System," *International Journal of E-Health and Medical Communications (IJEHMC)*, vol. 6, no. 4, pp. 62–76, 2015.

[11] A. Obiniyi, "Multi-Agent Based Patient Scheduling Using Ant Colony Optimization," *African Journal of Computing & ICT*, vol. 8, no. 2, 2015.

[12] V. M. L. Carvalho, "An Agent-Based Decision Support Environment for Public Health," in *Trends in Practical Applications of Agents, Multi-Agent Systems and Sustainability*. Springer, 2015, pp. 229–230.

[13] S. Sharma, C. S. Moon, A. Khogali, A. Haidous, A. Chabenne, C. Ojo, M. Jelebinkov, Y. Kurdi, and M. Ebadi, "Biomarkers in Parkinson's disease (recent update)." *Neurochem Int*, vol. 63, no. 3, pp. 201–229, Sep 2013.

[14] K.-C. Lan and W.-Y. Shih, "Early Diagnosis of Parkinsons Disease Using a Smartphone," *Procedia Computer Science*, vol. 34, pp. 305–312, 2014.

[15] C. Coste, B. Sijobert, R. Pissard-Gibollet, M. Pasquier, B. Espiau, and C. Geny, "Detection of Freezing of Gait in Parkinson Disease: Preliminary Results," *Sensors*, vol. 14, no. 4, pp. 6819–6827, Apr 2014.

[16] E. Forsaa, J. Larsen, T. Wentzel-Larsen, and G. Alves, "A 12-year population-based study of freezing of gait in Parkinsons disease," *Parkinsonism & Related Disorders*, vol. 21, no. 3, pp. 254–258, Mar 2015.

Authorized licensed use limited to: University of Cape Town. Downloaded on September 29,2022 at 09:32:43 UTC from IEEE Xplore. Restrictions apply.

[17] E. E. Tripoliti, A. T. Tzallas, M. G. Tsipouras, G. Rigas, and et al., "Automatic detection of freezing of gait events in patients with Parkinson's disease." *Comput Methods Programs Biomed*, vol. 110, no. 1, pp. 12–26, 2013.

[18] J. Westin, S. Ghiamati, M. Memedi, D. Nyholm, and et al., "A new computer method for assessing drawing impairment in Parkinsons disease," *Journal of Neuroscience Methods*, vol. 190, no. 1, pp. 143–148, Jun 2010.

[19] I. Mandal and N. Sairam, "Accurate telemonitoring of Parkinsons disease diagnosis using robust inference system," *International Journal of Medical Informatics*, vol. 82, no. 5, pp. 359–377, May 2013.

[20] A. Bandini, F. Giovannelli, S. Orlandi, S. Barbagallo, and et al., "Automatic identification of dysprosody in idiopathic Parkinsons disease," *Biomedical Signal Processing and Control*, vol. 17, pp. 47–54, Mar 2015.

[21] "10 Early Signs and Symptoms of Alzheimer's," URL: http://www.alz.org/alzheimers_disease_10_signs_of_alzheimers.asp [accessed: 2015-03-28].

[22] C. Franco, J. Demongeot, C. Villemazet, and N. Vuillerme, "Behavioral telemonitoring of the elderly at home: Detection of nycthemeral rhythms drifts from location data," in *Advanced Information Networking and Applications Workshops (WAINA), 2010 IEEE 24th International Conference on*. IEEE, 2010, pp. 759–766.

[23] R. Romdhane, E. Mulin, A. Derreumeaux, N. Zouba, and et al., "Automatic video monitoring system for assessment of Alzheimer's Disease symptoms," *The journal of nutrition, health & aging*, vol. 16, no. 3, pp. 213–218, Mar 2012.

[24] A. Konig, A. Satt, A. Sorin, R. Hoory, and et al., "Automatic speech analysis for the assessment of patients with predementia and Alzheimers disease," *Alzheimers & Dementia: Diagnosis, Assessment & Disease Monitoring*, vol. 1, no. 1, pp. 112–124, Mar 2015.

[25] "Psychosis: Symptoms, Causes & Risk Factors," URL: http://www.healthline.com/health/psychosis#Overview1/ [accessed: 2015-03-28].

[26] R. C. Teeple, J. P. Caplan, and T. A. Stern, "Visual hallucinations: differential diagnosis and treatment." *Prim Care Companion J Clin Psychiatry*, vol. 11, no. 1, pp. 26–32, 2009.

[27] S. S. Kulkarni, N. P. Reddy, and S. I. Hariharan, "Facial expression (mood) recognition from facial images using committee neural networks," *BioMed Eng OnLine*, vol. 8, no. 16, 2009.

[28] G. Valenza, M. Nardelli, A. Lanata, C. Gentili, and et al., "Wearable Monitoring for Mood Recognition in Bipolar Disorder Based on History-Dependent Long-Term Heart Rate Variability Analysis," *IEEE J. Biomed. Health Inform.*, vol. 18, no. 5, pp. 1625–1635, Sep 2014.

[29] K. Grauman, M. Betke, J. Gips, and G. Bradski, "Communication via eye blinks - detection and duration analysis in real time," *Proceedings of the 2001 IEEE Computer Society Conference on Computer Vision and Pattern Recognition. (CVPR)*, 2001.

[30] "Depression Diagnosis and Screening," URL: http://www.webmd.com/depression/guide/depression-diagnosis [accessed: 2015-03-28].

[31] G. Stratou, S. Scherer, J. Gratch, and L.-P. Morency, "Automatic Nonverbal Behavior Indicators of Depression and PTSD: Exploring Gender Differences," in *Affective Computing and Intelligent Interaction (ACII), 2013 Humaine Association Conference on*, 2013, pp. 147–152.

[32] B. Koley and D. Dey, "An ensemble system for automatic sleep stage classification using single channel EEG signal," *Computers in biology and medicine*, vol. 42, no. 12, pp. 1186–1195, 2012.

[33] A. Nassir and O. Barnea, "Wireless body-area network for detection of sleep disorders," in *Electrical & Electronics Engineers in Israel (IEEEI), 2012 IEEE 27th Convention of*, 2012, pp. 1–5.

[34] A. S. Elstein and A. Schwarz, "Clinical problem solving and diagnostic decision making: selective review of the cognitive literature," *Bmj*, vol. 324, no. 7339, pp. 729–732, 2002.

[35] "Protégé - A free, open-source ontology editor and framework for building intelligent systems," URL: http://protege.stanford.edu [accessed: 2015-03-28].

[36] J. A. Reggia, D. S. Nau, and P. Y. Wang, "Diagnostic expert systems based on a set covering model," *International journal of man-machine studies*, vol. 19, no. 5, pp. 437–460, 1983.

[37] J. A. Reggia, D. Nau, Y. Peng, and B. Perricone, "A theoretical foundation for abductive expert systems," *Approximate Reasoning In Expert Systems, North-Holland*, 1985.

[38] K. Kipli, A. Z. Kouzani, and I. R. A. Hamid, "Investigating machine learning techniques for detection of depression using structural mri volumetric features," *International journal of bioscience, biochemistry and bioinformatics*, vol. 3, no. 5, pp. 444–448, 2013.

[39] N. M. Labib and M. S. Badawy, "A proposed data mining model for the associated factors of alzheimers disease," in *Proceedings of the International Conference on Data Mining (DMIN)*, 2014.

[40] L. S. Kumar and A. Padmapriya, "ID3 algorithm performance of diagnosis for common disease," *International Journal of Advanced Research in Computer Science and Software Engineering*, vol. 2, no. 5, pp. 57–62, 2012.

[41] S. T. Moore, H. G. MacDougall, and W. G. Ondo, "Ambulatory monitoring of freezing of gait in Parkinsons disease," *Journal of Neuroscience Methods*, vol. 167, no. 2, pp. 340–348, Jan 2008.

[42] B. Manate, T.-F. Fortis, and V. Negru, "Optimizing cloud resources allocation for an Internet of Things architecture," *Scalable Computing: Practice and Experience*, vol. 15, no. 4, 2015.

[43] D. Petcu, B. Di Martino, S. Venticinque, M. Rak, and et al., "Experiences in building a mOSAIC of clouds," *Journal of Cloud Computing*, vol. 2, no. 1, pp. 1–22, 2013.

Authorized licensed use limited to: University of Cape Town. Downloaded on September 29,2022 at 09:32:43 UTC from IEEE Xplore. Restrictions apply.