Designing an IoT Network for the Diagnosis of Alzheimer's Disease Using OSTIS

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***Abstract*—The report is devoted to the development of the Internet of Things for the diagnosis of Alzheimer's disease (AD) using OSTIS technology. The structure of the ontology for describing the elements of AD disease is given. The article considers the construction of an IT diagnostic network of BA, which uses the semantic capabilities of the OSTIS platform for processing and analyzing medical data. The elements of describing the knowledge base, solvers and user interfaces using a component-based design approach are presented.**

***Keywords*—IoT network, Alzheimer's disease, user interface, IT diagnosis, ostis**

I. Introduction

In the contemporary era, marked by the advent of information technology, the progression of technological and scientific theories has led to the digitization and informatization of traditional medicine [1]. Smart hospitals, relying on an environment founded upon information and communication technologies, especially those optimized and automated by the Internet of Things (IoT) [2], have enhanced the efficiency and reliability of IT systems. IT diagnostics refers to the process of using information technology (IT) tools for diagnosing, analyzing, and solving technical issues. In the medical field, it involves the use of information technology, such as artificial intelligence, machine learning, and data analysis, to aid in medical diagnosis. This technology has the potential to improve the quality and safety of healthcare services [3]. Given that each disease requires a complex medical process, the IoT infrastructure must adhere to the medical rules and steps involved in the diagnostic process to meet the requirements of healthcare providers [4].

An IT network for intelligent detection of Alzheimer's disease can be defined as a comprehensive information technology system that integrates the collection, processing, pattern recognition, and interactive user interfaces of medical health data. This data may involve a variety of multimodal data, such as human behavior data, brain imaging data, or sound audio data, etc., providing support in the process of identifying and predicting signs of Alzheimer's disease, with system tasks that can be broken down into:

1) System Analysis and Simulation Task: The intelligent detection system for Alzheimer's disease analyzes data from diverse sources to build IT network, aiming to identify characteristics unique to Alzheimer's patients.
2) Prediction Task: By using information extracted from features, it effectively distinguishes between Alzheimer's patients and healthy control groups, achieving early detection or prediction of disease progression.
3) Management Task: Management of patient data in the Alzheimer's detection system involves ensuring the privacy and security of the data while providing necessary data to doctors and researchers to support the decision-making process.

The purpose of this paper is to introduce an approach that integrates IT diagnostic networks with OSTIS technology. The objective of this work is to enhance data interpretation capabilities and apply the principles of intelligent disease detection. Through a highly structured and semantic approach, this method aims to improve information processing, knowledge representation, and intelligent decision-making capabilities, enabling the model to be seamlessly optimized and utilized across various scenarios.

II. The ontology

OSTIS (Open Semantic Technology for Intelligent Systems) is closely related to ontology as a framework aimed at developing and implementing intelligent systems. The use of semantic technologies and ontology advocated by it finds application in IoT networks.

The ontology of the knowledge base of the intelligent Alzheimer's detection system can be subdivided into:

1) Theoretical concepts of Alzheimer's recognition
2) Applications of Alzheimer's recognition theory

To achieve interoperability between intelligent systems, it is necessary to develop an ontology for the theoretical concepts of Alzheimer's recognition. This ontology will cover the framework and basic theoretical foundation of Alzheimer's recognition, defining a hierarchical system to build the foundation for IT networks for Alzheimer's recognition, enabling these knowledge to be efficiently shared, understood, and utilized in IT networks.

Alzheimer's Recognition Theory Concept Ontology

:= [A collection of theoretical concepts of Alzheimer's recognition.]

:= [Instances of theoretical objects in the subject area of "Alzheimer's recognition" include key concepts and their relationships.]

⊂ *Ontology*

∋ *Specialized Terminology Categories for Alzheimer's Disease*

∋ *Data Form Categories for Alzheimer's Disease*

∋ *Feature Extraction Categories for Alzheimer's Disease*

∋ *Diagnostic Method Categories for Alzheimer's Disease*

Specialized Terminology Categories for Alzheimer's Disease

:= [Describes specialized terminology related to Alzheimer's, from the domain perspective, including corresponding medical terms and technical synonyms, defining the basic concepts, symptoms, and progression stages of the disease.]

:= [The pathological phenomenon existing in the human brain in the form of a neurodegenerative disease, whose origins can be genetic, environmental factors, or an interaction of both. At a given time point, the pathological state is determined through clinical assessment and biomarker testing, characterized by cognitive dysfunction, memory decline, executive function impairment, and language difficulties. Specialized terminology for Alzheimer's not only describes the clinical manifestations and neuropathological features but also includes concepts related to disease diagnosis and recognition process.]

∋ *Disease Process*

The disease process, referring to the entire process of disease development and its impact on an individual's health status, starting from its initial factors, including the mechanisms of disease onset, development stages, symptoms produced, and the final outcome (recovery, persistence, or deterioration). To describe and understand the disease process and its manifestations in different contexts, here is a hierarchical structure description of subcategories classified by different dimensions or properties for the disease [5].

Classified disease-relevant process by properties

⇒ *subdividing**:

{• *disease-relevant process by Frequency*
  - := [The frequency or commonness of the disease process.]
  - ⇒ *includes**:
    - {• *communly frequent disease-relevant process*
    - • *frequent disease-relevant process*
    - • *occasional disease-relevant process*
    - • *very frequent disease-relevant process*
    - }

• *disease-relevant process by pathogenic intensity*
  - := [The intensity or severity of the disease process's impact on individual health.]
  - ⇒ *includes**:
    - {• *highly impacting disease-relevant process*
    - • *lowly impacting disease-relevant process*
    - • *midly impacting disease-relevant process*
    - }

• *disease-relevant process by specificity*
  - := [The degree of association of the disease process with specific diseases, conditions or factors.]
  - ⇒ *includes**:
    - {• *Alzheimer Disease disease-relevant process*
    - • *Alzheimer Disease type disease-relevant process*
    - • *individual disease-relevant process*
    - • *life disease-relevant process*
    - • *life-style disease-relevant process*
    - • *neurodegenerative disease disease-relevant process*
    - • *pathogenic disease-relevant process*
    - }

}

In this way, the disease process is organized into different subcategories, each defined by a shared set of properties. Based on this structure, the following subcategory "identified disease-relevant process" supplements specific content and examples, including processes that have been confirmed in disease research to have a specific impact or role.

Identified disease-relevant process
⇒ *includes**:
{
- *environmental disease-relevant process*
- *gene-related disease-relevant process*
- *molecular disease-relevant process*
- *other disease-relevant process*
- *pathological disease-relevant process*
- *physiological disease-relevant process*

}

III. IT diagnostics network structure

When adopting IT diagnostics for the intelligent identification of neurological diseases, it is necessary to construct an IoT network structure tailored to the specific neurological condition. Based on the analysis, Alzheimer's disease is characterized by long-term progression and gradual worsening, affecting various aspects of an individual's cognitive functions, motor skills, and daily living abilities. It typically requires long-term management and treatment, and there is currently no possibility of complete cure through short-term treatment, making early stage identification and intervention particularly important.

Utilizing acoustic features for the automated detection of Alzheimer's disease is a promising research area. Broadly speaking, the application of IoT networks in IT diagnostics can be divided into three key steps: collection, processing, and analysis of sensor data. To achieve automation in detection tasks, we are developing an IoT network:

1) Sensor data collection: When users enter the client interaction page, the main page displays the required steps and instructions. Participants respond or describe based on the given questions or images, and the system collects and saves their voice data, which is then uploaded to a test library for assessment. The data can be stored locally, uploaded to the cloud, or decentralized.
2) Sensor data processing: Data processing can occur locally or on cloud servers, mainly involving data cleaning, extracting acoustic features, or preprocessing voice data.
3) Sensor data analysis: The extracted data features are sent to a previously trained model prediction agent, where machine learning algorithms deployed in the model provide analysis results. These data are then sent to servers for storage and also serve as a training set to improve the model's accuracy.

The client application displays the likelihood of a participant having Alzheimer's disease on the screen. The doctor's mobile application, on every device that has the app installed, shows real-time patient monitoring information from sensors in the cloud database. The detection results for participants are sent based on the user's registration information. The overall structure of the proposed framework is shown in Fig. 1, illustrating the network's basic structure, which consists of datasets, model prediction agents, participant data, the IoT platform, and mobile applications.

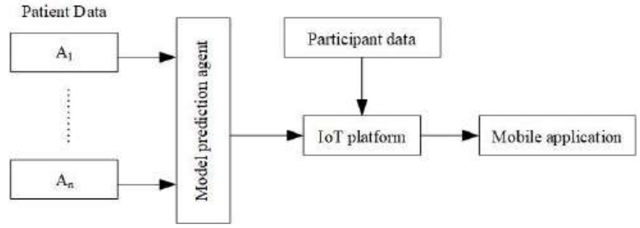

Figure 1. Overall structure of the proposed network.

IV. Distinguishing Voice Characteristics of Alzheimer's Patients

Taking the application of IoT technology and voice analysis for the diagnosis of neurological diseases as an example, the human ear is incapable of perceiving variations in sound and voice rhythm. However, advancements in technology enable automatic voice analysis to identify and extract acoustic and temporal parameters [6], making voice analysis of Alzheimer's patients a focal point of scholarly research. Clinically, these patients exhibit symptoms of unclear speech characterized by slowness, fluctuation, monotony, trembling, hesitation, weakness, inability to control over-breathing, loss of voice, low melody levels, and slower rhythms [7]. In semantic tasks, patients with Alzheimer's disease also perform poorly, often confusing names or unable to accurately name objects [8]. Non-verbal indicators predictive of dementia include the continuity of speech, the duration and proportion of silent segments, pitch (periodicity) related parameters. Useful linguistic markers require automatic voice recognition for assessment, including the richness of speech and the proportion of different parts of speech [9].

Based on the aforementioned voice characteristics of Alzheimer's patients, research in [10] has demonstrated the feasibility of using machine learning methods to distinguish between the voice transcripts of Alzheimer's patients and healthy individuals by analyzing the semantic information in patients' natural language expressions. By converting voice data into text and analyzing these texts with a Random Forest classifier, researchers were able to identify specific language features associated with Alzheimer's disease.

V. Proposed approach

In the development of an IT network for Alzheimer's disease diagnosis using OSTIS, the core components involve the development of a problem solver, knowledge base, and user interface. This is due to the OSTIS system architecture, which integrates a semantic model interpretation platform with a semantic model of the system itself described in SC-code, encompassing submodels for the knowledge base, interfaces, and problem solvers. A detailed description follows:

A. Development of the Solver and Knowledge Base.

The introduction of SC-code by OSTIS technology serves as a universal language for semantic expression of information in intelligent computing systems. It employs set theory for defining semantic aspects and graph theory for constructing syntactic structures, ensuring compatibility across different types of knowledge through semantic memory (sc-memory). This approach not only simplifies the description of various types of knowledge and models but also allows for the construction of an ontological model (sc-model) of any entity based on SC-code.

Developing a problem solver and knowledge base, especially for Alzheimer's disease using OSTIS technology, involves several key steps:

a) Knowledge Representation: This step involves defining knowledge about Alzheimer's disease, such as symptoms, diagnostic criteria, etc., and how this knowledge is represented within the OSTIS framework. The method of representation includes creating a semantic network to model the relationships and entities related to Alzheimer's disease.
b) Data Collection and Organization: Gathering and documenting data, where the structure of the data must be consistent with the chosen method of knowledge representation.
c) Knowledge Base Development: Importing data into the OSTIS system to establish a knowledge base, which may include concepts, predicates, and rules for controlling the logic of diagnosing Alzheimer's disease within the system.
d) Solver Implementation: Developing the solver involves creating algorithms that can navigate the knowledge base to provide diagnoses based on input data. This includes implementing reasoning mechanisms that can assess patient data against the knowledge base to identify the presence of Alzheimer's disease.
e) Data Storage: In compliance with medical data storage regulations, the system needs not only to possess a static knowledge base but also to have the capability to store dynamic data such as patient records and diagnostic results.

The semantic knowledge base is the cornerstone of semantic communication, forming the foundational part of the decision-making system. The data it contains are authoritative, referential, and diverse. For different domains, the objects encompassed by the knowledge base vary, aiming to integrate scattered knowledge within the domain, including historical data, real-time data, statistical analysis results, predictive models, as well as expert knowledge and experience. Through computer technology, originally scattered knowledge is recombined and stored in different locations, enabling decision-makers to quickly access relevant information and resources.

In application, the development of the knowledge base is primarily based on the information extracted, combined with the OSTIS framework, to construct a knowledge graph. This graph is further processed and refined to form a structured knowledge base. Storing semantically linked data about neurological diseases, it provides the necessary knowledge support for disease prediction.

System Knowledge Base
⊃ *Declarative Knowledge*
    ∋ *Alzheimer's Recognition Theory Concept Ontology*
⊃ *Procedural Knowledge*
    ⊃ *System Knowledge*
        ⇒ *splitting**:
            {• *Model Building Knowledge*
            • *Model Optimization Knowledge*
            • *Results Display Knowledge*
            }
    ⊃ *Static Knowledge*
        ∋ *System Process*
    ⊃ *Dynamic Knowledge*
        ∋ *Conditional Response in Specific Situations*

The problem solver performs basic actions of directly modifying and managing the knowledge base, offering a more dynamic component compared to the knowledge base itself. It handles information stored in the knowledge base to address specific problems, applying algorithms, rules, and reasoning techniques to interpret, analyze, and derive conclusions or solutions from available knowledge, making decisions or generating new knowledge. Semantically, these operations are considered actions performed within the memory of the acting entity, typically the OSTIS system itself, with the knowledge base viewed as its memory. Actions are executed based on the set problem, describing the internal state of the intelligent system or the required state of the external environment for different problem categories.

Figure 2 presents the SCG-code description of the speech classification task within the set-theoretical ontology.

Within the OSTIS Technology framework, to achieve the task of natural language processing, a specialized ostis-system can be developed. The sc-model of the problem solver is developed as a hierarchical system of agents (sc-agents), providing flexibility and modularity for the developed sc-agents. Abstract sc-agents are func-

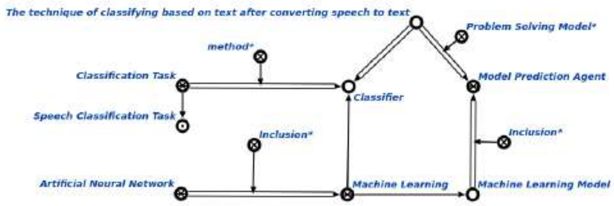

Figure 2. A fragment of the set-theoretic ontology for speech classification tasks.

tionally equivalent sc-agents of a certain category, with different instances implemented in various programming languages to address specific problems. In our work, to implement an intelligent IT diagnostic system for Alzheimer's disease integrated with OSTIS, converting natural language speech into diagnostic indicators required describing the entire process of natural language processing and building extraction rules. Since in the OSTIS technology framework, every action internally represents some transformation executed by a specific sc-agent (or a group of sc-agents), we consider the sc-model of the problem solver. The entire data processing workflow is a core component of the system, ensuring efficient and accurate collection, transmission, processing, and storage of data. An example of processing users' data within the system is shown in Figure 3.

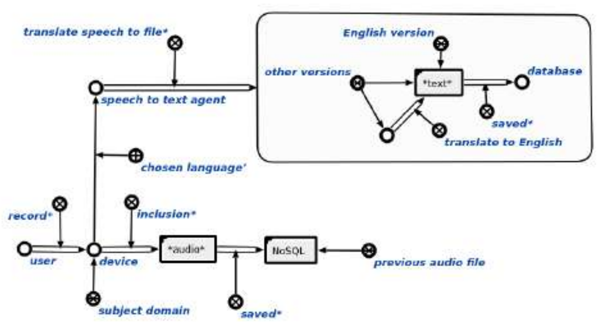

Figure 3. An example of processing users' data within the system.

B. Designing the User interface.

Designing the user interface for the diagnostics system requires careful consideration of the end-users, typically healthcare professionals and possibly patients or their families. The interface should be intuitive and facilitate easy navigation through the diagnostic process:

1) Information Input: Designing forms and input fields that allow for easy entry of patient data and symptoms.
2) Diagnostic Process Visualization: Providing visual cues or progress indicators that guide the user through the diagnostic process, helping them understand what stage the diagnosis is at and what steps are next.
3) Results Presentation: Displaying the diagnostic results in a clear, understandable format. This could include a summary of findings, confidence levels, and recommendations for further actions or treatments.

Due to the use of component approach, the development of the entire natural language interface comes down to development and improvement of separate specified components (e.g. knowledge base on natural language processing, component for natural language texts generation). The model of the process of responding to user needs and the components of inference engine was shown in figure 4.

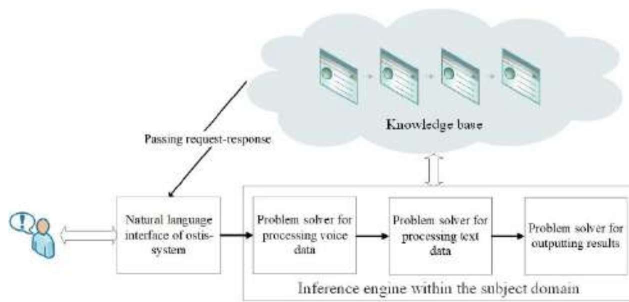

Figure 4. The model of the process of responding to user needs.

The user interface includes all the components required for user interaction and obtaining results. The general process of interacting with the user interface can be described as follows:

- The user reads all the necessary instructions.
- The user begins to record voice data according to the instructions.
- The user ends the recording action and uploads the data.
- The user presses the "Predict Data" button to receive the probability of illness corresponding to their voice data.
- The result is displayed in the result feedback area.

In the design of the user interface, taking the collection of voice data as an example, the client-side page allows participants to select from three functions: recording voice information, converting voice to text, and predicting outcomes. The voice-to-text conversion serves as an illustrative example of one method of data preprocessing. Developers may adapt or modify this functionality based on specific design requirements. After participants have recorded their voice information onto their phones, the device will save this voice data and carry out data preprocessing and feature extraction tasks. Upon activation of the "predict" function by the participant, the phone, acting as a client, will transmit the generated feature file to the server. Following the receipt of prediction results sent from the server or another agent, the phone will interpret these results and display them on the page.

User interface design is based on a component-based approach, any user interface component can be described in the ostis-system knowledge base. An illustration of the user interface displaying the probability of a participant being diagnosed with Alzheimer's disease is presented in Figure 5.

Figure 5. An example of the user interface

For the corresponding SCg-code description fragment within the OSTIS system knowledge base, see Figure 6.

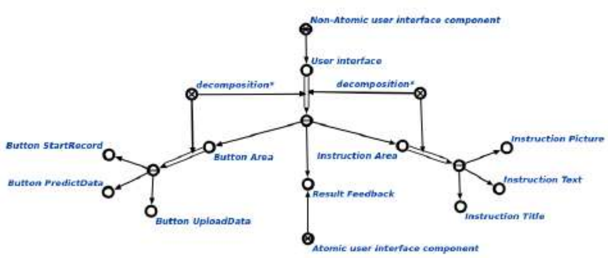

Figure 6. SCg-code of the user interface.

VI. Conclusion and future works

In the report, the authors present an approach to the design of an Internet of Things-based diagnostic network aimed at using the OSTIS platform to expand the possibilities of data interpretation within the intelligent process of diagnosing Alzheimer's disease. The structure of the ontology for the description of the subject area is given. The process of developing solvers, knowledge bases and user interfaces adapted for healthcare professionals and patients is described taking into account the stages from data collection to presentation of diagnostic results. In the future, the work will focus on improving the OSTIS-based OTNET to increase the accuracy of recognition and study its applicability to the treatment process, thereby expanding the possibilities of intelligent diagnostics in the field of medicine.

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РАЗРАБОТКА СЕТИ ИНТЕРНЕТА ВЕЩЕЙ ДЛЯ ДИАГНОСТИКИ БОЛЕЗНИ АЛЬЦГЕЙМЕРА С ИСПОЛЬЗОВАНИЕМ OSTIS

Вишняков В.А., Чуюэ Юй

Доклад посвящен разработке Интернета вещей для диагностики болезни Альцгеймера (БА) с использованием технологии OSTIS. Приведена структура онтологии для описания элементов заболевания БА. В статье рассматривается построение ИТ-диагностической сети БА, использующей семантические возможности платформы OSTIS для обработки и анализа медицинских данных. Представлены элементы описания базы знаний, решателей и пользовательского интерфейса с использованием компонентного подхода к проектированию.

Ключевые слова: сеть интернета вещей, болезнь Альцгеймера, база знаний, решатель, пользовательский интерфейс, ИТ-диагностика, OSTIS.

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