 doi:10.20944/preprints201612.0027.v1

Review

Robots to the Rescue: A Review of Studies on Differential Medical Diagnosis Employing Ontology-Based Chat Bot Technology

Bosede Edwards [1,*], Idris Muniru [1,2] and Adrian Cheok [1,3]

[1] Imagineering Institute (IDM Lab), 4, Lebuh Medini Utara, Nusajaya 79200, Malaysia; {idris, adrian}@imagineeringinstitute.org
[2] Universiti Teknologi Malaysia, Skudai, 81310, Johor, Malaysia
[3] University of London, London WC1E 7HU, UK
* Correspondence: bosede@imagineeringinstitute.org; Tel.: +60-187-69-9318

Abstract: Access to medical care is a global issue. Technology-aided approaches have been applied in addressing this. Interventions have however not focused on medical diagnosis as a fully automated procedure and available applications employ mainly text-based inputs rather than conversation in natural language. We explored the utility of ontology-based chatbot technology for the design of intelligent agents for medical diagnosis through a systematic review of the most recent related literature. English articles published in 2011-2016 returned 233 hits which yielded 11 relevant articles after a 3-stage screening. Findings showed that the creation of expert systems had been the focus of many the studies which utilize the *physician-system-patient* framework with system training based mostly on expert knowledge for designing web- or mobile phone-based applications that serve assistive purposes. Findings further indicated gaps in the design and evaluation of more effective systems deployable as standalone applications, for example, on an embodied robotic system. The need for technology supporting the physical examination part of diagnosis, connection to data sources on patients' vitals and medical history are also indicated in addition to the need for more qualitative work on natural language-based interaction. The system should be one that is continuously learning. Future works should also be directed towards the building of more robust knowledge base as well as evaluation of theory-based diagnostic methodological options

Keywords: chatbot technology; ontology-based systems; expert systems; diagnosis; conversational agents; robotics; human-robot interaction, physician-patient relationship, intelligent agents

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1. Introduction

Global issues with regards to health had focused on access, especially in low and medium income countries where a physician-patient ratio of 1:3500 had been reported [1]. The path to universal healthcare, as set out in the proposed universal health insurance scheme is paved by four key elements including equal care, cost-effective delivery, timely access and quality healthcare. In his foreword in the white paper [2], James Reilly stated that access should not be based on income but on need; this represent the only way to 'achieve a fair and just society'.

According to the World Health Organization [3], delivery and quality are all linked to access, as hindrances to access will result in the failure of other elements. Possible hindrances however incorporate diverse factors broadly viewed as financial and physical. Financial factors are mainly issues of affordability while physical issues incorporate cultural, political, socio-religious factors and resource issues (human and material). Even if material resources are made available, the lack of human resource will frustrate efforts being made. The concept of access, in terms of human resources, is therefore a critical issue that must be addressed to achieve the dream of a just and fair society [2].

The role of technological interventions in several fields and disciplines including medicine is no longer news. High precision procedures unparalleled by human practitioners had been recorded in robotic surgery; telemedicine for example, had been one of the means by which the issue of access had been addressed. It had been employed in outsourcing of medical services and in a number of other areas [4]. However, despite the advances noted in technology-aided procedures in several fields and disciplines and particularly, medicine, much progress has not been reported in fully automated technology-aided medical diagnosis [5] which is a key concept in health care delivery. Most of the studies available had reported technology as an interface. Successful models of fully automated systems able to make correct medical decisions are not yet available and procedures have remained almost completely traditional and human-dependent despite the complicated processes involved that makes the need for automation even stronger. Fully automated diagnosis, which could have been leveraged to address the 'access' need, has remained a future prospect in medical practice, accentuating the significance of insufficient expert service where it is most needed.

Most technological medical interventions have been assistive in nature [6,7]; supporting physicians in taking quick, evidence-based decisions. Designs of such systems have employed conversational agent approaches and have been based mostly on information available on the web. The challenge of the validity of such information however remains a critical issue. The promise of AI in making technology an integral part of healthcare delivery remains to be fully explored. Current trends however underscore the possibility of developments in the field of AI and robotics to provide answers to address healthcare issues more effectively.

2. State of the Art

2.1 *Artificial Intelligence and Robotics*

A lot of progress have been made in the field of AI applications and advances in machine learning had made possible the design of systems that are able to learn from available information to develop different kinds of systems [8]. Studies have reported on several interventions in the field of surgery and assistive therapies especially in geriatrics and with disabled patients [9]. Recent trends in AI and Human-Machine Interaction (HMI) is however beginning to move towards robotics, and the concept of Human-Robot Interaction (HRI) is becoming a common parlance in the field of AI.

The history of robotics dates back to the early and mid-1900s with the release of the science fiction movie 'Metropolis' which featured the first female robot in 1927 [10] and the establishment of MIT's artificial intelligence lab in 1959 [11]. Over the years, development in the field of robotics had swept through practically every discipline with a lot of progress witnessed in the use of robots for handling several routine and dangerous duties.

Robots are taking over from humans in several areas of human endeavours. From basic applications in simple systems to complex operations, robots have featured as human substitutes in several fields, not only handling dangerous and routine jobs, but performing the duties of professionals as well. This is so much so that robots are currently considered a great threat to human professionals [12]. The possibility of mass unemployment of humans in many fields is being envisaged in the future and a number of other concerns are also being raised based on current progress.

Interestingly, within certain fields where complicated human-human interactions laden with affective processes are involved (for example, in teaching and medical practice), there is the assumption that robots will only succeed in serving assistive purposes; machines are not equipped to take over from humans when it comes to certain characteristics like critical reasoning, thinking, language and affect that only humans are assumed to be capable of exhibiting. However, this is just an assumption; the current state of technological innovations was considered impossibilities by many some decades back.

 doi:10.20944/preprints201612.0027.v1

2.2 *Medical Robotics*

Medical robotics is less than 30 years old. Beginning in the early 1990s, it has grown to include the use of robots in teleconsultation and telemedicine, laboratory tests, surgical training, remote surgery and different forms of therapeutic interventions. Robots have shown exceptional skills in surgical procedures, being able to make possible high-precision surgery and other highly complex surgical procedures. For example, the Da Vinci robot is being used to perform surgery in very delicate and difficult-to-reach-areas in the body with a very high precision and minimal opening [13].

Much work in medical robotics had been done in the area of robotic surgery, robots as assistive devices, logistics aids and assistants in therapies for patients with physical disabilities. Robots have also been employed in therapies for children with cognitive disabilities including autistic and hyperactive children [14]. Generally, the role of robots had been seen mainly as assistants to the medical practitioner or physician since they have to be programmed to work in particular ways and are assumed to be unable to make their own decisions.

The importance attached to emotional intelligence, indicating the ability to communicate affective traits is another critical concept in human-human interaction which is believed by many to be a key deficiency in machines and a limitation in their effectiveness in engaging in human-focused activities.

Current developments in cognitive and affective computing are however beginning to show that the realization of this capabilities in machines may not be too far in the future as previously thought. The development of machines capable of expressing empathy, provide support, and even 'think' has been reported in recent studies. Robots have developed from the stationary, bolted 'equipment' of yesteryears into collaborative machines participating in different types of work requiring varying degree of movement and relating with humans in several ways.

2.3 *Conversational Agents and Medical Practice*

Exploring duties supposedly reserved for humans, like teaching and medical practice is fast becoming an area of concentrated studies in robotics and the ability to engage in interpersonal communication, express emotion and other affective traits are being addressed. Interpersonal communication is critical in medical practice as the diagnostic process marks the beginning of medical care. Hence, technology that addresses the diagnosis process is a much needed one.

The application of ontology-based chatbot systems is proving to be a promising area of research in this respect. Chatbot systems are computer technologies that enables verbal or textual communication. They can be programmed to utilize information databases as sources of knowledge. According to Satya Nadella of Microsoft, 'Chatbots are the new apps". Echoing the same opinion, David Marcus of Facebook had also said "threads are the new apps" [15]. Both expression, coming from top executives of the biggest players in the tech world has implications for the future of communication.

While chatbots are not necessarily new technologies, and have been known since the 1960s, their current status as entities not merely artificial but enabled for more engaging interaction and incorporating human 'traits' and capabilities have changed the way they are viewed. Much work had focused on chatbot technology in recent times and the ability to leverage it for the design of various conversational systems is being explored. The technology is however not without its challenges. In the words of [15], 'the developers need to spend a lot more time focusing on the personality and psychology of their bots', addressing one of the key challenges in chatbot technology.

2.4 *Traditional Medical Diagnosis*

Disease diagnosis involves medical decision-making which is a complex and specialized procedure. The importance of disease diagnosis cannot be over-emphasized. Its failure could represent the failure of the entire medical care procedure and could result into accidents or fatalities.

By the very nature of diseases, physicians are faced with the dilemma of leveraging on available information to make the best judgement when faced with diverse options especially as several diseases have similar symptoms. Cases of misdiagnosis are a common feature in medical practice as

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 6 December 2016 doi:10.20944/preprints201612.0027.v1

a result of factors ranging from inexperience to overconfidence and other human limitations including the influence of unfavourable occupational conditions, misunderstanding or misinterpretation of information or the more complex presentation of incomplete or outright false information by the patient. Above all these factors, human limitation in information processing, which must be brought to play in the integration of the huge data resulting from symptoms, medical and/or family history and other unknown variables to arrive at the best conclusion, presents a major challenge in medical practice.

2.5 Differential diagnosis

Diagnosis must be evidence-based. The traditional diagnostic protocol features history-taking linked with information from patients' vitals (temperature, blood pressure, pulse, etc.) and physical examination leading to differential diagnosis. This is followed by laboratory tests and/or radiology reports after which definitive diagnosis informs prescription/treatment/support/care as the case may be.

History-taking enables information not directly obvious in the patient's complaint. There are however conditions whereby history-taking is skipped and differential diagnosis follows comprehensive laboratory tests and/or radiology which then informs definitive diagnosis. This is the baseline diagnostic protocol. Though it is a more expensive protocol, it eliminates waste of time and effort expended in differential diagnosis using the traditional protocol

2.6 Benefits and Challenges of Technology-supported Medical Diagnosis

A number of algorithms have been created for addressing diagnostic procedures; examples include Iliad [16] and DXplain [17] among many others [18]. These algorithms are mostly based on limited datasets and as such, accuracy had been low when deployed in larger datasets or a different disease[5]. The issue of accuracy is however not negotiable within medical practice and matters of human welfare cannot be deployed in a system based on trial-and-error even though ironically, medical statistics have shown human error as a key factor in several ICU deaths [19,20]. This points to the greater need to improve diagnostic procedures and the associated costs. Current work in this area had leveraged on various capabilities offered by AI and the concept of expert systems had been explored and reported in many studies [21–23]

2.7 Expert Systems

Expert system (ES) are AI-based systems employed for problem-solving purposes [24]. They are systems designed to emulate expert knowledge and skills in specific fields. ESs are based on 'if-then' rules and as such are referred to as rule-based expert systems (RBES). The basic RBES architecture incorporates a knowledge expert, an interface for knowledge acquisition, an inference engine and a user-interface. The expert and the user are connected to the system through the relevant interfaces. RBESs are employed in AI for the design of many interaction-based interfaces including the conversational agents.

3. Methods and Procedure

In medical practice, ESs is employed in the design of systems including diagnostic protocols that provides self-help for the patient or support for the physician. ESs have also been employed in chatbot systems. Many studies have reported on the design of ontology-based chatbot systems that provides various services including diagnosis, though they are mostly text-based and deployed as web-based virtual agents. Reports are however scarce on the integration of available technologies in the design of conversational agents that are speech-based or deployed on robots. A review of studies within this area can enable the identification of gaps in the literature as well as the direction for new studies.

This initial study will look into recent work in the field of AI in medical practice with particular focus on ontology-based chatbot systems for the design of medical diagnosis agents. Future steps will

 doi:10.20944/preprints201612.0027.v1

be informed by findings from this initial study which will focus on answering the following questions:

i. What is the trend in ontology-based chatbot systems/technology for medical diagnosis?
ii. What main challenges are identified in the ontology-based chatbot systems/technology?
iii. What gaps are there in the literature on ontology-based chatbot systems for medical diagnosis?
iv. What are the key concepts to be addressed in the design of ontology-based chatbot systems for medical diagnosis?
v. What will be the focus of follow-up steps based on findings from this study?

3.1 Methodology

We proceed with a systematic literature review (SLR) to provide answers to the questions raised. Due to the recency of focused studies within this field, concepts have not been fully standardized and several terms are used to describe the interactions. In addition, there are not as yet any specific database of studies within the field. Various reports are available as personal or corporate blog write-ups, institution-based publications and articles published in databases of medicine, AI, HCI, intelligent systems, expert systems, human-machine interaction and several other related repositories. As such, considering the need to capture as many studies as possible, we opted for the Google Scholar platform.

This section reports on the procedure employed in the first stage of the study. The sampling (search) procedure is described in addition to the criteria employed in identifying studies to be included in the final review.

3.1.1 Search String

A single search string "medical diagnosis chat bots" was employed for the search (sampling). Searches were limited to the most recent works, hence, only studies published in English within the last five years (2011-2016) years were included in the study. 233 articles were returned from the search which after removal of duplicates yielded 171 articles.

3.1.2 Inclusion/Exclusion Criteria

Based on the objectives set for the study, the final studies were included based on their ability to satisfy the following conditions.

i. Studies within the medical field
ii. Directly related to medical diagnosis procedure or physician-patient relationship
iii. Addresses the use of ontology-based chat bot technology or other forms of rule-based systems for supporting diagnosis or creating conversational agents that support diagnosis.
iv. Conceptual or empirical studies covering any of the above concepts

Studies were excluded if they are:

i. within the medical field but not related to diagnostic procedures (e.g. accidents, emergency treatments, first aid, etc.)
ii. related to other medical diagnosis but not in terms of physician-patient relationship (e.g. services provided by other medical personnel like nurses, physiotherapists, etc.)
iii. Addresses ontology-based chat bot technology or other forms of rule-based systems but not focused on disease diagnosis or creating conversational agents that support diagnosis.

3.1.3 Screening and Further Filtering

Screening of the titles returned 95 articles which on abstract screening yielded only 9 relevant studies. The limited number of related articles also confirming the relative scarcity of extensive work in this area of study. Efforts were made to obtain PDFs for all the final articles to enable further searches on their reference lists for links to other relevant studies. Two (2) more studies were identified through the reference list scanning, resulting in a total of 11 articles. The methodology employed for the SLR process is presented graphically in Appendix A. The final articles were reviewed based on the objectives of the study. Table A1 (Appendix B) presents details on the analyses of the 11 articles reviewed in the study.

4. Findings

The review brought to fore a number of issues that must be critically considered in future works. Findings are reported in this section based on the questions raised to define the focus of the study.

4.1 Trends in ontology-based chatbot systems/technology for medical diagnosis

Machine-patient system type employing a text-based GUI and uses either a 'Yes/No only' option or predefined responses to reduce error (also reduce effectiveness and application) are the common trend. Knowledge base development or system training employed various means including crowdsourcing, literatures and human experts. Connection types noted include pattern-matching, smart pattern-matching and rule-based or case-based reasoning while system design employed Expert Systems, algorithm-based statistical data mining and system-diagnostic-care frameworks. Script theory is noted as an underlying theory for diagnostic approach.

4.2 Main challenges in the ontology-based chatbot systems/technology

There is a strong need for more flexible, speech-based system that is able to process phrases or sentences using pattern-matching. Enabling technology-based history-taking presents an obvious challenge. Challenges with natural language processing [25,26] or contextual understanding of language by the system is also a major challenge. The role of the doctor in physical examination must also be addressed. The issue of data safety and user privacy are also germane. More progress from the button- and text-based interfaces currently employed for most bots to efficient voice-based interfaces should also be taken seriously.

4.3 Gaps in the literature on ontology-based chatbot systems for medical diagnosis

More robust knowledge base built through system training that employs a combination of human experts, medical students, crowdsourcing, diagnostic databases and all the different array of literature sources including books, journals and reference sources. Consideration of other diagnostic theories and their relation to automated medical diagnosis is yet to be addressed. Theories can include any or a combination of the theory of first principles, utility theory, decision & probability theory, Wittgenstein theory of language, etc.

4.4 Key concepts to be addressed in the design of ontology-based chatbot systems for medical diagnosis

The need for the 'physical examination' part of pre-diagnosis can be supported through the electronic stethoscope, virtual connection of the system to data sources on patients' vitals and previous history. Facial recognition technology can provide a means of identifying individual patients. Further work is required on natural language-based interaction. Different types of technology were employed in the systems evaluated; the MediAssistEdge system presents a very robust approach that can provide a foundation that future improvements can be built on.

4.5 Focus of the follow-up steps based on findings from this study

The next steps in the study will focus on gaps identified in the review, especially on the design and evaluation of more effective systems that is deployable as a standalone application and useful for addressing access issues in relation to human resources in critically underserved areas and populations.

Development of a robotic medical practitioner with capabilities for differential diagnosis, physical examination, history-taking and interaction in human language.

 doi:10.20944/preprints201612.0027.v1

The robotic system will be further enabled to engage in continuous learning and updating of the knowledge base based on progresses made within the field as present in relevant databases, journals, books, etc.

The design will focus on the incorporation of elements of affect, known to be central in medical practice. The various dimensions of affect in terms of physician-patient relationships will be explored to aid system design that can be an effective substitute for the practitioner.

5 Conclusion

The application of ontology-based chat bot technology has been reported in many studies within different fields; however, success had been recorded for only simple systems requiring predetermined response strings or question-answer pairs that can easily be programmed. Medical practice requires a complex human-human interaction that is not easily simulated in human-machine settings. Previous work in automation of medical diagnosis has addressed issues in differential diagnosis including system training and input/output technology. The creation of expert systems had been the focus of many studies and system training had employed crowdsourcing and experts. Systems created employed the *physician-system-patient* design and are mostly designed to serve assistive purposes to medical doctors in the diagnostic process. Those employing the *patient-system* design only serve the 'where there is no doctor' type of purpose with limitation to common ailments. Deployment had employed the web or mobile phones; none of the studies reviewed had reported the use of a robotic system for deployment.

6 Future Works

Further works could consider the evaluation of theory-based diagnostic methodological options that can be considered in the development of future systems.

Concepts including safety engineering, data security, patients' confidentiality and rights are also among the critical issues to be considered.

Author Contributions: For research articles with several authors, a short paragraph specifying their individual contributions must be provided. The following statements should be used "Bosede Edwards conceived and designed the study; the review/analytical process were handled by Bosede and Idris Muniru. Bosede wrote the paper with input from Idris. Adrian Cheok provided guidance and supervision with final manuscript review and correction.

Conflicts of Interest: The authors declare no conflict of interest

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