Software Engineering in Medical Informatics: A Systematic Literature Review

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ABSTRACT
This study presents a systematic literature review to provide overall view of the application of Software Engineering (SE) in Medical Informatics (MI) field. Articles published from 2010 to 2019 from seven selected databases (Emerald, PubMed, IEEE, ACM, Taylor Francis, SAGE and Wiley) were investigated. The existing literature was analyzed, and the emerging areas of research in the medical informatics field have been identified. According to the findings of this study, medical informatics research has been applied in many fields but there is still potential of further research in different areas. Most of the reviewed studies were conducted on data mining, decision support, deep learning and IoT. Also, it can be said that most of the applications are provided as web-based instead of mobile applications. To conclude, the results of this study provides insights to the researchers about the research directions and the gaps in the literature in the MI and SE fields.

CCS Concepts
• Applied computing → Life and medical sciences → Health informatics • Information systems → Information systems applications → Decision support systems → Expert systems • Software and its engineering → Software creation and management → Software development process management → Software development methods → Agile software development.

Keywords
Medical informatics; Health informatics; Software engineering

1. INTRODUCTION
With the start of automation processes in the second half of the twentieth century, the progress of medical (health) informatics have been commenced [1]. Earlier, medical informatics was seen as a useful discipline, not only in the biomedical and health sciences but also in computer science [2]. However, when we look at the development of medical informatics, we can see that it has grown increasingly and become a must rather than a useful discipline. Medical informatics is located at the intersection of information technologies, computer science, social science, and health care practices [3]. Medical informatics help to ensure health for people around the world, as well as to contribute to the quality and efficiency of health services. Hence, medical informatics is a field of study which consists of examining and applying methods to improve the management of patient data, clinical information, population data and other information related to patient care and public health [4].

Medical informatics, as a multidisciplinary field, has also gained momentum in terms of research and application in the last few decades [3]. These multidisciplinary areas are used for problem solving or information processing in order to meet the demands of healthcare professionals in the health sector. This field focuses on the basic techniques, methods, resources, interventions, and devices required to improve the acquisition, analysis, processing, demonstration and use of information in health care [3]. To do such kind of processes, this field takes the advantage of information and communication technologies, web-based and mobile technologies, applications and systems. Medical informatics consist of many sub-fields that many health care organizations, professionals, health care givers and patients utilize. This sub-fields can be listed as, clinical decision support systems (CDSS), electronic health applications (e-health), and mobile health applications [3]. It can be said that the scope of the medical informatics is widened with the health information products, applications and systems, including tools and techniques for health care givers and patients [3]. Medical informatics is commonly agreed as a science, not an engineering discipline which depends on engineering-based approaches to the design and maintenance of health care software. Therefore, software has an important role in health care by taking over critical functions with the aim of improving the quality of health care for the patients and populations with a minimum cost [5]. Electronic health applications (e-health), patient record systems, CDSS, mobile health applications and educational systems constitute new forms of computer applications, which require innovative design methodologies of software engineering [5]. The main objective of this study is to come up with a general picture of the application of software engineering field in medical informatics. In this study, the existing MI studies are analyzed to ascertain insights of SE existence by addressing some research questions. Various databases such as Emerald, PubMed, IEEE, ACM, Taylor Francis, SAGE and Wiley (from 2010 to 2019) are explored to find relevant literature and finally 54 articles are selected as representatives of the MI and SE fields.

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2. METHOD

The concept of systematic literature reviews (SLRs) was introduced to improve an understanding of a specific field [6]. SLRs involve investigating a collection of related studies in order to gain some knowledge from a particular field [7]. A SLR study is one of the mostly used method to ascertain general insights to improve the knowledge in a specific area. Therefore, in this study the SLR methodology was used to better understand the existing medical informatics literature. Accordingly, research questions and keywords have been defined to identify the relevant studies by examining the existing literature then the results of the findings documented. The main purpose of this research is to better understand the application areas and the adoption of SE in MI. The scope of this paper consists of medical informatics research including health care, clinical and non-clinical studies. Collected articles were published as full research articles from Emerald, PubMed, IEEE, ACM, Taylor Francis, SAGE and Wiley databases between the years 2010 to till 25 April 2019. We searched "medical informatics" and "software engineering" search terms in title, abstract, or the main text of the article. Then we repeated the search with the terms "health informatics" and "software engineering" again in the title, abstract and main text of the article. We excluded the conference proceedings, book chapters, editorial and the articles not written in English. First, each article was assessed from its title and according to the inclusion (Table 1) and exclusion criteria (Table 2).

Table 1. Inclusion Criteria

IC#	Inclusion Criteria
1	Studies on the field of medical informatics and software engineering
2	Studies on the field of health informatics and software engineering
3	Studies that utilize software engineering techniques to develop efficient methods for health care
4	Studies that explain the development of a software tool that can be used for medical (health) informatics.

Table 2. Exclusion Criteria

EC#	Exclusion Criteria
1	The studies that do not address the medical informatics and software engineering concepts
2	The studies that are not written in English.
3	The papers that cannot be accessed in full text.
4	Conference proceedings, editorials, book chapters and review papers.

Secondly, each article was assessed by reading them critically from the full text. Initially there were 223 available articles. After performing the initial assessments and removal of the duplicates, article number decreased to 135. We excluded the review papers and the articles which did not address our research questions (Table 3) and finally come up with 54 articles for review (Figure 1).

Table 3. Research Questions

RQ#	Research Question
1	What are the medical fields that medical informatics and software engineering applied mostly?
2	Which countries are dominant in medical informatics and software engineering in terms of publication?
3	Which journals include papers on medical informatics and software engineering?
4	What are the tools/techniques that are mostly used in medical informatics?
5	What are the Software Development Life Cycle Methodologies used in medical informatics studies?
6	Are mobile applications frequently used for medical informatics?
7	How many of SE/MI papers include DSS/ML/AI?

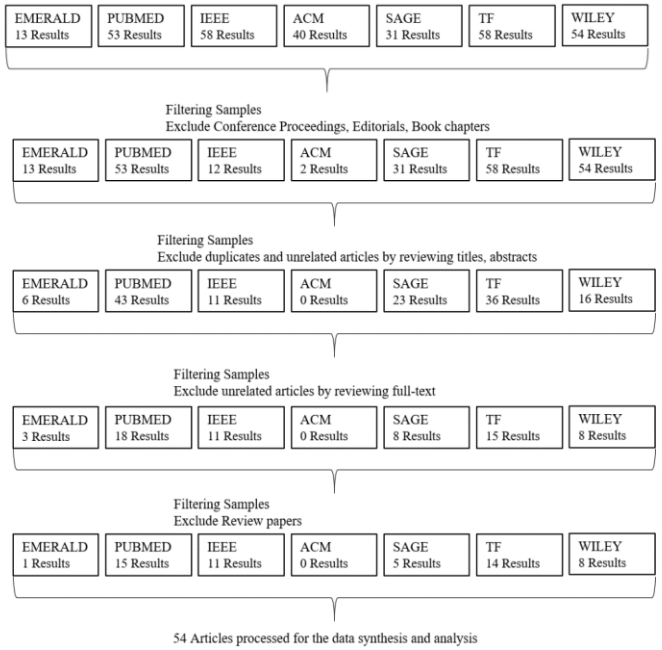

Figure 1. Sample Collection

3. FINDINGS

In recent years, the number of articles is increasing in this area. The number of publications in 2018 is 12 as can be seen from Figure 2. It indicates that the use of the medical informatics has increased in recent years and the use of it in different areas of health care has increased. If we look at the fact that the whole of 2019 has not been included in this study, there is a potential of the increased number of articles within this year. This is because medical informatics now has become an indispensable part of the health care and there are many benefits for health workers, patients and the community in this area.

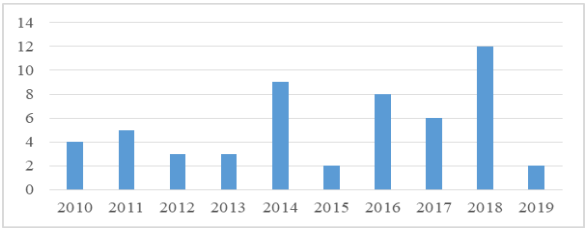

Figure 2. Number of Papers according to year

3.1 What are the medical fields that MI and SE applied mostly?

Medical informatics research has been extended in the fields such as surgery, pathology, heart diseases, home healthcare, diabetics, nursing and medical education (Figure 3). The use of medical informatics tools, which are developed by applying the fundamentals of SE, are essential for human and public health.

Although many useful studies have been performed in many health fields, many areas are still open to development as illustrated in Figure 3. Therefore, there is still potential of further research in these areas and it should be encouraged [3].

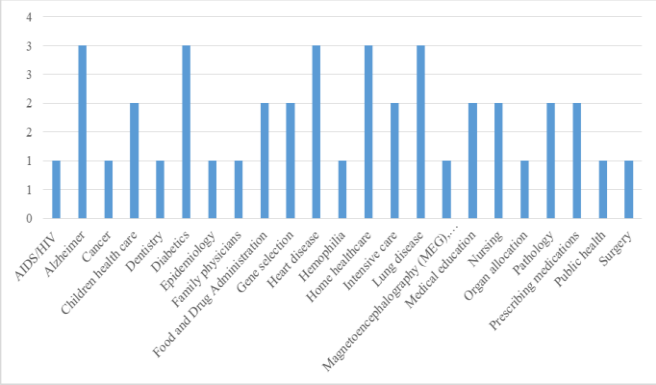

Figure 3. Number of Papers according to health field

3.2 Which countries are dominant in MI and SE in terms of publication?

According to the findings of this study, it can be seen from Figure 4 that many countries have been working on MI and SE. Figure 4 shows the number of publications according to the countries and USA, UK and China can be listed as the countries publishing the most articles in MI and SE field. They are followed by European and Asian countries. The fact that there are studies in this area from all spheres of the world and the increasing number of publications in recent years is an indication of how important this area is and how it is open for further development.

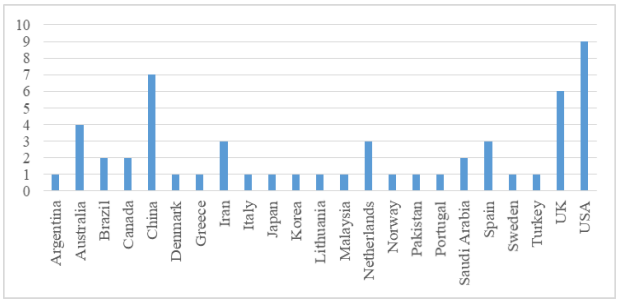

Figure 4. Number of papers according to the country

3.3 Which journals include papers on MI and SE?

Table 4 lists various publication names and the number of related papers. IEEE Journal of Biomedical and Health Informatics, with the 15%, is the most dominant journal followed by International Journal of Medical Informatics (9%). The other important channels are Behaviour & Information Technology (6%) and Enterprise Information Systems (6%) followed by the Journal of Biomedical Informatics (4%) and Theoretical Issues in Ergonomics Science (4%).

Table 4. Publication name and Number of papers

Publication Name	**%**
Behaviour & Information Technology	6
Biomedical Instrumentation & Technology	2
BMC Genomics	2
BS Asia Pacific Journal of Public Health	2
Cancer Informatics	2
Computer methods and programs in biomedicine	2
Computers in Biology and Medicine	2
Diamond Archives of Suicide Research	2
Electronics and Communications in Japan	2
Emergency Medicine Australasia	2
Enterprise Information Systems	6
Ergonomics	2
Health Informatics Journal	2
IEEE Journal of Biomedical and Health Informatics	15
IEEE Software	2
IEEE Transactions on Information Technology in Biomedicine	2
IEEE/ACM Transactions on Computational Biology and Bioinformatics	2
Informatics for Health and Social Care	2
Information Visualization	2
International Journal of Medical Informatics	9
International Journal of Pervasive Computing and Communications	2
Journal of Biomedical Informatics	4
Journal of Cognitive Engineering and Decision Making	2
Journal of Education and Health Promotion	2
Journal of Location Based Services	2
Journal of Medical Systems	2
Journal of Neuroscience Methods	2
Journal of Organizational Computing and Electronic Commerce	2
Journal of Software Maintenance and Evolution: Research and Practice	2
Journal of Software: Evolution and Process	2
Journal of Translational Medicine	2
Learning Health Systems	2
Medical Teacher	2
Systems Engineering	2
The Electronic Journal of Information Systems in Developing Countries	2
Theoretical Issues in Ergonomics Science	4
Transplant International	2

3.4 What are the tools/techniques that are mostly used in MI?

The present study found that the highest number of articles were published on data mining, decision support and deep learning (Figure 5). Utilization of such medical systems have many benefits compared to the current systems having problems in providing fast and accurate services to the health workers and patients [8]. In the field of medical informatics, the collected data is generally complex and heterogeneous hence obtaining perceptive information from this complex raw data is difficult to achieve [9]. Therefore, big data analysis for decision support and prediction is common in assessing a big dataset. The data mining and deep learning play a key role for performing the analysis of such complex data in an efficient way [10]. According to the study [11], the significance of statistical analysis on continuous health data for medicating heart diseases is important. Another study [12] mentioned a Fuzzy rule-based heart disease prediction system, which proposes content-based recommendations to heart disease patients. Therefore, data mining plays an important role in medication, treatment and diagnosing methods regarding patient specific data.

The second highest number of papers were published on IoT (Internet of Things). IoT integrates sensors, objects and smart nodes [13]. Without human intervention these combined items can communicate with each other in real time [13, 14]. Different IoT applications have been developed by professionals in order to observe patients' health [9]. Important data can be gathered easily in real time by these technologies. Use of IoT applications is increasing for observing patient's medical data in order to provide health care actions in case of emergencies [9]. In the literature, there are studies in medical informatics domain which mentioned the capabilities of IoT such as mobile health, wearable devices, patient online monitoring [15]. IoT provides many advantages and benefits and that is why it has a great popularity in health care [13].

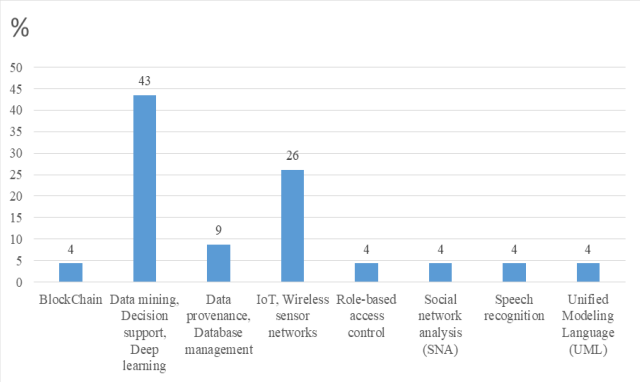

Figure 5. Tools/techniques used in Medical Informatics

3.5 What are the Software Development Life Cycle Methodologies used in MI studies?

Although in recent years the quantity of SE studies has improved gradually, most of them lack specifying software life cycles and methods [16-18]. There are various software process models such as the waterfall, agile, spiral, and Vee, which can help medical informatics system developers. Each software life cycle model has its specific prominence [19]. Figure 6 represents various life cycle methodologies used by different studies. This research found that most of the medical systems mentioned in existing literature were developed using the prototyping model.

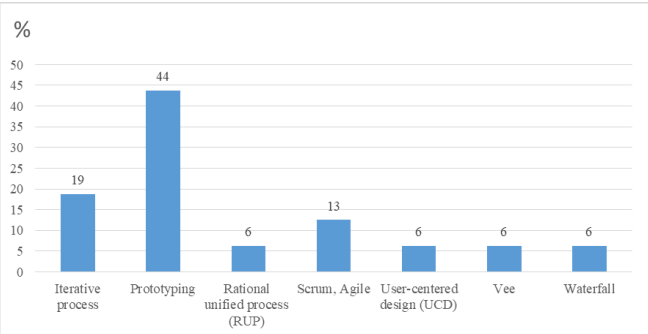

Figure 6. Software process models

In study [13] early version of waterfall software development life cycle model was used with some modifications. In waterfall model, firstly the requirements of a software or a system is gathered by the professionals followed by the analysis of the gathered requirements. Afterwards, the software professionals develop the design of the system based on the requirement analysis. Finally, professionals develop the system and related tests are performed [20]. On the other hand, the spiral and agile software development methods success rates depend on the software which will be developed. These methods are less preferable if there are physical, cost and the time constraints during the prototyping process [21]. The study [22] stated that the development of smart nursing homes is a cross-disciplinary process which includes building and mechanical design, hardware acquisition and software development. All these systems are interconnected, and it is very difficult to implement this integrated system in every iteration [22]. There is another software development method named the classical Vee model which highlights the need to define verification plans during requirements development. Also, there is a need for the continuous validation as well as risk and opportunity assessment with the stakeholders [23]. Study [18] proposed prototyping model to improve the model that would be used. Another study [24] mentioned the importance of using early prototypes to clarify design ideas.

3.6 Are mobile applications frequently used for medical informatics?

Publications can be grouped as web based, mobile and both web-based and mobile according to type of the application. The findings of this study show that most of the medical informatics applications are provided as web-based applications. There are several mobile applications, but the web-based applications are more dominant (Figure 7). Nowadays, we are able to carry out all of our operations through mobile devices. Therefore, medical informatics applications will be able to benefit from mobile devices. This study shows that mobile medical informatics applications is an area which needs further exploration.

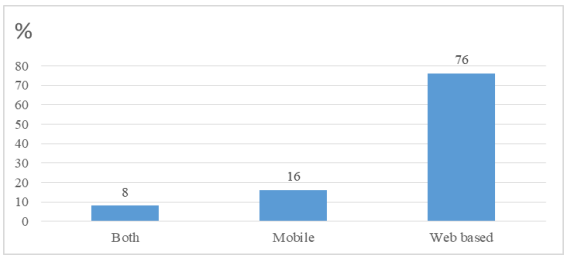

Figure 7. Type of the Medical applications

3.7 How many of SE/MI papers include Decision Support Systems?

The review found a number of articles published in relation to CDSS topic areas. Fifty-four percent of the reviewed articles mentioned about the CDSS. According to the literature, intelligent systems have an important role for providing necessary medications and treatments. These systems provide useful recommendations to the health care professionals for improving the given medical treatments and medications. Therefore, these systems can improve the patients and populations health and reduces the workload of health care professionals and expenses on health care. For example, [18] mentioned that CDSS can alert health professionals about drug interactions when they prescribe medications. Another study proposed a CDSS to offer a suite of services for the early detection and assessment for lung diseases which can be easily integrated into a healthcare providers' work-flow. Paper [25] proposed a hybrid model which provides disease prediction and medical recommendations to cardiac patients.

4. CONCLUSION

In this study, fifty-four journal papers were investigated with a systematic literature review process focusing on MI and SE fields. According to the findings of this study, the IoT has a great impact on medical informatics. In the healthcare sector, use of the IoT based applications offers a novel prototype for collecting and monitoring health data by sensors which improves the health care of patients. On the other hand, the scale and complexity of health data is a challenge for clinical practice and medical research. Results of this study reveal that most of the studies were conducted on machine learning techniques such as data mining, deep learning and decision support which brings novelty in medical informatics. The purpose of these techniques is to identify patterns from the data and then produce useful implications from the identified data. Another important finding of this study is that medical informatics studies mostly proposed CDSS for improving patient health care and for supporting the health professionals. Thus, software engineering methods and techniques should be employed in order to ensure the quality of medical systems. Results showed that the most preferable software development model in medical informatics field is prototyping. As the use of smartphones is increasing around the world therefore, mobile applications using sensors can provide useful information about our health. However, according to the findings of this study, there are not enough studies reporting use of mobile applications in this field and needs to be explored further. In this study, seven databases were used to search the literature and only the journal publications were considered. Therefore, future work will include performing SLR that will include other databases to widen the research study and to form new research questions to find more accurate status of research in this field. Although research in the field of medical informatics is not a completely new area however this study can provide insights to the researchers about emerging areas of innovative health systems and the areas with deficiencies which need to be studied further. It can potentially serve as a basis for researchers to build their own work in the field of medical informatics.

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