

Role of Smart Wearables in Remote Patient Monitoring for Diabetes

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Abstract—Diabetes is affecting people all over the world. Smart wearables are convenient alternatives to monitor diabetes and are rapidly adopted. Smart wearables enable remote patient monitoring which is a great boon for the elderly, wilderness care, and patients suffering from diabetic foot ulcers, and gestational diabetes. The objective of this review is to study the development, and trend in the use of smart wearables for diabetes treatment, and remote patient monitoring based on research papers available in the Scopus database. The present work examines the existing literature through network diagrams generated by the VOSviewer tool. Scopus is one of the largest databases used by researchers. Research papers from the year 1987 to 2023 were considered to observe the trend, and filters were applied to select the source type, “Journal”, language “English”, and “Article, Reviews, and Conference papers” from the document type. The final number of documents was ascertained after removing irrelevant documents and employing VOSviewer software to create network diagrams. Results indicate that a significant increase in research happened after the year 2019. Network diagrams revealed that the United States published the highest number of research publications. The analysis of co-authorship with keywords is discussed. This review includes future directions for researchers based on the analysis of network diagrams. The distinctive feature of this study is the unique way of presenting the analysis of VOSviewer diagrams.

Index Terms—Diabetes, Remote patient monitoring, Smart wearables, VOSviewer, Scopus

I. INTRODUCTION

A diabetic condition is created when the pancreas cannot produce insulin hormone inadequately or when cells in the human body cannot use insulin efficiently. Diabetes causes fluctuations in the glucose levels in the blood causing critical conditions like cardiovascular diseases, kidney failure, and nerve damage (Adams & Nsugbe, 2021). It is crucial to monitor the blood glucose level and maintain proper levels (Kennedy & Hales, 2018). Diabetic conditions in recent times are affecting thousands of people across the globe. This is attributed to a considerable decline in physical activity and an increase in the sedentary lifestyle of individuals (Kennedy & Hales, 2018). A potential solution for managing diabetes is early detection and continuous and remote patient monitoring (Ramesh et al., 2021). The monitoring of blood sugar levels includes collecting blood samples by finger prick followed by inconvenient analysis (Alhaddad et al., 2023). Wearable devices like smartphones, smartwatches, and personal health

devices assist in regularly monitoring glucose in the blood, measuring physiological parameters like blood pressure, and temperature, indicating increasing sugar levels, and predicting risk (Bent et al., 2021). Remote patient monitoring or telemedicine or telehealth was beneficial for patients with cardiovascular diseases, and diabetes (Farias et al., 2020) and treatment of elderly people. Remote patient monitoring provides healthcare based on digitally stored, and accessible health records (Dhediya et al, 2023). Figure 1. A schematic diagram of telemedicine or remote patient monitoring or telehealth of diabetic persons.

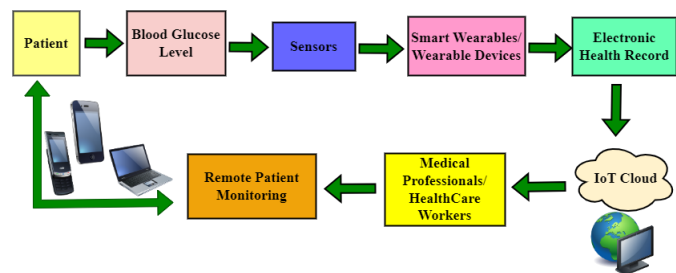


Fig. 1. A schematic diagram of Remote patient monitoring of diabetic persons

Telehealth connects patients residing in rural or urban sectors, and people from all socio-economic strata to promote and educate diabetes self-management (Davis, Allen, & Zhang, 2022). The blood sugar level data stored in electronic health records was reviewed by doctors for HbA1c and Type 2 diabetes patients (Lee, Greenfield & Pappas, 2018; Longwitz & Palokas, 2023). An exercise module tracked the physical activity of patients using a smartwatch, and combined with online meetings for Type 2 diabetic patients was reported (Mortensen, et al., 2023).

This review paper is based on the research articles found on the Scopus database related to smart wearables for remote patient monitoring specifically for diabetic people, and VOSviewer analysis. The use of smart wearables in the detection of diabetes, continuous tracking of blood sugar levels in a patient, and remote patient monitoring. The serious concerns of diabetic foot ulcers, early detection, and monitoring using wearables, and offloading devices are discussed in this study. Recently, pre-gestational, gestational, and post-pregnancy di-

abetes, neonatal care, and overweight issues are crucial in healthcare. Tracking, and monitoring sugar levels in pregnant women is included in the current study.

II. LITERATURE SURVEY

People suffering from diabetes must observe, and record blood glucose closely to avoid the risk of developing hypoglycemia, cardiovascular diseases, and kidney failures (Zhu et al., 2022). Diabetic patients face the threat of diabetic foot infection and related problems. Care of elderly diabetic patients, and pregnant women is crucial. Mobile healthcare empowers patients with type 2 diabetes with efficient monitoring of glucose levels, enables health and behavioral record maintenance, and relieves patients from frequent visits to clinics, and physicians (Kwan et al., 2022). To circumvent chronic diseases arising from uncontrolled blood glucose, biosensors, and wearables can be fixed at different positions on the human body synchronized with the Internet of Things and connected to the cloud for transferring information

A. Diabetic Foot Care

Diabetic people are affected by infection faster than ordinary people and infection of the foot can cause extreme issues and even amputation. To ascertain the timely diagnosis of a diabetic foot, comparing temperatures of the normal foot and affected foot using sensors embodied in wearables, which can avoid amputation was implemented as remote patient care (Arts, et al., 2022).

A smart wearable device that can be personalized to monitor the medical condition of a diabetic foot with temperature monitoring as a prime parameter leading to preservation of the foot (Beach et al., 2021). Remote patient monitoring is crucial to avoid infection, and amputation of the foot. Increasing the use of protective footwear is reported to help manage diabetic foot ulcers (Najafi et al., 2020). Offloading devices like contact casts and boots are known to redistribute pressure to reduce ulcer site pain and trauma. Healing of the diabetic foot depends on offloading devices used by the patient. A smartboot with a smartwatch connected to a cloud dashboard was investigated as an offloading device. The smart boot was checked for the balance of daily activities and the gait of the patient. Patient feedback was recorded, and the smartboot was evaluated for its sensitivity, fitting on the foot, and other parameters. The smartboot was non-invasive, comfortable, and innovative for healing diabetic foot ulcers (Park et al., 2023).

Remote patient monitoring to mitigate complications arising from diabetic foot ulcers was investigated through education and the use of mobile applications. The patients showed better self-care, self-efficiency, increased skin care, and awareness of the use of appropriate footwear (Kilic & Karadag, 2020). An early prediction of podiatric injury using sensors installed in a sock and recording the temperature and inflammation of the foot was a very successful experiment. The smart sock was able to detect and diagnose a foot injury as a remote patient monitoring system. However, a better algorithm to

enable detection of the ailment at an initial stage was required (Reyzelman et al., 2022).

B. Gestational Diabetes Care

Diabetes mellitus among pregnant women is a medical complication that must be treated with state-of-the-art maternal and neonatal care instruments. Remote patient monitoring through health tools for real-time blood sugar levels of pregnant women appeared as convenient and reliable. A mobile application connected to Bluetooth was employed to collect data on blood glucose levels, maintaining the electronic health record, which was visible to medical professionals and health-care persons. The system was implemented for many pregnant women and newborns and was found to be more accurate and reliable for better maternal and neonatal care (Kantorowska et al., 2023). Pregnant women in rural areas experienced better monitoring by doctors, developed self-awareness, and reduced check-up visits (Jones et al., 2023). Most women preferred pre-gestational and gestational diabetes, and antenatal care using a mobile phone gadget (Alqudah, et al., 2019).

Gestational overweight is becoming common and adds up several risk elements for both the mother and the newborn. Both women and caregivers believed that well-designed strategies, lifestyle changes, and health technology using smart wearables were required to reduce overweight (Saarikko et al., 2021). Telemedicine and mobile healthcare technology are fast adopted by patients and medical practitioners to monitor diet, and weight and track weight gain during pregnancy (Litman et al., 2022). Remote healthcare monitoring was reported to be helpful in the treatment and cessation of smoking habits in pregnant women (Joyce et al., 2021). The Scopus database renders the latest developments in this domain of research, and VOSviewer diagrams present a detailed insight.

III. RESEARCH METHODOLOGY

The Scopus database was used to obtain relevant publications. The search was conducted on September 5, 2023. The Scopus database was searched in Article Title, Abstract, Keywords for search terms, smart wearables OR remote patient monitoring, AND diabetes, to extract 1003 documents. Filters were applied for Source Type where "Journal", and language in which "English" was selected. Filter applied for Document type, wherein Articles, Reviews, and Conference papers were chosen. The research articles furnished after applying filters were 760. These 760 articles were selected and exported as a CSV file. Further checks were conducted to designate irrelevant articles. 80 articles were removed from the 760 to obtain a final 680 research articles. The schematic representation of the stepwise process of selecting relevant research articles is depicted in Figure 2.

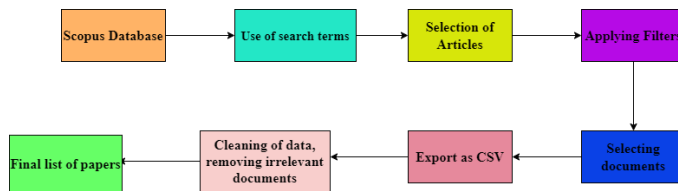


Fig. 2. A schematic diagram of Remote patient monitoring of diabetic persons

The present work is developed on the documents found on the Scopus database and using VOSviewer to render the network diagrams. The network diagrams and analysis are presented in the Analysis section of this study.

IV. RESEARCH METHODOLOGY

A year-wise account of several publications indicated that research was inconspicuous within the period from 1987 to 2012 as depicted by the Scopus database. A continuous but steady increase in number of research publications was observed from 2012 to 2019. However, a sharp increase in research papers was noted after year 2020, which indicates that a greater demand for smart wearables for diabetes and remote patient monitoring was created during and after the pandemic. Figure 3 shows the year-wise number of research publications over a duration from 1987 to 2022

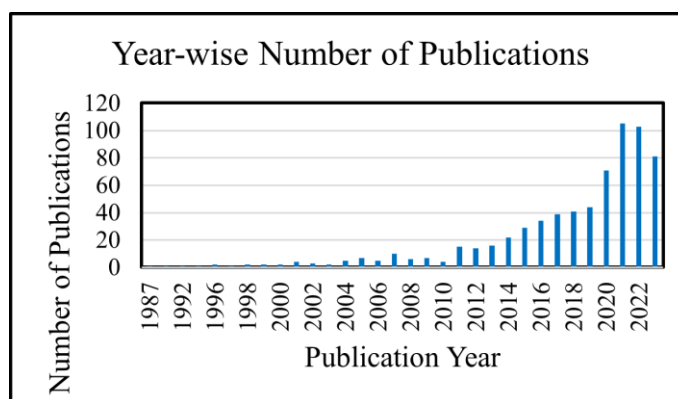


Fig. 3. Year-wise number of research publications

The network diagrams were obtained using the tool VOSviewer, and the analysis was studied. The relation between co-authorship of authors is shown in Figure 4. The minimum number of documents was set at 2, and the minimum citation was set at 0. There were 678 authors out of which 5 met the threshold. The analysis showed that all the authors, Albisser, A.M., Lanzola, G., Piras, E.M., Verwey, R., and Tildeshley, H.D. were working independently as the total link strength was observed to be zero.



Fig. 4. Co-authorship of authors

Figure 5 displays the co-authorship of countries. The minimum number of documents of a country was kept at 5 and minimum citations were set at 2. Of 96 countries, 31 met the threshold. The United States was noted to be on the forefront with maximum citations of 5416 and a total link strength of 75. The United Kingdom closely followed the United States with a total link strength of 71. Spain, France, and Germany were observed to show total link strength of 58, 52, and 51 respectively. These results suggest that the United States and the United Kingdom are leading in research in smart wearables for diabetes and remote patient monitoring, and co-authorship with other countries.

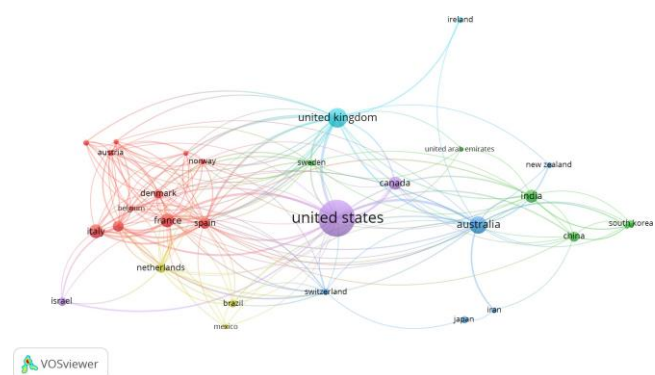


Fig. 5. Displays the Co-authorship of countries

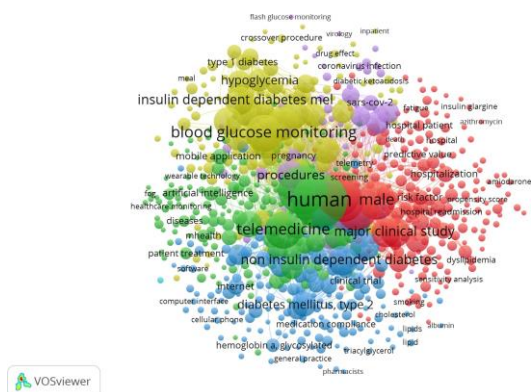


Fig. 6. Co-occurrences of all keywords

To understand the co-occurrences of all keywords the minimum number of documents was set at 5, and out of 5224 keywords 243 reached the threshold. Figure 6 shows that the keyword with the highest co-occurrence was ‘human’ followed by ‘humans’ with an occurrence of 565 and 451, and total link strength of 15882 and 13319 respectively. Keywords female, male, diabetes mellitus, telemedicine, adult, blood glucose monitoring, and glucose blood level were observed to show significant occurrence and total link strength. The co-occurrences of index keywords showed a similar result, suggesting that keywords blood glucose monitoring, and glucose blood level for humans are the most significant keywords.

V. CONCLUSIONS

Diabetes treatment for humans is crucially important for patients worldwide. The VOSviewer tool indicated that keywords imply that males, females, and adults have close total link strength. Although, the United States and the United Kingdom have the highest co-authorship with countries, Iran, Japan, and Ireland were found to have a minimum co-authorship with countries. Most research articles published in Scopus are in journals like the Journal of Diabetes Science, and Technology, and Diabetes Technology and Therapeutics. Journals like Telemedicine and E-Health, Journal of Medical Internet Research, and Diabetic Medicine are also preferred. Researchers may explore these journals for recent updates in diabetes, and remote patient monitoring using smart wearables. Although subject areas such as medicine, biochemistry, genetics, and molecular biology are at the top, subject domains like engineering, health professions, and computer science are close in competition. Researchers in the engineering domain may focus on investigating novel smart wearables for diabetes detection, control, and monitoring using remote patient monitoring.

to doctors and healthcare personnel. Also, wearables with specialized features to manage diabetes in pregnant women, neonatal care, diabetic foot care, obesity among children, physical activity, food intake, and lifestyle modification may be explored.

VI. SCOPE FOR FUTURE RESEARCH

As reflected in the Scopus database, and VOSviewer analysis, the growing interest in diabetes treatment using smart wearables and remote patient monitoring, there is a need for more investigation into fabricating smart wearables that accumulate and transfer data keeping it secure and easily accessible

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