# A Digital Twin Framework for Real – Time Diabetes Management

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# Introduction

Diabetes, especially Type 2 Diabetes, is difficult to control for the majority of people. It requires constant upkeep of aspects like blood glucose levels, diet, exercise, and medication every day. In the long term, this becomes difficult to continue, and the majority of patients struggle to keep their health under control. That's what fascinated me to create a project that might help — a real-time system offering customized support using digital twin technology. A digital twin is literally an online copy of one's health. It is loaded with real-time information from devices like glucose meters, smartwatches, and medical records. The virtual copy can also forecast what variations can take place in an individual's blood sugar, suggest the proper amount of insulin, and even alert them in advance if something happens. It is like having a brilliant diabetes butler. I chose this subject because diabetes is one of the most widespread and challenging to treat chronic illnesses of today's time, and my expectation is that technology can contribute a great deal in controlling it better. Having gone through several recent articles, I found that most of the researchers have gone ahead with studying digital twins for diabetes but nevertheless, there is a scarcity of real-time operation and genuinely personalised systems. This project will fill that gap by creating a digital twin platform that physicians and patients will be able to utilize on an everyday basis. It will provide good recommendations and predictions with real-world data, and it will be more supportive, reliable, and personalized to the patient.

# Problem Statement

Diabetes, and especially Type 2 Diabetes, is one of the most common chronic medical conditions on the planet. It is endured by millions of people daily, and many of them find it hard to manage. Blood sugar levels vary depending on what a person eats, how much activity they perform, how stressed they are, and when they last took medication. Even small changes in daily life can affect a person’s condition. But most of the time, treatment plans for diabetes don’t change that often — they are based on fixed routines, not real-time needs. This becomes a big problem because diabetes is different for every person. What works for one patient may not work for another. Many people end up guessing what they should do — should they eat something now? Should they skip a dose or take more insulin? Should they go for a walk or rest? Without the right support or guidance in real time, they can make mistakes. These mistakes may lead to serious health problems, like low or high blood sugar, nerve issues, heart problems, and even long-term damage to organs. The people who suffer the most are everyday patients — especially elderly people, those living in rural areas, or people who don’t have regular access to doctors. Doctors are also affected, because they can’t be available all the time for every patient Therefore, the patients either do not get the care on time or visit the hospital only when they have an aggravated condition. That's why this problem needs to be solved so badly. If we can give individuals the right assistance at the right time — before things become disastrous — we can prevent suffering, save health care pennies, and help people lead good

lives. After reading multiple recent studies, I realized digital twin technology is the key. A digital twin is basically a smart replica of one's health that lives on a computer. It collects real data from devices like glucose meters, watches, or fitness trackers. It draws inferences from the person's habits, medical background, and activities of daily life. Then it suggests — like when to eat, how much to walk, or whether their sugar levels are going to increase or decrease. It's basically like having a small doctor that follows you around. Some researchers have already tried using digital twins for diabetes. A few of the papers I studied showed really good results. Patients who used digital twin systems had better sugar control, used less medication, and felt more confident in handling their health. But most of these systems are still in testing. They’re not fully ready for everyday use, and very few of them work in real time. That’s the gap this project will try to fill. I want to create a simple and smart digital twin framework that works in real-time and is easy to use for people with Type 2 Diabetes. It should help both patients and doctors by giving live, personalised support that makes life with diabetes a little easier.

# Aims and Objectives

The overall objective of my project is to create a smart system that assists individuals with Diabetes to control their condition daily better than before. The system will be based on the idea of a digital twin — an imitation of an individual in virtual form utilizing real-time data to learn what is occurring in their body and provide useful recommendations. The idea is to have a real-time diabetes personal care assistant making suggestions based on the day's schedule, day-to-day habits, and available health data. Pre-scheduled treatment already exists for most diabetes patients. These are usually from an examination week or even months ago. Blood glucose levels, though, change every day, even every hour. People aren't always sure what to do when their sugar is increasing or decreasing — and occasionally, by the time they do something about it, it's too late. This is basically the first thing I'd like to explore in this project: the lack of real-time support that's based on a person's particular needs.

## Research Questions

* + - How do we develop a digital twin to aid in real-time diabetes care?
    - What information do we need from the patient to make the system work?
    - What machine learning algorithms will work best to predict fluctuations in blood sugar and suggest the appropriate measures?
    - How do I make this system lean and hassle-free enough for general use by normal people?

## Objectives

* + - Learn how digital twins have been used before, especially in healthcare
    - Collect or create the type of data needed — like blood sugar levels, food consumed, number of steps, and sleeping history.
    - Choose proper AI models, e.g., LSTM or Random Forest, to aid in making useful predictions.
    - Build a functional example (a prototype) illustrating how the system would function in the real world.
    - Test executing the system on data and check whether it gives useful advice and correct alerts.
    - Reflect on what was being done well and what could be done differently next time.

## Approach and Methods

I’ll begin by reading research papers to see what other experts have already tried. Then, I’ll design a basic version of the digital twin using Python. For the data, I’ll either use open-source patient data or create my own using safe, sample values. I’ll train and test AI models that can learn from this data and make predictions. Tools like TensorFlow, pandas, and scikit-learn will help me do this.

I will experiment with some different models including:

* + - LSTM, which is valuable in identifying time-based patterns (e.g., blood sugar fluctuation throughout the day).
    - CNNs (if using sensor-based signal data).
    - Random Forest, which is valuable in making decisions based on many different inputs.
    - Decision Trees – for simple, fast predictions in early tests.

The end system should be able to provide useful recommendations, like when to walk or eat, and issue pre-alarms when sugar gets too high or too low. The goal is to help people do a better job of taking care of their diabetes, day after day.

# Legal, Social, Ethical and Professional Considerations

This is a project involving working with health data, so there are some essential legal and ethical issues to address. Even when the project is being done using publicly available or simulated data, it would still have to comply with data protection laws such as GDPR (General Data Protection Regulation). If in the future the system must hold real patient information, then it would require proper consent, anonymisation, and safe handling of data. It is one of the key ethical concerns that the digital twin system should give advice that is safe and correct. If the system gives misleading guidance, it could cost someone their life. For this reason, the model will have to be tested well and clearly marked as a supporting tool, but never as a medical advice alternative. The customers must always be instructed to consult their physician. There also needs to be the guarantee of the fairness and inclusivity of the system. It must be able to perform well for a person of different ages, backgrounds, and abilities. Any machine learning

method used must be vetted for bias, especially if it has been trained on biased or unbalanced data. From a professional standpoint, the project must comply with best practice in software development, data ethics, and transparency with the patient's safety and responsibility in mind.

# Background

Digital twin technology has gained widespread appeal across all sectors such as aerospace, automotive, and manufacturing because it is possible to replicate systems virtually and optimize performance. Scientists have only recently started to investigate its potential application in the healthcare sector, or more broadly, chronic disease management. One of the most widespread chronic diseases worldwide, diabetes, has been a suitable subject for digital twin research. Literature shows increasing interest in the deployment of digital twins for real- time monitoring and customized care of Type 2 Diabetes (T2D) patients. Rad et al. (2024) described a knowledge graph-based digital twin framework that allows for adjusting treatment advice based on patient-specific data. Zhang et al. (2024) described an integrated system using wearable sensors for continuous health data. Their strategy utilizes machine learning models for forecasting blood glucose profiles and issuing early alerts. Cappon and Facchinetti (2024) developed a virtual pancreas simulation, and Thamotharan et al. (2023) used historical data for insulin dose requirement estimation. Although these articles are promising, they are largely at the experimental or proof-of-concept stage. In addition to research-driven activity, organizations like the Mayo Clinic Platform (2024) have also enlightened us on how digital twins can transform chronic disease care. What their findings reveal is that digital twins can allow for improved decision-making among healthcare personnel, reduce emergency visits, and enhance patient engagement. However, most of the currently available models are yet to be tested in clinical research environments and are not yet widely employed in day-to-day patient management platforms.

## Context Under Which the Project Is Conducted

The project will be conducted in a research academic environment with available open-source datasets and simulated wearable input data. The context is to develop a prototype that will demonstrate how digital twin technology can be applied practically to aid real-time Type 2 Diabetes management. The attributes such as glucose, diet, exercise, and sleep time — as implemented in research studies of Cappon and Facchinetti (2024) and Zhang et al. (2024) — will be used to train and test machine learning algorithms for accurate prediction of blood glucose and personalized suggestions. The final objective is to design a system that will be tested on simulated real-world situations for usability, accuracy, and response time.. This research also comes under the overall scholarship on the application of artificial intelligence (AI) and Internet of Things (IoT) devices to improve chronic disease care. By bringing these two domains together, the research can explore new avenues to improve diabetes self-care and patient outcomes.

## Relationship Between the Project and the State of the Art

Digital twins exist in domains other than medicine, while their use in healthcare is underway. Most current healthcare-related digital twins are offline or static. This research has the objective of advancing the state of the art by incorporating real-time feedback and patient engagement. Unlike current studies based on static or past data only, this research will model real-time data streams to enable adaptive decision-making. It is an organic continuation of research by Thamotharan et al. (2023), based solely on pre-recorded data, and Cappon and Facchinetti (2024), based mainly on theory. This research also explores the integration of lifestyle and behaviour data — a theme that historically has been underrepresented in digital health models. The proposed system will incorporate differences in patient activity and daily routines, offering a more responsive and precise prediction model. This shift towards lifestyle-sensitive and real- time systems is an essential move towards the use of digital twins in healthcare.

## How Well Established Is the Area Being Studied?

The overall concept of digital twins is well established in technology and engineering but not yet in healthcare — specifically not for chronic disease such as T2D. Some digital health startups and research groups have started working in this space, but most projects are in the early stages or small and highly specialized in focus. There is an unequivocal research gap with respect to general-purpose, real-time digital twin systems that can be realistically used by patients in daily life. While in its infancy, the area has sound foundation research. The AI models proposed for this project, namely LSTM (for time-series forecasting) and Random Forest (for classification and decision-making),CNN and Decision Trees are proven technologies in the data science domain. They have been used widely across fields like finance, weather, and now increasingly medicine. The biggest concern is to be able to convert these models into health-related data and then ensure that they provide health-relevant, safe, and accurate predictions. So, although the technology for the digital twin is not novel, its application to Type 2 Diabetes in real-world settings with personalised outputs is a relatively new development. This makes the project both relevant and innovative.

## Extension of Previous Work or a New Area?

This project builds upon previous work in the sense that it is taking from proven models and theories in digital health but also introducing new functionality. Compared to previous models, which used static patient data, this system is designed to mirror real-time feeds of data and update the patient's digital twin model in real time. The focus is on developing something practical, user-friendly, and adaptable. The idea of building a real-time, live-data-enabled digital twin has not been new, yet few researchers have carried the idea further than theoretical design. This project assists in moving from simulation towards practical application, which is a fundamental step further in research.

## How Established Are the Techniques and Theories?

The hypotheses underpinning this project — time-series forecasting using LSTM, ensemble learning using Random Forest, and personalized medicine — are highly established in practice and literature. Rad et al. (2024), Zhang et al. (2024), and others have employed similar approaches to gain successful outcomes. The performances and reliability of such models make them suitable candidates for this project. Furthermore, combining wearable data with machine learning has already proven useful for tracking heart conditions, sleep disorders, and fitness. Applying the same principle to diabetes is only adding value and building on what is already known in the field. Simulated and open-source data enable ethical and legal boundaries to be observed while maintaining realistic test environments. This is a highly prospective project to generate interest outside the academy. The healthcare industry is actively searching for approaches to augment chronic disease management with AI, wearable technology, and personalized medicine. Companies developing fitness trackers, continuous glucose monitoring (CGMs), and digital health platforms might find it useful to have a model such as this. Such a real-time digital twin system of operations would be used by hospitals to observe patients remotely, by doctors to make more accurate treatment decisions, and by patients to take greater control of their own wellbeing. Companies like the Mayo Clinic Platform (2024) are already spending on the above technologies, indicating a clear industry trend. In addition to that, governments and public health authorities are beginning to prioritize individualized care solutions as a mechanism to reduce hospital surges and improve long-term results. This project enables such efforts by offering an architecture that is scalable, flexible, and user focused.

## Final Thoughts

In short, the project is grounded in robust earlier research but advances the state of the art by creating an applied, real-time system that merges diabetes treatment with digital twin technology. It fills a clear gap in the state of the art and has strong implications for research in academia and real-world healthcare. By taking tried models to a new, more vibrant setting, and by overcoming technical as well as pragmatic hurdles, this project aims to deliver something of value as well as feasible — a move in the right direction down the road to intelligent, patient- centred diabetes treatment.

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| Student and First Supervisor Project Sign-off | | | | |
|  | Name | Signature | Date |
| STUDENT:  I agree to complete this project: | Riyaz baba Mohammed | Riyaz baba Mohammed | 30/05/2025 |
| SUPERVISOR:  I approve this project proposal: | Sameena Naaz | Sameena Naaz | 30/05/2025 |
| Supervisor Comments/Feedback | Proposal can be submitted | | |
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