A pathway to In-Memory Computing driven Wellness Digital Twin utilizing Remote Patient Monitoring System (WDT-RPMS)

Un camino hacia un Gemelo digital de bienestar impulsado por la computación en memoria utilizando el sistema de monitoreo remoto de pacientes (WDT-RPMS)

Kishore Kumar Kadari[1], Ali Shiri Sichani[2], Wilfrido Moreno[3]

1   Department of Electrical Engineering, University of South Florida. USA. Ph.D. candidate. Email: kadari@usf.edu
    https://orcid.org/0000-0003-3891-2446
2   Department of Electrical Engineering, University of South Florida. USA. Assistant Teaching Professor. Email: alishirisich@usf.edu
    https://orcid.org/0000-0002-7239-1341
3   Department of Electrical Engineering, University of South Florida. USA. Professor. Email: moreno@usf.edu
    https://orcid.org/0000-0001-7003-1177

Keywords

Memristor; in-memory computing; MBSE; precision medicine; healthcare; Digital Twin.

Abstract

With fast-paced digital transformation, precision medicine has been an essential part to elevate the conscience of healthcare with respect to the biopsychosocial model with the help of Remote Patient Monitoring Systems. Digital twins have been successful in many industries, in healthcare, it can optimize the wellness of the human body to improve physical and mental wellness including the non-diagnosed diseased populations and rural populations.

 In this paper, we discuss the challenges in terms of computing to implement a complex system called Wellness Digital Twin-based Remote Patient Monitoring System following Model-Based Systems Engineering (MBSE), we present the definition, needs of the digital twin in the context of wellness and healthcare, a feasibility study followed by a concept of operations. Subsequently, we present the requirements and architecture including In-memory computing, (Emerging Non-Volatile Memories, memristive devices) that will enhance sensing, analytics, and levers of action.

Palabras clave

Memristor; computación en memoria; MBSE; medicina de precisión; cuidado de la salud; gemelo digital.

Resumen

Con la rápida transformación digital, la medicina de precisión ha sido una parte esencial para elevar la conciencia de la atención médica con respecto al modelo biopsicosocial con la ayuda de sistemas de monitoreo remoto de pacientes. Los gemelos digitales han tenido éxito en muchas industrias, en la atención médica puede optimizar el bienestar del cuerpo humano para mejorar el bienestar físico y mental, incluidas las poblaciones enfermas no diagnosticadas y las poblaciones rurales.

 En este artículo, discutimos los desafíos en términos de computación para implementar un sistema complejo llamado Wellness Digital Twin-based Remote Patient Monitoring. Siguiendo la Ingeniería de Sistemas Basada en Modelos, presentamos la definición y las necesidades del gemelo digital en el contexto del Bienestar y la atención médica, un estudio de viabilidad seguido de un concepto de operaciones. Posteriormente, presentamos los requisitos y la arquitectura, incluida la computación en memoria (memorias emergentes no volátiles, dispositivos memristivos) que mejorarán la detección, el análisis y las palancas de acción.

Introduction

Healthcare services are going through a digital transformation [1] due to increasing data, improving computing power, high-speed communication systems [2] and mobile connectivity technologies. A study in Europe [3] about the key barriers in the healthcare sector emphasized the necessity of remote patient monitoring and the Wellness Digital Twin (WDT).
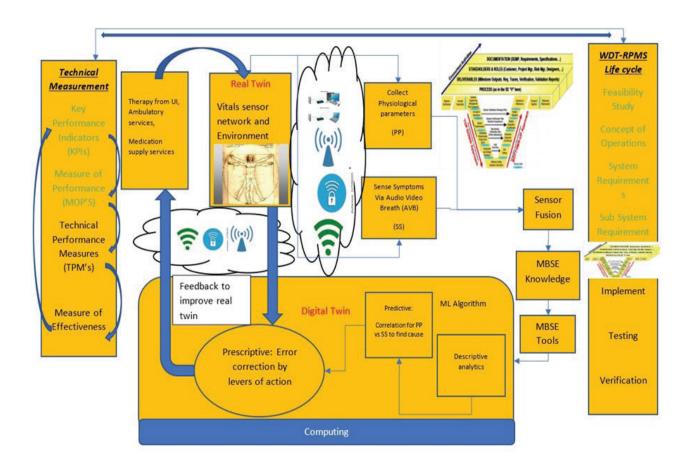
Figure 1. Wellness Digital Twin using Remote Patient Monitoring System.

Definition of Wellness Digital Twin (WDT)

1. Definition of Wellness Digital Twin (WDT): "Digital twins enable the monitoring, understanding, and optimization of all functioning of humans, and provide constant health insight to improve quality of life, and well-being" [4] From the above definition, the features from literature are data visualization, prediction, intelligence, analysis, decision making, and feedback loop [4]

2. Definition of Electronic Health: FDA states eHealth as a digital informational tool between healthcare and users, World Health Organization (WHO) states it as safe use of information and communication [3].

3. Definition of Remote Patient Monitoring Systems (RPMS): RPMS is a combination of organizational techniques, Electronic Health [3], engaging users using information and training [5].

4. Definition of Model-Based Systems Engineering (MBSE): MBSE is an integrated, consistent, coherent system modeling methodology that uses Systems Modeling Language (SysML), modeling methods, and modeling tools for the design, modeling, synthesis, and verification of complex systems.

In [5], the necessity of a systematic methodology for RPMS is well specified. The complexity of WDT-RPMS due to the great diversity of stakeholders requires the use of methodologies such as design thinking [6] and Model-Based System Engineering (MBSE) [7], [8] throughout the life

cycle. A system model captures design decisions as an element in a repository. The multiple elements are linked and stored in a database in the systems model. [8] An MBSE modeling tool, Magic System of Systems is used for the life cycle stages depicted in figure 1.

Feasibility study

About 80% of health spending in 2019 went towards care and treatment. 60% of spending is expected to be invested in improving health and well-being by 2040. [9] Consumers shall be empowered to monitor their health using technologies that can detect the initial stages of disease in asymptomatic people and convey drivers of health early which in turn help to prevent diseases. [4], [9]

Existing RPM services such as Extension for Community Healthcare Outcomes (ECHO) that deliver care for cancer [10], and hepatitis C virus treatment [11] played a key role in serving remote parts of New Mexico.

1. **Business Plan**: WDT-RPMS is a subscription-based model. The payment is of two types. The estimated selling price would be $150 (USD) for hardware with one year warranty. The estimated selling price for the subscription of the private consumer is $29 (USD) per month. The selling price for the subscription of Government consumers is $160 (USD) per month. Computer Vision is the current focus of the WDT-RPMS for patient pose monitoring to deliver its service in at least two years into the market.

2. **Holistic approach to wellness**: This research is focused on creating a holistic wellness-based system through digital twins using data acquired from real humans also called "real twins" [4]. The data creation, maintenance, and digital transformation are utilized to increase the positive outcomes for the real twin [12]. While healthcare monitoring is pervasive [3], [13], [14] and complex [12], the Wellness Digital Twin utilizes Remote Patient Monitoring Services (RPMS) and is referred to it as WDT-RPMS. WDT-RPMS network data is combined with Electronic Medical Records (EMR) and other datasets to reveal hidden insights into population health outcomes.

3. **Advances in Computing**: The technological advances in both communication (wireless communication services [2]) and computing research enable digital transformation. The existing computers have von Neumann architecture in which the computation and the memory are physically separated. The data is fetched from memory and transported to the processing unit, where computation happens, and then transported back to the memory unit for storage purposes. The transportation of data between the processing unit and memory costs performance as a memory wall and the high-power dissipation. [15] In-memory process using emerging Nonvolatile Memories (eNVM) specifically, memristive devices will accelerate computing rate with low energy consumption, and low latency.

Methods- Concept of Operations for WDT-RPMS

The main purpose of the WDT-RPMS system is to improve health outcomes for the patients which directly reduces the cost and improves the quality of health care. WDT-RPMS addresses the large undiagnosed diseased population. WDT-RPMS are designed to minimize Emergency room visits, hospital admissions, and re-admissions and to reduce overall healthcare costs.

RPMS-based WDT system remotely captures health information from users. Information is securely transmitted to the platform in the cloud. In addition, the system provides patient information to healthcare providers and authorized family members. The WDT has its own Artificially Intelligent robotic system to enable precision medicine using RPMS. The robotic

system sense and acts for monitoring the patients to help care providers to decrease the effects of chronic disease and to increase well-being with the help of descriptive analytics, predictive analytics, and prescriptive analytics.

The users of WDT-RPMS technology are doctors, patients, and caregivers. A sample of stakeholders for a WDT-RPMS are sales, marketing, medical support team, technical support team, development, and testing team.

Stakeholder needs:

Stakeholder's needs are collected from individual stakeholders as follows.

- To monitor vitals, which include blood pressure, glucose levels, body temperature, oxygen levels in the blood, body weight, and respiration rate. [16]

- To monitor the patient bedside pose using the camera. [17], [18]

- To monitor the breath contents and volatile organic compounds (VOC) information to diagnose pulmonary disorders, especially lung cancer the second most common cancer. [19]

- To collect the speech and respiratory symptoms using a microphone. [20]

- To perform real-time communication between patient information and doctor during alerts.

- To access historical patient data

- To provide secure data encryption during transmission and at rest for meeting Health Insurance Portability and Accountability Act (HIPAA).

- To meet Food and drug administration (FDA) compliance for home health devices.

- The ontology of the concept shows the flow of the operations sequentially in figure 2, but it could be more dynamic in real-time.
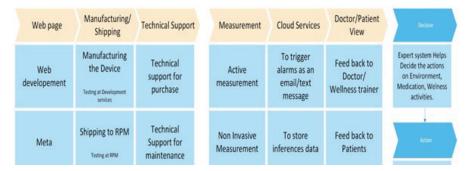

Figure 2. Operating Concept (OpsCon).

Opportunities and Challenges in Computing

Edge computing makes real-time inferences for large data sets using current advances in parallel computing. Internet of Things that are connected to Cloud-based computing can tune the machine learning-based models before deployment on the edge devices. The existing solutions are using parallelism through a Graphical Processing Unit (GPU) by utilizing multiple cores, each with the shared transportation connected with the memory. Another recent development is accelerators for specific applications, the Tensor Processing Unit (TPU) has been developed for the acceleration of Multiply-Accumulate (MAC) operation. Another progression is through elevating the memory bandwidth (the rate at which the data is transported while reading or

storing it back between processor and semiconductor memory) such as hybrid memory cube, and hybrid bandwidth memory. The latest advancement that has come to overcome the memory wall (the transportation gap between the processing space and the storage space) is a Resistive switching device. [15] An efficient edge computing, video processing pipeline subsystem with low latency and power that can perform millions of complex concurrent arithmetic operations per second is required. With the recent advancements in Resistive switching devices, Resistive RAM (RRAM) has achieved an ultra-low switching power and compatibility in-process fabrication as Complementary Metal Oxide Semiconductor (CMOS).

Results: Requirements and High-level architecture

WDT-RPMS system's high-level architecture and the state machine behavior of WDT-RPMS is built using the Magic System of Systems Model-based Systems Engineering tool as shown in figure 3, figure 4.

We summarize the sub system's requirements for the next stages of developing WDT-RPMS. The WDT-RPMS consists of sensors that acquire the vitals data, a microcontroller that processes the data, and a communication module that transmits the data and/or inferences to the cloud. The interface from the microcontroller to the mobile applications shall be via Bluetooth. The Nordic part shall be used to transmit data from Bluetooth to display on an application. The WDT-based RPMS is discussed in detail in the following subsections.

Computing:

The WDT-RPMS shall use RRAM-based computing (currently prototyping on Raspberry pi 4B and/or NVIDIA Jetson Nano microcontrollers). The cost of the cooling system shall be reduced due to RRAM revitalizing the data centers by utilizing the RRAM-based Convolutional Neural Networks (CNN) system [21].

Sensing

Medical sensing Devices shall be used to monitor the patients using evolving technologies to decrease the bridge between the healthcare providers and the patients by availing appropriate information technology systems.

1. **Environment sensing**: The autonomous Artificial Intelligence (AI) agent shall be able to sense the Sensor Variables (SV) like temperature (thermometer), airflow level (fan ON and OFF cases), humidity, and dust particle density (from particle sensor). Environment sensing is important while sensing the vitals because it is also dependent on the environment a person is in.

2. **Audio Sensing**: The acoustic data (Sound Symptoms for disease) collected by the microphone (embedded in a watch or smartphone application) with respect to time and location (To keep track of the allergens) whenever required shall be sensed. The Agent shall be able to detect the oxygen quantity in the blood and pulse rate to monitor the dust allergens [20].

3. **Video Sensing**: It shall help monitor the user's pose for conditions such as Stroke, Arrhythmia, Pregnancy, COVID/Long COVID, Obstructive Sleep Apnea, Old-age patients, and kids. The sleep pose dataset shall be used to make a model for classifying a patient's pose in bed. The video latency shall be less than 130 milliseconds using the raspberry pi camera.

4. **Breath Sensing**: The volatile organic compounds shall be sensed through nasal and oral breath contents to monitor lungs and gut health, respectively. Breathing rate shall be monitored by the microphone when needed.

5. **Vital sensing**: The vital sensing shall sense the blood pressure, glucose levels, body temperature, oxygen levels, and body weight. [22]
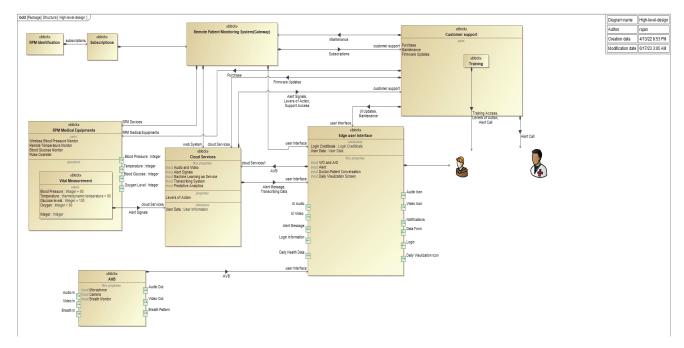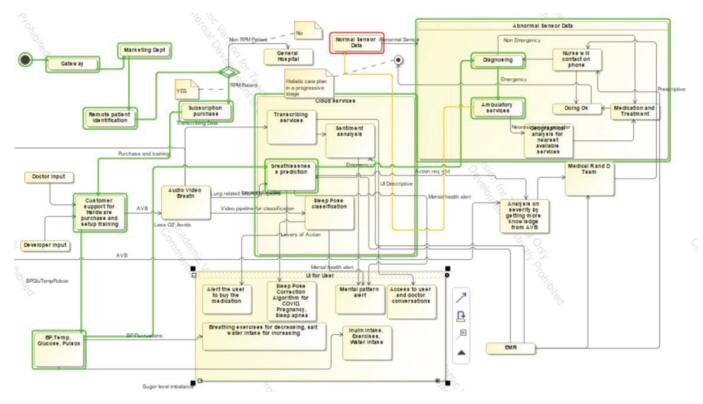

Figure 3. High-level Architecture.

Figure 4. Simulation of State machine Behavior of the WDT-based RPMS.

Intelligence

1. Descriptive analytics: The sensors are used to convert the useful data in the form of text for further analytics. There are different forms of transcribing text from the given sensors.

    • Environment sensing to the text about the temperature, humidity, particle sensor readings, and GPS location.

    • Audio and Video to text from the time stamps and poses in that respective time stamps.

    • Breath sensor to text that shows the nature of the gut throughout the day.

    • Vitals to text to record the anomalies of the vitals.

2. Predictive analytics (Alerts): According to [23] the monitoring of vital signs can be the basis for the prediction of patient health status. Some of the different kinds of alerts discussed in the behavior of the system are

    • Alert user to buy medication for respective conditions

    • Breathlessness: Chronic Obstructive Pulmonary Disease (COPD) exacerbation alert, Corona Virus Disease (COVID) alert

    • Physiological: Blood Pressure (BP) fluctuations alert, Sugar level fluctuations alerts

    • Mental health alerts

To make the WDT-RPMS system efficient, constraints like genetic information, age, etc. shall be considered from Electronic Medical Records (EMR).

Levers of Action *(Prescriptions)*

1. To send an alert for Sleep pose correction based on scientific evidence. Levers of actions are shown with the problem against the solution below.

    • COVID/Long COVID Patient - to Prone position for better breathing. [24]

    • Pregnant women -to the left side to decrease stomach-related inconveniences [25]

    • Obstructive sleep apnea- Side-way sleeping [25]

2. To send an alert to do evidence-based breathing exercises

    • Slow and regular breathing can lower blood pressure (BP). [26]

    • Mental health: SKY breath reduces stress levels.[27], [28]

Conclusion

In-memory computing and MBSE make WDT-RPMS a reliable solution for precision medicine to improve individual health outcomes, thus it contributes to improving global health outcomes.

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Illustration 1. Presented poster at LAEDC 2022.