Grenze International Journal of Engineering and Technology, January Issue

Next – Gen Smart Cloth Monitoring with Digital Twin Technology: Sensor Integration and Cloud Computing

Divya Rangari[1] and Vinaya Gohokar[2]
[1-2]Department of Electrical and Electronics Engineering, Dr. Vishwanath Karad MIT World Peace University, Pune, India
Email: rangaridivya111@gmail.com, vinaya.gohokar@mitwpu.edu.in

***Abstract*—In this era of technological advancements, wearable technology stands out as a rapidly evolving technology. One of these wearable technologies is Smart clothing. This combination consists of electronic components either sewed into the fabric or attached to the fabric which enhances the functionality and comfort of everyday clothing. This paper proposes the execution of digital twin systems for smart clothing by integrating the sensors with ESP32 controllers and using Blynk cloud platform. The cloud platform provides secure storage, analysing and visualising the collected data. With the help of Unity platform, a digital twin is created for smart clothing which mirrors the real-world data in virtual reality. By using the digital twin, it is possible to investigate the effectiveness of smart cloth, in its application in healthcare, sports performance analysis and more. This research verifies the dependability and validity of monitoring systems and lays groundwork for advancements in wearable technology and personalised healthcare.**

***Index Terms*— digital twin, smart clothing, monitoring, fitness, sensors.**

I. INTRODUCTION

Technological advancements have led to the confluence of wearable technology and digital innovation, culminating in the development of smart clothing. A high-quality wearable is one that you hardly notice you are wearing for most of the time, it offers a breathable experience to the user. The data collected from the smart cloth provides insights to the user's health status, activity patterns, which can be used to personalise the health monitoring and performance optimization. Importance of smart apparel can be divided into multiple categories such as comfort, disease detection, health monitoring, accurate measurements and more. Smart apparel provides considerable utility for patients that require uninterrupted surveillance [7]. They also have the potential in detecting cardiovascular ailments [16]. For fitness enthusiasts, smart apparel provides real time feedback which helps in improving their exercise routines for optimised outcomes [27]. Smart apparel can be made to adapt the individual's comfort preference [28]. Furthermore, this type of clothing facilitates seamless connectivity to various devices through which we can have hands-free communication, music management, notification responses and optimising overall usage of an electronic device [30]. The Table 1 shows different types of smart apparel or smart devices which are currently present in the market and are in trend.
Smart wearables gadgets such as smart watches (Fig. 1A) or wristband have many sophisticated functionalities, for example they display all types of notifications received on the paired smartphone whether its incoming calls or text message or email. They meticulously track user activity such as step count, calories burned during physical exercise, heart rate, alarm or using the web and more.

Grenze ID: 01.GIJET.11.1.513

Smart sock (Fig. 1B) devices operate by continuously monitoring the temperature levels from the six distinct points on each foot throughout the day. Remarkably, these socks obviate the need of plug-in charging, as they are automatically activated when the user wears them and deactivated upon removal. To facilitate data transmission the hub is required to be connected to a power source. Moreover, this technology exhibits machine washable properties and has a life span of one year [29]. One of the examples for smart socks is Sensoria Smart socks which monitors the foot pressure distribution during walking, running and provides insights in running techniques. It also helps to prevent common injuries such as stress fractures and plantar fasciitis.

TABLE I. DIFFERENT TYPES OF SMART TECHNOLOGIES PRESENT IN THE MARKET

Types	Manufacturer	Uses
Smart Watch	Samsung, Apple, FireBolt, Fastrack	Calls, messages, measuring body parameters like calories burnt etc.
Smart Sock	Sensoria	Monitor foot pressure distribution during walking or running.
Denim Jacket	Levi's	Clicking pictures, answering calls, music control.
Nadi X Yoga Pants	Wearable X	Guides user in achieving proper yoga poses.
Ralph Lauren Polo Tech Shirt	Ralph Lauren	Tracks heart rate, breathing depth and stress levels during workouts.
Hexoskin Smart Shirts	Hexoskin	Monitors heart rate and sleeping patterns.
OMSignal Biometric Apprel	OMSignal	Monitors heart rate, breathing rate and calorie expenditure.
Athos Smart apparel	Athos	Monitor muscle activity.

The denim trucker jacket (Fig. 1C) has an inbuilt jacquard sensor embedded on the left sleeve. This sensor allows the jacket to pair with a smartphone via Bluetooth, which allows the user to perform basic actions, receive alerts and respond to them without the need to divert their gaze to the screen. It includes playing music, call management (acceptance or rejection), clicking pictures. The jacquard mobile application user has the flexibility to customise different gestures to different actions, user can assign different led lights for different notifications for better understanding. The objective behind this jacket is to effortlessly interact with the digital realm while maintaining smooth integration with real world activities [30]. Similarly, some other examples are Athos smart apparel, Hexoskin smart shirts, Sensoria fitness apparel, Ralph Lauren polo tech shirt (Fig. 1D). Flexible pressure sensors are attached at the knee-joint of the pants. This sensor detects any strains in knee muscles and identifies any potential injuries that may arise due to the muscle strain. This technology helps in preventing any kind of knee injury [8]. Smart pants present in the market are Nadi X Yoga Pants which helps the users to achieve proper yoga poses.

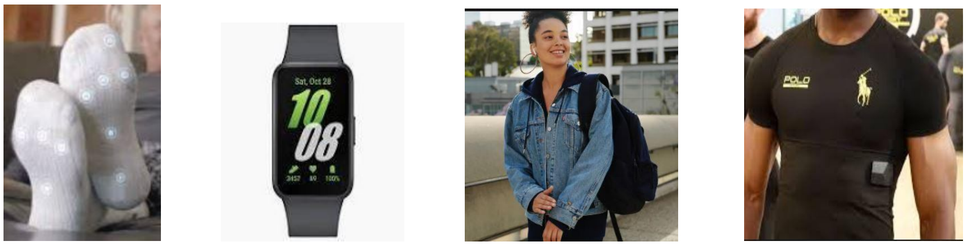


Fig. 1A Smart Socks   Fig. 1B Smart Watch   Fig. 1C Jacket   Fig. 1D Tech Shirt

Improved decision making can help us improve the performance of the smart cloth. Digital Twin, which can also be described as the virtual counterpart of a physical asset can help in optimising the performance of smart cloth. It enables real time data prediction, monitoring and control. Digital twin manifests as a virtual counterpart of the user providing real-time status within a virtual environment and giving back feedback to the user. Since the Digital twin records real world data, we can use this information to make improvements in the next generation of products and to identify faults that require rectification by technicians which serves as foundation for future iteration of products. By creating a digital twin, manufacturers can improve the behaviour and optimise the performance in real time. It is responsible for

- Operational efficiency: The digital twin technology can detect issues that were previously overlooked and empowers the businesses to optimise processes and suggest improvements.
- Product improvements: Designers can use the observations from this technology for refinements in designs and introduce subsequent features in product iterations.
- Improve service quality: Guides service technicians and customers via augmented reality to deliver expert assistance.

- Personalized Healthcare: The system is capable of being customised according to the user's needs and requirements. Overall user experience is enhanced by customising the garment with interactive features.
- Remote Monitoring: Digital twin enables remote monitoring for patients requiring continuous monitoring.

This paper proposes a digital twin for smart cloth. Section 2 explains the methodology detailing the sensors used in the implementation. Last section presents the results, conclusion and future directions.

II. METHODOLOGY

This proposed work focuses on the development and implementation of a digital twin system for smart clothing by integrating sensors with ESP32 controller and utilizing the Blynk cloud platform. The following steps outline the methodology used:

- To detect the heart rate and blood oxygen, sensor MAX30102 is used and for temperature, MLX90614 sensor is used. These sensors can be attached to the fabric, such that they do not compromise the comfort of clothing. To interface these sensors, read data and transmit the data wirelessly ESP32 microcontroller is used.
- Once the sensors read data, ESP32 is programmed to send this data to Blynk Cloud Platform using Wi-Fi, where this data is stored and can be used for future references.
- A new account was created on Blynk Cloud Platform and necessary configurations were created to store the data. Dashboard was designed in such a way that real-time data can be visualized and the previous stored data is also shown.
- To create a digital twin Unity 3D platform is used, this platform mirrors the real-time data collected by the sensors. To ensure seamless transmission of data an API key is used to transmit the data from Blynk cloud to Unity 3D. The digital twin is designed to update the parameters whenever there is a change in data collected by the sensors.
- Initially the prototype was tested in different conditions to evaluate the reliability and performance. The collected data was then compared to the data collected by a smart watch to validate the accuracy of the prototype.
- The data collected is safely stored on Blynk cloud for future analysis. Results can be analysed using both the Unity 3D and Blynk platform.

Figure 2 explains the system block diagram. It mainly consists of Hardware Module, Software Module, Cloud and the Feedback mechanism. This section details every module.

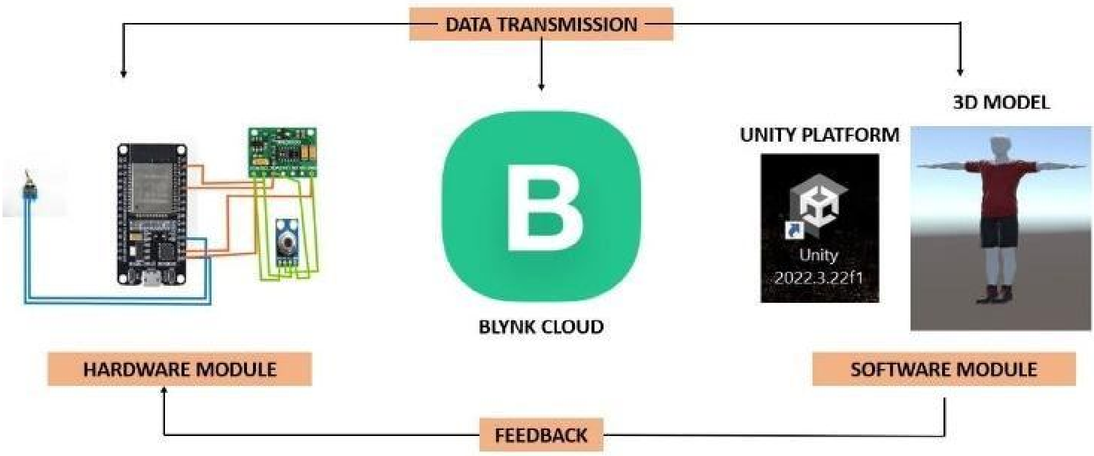


Fig. 2 System Block Diagram

A. Hardware Module

The proposed work uses MAX30102 which measures blood oxygen levels, heart rate and MLX90614 which measures the body temperature. ESP32 is used as the central processing unit. The gathered data is saved in the Blynk cloud, feedback is given to the user if any of the parameters crosses its normal limit. Hence, notifying the user that they need to relax.

The figure 3 shows the connection between sensors and ESP32. The temperature sensor MLX60914 and oximeter MAX30100 integrated with ESP32 controller are present in physical space.

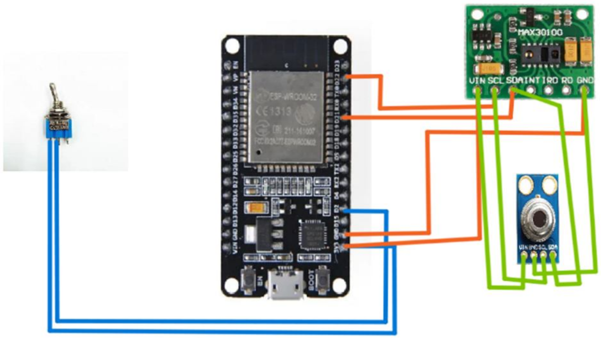
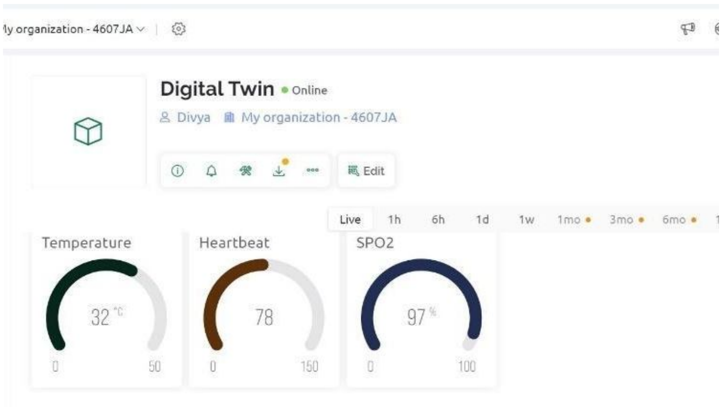


Fig. 3 Connection Diagram

The normal range of body temperature is 35°C -37 °C, blood oxygen level is 95% to 100% and heart rate is 60-100 beats per minute (bpm). During workout the body temperature increases due to increased metabolic activity and heat production which can lead to heat-related illness. Blood oxygen levels usually remain stable and may slightly increase during exercise. Heart rate increases during exercise as demand for oxygen increases in the body but returns to its normal rate after exercise and a faster decline in heart rate usually means better cardiovascular fitness. The data gathered from the sensors is stored on the Blynk cloud platform using Wi-Fi connectivity. The figure 4 shows screenshot from Blynk cloud.



Visualisation of data on the cloud

We have compared the response of our system parameters with those obtained from a smart watch. The parameters observed are heart rate, blood oxygen levels and temperature of the body. Table 5 shows heart rate, Table 6 shows blood oxygen levels and Table 7 shows body temperature. From the data it is observed that almost sensors are placed at the body, we receive more accurate data than a smart watch.

TABLE II. HEART RATE

Sr. no	Smart Watch (in BPM)	Our System (in BPM)	Error (in BPM)
1	73	78	5
2	75	78	3
3	79	81	2
4	86	88	2
5	118	130	12

TABLE III. BLOOD OXYGEN LEVELS

Sr. no	Smart Watch	Our System	Error
1	98%	96%	2
2	97%	93%	4
3	96%	97%	1
4	97%	96%	1
5	98%	97%	1

TABLE IV. TEMPERATURE

Sr. no	**Smart Watch (°C)**	**Our System (°C)**	**Error (°C)**
1	31	32	1
2	32	33	1
3	33	34	1
4	32	33	1
5	31	31	0

B. Digital Twin Implementation

There are various digital twin platforms including Blender, Siemens digital twin platform, Microsoft Azure, Dassault 3D Experience, PTC Thing Worx and Unity 3D. This project uses Unity 3D to display the real-time state of the user in virtual space. A 3D model of the user is constructed using Unity3D platform which replicates the physical domain and gives feedback to the user if any of the sensors crosses its desired limits. We have also connected a switch so that we can select which body parameter to measure first. The data gathered from the sensors will be saved on Blynk cloud platform. Unity will fetch data from Blynk cloud and display it on the 3D model. Steps involved in the design of Digital Twin are as follows:

Step 1: A human model is created with Blender modelling tool. Beginning with basic shapes like cylinders, spheres etc. then refined it to create limbs, heads and torso.

Step 2: Once human model was completed, we started with separate meshes for T-shirts, shorts and shoes, using Blenders sculpting and modelling tools to shape the clothing meshes around the body.

Step 3: UV unwrap both the human model and the clothing meshes to prepare them for texturing. This step ensures that textures will be applied accurately to the model’s surface.

Step 4: Texturing – create textures for the human model and clothing using either Blender’s built in texture painting tool or external software. Apply the texture to the corresponding UV maps.

Step 5: Rigging – rig the human model with armature (skeleton) using Blender’s rigging tools. Ensure that the armature is properly aligned with model’s mesh and has the necessary bones for animation.

Step 6: Weight Painting – assign vertex height to the mesh to define how each part of the model deforms when animated, using Blender’s weight painting tools to adjust the influence of each bone on the mesh.

Step 7: Animation – create animation for the model by using Blender’s animation tool. Pose the rig to create keyframes for different actions such as walking, running or idle pose.

Step 8: Export as FBX – once the model, texture, rig and animations are complete export the entire scene as an FBX file from Blender. Make sure to include all necessary materials and animations in the export settings.

Step 9: Import to Unity – open your unity project and import the FBX file into the assets folder. Unity will import the model along with its textures, rig and animations.

Step 10: Set-up in Unity – drag the imported FBX file into the scene to place the model. Configure any additional settings physics collider or animation controller as needed. Test the model in Unity scene to ensure everything is working correctly.

Step 11: Adding Script – once model is ready, add the code in C sharp which fetches the data from cloud and is displayed on the model in Unity.

Figure 5 shows the results after implementation of Digital Twin.

Fig. 5 Visualisation of Digital Twin

III. CONCLUSION

The integration of digital twin systems with smart clothing marks a significant advancement in wearable technology. By utilizing ESP32 controllers and the Blynk cloud platform, we have developed an efficient system for data storage, analysis, and visualization. The Unity platform to create a digital twin allows for real-time mirroring of data in a virtual environment, providing valuable insights into the performance and effectiveness of smart clothing. This innovative approach not only enhances the functionality and comfort of everyday clothing but also opens new possibilities for applications in healthcare, sports performance analysis, and beyond. In summary, the evolution of Digital twin technology with smart apparel and textile enhancement will represent a paradigmatic shift in intersection of technology and fashion, ushering a new era of interconnected and intelligent clothing, personalized healthcare and wearable technology.

FUTURE SCOPE

Integrating more advanced and varied sensors into smart clothing to capture a wider range of physiological and environmental data, improving the comprehensiveness of monitoring can be the future scope. In addition
AI and machine learning algorithms can enhance the analysis of collected data, enabling more accurate predictions and personalized recommendations for users.

REFERENCES

[1] Yu, Feng, et al. "Smart clothing system with multiple sensors based on digital twin technology." IEEE Internet of Things Journal 10.7 (2022): 6377-6387.

[2] Lai, Ching-I., Chang-Franw Lee, and Fu-Jin Wei. "Smart clothing as a noninvasive method to measure the physiological cardiac parameters." Healthcare. Vol. 9. No. 10. MDPI, 2021.

[3] Koyama, Yuya, Michiko Nishiyama, and Kazuhiro Watanabe. "Smart textile using hetero-core optical fiber for heartbeat and respiration monitoring." IEEE Sensors Journal 18.15 (2018): 6175-6180.

[4] Kubicek, Jan, et al. "Recent trends, construction, and applications of smart textiles and clothing for monitoring of health activity: A comprehensive multidisciplinary review." IEEE Reviews in Biomedical Engineering 15 (2020): 36-60.

[5] Liu, Zhishuo, Simeng Lin, and Han Li. "Production Scheduling of Regional Industrial Clusters Based on Customization Oriented Smart Garment Ecosystem." International Journal of Crowd Science 7.1 (2023): 1-9.

[6] Liang, Zhen, et al. "Smart Garment: A long-term feasible, whole-body textile pressure sensing system." IEEE Sensors Journal (2023).

[7] Meng, Keyu, et al. "A wireless textile-based sensor system for self-powered personalized health care." Matter 2.4 (2020): 896-907.

[8] Yu, Miao, et al. "Development and design of flexible sensors used in pressure-monitoring sports pants for human knee joints." IEEE Sensors Journal 21.22 (2021): 25400-25408.

[9] Miao, Yiming, et al. "Green cognitive body sensor network: architecture, energy harvesting, and smart clothing-based applications." IEEE Sensors Journal 19.19 (2018): 8371-8378.

[10] Rasheed, Adil, Omer San, and Trond Kvamsdal. "Digital twin: Values, challenges and enablers from a modeling perspective." IEEE access 8 (2020): 21980-22012.

[11] De Benedictis, Alessandra, et al. "Digital twins in healthcare: an architectural proposal and its application in a social distancing case study." IEEE Journal of Biomedical and Health Informatics 27.10 (2022): 5143-5154.

[12] Fuller, Aidan, et al. "Digital twin: Enabling technologies, challenges and open research." IEEE access 8 (2020): 108952-108971.

[13] Wang, Yuntao, et al. "A survey on digital twins: Architecture, enabling technologies, security and privacy, and future prospects." IEEE Internet of Things Journal 10.17 (2023): 14965-14987.

[14] Tao, Fei, et al. "Digital twin in industry: State-of-the-art." IEEE Transactions on industrial informatics 15.4 (2018): 2405-2415.

[15] Caesar, Birte, et al. "Digital Twin Framework for Reconfiguration Management: Concept & Evaluation." IEEE Access (2023).

[16] Chang, Wei-Ting, et al. "Design of smart clothing with automatic cardiovascular diseases detection." IEEE Transactions on Human-Machine Systems (2023).

[17] Yang, Ming, and JunHui Cheng. "Research and development of smart health monitoring clothing system." 2018 37th Chinese Control Conference (CCC). IEEE, 2018.

[18] Xu, Jun, et al. "Development and evaluation of a respiratory monitoring smart garment based on notched optical fiber sensing fabric." IEEE Sensors Journal 22.15 (2022): 14892-14902.

[19] Seneviratne, Suranga, et al. "A survey of wearable devices and challenges." IEEE Communications Surveys & Tutorials 19.4 (2017): 2573-2620.

[20] Seneviratne, Suranga, et al. "A survey of wearable devices and challenges." IEEE Communications Surveys & Tutorials 19.4 (2017): 2573-2620.

[21] Chen, Min, et al. "Edge cognitive computing based smart healthcare system." Future Generation Computer Systems 86 (2018): 403-411.
[22] Anguita, Davide, et al. "A public domain dataset for human activity recognition using smartphones." Esann. Vol. 3. 2013.
[23] Lee, Hyunseung, and Kyungsoon Baek. "Developing a smart multifunctional outdoor jacket with wearable sensing technology for user health and safety." Multimedia Tools and Applications 80.21 (2021): 32273-32310.
[24] Sánchez, Graciela, Cristian Castro, and David Mauricio. "Roadmap of projects for the design of clothing with wearable technology." 2022 IEEE Engineering International Research Conference (EIRCON). IEEE, 2022.
[25] Lin, Chung-Chih, et al. "Intelligent health monitoring system based on smart clothing." International Journal of Distributed Sensor Networks 14.8 (2018): 1550147718794318.
[26] Sima, Karel, et al. "System for testing and evaluating the thermal comfort of smart textiles clothing." 2020 43rd International Spring Seminar on Electronics Technology (ISSE). IEEE, 2020.
[27] Montes, Jeffrey, et al. "Reliability and validation of the hexoskin wearable bio-collection device during walking conditions." International journal of exercise science 11.7 (2018): 806.
[28] Sahta, I., et al. "The control of human thermal comfort by the smart clothing." SHS Web of Conferences. Vol. 10. EDP Sciences, 2014.
[29] Scholten, Henk Jan, et al. "Utilization of a smart sock for the remote monitoring of patients with peripheral neuropathy: cross-sectional study of a real-world registry." JMIR Formative Research 6.3 (2022): e32934.
[30] Kumar, Aayush, et al. "JacquardToolkit: enabling interactions with the Levi's Jacquard jacket." Proceedings of the 2019 ACM International Symposium on Wearable Computers. 2019.