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Wearable Evolution: Mapping the Strengths, Weaknesses, Opportunities, and Threats of Smart Clothing

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ABSTRACT

Smart Clothing is a part of rapidly evolving wearable technology sector. It is an outcome of the idea of merging electronics and technology with clothing to impart a functional aspect to clothing in addition to the traditional ones.The journey from a concept to the present-day innovative products presents a transformation in design philosophy with the integration of electronics and clothing, beginning a new age of user centric design. Global market trends also indicate a strong growth in wearable technology sector with applications like health monitoring, elderly care, daily life aid, fitness tracking, sports, fashion, entertainment, self-defense etc. Considering different aspects of wearable technologies, the present study is an attempt to analyze the strengths, scrutinize weaknesses, explore opportunities, and address threats associated with smart clothing.

Key Words : Wearable technology, Smart clothing, Strength, Challenges, Opportunities, threats

INTRODUCTION

Smart Clothing is a rapidly evolving branch of wearable technology sector. By integrating electronics with clothing, it brings together the fields of technology and fashion to impart functionality beyond regular clothing and revolutionize the way in which a wearer interacts with their clothing and the environment. It marks a shift by which garments are not merely fabrics but a participant in a person's life, assisting and easing out daily functions. It is aimed at increasing utility while maintaining comfort.

Smart clothing is embedded with sensors, actuators, control system, communication modules and power supply source (Fernandez-Carames & Fraga-Lamas, 2018). Display unitsare also included depending upon case and requirement. Sensors gather real time data from the environment (eg. Temperature, UV, light intensity, air pollution, motion, pressure applied) or the wearers body (eg.heart rate, body temperature). This collected data acts like a stimulus for the entire smart clothing system. 'Brain of the clothing'- the control system processes the data received from sensors as per their pre-defined algorithm and sends command to actuators (eg. - vibration motors, light, sound) for performing physical action. The communication module is responsible for exchange of data between the clothing item and external device (like a smartphone), cloud storage, or a network like IoT. Bluetooth, Wi-Fi, Near Field Communication (NFC) and other communication protocols are used to establish connectivity and interactivity of clothing. By virtue of its capability of continuous data transfer and synchronization, smart clothes offer connectivity and customization which makes them useful for diverse applications like health monitoring and diagnostics, hazard detection, fitness tracking, sports performance enhancement, posture correction, self-defense, military use, fashion and entertainment, sleepwear, elderly wear, daily life aid for specially abled and many more to come. Garments embedded with emergency alert systems possess the capability of notifying selected contacts in case of distress

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condition of the wearer as sensed by the sensors. This finds application for women and child safety. Use of environmental sensors for sensing UV exposure, surrounding temperature, air borne harmful chemicals (air pollution) is primarily meant for comfort and well-being of the wearer, but such data will also raise awareness towards the environment and lead to a broader societal shift towards environmental consciousness and sustainable practices. From this it is evident that application of such clothing is not confined to a singular domain, rather it has the capability to merge into numerous dimensions of our life.

A wide spectrum of possibilities opens with the integration of smart clothes with Internet of Things (IoT) technology to enable their communication with other devices of the IoT ecosystem. Amidst all the developments and advancements happening on a daily basis, this paper presents a SWOT analysis on smart clothing. The rationale behind conducting such analysis is the need to comprehend the multifaceted forces directing the trajectory of future progress. By analyzing the strengths, scrutinizing weaknesses, exploring opportunities, and addressing threats in this area, the aim is to put up a comprehensive assessment for understanding those factors which are and will be determining the upcoming challenges and success of smart clothing technology. This analysis is also aimed at generating insights to guide the stakeholders, policymakers, researchers, and potential users. It is also an endeavor to support the sustainable development of smart clothing as "Next Generation of Clothing".

METHODOLOGY

The current SWOT analysis is based on secondary data. Literature in the form of research articles, research reports, e-books, review articles, conference proceedings, official websites of smart clothing manufacturers, market trend reports, consumer surveys, published expert opinion have been searched for using the keywords- concept of smart clothing, use of smart clothing in various fields, innovations with smart clothing, benefits, challenges, opportunities associated with smart clothing, consumer perception, consumer preferences and feedback, consumer resistance or acceptance, threats and privacy issues, perceived v/s actual outcomes. All data collected has been reviewed, relevant data has been filtered out and further categorized as strength, weakness, opportunity, or a threat in the form of a matrix displayed as Table 1 in the results section of this paper. Sources of data include online research databases like Shodhganga, Google Scholar, reputed research journals (Sage, Springer, Taylor & Francis etc.), Research Gate, MDPI.

RESULTS AND DISCUSSION

Data obtained as per the above stated methodology was studied and analyzed. Further it was grouped into strengths, weaknesses, opportunities, and threats and is presented below as Table 1.

Table 1: SWOT Matrix

Strength	Weakness
• Design along with functionality and comfort is of great interest of future consumers.(Jiang, Stange, Bätcke, Sultanova, & Sabantina, 2021) • Enhancement in creativity of designers and more design liberalization through embedded electronics allows integration into mainstream fashion with a wide range of garment styles leading to increase in consumer acceptance. • Monitoring of physiological activity for enhanced performance and health monitoring for overall well-being. • Data support for accurate diagnosis and assessment of health condition.(Sherrif, 2018) • Aid for elderly care without compromising comfort or independence. More economical than conventional methods.(DeccanChronicle, 2020) • Continuous vitals monitoring, risk assessment, generation of early warnings(Jiang, Stange, Bätcke, Sultanova, & Sabantina, 2021), prevention of accidents and injuries (Kosobudzka, 2023)	• High price in relation to currently realised benefits(Jiang, Stange, Bätcke, Sultanova, & Sabantina, 2021) • Limited washability, battery size (Jiang, Stange, Bätcke, Sultanova, & Sabantina, 2021) and sophisticated handling. • Requires the user to be technology friendly. • Not tested for use in diverse conditions. • Current garment manufacturing unitsare not suitable for smart clothing manufacturing. (Jiang, Stange, Bätcke, Sultanova, & Sabantina, 2021) • Manufacturing of such clothing requires availability of technically trained staff. • Requirement of special sales personnel who possess precise and detailed information about all aspects of the garment. • Lack of mass data management architecture for managing complex data (Park *et al.*, 2012).

Contd…. Table 1

Table 1 contd…

• Wide scope for customisation. • Market value- 2.62 billion in 2022 which is forecasted to be 20.35 billion till 2030. Strong Growth in market share with a CAGR 26.70% over 2023-2030. (DataBridgeMarketResearch, 2023) • By analysis of data collected, design of product will be more consumer centric with greater level of similarity to actual requirement. • Cross industry collaborations. (Jacquard by Google, n.d.) Advances in the field of Graphic User Interface provides data in user friendly manner.	• Impractical for usage on large scale without cleaning, revision, and integration (due to errors and different standards of measuring devices) (Chen, Ma, Song, Lai, & Hu, 2016) • Lack of frequent upgrade can reduce compatibility and utility.
Opportunities	**Threats**
• Technology developments can revolutionize design thinking. (Jiang, Stange, Bätcke, Sultanova, & Sabantina, 2021) • Ample of undiscovered applications (Jiang, Stange, Bätcke, Sultanova, & Sabantina, 2021) • Developments in e-textiles (Jiang, Stange, Bätcke, Sultanova, & Sabantina, 2021) • Integration with IoT will open wide spectrum of possibilities in application(Fernandez-Carames & Fraga-Lamas, 2018) • Advancements in connectivity. • Research and Development for advanced and compact energy harvesting material will have a positive impact on reducing dependence on energy storage equipment and result is a self-sufficient system. (Dolez, 2021) • Growth in demand due to global climate change conditions. (Patwary, 2022) • Growth rate indicates business expansion opportunities. • Target population growth due to increasing technology acceptance. • Investment boom (ETOnline, 2023) (Global Data, 2023) • Growth in virtual market presents a better opportunity to display a visualisation of such garments and their functionality in 3D.	• Psychological stress issues. (Patwary, 2022) • Data security- sensitive data at risk(Patwary, 2022) • Inconfidence regarding access of data. • Unestablished safety for use by people with medical implants. (Chen, Ma, Song, Lai, & Hu, 2016) • Lack of maintenance services. • Legal Hazard (Ziccardi, 2020) • Improper disposal of such garments will lead to accumulation of hazardous electronic waste.(Needhidasan, Samuel, & Chidambaram, 2014) • Metal and nanoparticle absorption through skin (Mondal, 2018) • Improper handling can lead to accidental shocks, overheating or complete system damage. • Effects of continuous exposure to electromagnetic waves (for communication) emitted by smart clothing are not well established.

Strengths:

Here is a discussion of strengths of smart clothing.

Fashionable design, enhanced functionality along with ease of wearing smart clothes are major points of interest to future consumers.

Smart clothing monitors heath parameters of athletes while performance and provides important information regarding fatigue reduction and performance enhancement. Monitoring of physiological activity also aids in posture correction in daily life (Cision, 2015), correction for yoga helps in health improvement (Posture Monitoring and Vibrational Guidance, n.d.), breathing monitoring for stress detection and relief (MYSA, n.d.), smart active wear for fitness tracking (Apparel Resources, 2018).

Smart Clothing provides data support for accurate diagnosis, assessment of health conditions and treatment planning (Sherrif, 2018).

Smart Wearables find application in daily life support for specially abled (Srivastava and Singh, 2018). It is also establishing its importance for elderly care without compromising comfort or independence. It is more economic than conventional methods like employing a nurse or a caretaker who are prone to committing errors in performing their duties. Continuous vitals monitoring, risk assessment, generation of early warnings (Jiang, Stange, Bätcke, Sultanova, & Sabantina, 2021) like in case of heart attacks- continuous monitoring of cardiac activity and detection of irregularities can result generation of early warning for timely medical intervention leading to better consequences.

Moreover, scope for customization and capability of integration of the concept of smart clothing with a range of garment styles increases its acceptance with a wide variety of consumers.

Market value of wearable technology sector was

2.62 billion in 2022 which is forecasted to be 20.35 billion till 2030. Strong Growth in market share with a CAGR 26.70% over 2023-2030. (Data Bridge Market Research, 2023)

By analysis of data collected through smart clothes, understanding of consumer lifestyle and requirements is possible and design of product will become more consumer centric with greater level of similarity to actual requirement.

Cross industry collaborations. (Jacquard by Google, n.d.) is a key strength and paves way for breakthrough developments in the field of smart clothing sector.

Advances in the field of Graphic User Interface provides data in user friendly manner. Chunks of data collected through smart clothing is difficult to understand and interpret. Graphic User Interface makes it possible to present data in an organised manner making it easy to interpret and bring out conclusions. Continuous research in user-friendly graphic interface development makes complex data and analysis available to all which is essential for complete utilization of functionalities of smart garment.

Weakness:

A major weakness of smart clothing is high price in relation to the currently realised benefits. Factors adding up to increased cost are conductive fibres, advanced sensors and their integration into the clothing, manufacturing is labour intensive process and its currently being done at a small scale.

Smart Clothing cannot undergo usual laundry process and offers limited washability. It requires special handling while washing due to the possibility of damage or wear and tear to electronic components. R&D in the field of waterproof and washable electronic components may change this condition in future but in present situation, is a weakness which discourages its use.

Smart clothing is embedded with electronic units which require power supplied by a battery to function as per program. Battery size and placement is again a discouraging factor that adds bulk to clothing. Research related to development of ultra-thin flexible batteries is currently in nascent stage and requires rigorous testing in all aspects of functionalities.

When it comes to the user's end, it requires a user to have a certain level of technological education. A technically inexperienced or uneducated person cannot handle a smart garment and utilize its functionalities. Moreover, they will not be able to understand and interpret data collected through the garment and its use.

Smart Clothing is not tested to work in diverse conditions. It has pre-defined conditions of working so use of such garments is limited to areas where the condition is being satisfied.

At the manufacturing end, the present garment manufacturing units/ factories are not suitable for manufacturing of smart clothing. To produce such garments, new equipment has to be set up to deal with electronic components, production plans need to be re-planned, technically trained staff has to be employed at multiple points of the production line which is a capital-intensive task. Some part of the current manufacturing workforce will have to be replaced with technical experts throughout the manufacturing system. Similar situation applies on sales staff. At every selling point, it will have to be mandatory to employ a specialist who has detailed and updated knowledge about all technical and functional aspects of the garment so that sales queries can be addressed.

Smart clothing collects data continuously. When used by masses, accumulation of data will be in such a large quantity which will eventually require proportionally large data management architecture which should be capable of filtering out useless data, analysis of data, storage of relevant data along with ensuring data security at the same time, development of which is labour, time and budget intensive work even for technology giants.

Current versions of smart clothes are impractical to be used on a large scale because the data is collected by different sensors on the clothing which work on different standards. Also, the data collected is not error free. All data collected needs to be cleaned, revised, and integrated together to get some meaningful information. Without this, data collected is just equivalent to useless long list of figures.

Software requires frequent upgrades to function at their optimum capacities and give desired results. Frequent upgrades in software of connected device can reduce the compatibility of smart garment (which is not frequently upgraded) with the connected device and result in malfunction or make the garment useless from technical functionality aspect resulting in shortening of smart garment life span.

Opportunities:

Opportunities associated with the field of smart

clothing are discussed as follows:

Ongoing research and development in the field of e-textiles like organic electronic material (Stegmair, 2012), miniature microprocessor embedded in textile (Hughes-Riley, Dias, & Cork, 2018), energy harvesting textiles, conductive ink, flexible sensing components (Mondal, 2018) open up opportunities for development of improved and more productive versions of smart clothing.

Integration of Smart Clothing system with IoT will enable establishment of a connection between the garment and other devices within the IoT system. Doing so will result in new applications like opening doors on approaching nearby, authenticating transactions, controlling sequence of actions within the IoT connected devices etc. (Fernandez-Carames & Fraga-Lamas, 2018).

Advancements in communication technology like 5G along with artificial intelligence can enable better communication with and among smart garments with better functionality and enhanced performance.

Research and Development for advanced and compact energy harvesting material will have a positive impact on reducing dependence on energy storage equipment and result is a self-sufficient system. Current dependence on energy source can even get eliminated.

A report by (Data Bridge Market Research, 2023) indicated strong growth in market share of smart wearables with a CAGR 26.70% over 2023-2030 which implies business expansion opportunities in this sector. Increase in investment as per (ET Online, 2023) and (Global Data, 2023) reports indicates supports the notion of increasing opportunities for development in smart wearable sector. Further, increase in technology acceptance around the globe is leading to growth in target population of smart wearables.

Growth in virtual market presents a better opportunity to display a visualisation of such garments and their functionality in 3D. It will potentially serve as a platform for better display and demonstration of functionalities through 3 D simulations and virtual reality leading to better understanding of all features and services at the consumers end. Consumers will have better visualisation of how the garment will integrate into their lifestyle.

Threats:

Here is a discussion on threats associated with smart clothing.

Smart Clothes continuously monitors data (For example- Health related parameters) and make it available on a connected device. Such data is easy to access with a single tap or click. Data is essential for monitoring and better understanding of any situation, but its easy availability also leads to over emphasis and analysis, anxiety disorders, and psychological stress issues in the human mind.

Data Security is another major threat. Personal data is sensitive in nature and reveals personal life details about the person concerned. As a wide variety of personal data is collected, its security is a major concern. Health parameters of individuals reflect the health status of the society, especially when it comes to health-related data of security/ military personnel- leakage of such data is a threat to national security. Continuous location tracking is a threat to privacy, security and freedom if accessed by unauthorized persons or someone with malicious intentions. There is still a question in the mind of users about- Who all have access to the data being collected? Where is the data being stored? Is it kept secure enough to be inaccessible by people/agencies other than the one already disclosed? In essence, data security is still a threat which discourages users in adoption of smart clothes. Additionally, loss of a peripheral that allows access to central system is a potential threat to data safety.

Safety of smart clothing use by people with medical implants is still unestablished. Interference of electronic parts on the clothing with the working of medical implants like pacemakers is still a threat which is yet to be clarified through research.

Lack of maintenance services like diagnosis and repair of malfunctioning electronic parts, unexpected error occurrence is a condition which leaves the entire garment useless and is a threat to adoption of smart clothing. Such garments need to be tested at regular time intervals for proper functioning which also requires dedicated facilities.

Presently there is absence of any legislation or established standards on storage, use, handling and transfer of data collected through smart clothing. No accountability of data handling has been fixed which is a potential threat.

Smart Clothing has embedded metal parts and nanoparticles. Nanoparticles enter the human body through skin which is a threat to human health. Absorption through skin depends on how they are placed throughout the garment.

Smart Garments require special handling. Improper

handling can lead to accidental shocks, overheating or complete system damage.

Effects of continuous exposure to electromagnetic waves (for communication) emitted by smart clothing are not well established so considered as a potential threat until safety is fully established.

Conclusion:

Smart clothing is an emerging field in the present and has positive prospects. Every field has its own strengths, weaknesses, opportunities, and threats associated along with. Analysis and understanding of these aspects are crucial in ensuring sustainable and long-term growth. As we delve into the intricacies, it is quite clear that fashion and technology are together opening a myriad of possibilities. While moving towards future progress, SWOT analysis proves beneficial to industry stakeholders, policymakers, researchers, designers, and all associated with this field. Collective efforts to address weakness and threats, leverage strengths and explore opportunities to their fullest potential will contribute to user acceptance and sustainable growth.

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