3D Printing Technique Application in the Smart Wearable Devices

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Abstract. Smart wearable devices are a prominent topic in contemporary scientific research. Significant advancements have been made by researchers in leveraging 3D printing technology for the production and manufacturing of wearable smart devices. However, numerous challenges still exist in their widespread industrial application. Consequently, the primary research topic of this paper is the application of additive manufacturing technology in smart wearable devices. This paper applies some methods to explore this problem, such as accumulating data, staying updated with the latest research progress, and integrating and analyzing the collected data comprehensively. It researches the application of 3D printing technology in smart watches, smart clothing, and medical wearable devices. The study finds that the wearable devices manufactured by 3D printing have the characteristics of personalized production, customized services, reduced micro-processing needs, and so on. In the future, the development trend of smart wearable devices produced by additive manufacturing technology will be towards comfort, miniaturization, pluralism, and professionalization. In addition, smart wearable devices are anticipated to generate significant socioeconomic benefits.

Keywords: Smart Wearable Devices; Additive Manufacturing; Application

1 Introduction

Over the past several decades, it has been clear to witness a multitude of significant innovations within the realm of technology, one of which is the advent of 3D printing. Initially employed in the production of small-scale models, its usage has since proliferated across various industry sectors. The acceleration of growth within the domain of 3D printing has been truly remarkable, presenting manufacturers with unprecedented possibilities due to its capability to swiftly create complex components while minimizing waste. Additionally, the surge in the ubiquity of intelligent wearable devices in the consumer electronics market has been equally dramatic. From health monitoring gadg-

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ets to virtual reality headsets, an array of products continuously redefines users' understanding of technology. Within this context, the employment of 3D printing in the fabrication of intelligent wearable devices can not only enhance their customization but also offer abundant potential for design and functional innovations.

Nevertheless, despite the immense potential yielded by the convergence of these two major technologies, it also presents a myriad of challenges. Firstly, it is about safety and product quality. in some industries, like construction, they are likely to use 3D printing. but usually, the machine is very large, which creates some potential dangers. in this case, how to manipulate the machine safely and effectively becomes an issue. Additionally, this technology has not yet fully proliferated, encountering certain technological impediments. Therefore, a considerable journey remains before the 3D printing industry can attain profitability.

2 Literature Review

The genesis of wearable technology can be traced back to the 1960s, at the prestigious Massachusetts Institute of Technology's Media Lab, after which its evolution has been remarkable [1]. Intelligent wearable devices, as a form of portable electronic gadgets, amalgamate sensing, processing, storage, and communication capabilities into one [2]. These devices obtain data through contact with the user and transmit or store this data in real time. Hence, users can better understand their health and adjust their lifestyle accordingly. Users can either don these devices directly or opt for their integration with apparel or other commodities to impact distinctive functionalities such as monitoring, communication, treatment, assistance, and entertainment, to name a few. In recent years, the rapid expansion of wearable devices has been inexorable. As the depth and breadth of industrial production requirements elevate steadily, these devices are intertwining with multiple sectors to design wearables that meet the diverse needs of user scenarios. Presently, the market concentration of developed wearable devices is predominantly on intelligent clothing, smart watches and bracelets, smart glasses, health tracking devices, and medical equipment. The research and developmental focus are directed towards further miniaturization and weight reduction of these devices.

3D printing technology enables swift and integrated shaping of components with complex structures [3]. This transformative technology has emerged as a significant area of research in the realm of intelligent wearable devices. 3D printing facilitates the customization of wearable devices, catering to consumers' individualistic and diversified needs. It enhances the recovery and utilization rate of raw materials, thereby economizing production costs and augmenting production efficiency [4].

2.1 Flexible Sensor in 3D Technology Application

Due to the limitation in the traditional rigid sensor with aspects of sensibility, sensibility, elasticity which restricts its effects as a wearable sensor. With the development of materiel, manufacture, and nanotechnology, the novel flexible sensor with tunable performance, bio-capability, stability, and considerable electrical conductivity has been invented and gained increasing attention in the application of new wearable sensor servicing for robotics, healthcare, and human-machine interaction. according to the structure and mechanism of the flexible pressure sensor, there are four types of pressure sensors: piezoresistive sensor, capacitive sensor, piezoelectricity sensor, triboelectric sensor.

Table 1. Main characteristic of six pressure sensor

Flexible sensor	mechanism	application	advantages	disadvantages
Piezoresistive	Pressure affects the resistance of components	Heath care, medicine diagnosis and human-machine interaction	Rapid response	Limited accuracy and measuring range, disturbed evidently by temperature
Capacitive	Deformation affects the structure of components, changing the capacity	Wireless transmission, medicine diagnosis, electronic skin patch	Simple capacitive structure, quick response, high accuracy	Complex circuit, affected by temperature.
Piezo-electric	Piezoelectric effect with pressure and deformation	Wearable electronic device	Quick response (70ms)，flexibility durable，biodegradable	Low output signal intensity 、affected by temperature
Tribo-electric	Based on friction on nano generator, generate signal via triboelectric effect	Electric skin patch for health care	Flexible, non-irritating, durable	Weak output signal

2.2 Flexible Sensor in 3D Technology Application

To accumulate the current development of the wearable device, The new wearable sensor should be flexible, stretchable, durable, biocompatibility, and to match the features of these flexible sensors, a new manufacture that fabricate sensor with conductive nano material and soft polymers is developed [5][6]. via distributing the conductive nano material into these elastic material in certain pattern, these materials can perform high electronic conductivity and tuning capability while maintaining stability and flexibility, enhancing its application in health care and robotics [7].

Usually, these flexible are made of two types of material, stretchable polymers, and conductive nanomaterial. Strength polymers usually be used as the base material to compose the main structure and determine the physical features [8-10]. Additionally, Conductive nanomaterials mainly have carbon materials, metal materials, liquid metals, and conducting polymers [11]. Additionally, the distribution of the nano conductive fillers into the polymers forms essential effects in the sensing property and electronic conductivity with the construction of a conductive network [11].

2.3 Flexible Sensor in 3D Technology Application

Before the 3D printing technique was applied in the manufacture of flexible sensors, there has several traditional techniques developed for fabricating novel wearable devices. However, these techniques usually are applied to obtain components which is durable and be of stable electronic performance but can hardly tuned [12].

3D printing technique can make products via printing slices divided from the designed module [13]. First, generate a 3D model using professional design software or a scanner and transform it into a file formation. Secondly, slicing software is uses the saved file to yield file control the printing path and build up the module layers by layers [12]. There has six major 3d printing techniques used for manufacturing the flexible sensor: direct-ink writing (DIW), fused deposition modeling (FDM), stereolithography (SLA), binder jetting (BJ), inkjet printing (IJ), selective laser sintering (SLS).

Compared to traditional techniques, 3D printing gains advantages in inexpensiveness, scalability, customization, efficiency, and especially tunability via precise structure control with decreased waste.

3 Intelligent wearable sensor

3.1 Smart Switch

Currently, with the rapid advancement of technology, the emergence of smartwatches, diverging from the traditional timepiece, has become the cynosure of all eyes. These devices, equipped not only to display time but also to embody an advanced intelligent system capable of interfacing with smartphone systems, have engendered an array of practical, multifunctional uses. These uses span from everyday needs such as checking the weather and time, to immediate communication, physical activity monitoring, and health management (Fig. 1).

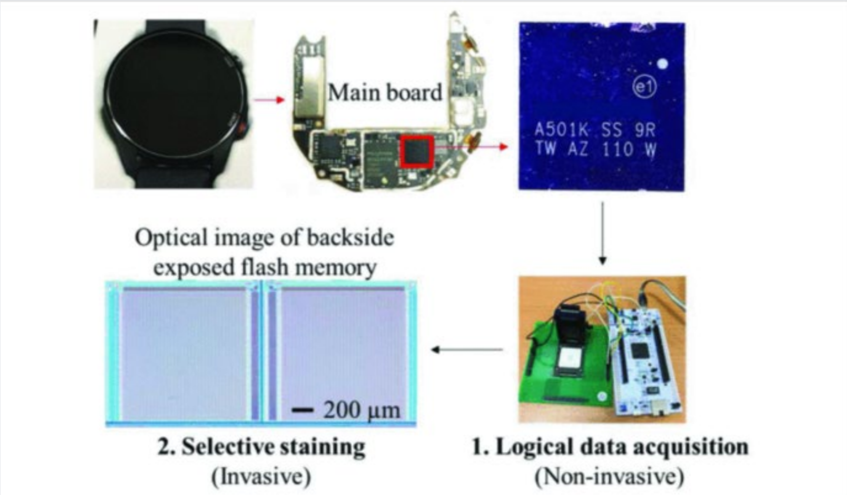

Fig. 1. Sample preparation flow for flash memory extraction, including watch teardown, logical data acquisition, and exposure of flash memory for selective staining through invasive backside reprocessing. [1]

The demand for smartwatches is developing towards personalization, customization, and flexibility. The advent of 3D printing technology offers enhanced possibilities and feasibility in meeting these demands, such as the industrial production of fingerprint sensor touch screens through inkjet printing. Ink-Jet Printing (IJP) technology is a 3D printing methodology based on ink ejection technology. The principle of its operation revolves around the print head depositing 3D printing material in droplet form onto a base via a nozzle, followed by cooling, solvent evaporation, or chemical changes to solidify the printed ink material, sequentially creating printed components. IJP enables the components with rapidity, efficiency, and a remarkable level of design flexibility. Today, IJP technology, on account of its simplicity and potential for large-scale efficient production, has increasing potential in industrial production, particularly in areas such as localized electroplating and fingerprint sensor touch screens [13]. Hence, IJP technology presents new possibilities in the fabrication of smartwatches and wristbands.

Compared to traditional manufacturing techniques, IJP technology is more flexible, customizable, eco-friendly, cost-effective, and productive. Its flexibility denotes automatic adjustment capabilities, enabling high-efficiency batch production of diverse components within a certain range and timely product adjustments to meet market conditions. Further, components produced by IJP technology can reach a tensile strength of 190.5 MPa. Therefore, while IJP technology can provide users with exclusive customization services, it is also suitable for large-scale mass production.

Nevertheless, the varieties of high-functioning conductive inks are limited, and the IJP process chain has its complexities, including the generation of highly dynamic ink droplets, intricate interactions between droplets and substrates, curing and post-processing programs, and compatibility of multi-material processes. Therefore, applying

IJP technology for the industrial production of products like smartwatches and wristbands still requires further research.

3.2 Smart Clothing

Modern clothing, thanks to advancements in science and technology, now incorporates technology and art. These clothes are not just for wearing, but also cater to people's aesthetics and health needs. Smart clothing is a type of modern clothing that includes technology like sensors or conductive fibers to increase their functionality. These innovations enable clothing to monitor, amass, store, transmit, and process data, thereby interacting with either the user or the environment in a myriad of way (Fig. 2).

Fig. 2. The sports T-shirt with various colors [1].

It is lengthy and complex between the traditional costume design and production, encompassing numerous stages. Influenced by factors such as production techniques and raw materials, it often fails to fully realize the designer's vision. The highly integrated forming process of 3D printing technology, however, enables the rapid completion of product design, processing, and formation, thus drastically conserving raw materials while reducing the waste of resources incurred by repeated pattern drafting [14]. Concurrently, 3D printing technology transcends the constraints of modeling and structure, thereby fully unlocking the freedom of design and showcasing the designer's abundant imagination.

3D printing technology particularly gain advantages with apparel. Following the introduction of the first 3D printed product to the market, an increasing number of clothing designers are incorporating this technology into their creations [15]. The application and development of 3D printing in the domestic and international apparel industry is multidimensional. Nike, Adidas, and Under Armour tries to drive trend in the market. These companies have begun emphasizing customization. Take Nike as an example, the company employs 3D-printed weaving technology to craft professional shoes for American national athlete Allyson Felix. Astonishingly, the production cycle has been dramatically reduced from roughly three months to merely a few hours, implying that suppliers can instantly create and furnish new, fitting shoes for the athlete [16].

Subsequently, Under Armour introduced a 3D printed component named "Archi-Tech Futurist" [17]. Compared to prior Nike sports shoes, it alters the shoe sole using 3D-printed weaving technology, enhancing the support on athletes while gaining the cushion value. Indeed, 3D-printed weaving technology does have a few drawbacks.

Due to the limitations of raw materials, the product is not as flexible and comfortable as traditional ones. Moreover, the high cost and limited targeted consumers make profitability challenging [18].

3.3 Smart Switch

Wearable medical devices have the potential to integrate doctors, patients, and cloud-based systems. Applying these devices in clinical medicine can provide accurate and effective patient monitoring and data collection, which is beneficial for disease prevention and treatment.

Human skin serves as a "bridge" connecting the brain to the external environment, and it could provide the body with abundant feedback by touching, temperature, and pressure. Electronic skin is expected to be applied in various fields in the future, for example, wearable devices that continuously monitor users' movements, body temperature, and blood pressure [19]. New electronic skin sensors produced by 3D printing have more significant improvement in efficiency, specificity, low power consumption, cost-effectiveness, stretch-ability and convenience (Fig. 3) [20].

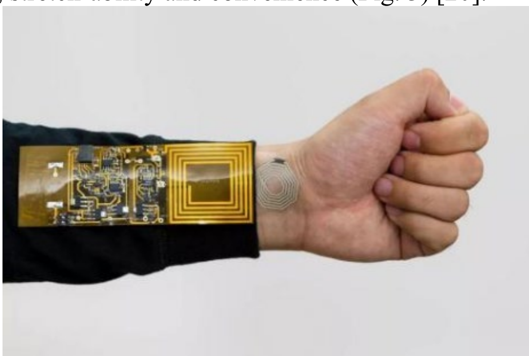

Fig. 3. Electronic skin [20].

For example, Apple has claimed that it plans to use 3D printing technology to manufacture components for wearable devices in the future. Biometric sensors in wearable devices are commonly used to monitor the physiological parameters of the wearer in real-time, such as heart rate, blood oxygen levels, and blood pressure, thereby enabling the monitoring of health status.

Recently, a team from the Shanghai Institute of High-speed Research of the Chinese Academy of Sciences has made significant progress in the research of 3D-printed flexible tactile sensors for carbon materials. The team has fabricated polydimethylsiloxane (PDMS) microspheres using an emulsification method by mimicking the structure and sensing mechanism of human skin. Furthermore, they used an uncured PDMS-graphene hybrid solution to coat the PDMS microspheres, resulting in graphene-PDMS microsphere ink that can be extruded through a nozzle to form three-dimensional structures. After heat curing, these structures can be shaped into multifunctional electronic skin sensors with fingerprint-like microstructures. This sensor is not only sensitive to pressure but also capable of effectively providing feedback on the magnitude of friction.

Utilizing this characteristic, the sensor can distinguish surfaces with different microscale roughness, effectively differentiating and recognizing the microtopography and hardness information of object surfaces. Through wind load experiments, the research team has verified that the graphene-PDMS microsphere tactile sensors they constructed also effectively respond to fluids such as gas. These research results indicate that the graphene-PDMS microsphere tactile sensors can not only be used for detecting surfaces with different roughness levels but also for fluid flow monitoring, sound detection, and more. This work provides a new approach for wearable sensing and offers new insights into the development of electronic skin [21].

Wearable biosensors in sweat can be used for biological monitoring and have applications in four areas. The first is diabetes and cardiovascular health detection, monitoring biomarkers like glucose and lactic acid. The second is early diagnosis of cancer, which is achieved by monitoring tumor-related biomarkers in sweat. The third is wearable biosensors offer the following advantages: non-invasive sampling, enabling for painless monitoring of key indicators. The fourth is real-time monitoring, continuously tracking biochemical markers in sweat and providing real-time tracking of physiological status. At the same time, there are areas for improvement in the field of 3D printing, such as further development of new printable soft functional materials, increasing the diversity of material choices, and optimizing printing parameters to improve molding progress and mechanical strength [22].

4 Conclusion

This paper illustrates the applications and characteristics of additive manufacturing technology across three distinct smart wearable devices, including the smartwatch, the smart clothing and medical wearable devices. Through comprehensive research, it observes that smart wearable devices fabricated by 3D printing technology effectively cater to the users' requirements in contemporary society, like personalized, customized, adaptable, and diverse. Although 3D printing technology is rapidly advancing at present, such as ink-jet printing technology, applications of that in the field of smart wearable equipment are still in a development stage. Consequently, it remains that researchers need a good deal of effort, such as explorations, experiments and tries, to achieve industrial mass production application in 3D printing technology.

The reasons for this can be explained as follows. Firstly, there are craft compatibility issues between multiple materials in the printing process. Different materials possess distinct characteristics. Hence it is essential to adjust printer parameters and processing procedures according to unique requirements of various materials during the printing process. It means further investigations are required in the field of 3D printer and processing craft. Secondly, realization of large-scale production is another concern. The application of 3D printing technology for mass production necessitates a stable and efficient process chain, including diversified processes, such as cure processing, post-processing. It still calls for more in-depth research.

Based on what is mentioned in this paper before, it provides valuable insights for researchers to gain a deeper and more comprehensive understanding of the application associated with additive manufacturing technology, especially in the field of smart wearable devices. It also provides a perspective for researchers on exploring, investigating, and experimenting the feasibility of industrial large-scale production utilizing 3D printing technology.

In the future, smart wearable devices are projected to have a wider and more various range of application domains, including virtual reality, human-computer interaction, rehabilitation nursing, and more. The products fabricated by 3D printing technology are anticipated to develop towards comfort, convenience, miniaturization, diversity, and uniqueness.

Authors Contribution

All the authors contributed equally, and their names were listed in alphabetical order.

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