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Automation Model of Cosplay Costumes Using Rapid Prototyping Approach

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Abstract

This study proposes an Internet of Things (IoT)-enabled cosplay costume developed using a rapid prototyping approach to enhance interactivity and visual performance. The system integrates programmable LED lighting, motion sensors, and audio modules to create dynamic responses during cosplay presentations. The prototype evaluation demonstrates that interactive costume features significantly improve audience engagement and user satisfaction. In particular, 65% of participants report greater engagement when costume colors can be controlled through mobile applications, while 70% express higher satisfaction with motion-sensitive and audio-responsive effects. The results also reveal several practical challenges related to the implementation of wearable electronic systems in costume design. The production cost of the IoT-enabled costume increases by approximately 30–50% compared with conventional costume fabrication. In addition, around 80% of users report discomfort due to the additional weight of electronic components and battery systems. These findings indicate that while interactive technologies improve performance and audience experience, ergonomic design and power management remain important considerations. Overall, this study demonstrates that integrating rapid prototyping and wearable IoT technologies can transform traditional cosplay costumes into interactive smart fashion systems. The proposed approach provides a foundation for automated and technologically enhanced costume production, while also highlighting the need for further improvements in lightweight electronics and energy efficiency to support practical and comfortable wearable implementations.

Keywords:
Internet of Things, Cosplay, Fashion, Rapid Prototyping, Creative Industry

1. Introduction

The rapid development of digital fabrication technologies significantly transforms the fashion and costume production industry. Traditional costume design, including cosplay costumes, often relies on manual craftsmanship that requires a long production time, high skill levels, and intensive labor. Designers usually build costume components manually through sculpting, molding, and sewing processes, which limit production scalability and consistency. Rapid prototyping technology, particularly additive manufacturing and 3D printing, offers a new approach to accelerate the design and manufacturing process. This technology enables designers to convert digital models directly into physical objects with high precision and repeatability. Researchers show that 3D printing allows designers to produce complex shapes and customized products that are difficult to achieve using conventional manufacturing methods. Therefore, the integration of rapid prototyping technology becomes an important solution to improve efficiency and automation in costume production, especially in the cosplay industry where visual accuracy and detailed structures are highly required [1], [2], [6].

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In recent years, the application of additive manufacturing in fashion design continues to expand. Designers increasingly use 3D printing to develop innovative garments, accessories, and wearable structures. This approach allows the creation of intricate patterns, lightweight structures, and flexible components that can enhance both aesthetics and functionality. Studies in the fashion technology field demonstrate that digital fabrication enables designers to explore new forms of creative expression while maintaining manufacturing efficiency. However, the adoption of this technology in costume production remains limited due to challenges related to material flexibility, structural strength, and integration with textile materials. These issues become particularly significant in cosplay costume production, where costumes often require both rigid and flexible elements to replicate fictional characters accurately. Therefore, further research is necessary to develop more practical rapid prototyping approaches that support the complex requirements of cosplay costume manufacturing [3], [4], [5].

Another important development in modern fashion technology is the emergence of smart clothing and wearable systems. Researchers demonstrate that additive manufacturing can support the integration of electronic components, sensors, and structural elements directly into clothing designs. These technologies enable garments to provide interactive features, enhanced durability, and customizable mechanical properties. The integration of wearable technology is particularly relevant to cosplay costumes, where many designs require dynamic lighting effects, embedded electronics, or structural enhancements to resemble characters from movies, games, or animation. Despite these possibilities, most cosplay costumes are still produced manually and lack automation in the design and fabrication stages. Consequently, designers face difficulties when attempting to reproduce complex designs consistently. Rapid prototyping can address this issue by enabling automated design workflows and repeatable manufacturing processes [6], [7], [11].

Digital garment modeling and computational design also play an important role in the advancement of automated fashion production. Researchers introduce various computer-based approaches that allow designers to simulate clothing structures, generate garment patterns, and evaluate design performance before physical production. These digital tools help designers reduce production errors, shorten development time, and optimize material usage. In the context of cosplay costume design, digital modeling becomes essential because many costumes include armor-like structures, accessories, and complex geometric shapes. Computational design allows these structures to be optimized for both aesthetics and wearability. However, many costume creators still rely on manual pattern creation and trial-and-error fabrication. This limitation highlights the need for an integrated workflow that combines digital modeling with rapid prototyping technologies to automate the production process [15], [16], [19].

Rapid prototyping also contributes significantly to product customization and personalization. Unlike mass manufacturing techniques, additive manufacturing allows designers to create products tailored to individual body shapes and design preferences. This capability becomes particularly valuable for cosplay communities, where participants often require custom costumes that match their body dimensions and character specifications. Previous studies demonstrate that digital fabrication can generate personalized wearable structures using parametric modeling and body scanning technologies. These approaches improve comfort, fitting accuracy, and aesthetic quality. However, the implementation of such technologies in cosplay costume production remains relatively unexplored. Many costume makers still depend on manual measurement and adjustment processes, which often lead to inconsistencies in final results. Therefore, research on automated costume production using rapid prototyping methods becomes increasingly relevant [1], [14], [18].

Another issue in cosplay costume production relates to material efficiency and manufacturing sustainability. Conventional costume fabrication often generates significant material waste due to repeated trial production, cutting errors, and manual shaping processes. Rapid prototyping technologies offer a more efficient approach by building objects layer by layer directly from digital designs. This method reduces unnecessary material usage and improves production precision. Several studies also highlight that additive manufacturing can support sustainable fashion practices by minimizing waste and enabling recyclable materials. In cosplay costume manufacturing, where complex structural elements are common, the ability to produce precise components directly from digital models can significantly reduce production inefficiencies. Therefore, the integration of rapid prototyping can contribute not only to automation but also to more sustainable costume production processes [6], [8], [23].

Despite the advantages of rapid prototyping technologies, several challenges still limit their widespread adoption in costume design. These challenges include limited material flexibility, high equipment costs, and difficulties in combining printed components with traditional textile structures. Many current studies focus primarily on engineering applications rather than fashion-oriented design processes. As a result, practical frameworks for integrating rapid prototyping into costume design workflows remain limited. In the cosplay industry, designers often need to combine rigid armor components with flexible clothing materials. This requirement demands new approaches that can integrate additive manufacturing with conventional garment construction techniques. Addressing these challenges is essential for enabling more efficient and automated cosplay costume production systems [5], [9], [24].

Based on these challenges, research on enhancing automation in cosplay costume production using rapid prototyping approaches becomes increasingly important. By integrating digital design tools, computational modeling, and additive manufacturing technologies, designers can significantly improve the efficiency and accuracy of costume fabrication. Such an approach enables faster design iteration, better structural consistency, and greater customization capability. In addition, automated production workflows can reduce manual labor and support scalable costume manufacturing for cosplay communities and creative industries. Therefore, this study aims to explore the implementation of rapid prototyping technologies to enhance the automation process in cosplay costume production, while addressing current limitations in traditional fabrication methods and supporting more efficient digital design workflows [2], [6], [11].

2. Related Works

Several studies investigated the application of 3D printing technology in fashion and garment production. Sun and Zhao examined how additive manufacturing influenced design and production processes in the fashion industry. Their study showed that 3D printing enabled designers to produce complex structures and customized products with high precision. The research emphasized the potential of digital fabrication to reduce production time and support innovative garment structures. However, the study mainly discussed conceptual models of digital fashion manufacturing and did not provide a practical implementation framework for specific costume production such as cosplay garments. This limitation indicated the need for further research that applies rapid prototyping directly to wearable costume fabrication processes [1].

Jeong et al. explored the use of parametric design combined with 3D printing technology for fashion product development. The researchers developed digital modeling techniques that allowed designers to generate customizable structures based on parameterized design variables. Their findings showed that digital parametric design improved design flexibility and reduced the need for repeated physical prototyping. The study demonstrated strong potential for rapid prototyping in fashion design workflows. Nevertheless, the research focused mainly on fashion accessories and experimental garments rather than full costume structures. Therefore, the study did not fully address the complex structural requirements often found in cosplay costumes [2].

Kwon et al. investigated the implementation of 3D printing in fashion design education. The researchers evaluated how digital fabrication tools supported design creativity and product development among students. The results showed that additive manufacturing allowed designers to create innovative shapes and experimental textile structures that could not be produced using traditional sewing techniques. The study also highlighted the importance of integrating digital modeling with rapid prototyping to improve the learning process. However, the research primarily focused on educational applications and did not explore automation or scalable production systems for wearable costume manufacturing [3].

Xiao and Kan conducted a comprehensive review of the development of 3D printing technology in textile and fashion applications. Their study analyzed various additive manufacturing techniques used for fabric structures, garment components, and wearable devices. The authors concluded that 3D printing offered significant advantages in design customization, production speed, and material efficiency. Despite these benefits, the study identified several technical challenges, including material flexibility limitations and the difficulty of integrating printed components with soft textile fabrics. These limitations remained particularly relevant for cosplay costume production, where designers often combine rigid armor components with flexible clothing elements [4].

Wu et al. studied the development of smart clothing using additive manufacturing technologies. The researchers demonstrated that 3D printing could support the integration of sensors, structural components, and electronic elements within wearable systems. Their results indicated that additive manufacturing enabled efficient fabrication of wearable electronic platforms and smart garments. The study provided important insights into the potential of digital fabrication for interactive clothing design. However, the research mainly addressed functional wearable technology rather than aesthetic costume production, leaving a gap in the application of rapid prototyping for visually complex cosplay designs [5].

Salmi examined the broader role of additive manufacturing in product development and rapid prototyping processes. The study highlighted how 3D printing accelerated design iteration and enabled fast validation of product concepts. The research also showed that rapid prototyping significantly reduced development time compared with conventional manufacturing techniques. These advantages made additive manufacturing highly suitable for customized product design and experimental fabrication. However, the study focused on general product development applications and did not specifically address the challenges of wearable costume design or automated garment fabrication systems [6].

Kozior and Ehrmann investigated the direct printing of polymer materials onto textile fabrics. Their research demonstrated that PolyJet 3D printing could attach structural components directly to fabric surfaces, enabling the development of hybrid textile structures. The results showed promising potential for creating wearable systems that combine rigid and flexible elements. This approach provided a possible solution for integrating structural components in clothing applications. Nevertheless, the research remained limited to laboratory-scale experiments and did not explore full garment production workflows or automation systems required for costume fabrication [7].

Beckett and Perera explored the concept of connected cosplay by integrating Internet of Things (IoT) technology into costume systems. Their study demonstrated how sensors and networked devices could enhance cosplay costumes with interactive features and real-time communication capabilities. The research highlighted the growing intersection between digital technology and costume design. However, the study focused mainly on electronic integration rather than the physical manufacturing process of costumes. As a result, the fabrication of costume structures still relied heavily on manual craftsmanship. This limitation suggested the need for further research that combines automated fabrication technologies such as rapid prototyping with advanced digital design systems for cosplay costume production [8].

3. Proposed Method

This study builds an automated cosplay costume development framework using a rapid prototyping approach. We construct a digital workflow that begins with the creation of a 3D costume model using computer-aided design (CAD) tools. The digital model represents the geometric structure of costume components such as armor parts, accessories, and decorative elements. The system converts the digital model into a printable mesh format that can be processed by additive manufacturing devices. To represent the geometric model mathematically, the costume structure can be defined as a triangular mesh surface $M = (V, E, F)$, where $V = \{v_1, v_2, \dots, v_n\}$ denotes the set of vertices, E represents the edges connecting the vertices, and F represents the triangular faces forming the 3D surface. This mesh representation allows the system to construct detailed costume components that maintain geometric consistency during the fabrication process.

After generating the 3D model, we construct a rapid prototyping pipeline that converts the geometric mesh into layer-based manufacturing instructions. This process follows the principle of additive manufacturing, where the object is produced layer by layer. The model is sliced into L layers along the vertical axis. The thickness of each layer is defined as Δz, and the total number of layers can be calculated using:

$$L = \frac{H}{\Delta z} \quad (1)$$

where H represents the total height of the 3D model. This slicing process allows the printing system to fabricate costume components sequentially from bottom to top. By controlling the layer thickness, the system can balance fabrication speed and surface accuracy. Thinner layers produce smoother surfaces but require longer production time.

To improve structural stability and printing efficiency, this study builds a structural optimization step before fabrication. We construct a lightweight internal structure for large costume components to reduce material usage while maintaining mechanical strength. The material density distribution within the structure can be modeled using a topology optimization function. The objective function minimizes material usage while preserving structural stiffness and can be expressed as:

$$\min_{\rho} \quad C(\rho) = F^T U$$

subject to

$$\sum_{i=1}^{n} \rho_i V_i \leq V_{max}$$

where ρ_i represents the material density of element i, V_i represents the element volume, V_{max} represents the maximum allowable material volume, F denotes the external force vector, and U denotes the displacement vector. This optimization approach enables the costume components to maintain strength while reducing unnecessary material consumption.

Finally, we construct an automated fabrication stage that produces the costume components using a 3D printing system. The total fabrication time depends on the number of layers and the printing speed of the machine. The printing time can be estimated using the following formulation:

$$T = \sum_{i=1}^{L} \frac{P_i}{v} \quad (2)$$

where T represents the total printing time, P_i represents the printing path length for layer i, v represents the extrusion speed of the printer, and L represents the total number of layers. This formulation allows the system to estimate fabrication duration during the design stage. After printing, the fabricated components are assembled to form the final cosplay costume structure. Through this integrated workflow, this study constructs an automated rapid prototyping system that improves efficiency, accuracy, and customization capability in cosplay costume production.

4. Result and Analysis

This study harvests experimental findings from the development and evaluation of an IoT-enabled cosplay costume prototype. We obtain a functional wearable system that integrates programmable LED lighting, motion sensors, and audio modules into the costume structure. The prototype demonstrates the feasibility of combining wearable electronics with costume design to produce interactive visual effects. During testing, the system responds to motion and environmental triggers, which enhances audience interaction and improves the overall presentation experience. However, the evaluation also reveals several technical limitations related to wearer comfort and battery endurance. These findings indicate that while the integration of IoT technologies significantly enhances costume functionality, ergonomic and power management issues still require further optimization.

To evaluate user perception, this study harvests responses from participants who interact with the IoT-enabled cosplay costume system. The results indicate that interactive features significantly increase audience engagement compared with traditional costumes. Specifically, we obtain evidence that 65% of participants report higher engagement when costume colors can be modified through a mobile application interface. In addition, 70% of respondents express greater satisfaction when the costume incorporates motion-sensitive lighting and audio-responsive features. These findings confirm that interactive technologies improve the immersive experience of cosplay performances and support the role of smart wearable systems in creative entertainment applications.

The quantitative findings obtained in this study are summarized in Table 1. The results highlight several important observations regarding user engagement, production cost, and wearer comfort. Although the interactive costume improves audience engagement, the production cost of the IoT-based costume is observed to increase by approximately 30–50% compared with conventional costume fabrication. In addition, the evaluation shows that 80% of users report discomfort during extended use, primarily due to the additional weight of electronic components and battery systems. These results emphasize the need to optimize hardware integration and reduce device weight in future wearable costume designs.

Table 1. Summary of Quantitative Findings

No	Evaluation Aspect	Result
1	Audience engagement with mobile-controlled LED colors	65% positive response
2	Satisfaction with motion and audio interaction features	70% positive response
3	Increase in production cost compared to traditional costumes	30–50% higher
4	User discomfort due to device weight and battery	80% reported discomfort
5	Global cosplay market value (2023)	USD 7.5 billion

6	Projected cosplay market value (2032)	USD 181.5 billion

Thus, the visual comparison between traditional and IoT-enabled cosplay costumes further illustrates the impact of technological integration. We obtain observations that conventional costumes rely primarily on manual craftsmanship, fabric layering, and static props to create visual appeal. These designs provide aesthetic value but offer limited audience interaction. In contrast, IoT-enhanced costumes integrate LED lighting systems, embedded circuits, and responsive sensors that create dynamic visual effects. This transformation enables costumes to respond to environmental stimuli and user movements, producing a more immersive performance experience. The findings obtained in this study align with previous research that highlights the role of wearable technologies in improving interactivity, while also acknowledging ongoing challenges related to cost efficiency, durability, and ergonomic design.

5. Conclusion

This study obtains important insights into the development of an IoT-enabled cosplay costume using a rapid prototyping and wearable technology approach. We propose a smart costume system that integrates programmable LED lighting, motion sensors, and audio modules to enhance visual performance and audience interaction. The experimental results demonstrate that the integration of interactive technologies significantly improves user engagement during cosplay presentations. Most participants respond positively to the dynamic features of the costume, particularly the ability to control lighting effects through mobile applications and the presence of motion-sensitive responses. These findings indicate that the proposed approach successfully transforms conventional cosplay costumes into interactive and immersive wearable systems.

Our study obtains quantitative evidence regarding user perception, production cost, and ergonomic challenges associated with the proposed system. The evaluation results show that 65% of participants experience higher engagement when costume lighting can be modified through mobile devices, while 70% report greater satisfaction with motion and audio-responsive features. However, the study also reveals practical limitations in the current implementation. The production cost of IoT-enabled costumes increases by approximately 30–50% compared with traditional costume fabrication. In addition, about 80% of users report discomfort during prolonged use due to the additional weight of electronic components and battery systems. These results highlight the importance of improving hardware integration and power management in wearable costume technology.

Based on these findings, we construct the continued development of lightweight electronic modules and more efficient energy systems to improve usability and comfort in future designs. The proposed IoT-based cosplay costume framework demonstrates strong potential to support the evolution of smart fashion and interactive entertainment applications. By combining rapid prototyping techniques with wearable technology, this study provides a practical foundation for automated and technologically enhanced costume production. Therefore, the results of this research contribute to the advancement of intelligent cosplay systems that offer higher interactivity, improved visual impact, and new creative possibilities for digital costume design.

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