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An Interactive Digital Somatosensory Game System That Implements a Decision Tree Algorithm

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ABSTRACT Trends in digital games and game-based learning development are gradually moving toward physical interactivity and man–machine experiential input. In this study, a motion-sensing wireless handle created by the Industrial Technology Research Institute of Taiwan was applied to a PC-based digital somatosensory learning system. Through wireless signal transmission, a decision tree algorithm was used to verify and analyze the information for determining the corresponding functions and motion-sensing identification. The enhanced accuracy and validity rate of action judgments of physical action signals (action-end device) sent to the somatosensory system can increase the efficiency of instant interaction and fluency between the interface and game system. The research results can be used to develop somatosensory games, add to the collective knowledge in this field, and improve future system efficacy. This study can help developers working on digital games and in other related fields to understand the engines and hardware principles of somatosensory games. Moreover, because ideas are presented without excessive complexity, the results may encourage students to develop somatosensory games.

INDEX TERMS Somatosensory game, wireless motion sensing, decision tree.

I. INTRODUCTION

The digital content industry is central to the knowledge-based economy and digital economic development. The digital content industry is a part of Taiwan's "Two Trillion and Twin Star Industries Development Program," and the digital game industry is a high-growth field with the most potential for generating high-output values. The Internet has become ubiquitous in modern society and is an essential platform for digital games; the widespread network provides high-growth potential for online games in the digital content leisure industry [1], [2]. However, with the exception of interactive electronic whiteboards, the use of digital content to teach students has not become widespread. Moreover, the adoption of electronic whiteboards has been limited to some fields, and direct interaction with students is limited [3].

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The possibility of using information technology and digital content for teaching continues to attract educators. Rapid developments in information technology and the ubiquity of computers have considerably changed the field of education. In the information age, the ability to access information and use a computer are essential skills for participating in the knowledge economy, and governments should encourage and promote the acquisition of these skills. Many educators and policy makers believe that technology can be a catalyst for educational reform. Technology can also become more interactive. It possesses more intelligence, more features, and higher capacity [4]. Therefore, a digital learning system can help overcome spatial limitations and enrich teaching content [5].

Because digital learning has received considerable attention and has been promoted, the implementation of digital learning platforms has become increasingly popular in schools and educational programs including military training classes, mathematics, and science [6]–[8]. However, these systems require additional improvements to facilitate direct and indirect interactions between students and teachers. In addition, many studies have indicated that several problems occur when merging information technology and teaching, for example, the lack of understanding and knowledge of instructional integration techniques [9]. Moreover, the lack of technical support, admonition, personal technical background, personal motivation, and the burden of teaching can have adverse effects on the integration of technology into teaching [10]. Nevertheless, Taiwan's incorporation of information technology in classrooms has considerably improved the educational environment, and many scholars believe that technology can be an effective educational tool for teachers and students and can facilitate thinking, cooperation, and communication. Experts also believe that information technology can promote educational changes [11]. Taiwanese scholars have proposed that teaching combined with information technology can diversify and individualize learning, enhance learning effects, and increase the vitality of teaching activities [12]. In addition, Jones and Paolucci contend that technology can enhance students' motivation and their learning abilities [13]. Although interactive whiteboards (IWBs) are being used in teaching, they are associated with several problems, such as users cannot read the writing; hence, the board requires orientating, and it wobbles. Some hardware problems may occur; for example, speakers cannot be linked to IWBs, scanners are not compatible with IWBs, and the size of the board. Some users have stated that the IWB affects the pace of lessons because teachers move on too quickly. IWBs cause headaches and sore eyes [14]. Therefore, many improvements are still required. Currently, interactive tools such as PowerPoint, emails, and Internet search engines cannot be directly used in classrooms. Consequently, creating an interactive somatosensory system that can solve these problems becomes necessary.

Numerous wireless technologies are available for meeting current home entertainment requirements, including wireless display (WiDi), wireless HD (WIHD), and wireless home digital interface (WHDI). Intel developed the WiDi technology and integrated it into its notebook chips; the video content is then transferred to a standard HDTV. Sony and Toshiba notebooks use this technology in their popular models. SiBEAM proposed a 60-GHz WIHD module to accelerate the development of wireless display designs for medical and industrial applications [15], [16]. WIHD transfers data directly from computing devices to an HDTV. The computing device does not need to be a traditional laptop but rather a small device, such as a netbook, which acts as a content provider (e.g., through Netflix) that receives and broadcasts signals. WHDI offers a revolutionary approach to transmitting uncompressed signals and has been implemented by Sony, LG, Samsung, Hitachi, Sharp, and Motorola [17]. The motion-sensing hardware and network communications created by the Industrial Technology Research Institute of Taiwan (ITRI) are used to achieve motion-sensing interaction agreements and to integrate and develop hardware and software. ITRI was established in 1973 with the aim of upgrading the technological capability of Taiwan's small and medium enterprises (SMEs) [18]. The motion sensor was used to convert actions into electronic signals that are then sent to a personal computer (PC) through a wireless transmission. The PC computes and determines the appropriate motion to generate the effect of Internet-based virtual interactions. A tree algorithm (decision tree) is used to determine the corresponding actions. A quick and uncomplicated decision tree enables the quick determination of the corresponding actions even if numerous signals are sent to the server side. The results indicate that using a decision tree to judge corresponding motion-sensing signals and to compare samples can strengthen physical motion signals. Therefore, a decision tree can improve the correctness and efficacy of virtual game-character's actions, consequently enhancing the interactive fluency between digital game machines and users.

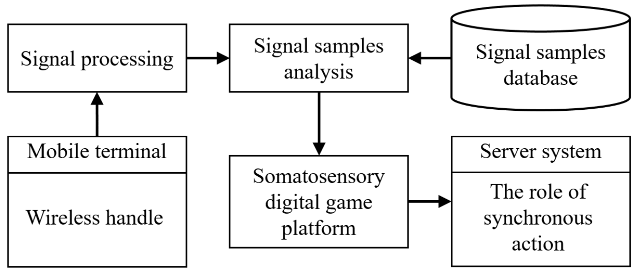

FIGURE 1. System construction.

II. METHODS

A. SYSTEM CONSTRUCTION

In this study, a decision tree was applied to a somatosensory interactive game system, and the entire framework is depicted in Fig. 1. The framework is divided into six parts: mobile terminal, signal processing, signals analysis, signal samples analysis, signal sample database, and server systems. The mobile terminal is an input system. When users start the system, signals are sent and received. Then, signals are processed and compared with samples in the sample database and are changed into corresponding signals. Finally, the server system outputs signals to a somatosensory game platform and causes game-character's to perform corresponding movements.

B. DECISION TREE

Decision trees are decision support tools that use a tree-like graph or model to determine possible consequences [19]–[22]. Normally, a decision tree is constructed from top to bottom, and each event or condition leads to two or more possible events causing various results. The entire process can be drawn into a graph that resembles a tree; therefore, the graph is called a decision tree. A decision tree is a method that can easily confirm a decision. It can help users to not only understand questions but also solve problems.

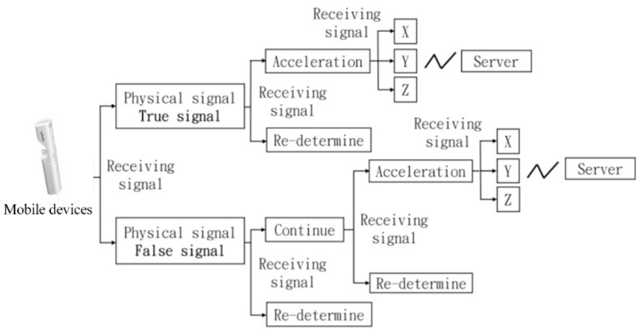

FIGURE 2. Construction of signal branches.

This process can assist users in making decisions or selecting factors in a step-by-step manner [23]–[25].

A decision tree is not only a common method for information processing but also a forecasting model in the machine learning field. It maps object attributes and object values. In a decision tree, each node represents an event or a condition, and each forked path represents a possible attribute value. Moreover, each leaf node represents the event's values from the corresponding root node to the leaf node. A decision tree can be divided into two or four types: two key types are classification and regression trees (CART) and chi-square automatic interaction detector (CHAID) [21], [26], [27]; CART was used in this study. CART combines sort trees and regression trees.

C. SIGNAL TRANSMISSION SYSTEM DESIGN

An elementary decision tree has three types of nodes: decision nodes, chance nodes, and end nodes. In this paper, each branch of a decision tree represents a tree structure (corresponding function), and its branches classify events (corresponding function). Each decision tree relies on the corresponding state to perform a signal-connecting test. A wireless mobile terminal (device) transmits signals, which are then determined. First, the wireless mobile terminal determines the signals of physical actions and whether they are corresponding (actual) or noise signals. If they are not actual signals, the signals are re-determined. If they are actual signals, the three-axis acceleration device respectively determines the x-, y-, and z-axis signals. The decision tree is illustrated in Fig. 2.

In this study, the x-, y-, and z-axis signals produced signals after filtering noise signals through a low-pass filter. Then, the signals were sent to the server through the wireless transmission module. After receiving signals, the server compares signals to samples from the sample database and then performs corresponding functions. The flowchart is displayed in Fig. 3.

In this study, a database for a three-axis acceleration device was established to test the accuracy of signals. After the server receives the signals (analog/digital), the digital signals are determined and compared with signals from the sample database. Finally, the correct signals cause the role to perform corresponding actions. The signal process is illustrated in Fig. 4.

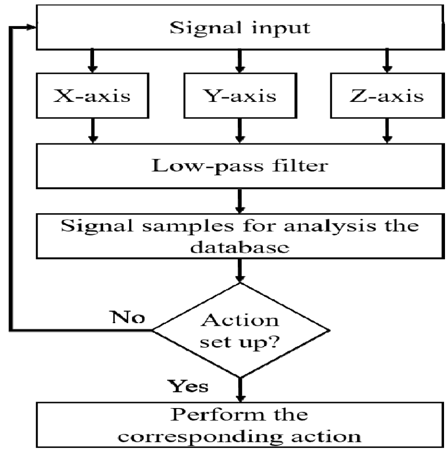

FIGURE 3. Signal transmission to server.

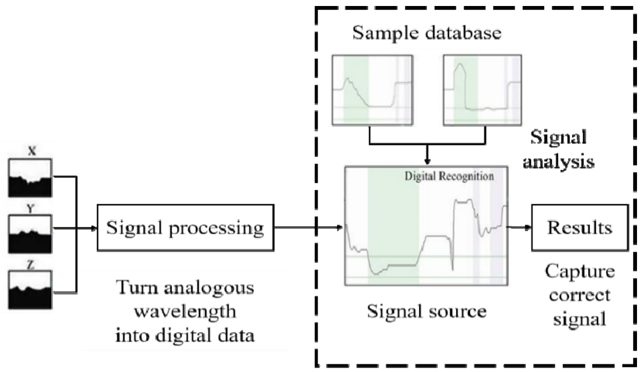

FIGURE 4. Signal processing.

Parameter settings:

In this paper, the parameters are set as follows:

1. Output the motion sensitivity with a sensitivity of ±3G.
2. The transmission frequency of the wireless transmission model is 2.4 GHz.
3. With respect to action changes, a group of three-axis (x, y, and z) acceleration values are transmitted at least every 10 min.
4. The signal measurement chart setting is as follows: high voltage = 3.3 V and low voltage = 0 V.

D. MOTION-SENSING IDENTIFICATION TECHNOLOGY

Movement variation is a major factor in the motion-sensing identification structure. Because of the difficulty in measuring movement variation, the resolution and accuracy must be considered to ensure overall stability and fluency of the system's operation.

In this study, the hand-held motion sensor invented by ITRI was adopted. When the hand-held motion sensor detects a user's movements, it converts analog signals into digital signals immediately. Then, the digital signals are sent to the server side through the wireless transmission device. After comparison with the signals from the signal sample

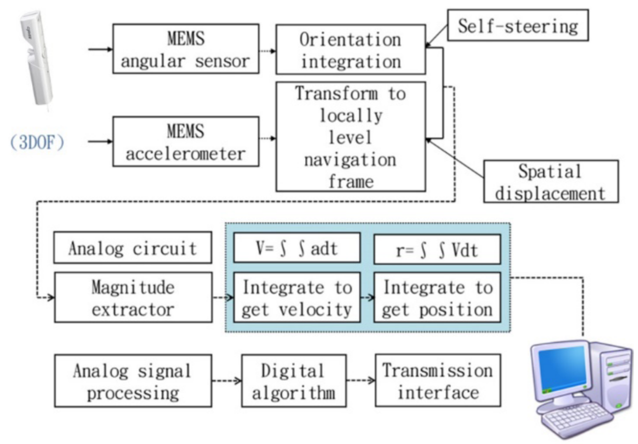

FIGURE 5. Signal processing flow from sensor to server.

database, the correct signals are selected. Finally, the proper signals cause the roles to perform the corresponding functions or movements and achieve strong interactive effects. The signal processing technology, hardware circuit structure, computer I/O input, and other technologies required for this study are illustrated in Fig. 5.

E. SOMATOSENSORY GAME PLATFORM STRUCTURE: HIGH-LEVEL GAME ENGINE

To achieve realistic input effects from body movements, motion-sensing identification should be executed immediately on the platform. In this study, a high-level game engine was adopted to achieve realistic input effects. We used a golf game to evaluate the body movement accuracy rate. The golf game has a motion-sensing function; that is, the motion-sensing technology can directly control the motion in the game through actions performed in the physical environment. The design emphasizes measuring geometric path signals through the sensor from a user's actual body (hand) movement trajectory; the signals are determined, and the results are sent to the server. Therefore, bilateral instant interaction can be achieved. The structure is depicted in Fig. 6. When the hand-held motion sensor sends out signals, they are transformed into digital signals for comparison with signals from the sample database. Once the comparison is complete, the role performs the corresponding actions.

III. RESULTS AND DISCUSSION

In this study, hardware and software integration and an algorithm were mainly implemented. In a compound motion-sensing interaction system, a built-in motion-sensing module is mainly used to sense a body's natural movements. Our handle contains inertial sensors, which uses a gravity sensor (accelerometer), gyroscope (angular velocity), and magnetic sensor (magnetic field) to obtain physical parameters indicating user movements. The system then simulates the user in space according to physical parameter conversion; thus, the sense of body movements in a measurement space is more accurate in our handle than that in handles with

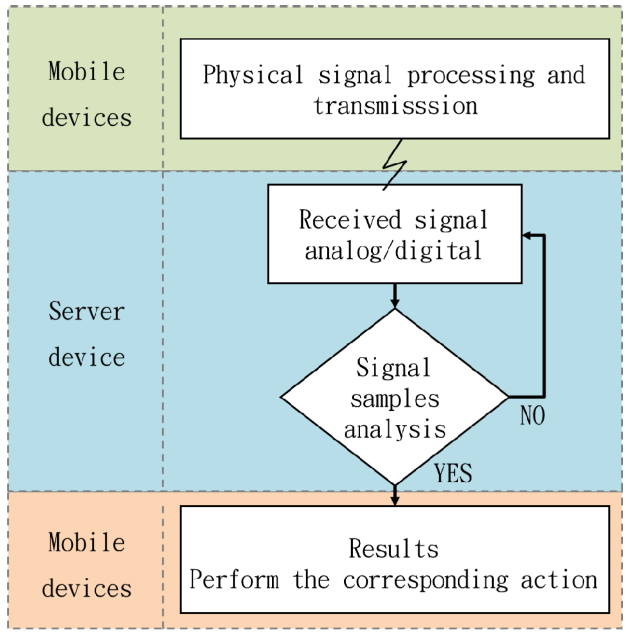

FIGURE 6. Somatosensory system transmission structure.

a single sensor. When the sensor converts actions into digital signals, these signals are amplified using a circuit, after which they are transmitted to a chip and are then integrated using sensors, signal adjustment, and other elements. Finally, through wireless transmission, the signals are sent to the computer; the game server then calculates, judges, and executes appropriate movements. Consequently, users can move their body and instantly control movements on the interactive platform. This is a novel mode of operation. We defined θ to be the angle between the x-, y-, and z-axes of the sensor and acceleration of gravity. The angle between acceleration signals A_x, A_y, and A_z and the direction of acceleration of gravity from the three axes of the sensor can be expressed as

$$\theta = \tan^1(\frac{\sqrt{A_x^2 + A_y^2}}{A_z}) \tag{1}$$

Considering the peak value of the swing datum A_z as standard, the formula is used to calculate the swing datum A_z. The range of θ for a left-curving ball is 0.407–0.664, and that for a right-curving ball is 0.692–0.760. Fig. 7 illustrates the sensing value ranges for right- and left-curving balls. Three conditions can be obtained as follows:

1. When A_x = 1600–2130, A_y = 1900–2300, and A_z = 2048–2400, the action is considered a swing (before down swing).
2. When A_x, A_y, and A_z conform to A_x = 2500–3000, A_y = 1–900, and A_z = 2100–3950, add the θ value to judge whether the left-curving ball is between 0.407 and 0.664 (slice). If they conform to A_x = 2200–3700, A_y = 1–900, and A_z = 2500–3700, add the θ value to judge whether the right-curving ball is between 0.692 and 0.760. If A_x, A_y, and A_z conform to A_x = 1450–2700,

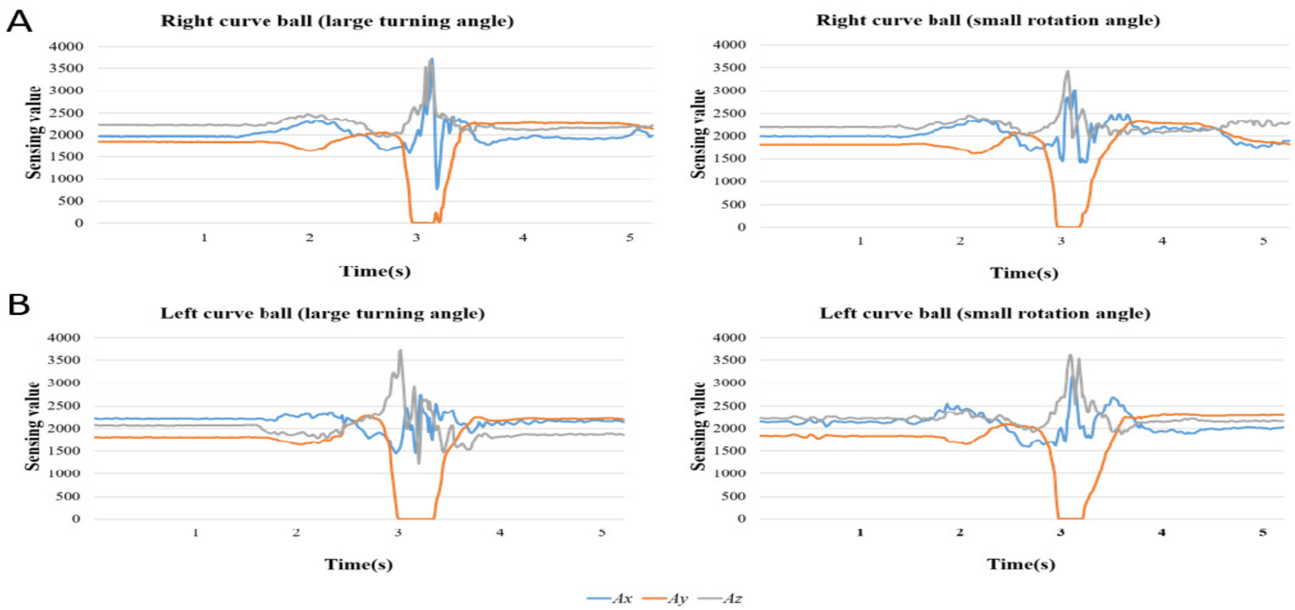

FIGURE 7. (A) A_y = 1–900 is the instant in which the ball is hit. (B) A_y = 1–900 is the instant in which the ball is hit.

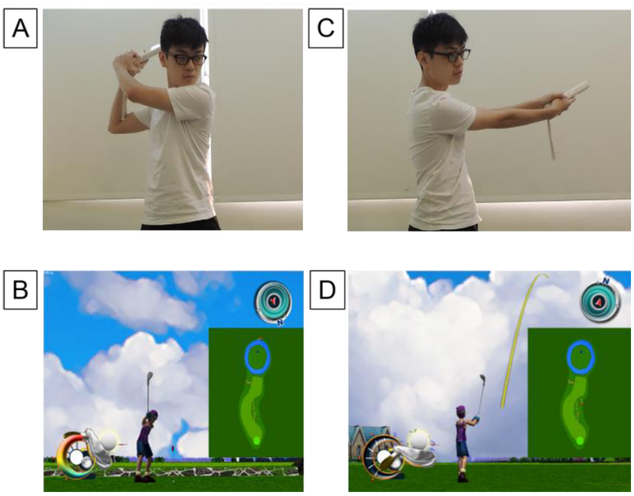

FIGURE 8. (A) User ready for down swing. (B) Game system ready for down swing. (C) User after down swing. (D) Game system finishes down swing.

A_y = 1–900, and A_z = 500–3500 (hook), the ball is judged as hit; otherwise, it is not.

3. When A_x, A_y, and A_z conform to A_x = 2100–2500, A_y = 1850–2400, and A_z = 1900–2500, the left curl ball ends, and when they conform to A_x = 1300–2500 (after down swing and slice), A_y = 1850–2300, and A_z = 2050–2400, the right curl ball ends, which is judged as an effective swing (after down swing and hook); otherwise, an invalid swing is judged.

To verify that the decision tree facilitates the precise execution of movements, 100 users participated in the experiment detailed hereafter. Operators were divided into two groups. Operators in group A used a somatosensory game system without a decision tree. Operators in group B used a somatosensory game system with a decision tree. Each operator performed four actions 10 times: before down swing, after down swing, putter-left, and putter-right slice and hook. The corresponding movement accuracy of groups A and B in the somatosensory interactive game system was evaluated.

To confirm the accuracy of body movements, the hand-held motion sensor and somatosensory interactive game system were tested to determine whether they could produce corresponding actions. Movements performed for the test were divided into four types: before down swing, after down swing, putter-left, and putter-right slice and hook. Two groups were selected for each type. Sample comparison was performed only for one group. The test data are presented in Table I. As evident in Table 1, the average movement accuracy of four samples when the decision tree was not used was approximately 31%, whereas that when the decision tree was employed was 94%. From these results, we conclude that a decision tree can considerably increase the accuracy rate. To achieve real instant detection of free motion, signal processing was strengthened for immediately determining the accelerometer values of x-, y-, and z-axes. Moreover, the accuracy and fluency of body action determination were enhanced.

The study results were applied to a somatosensory interactive game system at a camp held. When a user prepared to swing the club down and strike a golf ball, as depicted in Fig. 8A, the game system also executed the same action (Fig. 8B). When a user executed the down swing, the motion sensor (mobile side) followed the user's movement from the back-bottom to front (Fig. 8C). At the same time, the game system followed the user's action (Fig. 8D). In this study, the decision tree algorithm was adopted to determine the corresponding motion-sensing signals and comparison with

TABLE 1. Summary of body movement accuracy rate test of somatosensory system.

Action	No sample compared						Sample compared					
Type	A						B					
Sample	Before down swing	After down swing	Putter left	Putter right	Hook	Slice	Before down swing	After down swing	Putter left	Putter right	Hook	Slice
Accuracy	32%	33%	27%	28%	33%	33%	95%	95%	94%	95%	92%	93%

The data of 100 users who participated in an experiment are shown in supplementary Table S1.

signals from the sample database. It increased the accuracy and efficiency of body motion signal inputs to the server and the fluidity of interaction between users and roles in a somatosensory game.

Before the execution of the decision tree algorithm, the three axes of the incoming sensing signal were not distinguished, but rather the simple incoming sensing signal was compared with the motion signal (action database). Therefore, the correct signals can exhibit a large error. In this study, the decision tree was used to divide the sensing signal in the three signal components of x-, y-, and z-axes, and the noise then was filtered out by using a filter. The method effectively reduced the sensing judgment and improved the accuracy of the action comparison operation in accordance with the corresponding action. This interactive platform can be used for teaching that incorporates digital somatosensory games. Building a comprehensive interactive somatosensory teaching system can solve the problem of student disengagement, which is encountered in the traditional learning environment. The main purpose of the somatosensory system is to replace the traditional teaching environment, because an intuitive somatosensory interactive system may increase the comfort and engagement of teachers and students. Such a dynamic learning environment may help create an engaging and interactive in-class atmosphere. The decision tree calculus somatosensory technology can be applied to such systems for digital somatosensory skill learning, 3D virtual reality, motion monitoring, health care, and other applications. It has a wide range of industrial applications and development benefits. Our handle has wireless multimedia streaming technology specifications that are comparable to those of other handles, such as maximum resolution support, delay time, and transmission distance. Our handle has the advantages of high transmission performance, low power consumption, high identification rate, and long transmission distance. Moreover, such a system has the advantage of deploying easily understood game engines and the hardware principles of somatosensory games.

Future study prospects for this digital somatosensory interactive game system can be divided into four categories as follows:

1. Industry–academic cooperation: Industries can cooperate with schools for developing innovative digital somatosensory interactive game system technology. Industries can help schools undertake game research and provide students professional training. After training, well-trained students can assist industries to develop a platform of related digital content.
2. Social service: Through digital somatosensory interactive game systems, interactions such as sharing and discussion among students, teachers, and other stakeholders can be greatly enhanced.
3. Medical rehabilitation application: Because of the convenient and practical digital somatosensory interactive game system, medical rehabilitation technology can move toward the digital era.
4. Distance education: By using an interactive learning system in class, students' learning outcomes can be recorded. Moreover, it can reduce the stress experienced by students when they interact face-to-face with teachers. Additionally, using this system can help track learning, and the record can help teachers analyze students' learning outcomes and can be used as a reference for planning individual remedial teaching.

IV. CONCLUSION

In this study, the technology of a somatosensory game system was demonstrated as mature and stable. The decision tree algorithm was used to determine corresponding movements in the system, and it can be applied to compatible somatosensory game development with the interface input projects. The uncomplicated decision tree algorithm can be used to advantageously reduce the threshold for beginners. Moreover, the benefits of training students and developing innovative somatosensory game technologies are long-term and obvious.

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