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Research on the development and application of force tactile interaction technology in China

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Abstract

As an advanced human-computer interaction mode to simulate physical touch sense, force tactile interaction technology is gradually becoming a bridge connecting digital and reality. This paper summarizes the development of force tactile interaction technology, from early mechanical devices to modern intelligent tactile systems, after many technical innovations. This paper focuses on the content of the China Force Touch technology and application conference, shows the technology frontier and interdisciplinary communication, and summarizes the research and application team, as well as the software copyright and patent. In addition, the paper expounds on the wide application of force tactile technology in the meta-universe, robots, intelligent devices, car driving, education and other fields, and predicts its far-reaching impact on society and future development trends, emphasizing the importance of intelligent, personalized and cross-field integration.

Keywords: Force touch interaction technology, application status, China force touch conference

1. INTRODUCTION

As an advanced human-computer interaction paradigm, force tactile interaction technology enables users to perceive and respond to physical properties such as force, pressure, texture, and vibration in digital or virtual environments. Unlike conventional interfaces limited to visual and auditory feedback, this technology integrates tactile sensors, actuators, and intelligent control algorithms to simulate realistic force

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and tactile feedback, creating a critical bridge between digital systems and human physical perception.

From its origins in rudimentary mechanical devices to today's intelligent systems, the evolution of force tactile interaction has significantly enhanced user immersion and operational precision across diverse fields. In virtual reality (VR), it allows users to "feel" digital objects through artificial force responses; in medical applications, it revolutionizes simulation training and remote surgery by delivering lifelike tissue resistance; in industrial automation, it enables precise remote control of robotic systems. Beyond improving user experience, the technology has emerged as a cornerstone of next-generation perceptual interfaces, playing pivotal roles in domains such as smart devices and human-robot collaboration.

This paper systematically examines the developmental trajectory, core technologies (including sensor-actuator integration and adaptive algorithms), current research advancements, and cross-domain applications of force tactile interaction. By analyzing its transformative impact on healthcare, industry, and digital interaction paradigms, we aim to elucidate its multi-dimensional value while exploring future trends toward more natural, intuitive, and context-aware systems. The synthesis provides actionable insights to inspire next-phase innovations in this convergence of haptic science and intelligent interaction design.

2. OVERVIEW OF THE DEVELOPMENT OF TWO-FORCE TACTILE INTERACTION TECHNOLOGY

2.1. Development context

The evolution of force tactile interaction technology has developed from a simple mechanical device in the early stages to a complex intelligent tactile system today, and it has experienced several stages of technological innovation and theoretical breakthroughs. The evolution from early mechanical devices to modern intelligent haptic systems reflects the efforts of human beings to pursue more natural and intuitive human-computer interaction[1], as shown in Table 1[2]. Each technological advance in this process has greatly expanded the possibilities for us to perceive and manipulate the virtual and remote worlds.

2.2. Technological development process

The development process of force tactile interaction technology has gone through three stages, including the early exploration stage, the early commercialization stage and the modern intelligence, as shown in Figure 1. In the early exploratory phase, researchers began trying to design and manufacture mechanical devices that could provide force feedback. This period also witnessed the development of the physiological models of touch perception and the basic theories of force feedback control algorithms. These theoretical studies help scientists understand how humans perceive external stimuli through skin receptors and apply these principles to the design of machines; in the early stages of commercialization, with technological advances, tactile gloves such as CyberGlove appeared on the market, and force feedback arms such as PhantomDesktop, providing a new way to interact with virtual objects. Moreover, the initial application in the field of game and medical treatment, such as Da Vinci surgical robot; In the modern intelligent stage, with the progress of material science, flexible electronic technology and soft robot technology have developed rapidly, making it possible to develop wearable tactile skin closer to the natural touch of the human body. Additionally, with the development of AI technology, AI is being used to develop adaptive haptic systems that can automatically adjust their response patterns based on real-time user feedback to provide a more personalized experience. Moreover, in the process of constructing the meta-universe, the immersive tactile interaction is considered as one of the key factors in enhancing the user experience.

2.3. Analysis of core technologies

The rapid development of tactile interaction is due to the innovation of hardware technology, the

Table 1. Development context of force tactile interaction technology

Time	Key technology development	Application area	Technical features/examples
In the early 20th century	The earliest force-feedback devices began to appear	Flight simulator	Use mechanical components such as springs and motors to generate resistance or vibration to imitate physical phenomena in the real world; the control column used in the flight simulator provide basic force feedback to help pilots experience different airflow conditions encountered during flight
The second half of the 20th century	Force feedback technology began to shift to electronic and digital	Video game	More complex and precise force feedback devices, such as the joystick and steering wheel, provided a more realistic interactive experience through mechanisms such as electric motors; researchers began to explore controls of electrical signals to simulate virtual objects
The 21st century	Tactile feedback technology is gradually maturing	Consumer electronics (smartphones, tablets, *etc.*)	In addition to traditional vibration reminders, modern devices can provide a variety of tactile feedback through a sophisticated tactile engine, allowing users to feel different types of touch responses, such as the texture changes when clicking and swiping
	Force-tactile interaction technology has reached new heights	VR, AR	In the field of VR and AR, users can wear specially designed gloves or other wearable devices that can simulate extremely delicate tactile sensation in a virtual environment, including weight, texture and temperature
		Medical and surgical robots, intelligent artificial limbs	In the medical field, it can help doctors improve the accuracy of the surgery, or allow the prosthetic wearer to restore some sensory function

VR: Virtual reality; AR: augmented reality.

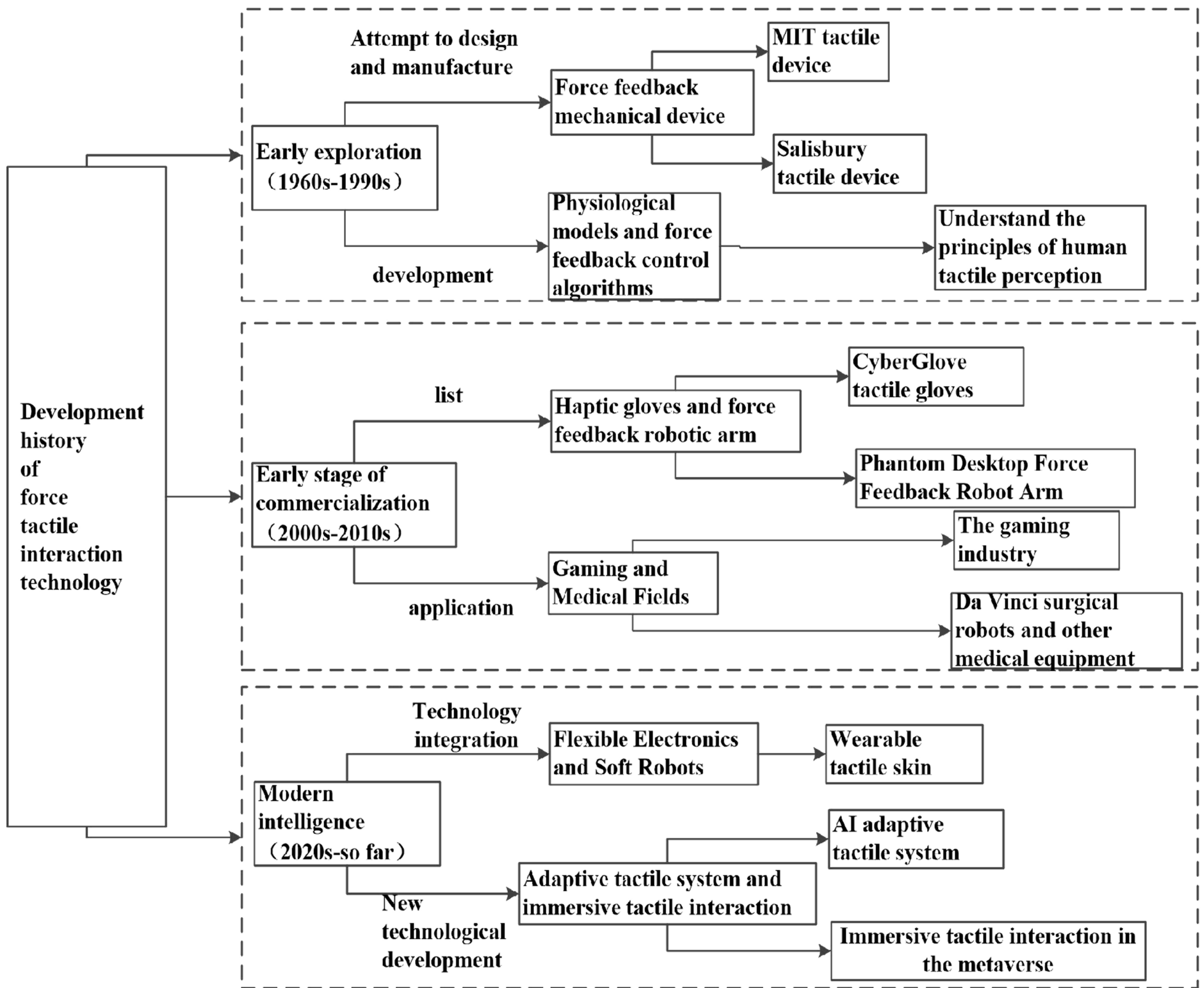

Figure 1. Development history diagram of force tactile interaction technology.

optimization of software and algorithms, and the advancement of multimodal fusion technology, as shown in Table 2. At the hardware level, piezoelectric, capacitive, fiber optic tactile sensors and distributed force sensing arrays provide high precision tactile information, while electromagnetic actuators[3], electroactive polymers and pneumatic/hydraulic drive realize diversified tactile feedback mechanisms[4]; Breakthroughs in flexible electronic technology, such as stretchable circuits and electronic skin, further promote the naturalization and high efficiency of tactile equipment. At the software and algorithm level, tactile rendering, impedance/conduction control and AI-based real-time adaptive control algorithm improve the realistic and personalized experience of tactile feedback, while tactile signal compression technology and low-delay transmission protocol guarantee efficient data processing and real-time feedback. In addition, at the level of multimodal fusion technology, especially the cross-modal interaction between touch and vision and hearing, along with the combination of brain-computer interface and tactile feedback, we create a richer and more immersive experience for users, especially in the field of VR and neural tactile reconstruction, showing great potential. These comprehensive technological advances have significantly enhanced the nature and intuition of human-computer interaction, bringing innovative solutions to various industries[5].

In recent years, linear resonant actuators (LRA) have become increasingly prominent in wearable haptic and rehabilitation devices due to their compact size, fast response time, and high energy efficiency. Compared with traditional eccentric rotating mass (ERM) actuators, LRAs offer more precise and localized vibration feedback, which is crucial for delivering controlled tactile stimulation in rehabilitation scenarios. LRAs operate by vibrating a mass on a spring at its resonant frequency, enabling lower power consumption and quieter operation. Furthermore, their planar form factor makes them better suited for integration into thin and flexible wearables. These characteristics make LRAs particularly advantageous in applications such as finger rehabilitation gloves, prosthetic sensory feedback systems, and smart tactile bands, where responsiveness and comfort are key.

Despite the promising potential of cross-modal interaction - especially between tactile, visual, and auditory channels - there remain several key challenges. First, temporal synchronization between modalities is difficult to maintain due to varying sensor response times and processing latencies, often leading to a fragmented user experience. Second, data heterogeneity from different sensory sources increases the complexity of fusion algorithms, making it harder to ensure coherent and accurate interpretation. Third, the cognitive load imposed on users during multimodal feedback can hinder usability if not properly designed. To address these issues, recent solutions include: (1) using time-stamping and real-time signal alignment protocols to ensure temporal coherence; (2) employing deep learning-based feature fusion models (e.g., transformer or graph neural networks) for robust interpretation across modalities; and (3) incorporating adaptive feedback mechanisms based on user behavior and bio-signals to reduce cognitive overload. These approaches collectively enhance the realism, responsiveness, and intuitiveness of cross-modal interaction systems.

3. RESEARCH STATUS OF TACTILE INTERACTION TECHNOLOGY IN CHINA

3.1. Force tactile technology and application conference

The core technology of tactile interaction constitutes the cornerstone of its development and lays the theoretical and technical foundation for its extensive application in various fields. However, the development of technology without continuous communication and innovation hinders progress. In the evolution of force tactile technology, how to achieve efficient dissemination, promote cooperation across various industries, and advance further development has become key. In this context, force tactile technology-related conferences provide an exclusive platform for communication and discussion.

Table 2. Display table of the core technologies of force-based tactile interaction

Class	Subclass	Key technology/progress	Influence
Hardware	Tactile type sensor	Piezoelectric type, capacitive, optical fiber type Distributed force-sensing array	Provide high-precision tactile information
	The actuator and the driver	Electromagnetic actuators, electroactive polymer Pneumatic/hydraulic drive	Achieve diverse tactile feedback
	Flexible electronics	Stretchable circuit, electronic skin	Promote the nature and high efficiency of tactile equipment
Software and algorithms	Touch rendering	Force field modeling, haptic texture rendering, physics-based haptic simulation, and multi-channel haptic feedback integration	Enhance the authenticity of the tactile feedback
	Control algorithm	Impedance/conduction control, AI-based adaptive control	Enhance the personalized experience
	Data processing and transmission	Touch signal compression technology, low-delay transmission protocol	Ensure efficient data processing and immediate feedback
Multimodal fusion technique	Cross-modal interaction	The combination of touch with vision and hearing	Create a rich and immersive experience
	Brain-computer interface	Combined with the tactile feedback	Demonstrate potential in VR and neural tactile reconstruction

VR: Virtual reality.

Among them, the China Touch Technology and Application Conference emerged. Since the first conference was held, the China Touch Technology and Application Conference has been successfully held for three sessions, and the fourth session will be opened in 2025. Reviewing its development history, each conference is closely around the force of tactile technology, and constantly expands the depth and breadth of communication. On June 5, 2021, the first conference was held in Nanjing, with the theme of “Force tactile perception interaction, new technology leading the future”. More than 250 experts and enterprise representatives from over 80 universities and research institutes and over 70 industrial enterprises attended the conference. Song Aiguo, the initiator of the conference, stressed the core position of force tactile technology in the fields of robot, human-computer interaction and VR. Totally, 18 experts shared reports on the realization of technology and its application in advanced manufacturing, medical rehabilitation, virtual teaching and other fields. At the same time, the preparatory meeting for the establishment of the Special Committee of the Chinese Society of Instrumentation was also held, which opened a new chapter in the organizational development of the industry.

From April 21 to 22, 2023, the second conference was held in Nanjing. The theme, “Feel the World, Touch the Future”, carried profound meaning. The number of participants increased significantly to more than 500, including industry experts and manufacturer representatives from national and international scientific research institutions. The conference focused on the cross-application of force tactile technology in human-machine interaction, robotics, and VR. Academician Teng Gao of Southeast University, Professor Xiao-Ping Liu of the Canadian Academy of Engineering, and Professor Sun from Tsinghua University delivered keynote speeches, sharing the latest research progress. The conference also elected the first members of the Force Tactile Perception and Interaction Committee under the Chinese Instrument and Control Society, marking a solid organizational foundation for further industry exchange and cooperation.

On May 25-26, 2024, the third conference was held in Tianjin with the theme “Perception Powers the Future, Touch Helps the World”. More than 100 universities participated, and the number of attendees remained stable at over 500. The conference deeply explored tactile sensing and perception technologies, covering a range of popular application fields such as biomedicine, surgical robotics, and flexible electronics. Meng Qinghu, Academician of the Southern University of Science and Technology, and Hou

Zengguang, a researcher at the Institute of Automation, Chinese Academy of Sciences, shared cutting-edge achievements. The conference not only hosted four professional forums, but also organized special graduate and youth forums, injecting fresh talent into the industry and further promoting interdisciplinary exchange and industry–university–research cooperation.

The fourth conference will be held on April 18-20,2025 in Nanchang, Jiangxi, China, with the theme of "Touching the world, shaping the future". The conference will focus on the frontier directions such as tactile sensors, embodied intelligence and human-machine integration, and continue to lead the development trend of the industry through keynote reports, oral and wall newspaper demonstrations, seminars and other rich activities.

From the steady growth of the number of participants, as well as the continuous expansion and deepening of the theme and content of the conference, we can clearly see the gradual improvement of the influence of the conference. It not only promotes technological exchange and innovation, but also promotes the practical application of tactile technology in medical treatment, rehabilitation, industrial manufacturing and other fields at the social level, improving people's livelihood while helping industrial upgrading. In the development process of tactile technology, the conference greatly accelerated the technological breakthrough and application expansion, deepened the cooperation between industry, university and research, and became an indispensable force in the development of the industry.

Beyond technological sharing, the China Force Tactile Technology and Application Conference has played a pivotal role in fostering interdisciplinary collaboration between academia and industry. Through joint forums, expert dialogues, and collaborative project showcases, the conference has connected universities, research institutes, and technology enterprises, forming a collaborative innovation ecosystem. For instance, several joint research projects and technology transfer initiatives were initiated on-site, accelerating the transformation of laboratory prototypes into commercially viable products. The establishment of specialized committees and youth forums has also nurtured academic leadership and entrepreneurial synergy, enabling a seamless flow of talent, knowledge, and capital across disciplinary and sectoral boundaries.

3.2. Research and application team

In China, the research and development of tactile interaction technology has made some progress in many universities, research institutions and enterprises. At present, some research teams are in the leading position in the research and development of tactile interaction technology, which promotes the rapid development of the technology in many fields such as medical treatment, robotics and VR technology. As shown in Table 3.

Force tactile interaction technology in domestic research and development work is booming, involving multiple fields and levels, such as tactile feedback and tactile sensors, smartphones, wearable devices, VR, intelligent driving, medical and robot, VR and games, force tactile interaction technology research and application for the future application and development has laid a solid foundation.

3.3. Patent and soft works

As an important branch of the field of human-computer interaction, force tactile interaction technology has attracted extensive attention and research in recent years. It can not only provide users with a more real and intuitive interactive experience, but also show great application potential in many fields such as medical treatment, robotics and VR. With the continuous progress of technology and innovation, more and more teams and enterprises began to force in the research and application of tactile interaction technology, and in

Table 3. Introduction of the research team

Research team	Highlight the research content
Shanghai Jiao Tong University Professor Gao Feng *et al.*	Joint SuoChen Science and Technology developed a six-foot guide robot integrating auditory, touch, and force interaction. It can realize touch and force interaction, with the robot providing stable traction and accurate steering torque to guide the blind forward and turn through a stick. At the same time, the blind can also dynamically adjust the robot's walking speed by pushing the stick, realizing force perception feedback control. This unique interaction design not only enhances the practicality of the robot but also improves the safety and comfort of blind walking[6]
Department of Electronics and Computer Engineering, Hong Kong University of Science and Technology Professor Shen Yajing *et al.*	The research team developed PhyTac, a hand-centric, digital-channel-based tactile interaction system. The system can be directly applied to the measurement of the handgrip strength distribution, which is of great significance for the assessment and treatment of many diseases, such as stroke and rheumatoid arthritis. Compared to other potential solutions (such as tactile gloves), the PhyTac system is more robust, easy to use, and unbound by physical limitations[7]
Beijing University of Aeronautics and Astronautics Professor Wang Dang *et al.*	Focusing on the force tactile interaction technology in VR and AR, it has developed the desktop force tactile interaction devices and the wearable force tactile feedback devices, which are widely used in the healthcare and aerospace fields[8]
Suzhou University Professor Wang Lihui *et al.*	In order to enrich the tactile information perceived by artificial equipment, a new type of triboelectric-photoelectric hybrid tactile sensor is proposed, which is characterized by short response time and high output linearity, and is suitable for human-computer interaction equipment. The sensor demonstrated good utility in haptic interaction tasks such as text typing and figure drawing[8]
Southeast China University Professor Song Aiguo *et al.*	The team has delved into force tactile sensing and interaction technologies, with a focus on industrial robot force control and teleoperation. It has also participated in multiple national-level scientific research projects, advancing the application of force tactile technologies in the robotics field[9]
Nanchang University School of Advanced Manufacturing	Participated in several industry-academia-research collaborative projects on force tactile technology and advanced its application in industrial robots and VR[10]
Foshan Zengcheng Intelligent Technology Co., LTD	Co-organized the 2025 4th China Force Tactile Technology and Application Conference. Collaborated with Jiangxi-based research teams to focus on industrial robot force tactile technology, especially in force feedback and tactile sensing innovation[11]
Nanjing Xianrui Robotics Technology Research Institute	The institute has worked with Jiangxi University research teams to focus on force tactile technology in healthcare, particularly in remote-operation robots and tactile feedback systems. It has made key progress and, with Shanghai XinTouch Information Technology Co., Ltd., developed the world's first acupuncture simulation training system[12]
West Lake University Professor Jiang Hanqing *et al.*	Inspired by the origami technique, we proposed the concept of "active touch", and innovatively introduced the concept of stiffness into the meta-universe. Based on this, a high-fidelity active mechanical tactile interaction system is developed, which can simulate the stiffness and pinching of objects, providing a new tactile perception dimension for the meta-universe. The system has wide applications in VR and entertainment[13]
Southern University of Science and Technology Professor Guo Chuanfei *et al.*	Developed a flexible sliding sensor that simulates human fingerprint characteristics, which can recognize the delicate surface texture of the object and improve the fine tactile perception ability of the robot and prosthesis. The technology has potential applications in VR and consumer electronics products[14]
Professional Committee of Tactile Perception and Interaction of Chinese Society of Instrumentation	It is committed to driving the scientific research and application of tactile technology in the fields of human-machine integration robot, VR and other fields, and promoting interdisciplinary academic exchanges and industry-university-research cooperation. The establishment of the special committee has provided an excellent academic organization platform for domestic researchers, and promoted the research and development of the industry frontier technology and the key technology breakthroughs in the industry[15]
Shanghai Xintouch Information Technology Co., LTD	In cooperation with universities and research institutions in Jiangxi Province, the company has developed the "holographic immersive tactile interactive training platform", which is widely used in medical teaching and VR training, and won the "VR/AR Annual Innovation Award" at the 2021 World VR Industry Conference[16]

VR: Virtual reality; AR: augmented reality.

the process of a series of important software copyright and patent achievements [Tables 4 and 5][17].

Force haptic interaction technology has made remarkable achievements in both hardware and software. Innovative devices such as wearable devices and haptic feedback systems provide real and intuitive interactive experience, while software systems such as haptic feedback control, information collection and perception offer important support for the realization of technology. However, there is still a lack of research on customized development and standardization. In the future, with the development of artificial intelligence, big data and augmented reality (AR) technologies, the tactile interaction technology is expected to achieve breakthroughs in the fields of personalized interaction, immersive environment construction and education and entertainment, showing a broader application potential.

Table 4. Patent table related to force tactile interaction technology

Related patents	Application unit	Date of application	Primary coverage
Touch perception substrate and tactile feedback device	Beijing BOE Technology Development Co., LTD	2024.10.29	For a tactile sensing substrate and a tactile feedback device, the tactile sensing substrate includes a substrate, a piezoelectric layer and an electrode layer; the piezoelectric layer includes at least one piezoelectric unit; a first electrode and a second electrode; wherein the substrate includes a substrate surface facing the piezoelectric layer, the first and second electrodes on the unit in a direction parallel to the substrate surface
A temperature-pressure tactile sensor based on self-osmosis assembly	Beijing University of Chemical Technology	2024.10.21	The present invention provides a temperature and pressure tactile sensor based on self-osmosis assembly and a preparation method, and the multilayer composite PON film of the tactile sensor includes a P-type sensing layer, an N-type sensing layer, an intermediate insulation layer, and an outermost packaging layer
Multi-dimensional finger force tactile feedback device, method and system	Shandong University	2024.05.29	The present invention provides a multi-dimensional finger force tactile feedback device, method and system; the feedback device includes five link mechanism, crank connecting rod mechanism, drive mechanism, slide table mechanism and finger base; the present invention can be used to interact with the virtual environment to realize the tactile properties of the virtual object in the virtual scene, and an improved self-disturbance control algorithm for multi-directional force tactile perception, which provides important value for human-computer interaction technology and tactile perception technology
Force-induced tactile feedback device	Nanchang Virtual Reality Research Institute Co., Ltd	2024.05.28	The present invention provides a force tactile feedback device comprising a force feedback arm with a user hand end controlling the user to operate the force feedback arm and a position sensor for detecting position information for the movement of the force feedback arm
An intelligent dexterous prosthetic system for multimodal force tactile perception and stimulation feedback	The Institute of National Defense Science and Technology Innovation of the PLA Academy of Military Sciences	2024.04.30	The present invention belongs to the field of medical rehabilitation. An intelligent dexterous prosthetic system for multimodal force tactile perception and stimulation feedback, including an upper machine module, a lower machine module and a receiving chamber module and the palm, back of the hand, finger, wrist and arm corresponding to the position of the human upper limb
An airbag type dynamic force touch sensing device	University of Ningbo	2024.03.08	The present invention discloses an airbag type dynamic force tactile sensing device, which includes a base, the airbag support frame, the airbag, the inflation pump and the exhaust pump, the airbag support frame and the airbag are fixed on the upper end of the base, located in the airbag, the inflation pump and the exhaust pump are fixed in the base, and exhaust the airbag, the active support components are fixed with a plurality of independent up and down, the active support assembly is fixed with the upper end of the airbag, and used to control the shape change of the upper surface of the airbag
Monitoring system for hand rehabilitation training based on force tactile gloves	Nanjing University of Information Science and Technology	2024.01.15	This application relates to a hand rehabilitation training monitoring system based on force tactile gloves. The system includes: reading the current pressure data by the tactile glove device to determine the data to be transmitted to the terminal device
Vibrotactile actuator and control method, evaluation method and wearable rehabilitation device	Zhejiang College, Tongji University	2024.01.08	The present invention discloses a vibrational actuator, a control method, an evaluation method, and a wearable rehabilitation device. The vibrational actuator includes a plurality of LRA actuators. A plurality of LRA actuators are separately arranged in mechanical isolation to form a spatial tetrahedral structure for synthesis to generate an arbitrary tactile force vector
A method, system, and device for the visually impaired to recognize a virtual texture	Nanjing University of Information Science and Technology	2024.01.08	The present invention discloses a method, system and device for recognizing the visually impaired virtual texture, which belongs to the field of machine learning and digital education of the visually impaired
A multimodal-based tactile feedback interaction system	Nanchang University	2023.12.25	The invention discloses a multimodal non-contact force tactile feedback interactive system, including: penetrating glass, penetrating touch screen, ultrasonic transducer array, controller and housing. The invention solves the deficiency of traditional interactive devices in force tactile feedback and multimodal display ability
Force tactile stimulation system and force tactile stimulation method based on focused ultrasound	Shenzhen Institute of Advanced Technology, Chinese Academy of Sciences	2023.12.14	The present invention discloses a force tactile stimulation system based on focused ultrasound, comprising ultrasonic waveform generation module for generating ultrasonic waveform; power amplification module, connected to the ultrasonic waveform generation module for signal transfer to the ultrasonic waveform
A method for instant scanning of physical objects	Southeast China University	2023.06.16	A remote force tactile reproduction method for instant scanning of physical objects. In the application scenario of physical digital modeling, the present invention can provide remote users with real force tactile feedback of objects in the real world and improve the interactive experience of objects in a virtual environment

A virtual simulation method based on force feedback	Institutes of Technology of South China	2023.05.16	The invention provides a virtual simulation method based on force feedback, including steps: constructing a virtual training scenario for foraminal mirror surgery, establishing a deformable physical model of the virtual nucleus pulposus based on the physical point method, and extracting the virtual nucleus pulposus in the virtual environment by a force-tactile interaction device
A flexible force tactile sensing device for the dynamic measurement of fluid motion	Nanchang University	2022.11.14	The present invention discloses a flexible force tactile sensing device for the measurement of fluid motion dynamics, including a control body and a master control body

LRA: Linear resonant actuators.

Table 5. Soft description table of force tactile interaction technology

Related soft	Application unit	Record date
Force touch sense perception system	Shenzhen Institute of Advanced Technology, Chinese Academy of Sciences	On January 17, 2025
Computer tactile system based on STM 32	Inner Mongolia University of Technology	On December 26, 2024
Based on traditional Chinese medicine theory and tactile technology, low simple anal fistula surgery imitation real training platform	Shanghai Pudong New Area Gongli Hospital	On December 5, 2024
Touch-perception fuzzy audio system	China Academy of Fine Arts	On November 7, 2024
Finger high-score and high-dimensional visual and tactile force sensing system	Beijing Pineal Robot Technology Co., LTD	On August 18, 2023
A GelStereo tactile sensing platform based on sliding tactile sensing	Jiangsu Ruidong Intelligent Technology Co., LTD	On August 11, 2023
The UAV VR tactile feedback system	Changchun Oluke UAV Technology Co., LTD	On May 23, 2019
The 3D printed tactile design software	Beijing Huaxia Weixun Technology Co., LTD	On April 30, 2015

VR: Virtual reality.

3.4. Comparative analysis: advantages of China in haptic feedback research

Compared with global leaders such as the United States and Japan, China has shown unique advantages in the field of force tactile interaction research. First, China's strong policy support and funding in emerging technologies, including AI, robotics, and smart manufacturing, provide a fertile ground for the rapid development of haptic technologies. Second, China emphasizes application-driven innovation, enabling faster deployment of haptic systems in education, healthcare, and industrial training scenarios. Third, the scale and coordination of Chinese academic-industry collaboration - highlighted by national conferences and joint research platforms - are leading to high efficiency in knowledge translation and commercialization. While the US excels in foundational theory and advanced sensor design, and Japan leads in hardware miniaturization and precision, China's advantage lies in integrated application ecosystems, rapid product iteration, and policy-enabled scale deployment.

4. APPLICATION OF TACTILE INTERACTION TECHNOLOGY IN CHINA

As an advanced human-computer interaction technology, tactile interaction technology can bring real immersive experience to operators, which is widely used in various fields to improve people's experience and work efficiency, mainly reflected in the following aspects.

4.1. Metacognition and VR

4.1.1. Medical treatment

In the medical field, the force-tactile interaction technology has revolutionized surgical training. With the force feedback handle, tactile gloves and other devices, medical students and doctors are able to simulate various complex operations, such as heart bypass grafting and brain tumor cutting, in a virtual environment[19]. In addition, through real-time perception of the contact force between surgical instruments and virtual tissues and organs, such as resistance during cutting and pulling force during suture, it can greatly improve the surgical skills and proficiency, and reduce the risks in real surgery. In telemedicine surgery, doctors can use the tactile interaction device to remotely control the surgical robot, break through the space limit, and provide timely treatment for patients in remote areas. At the same time, they can sense the tissue resistance and hardness changes encountered in the operation through force feedback to ensure the accuracy of the operation[18].

4.1.2. Aerospace

In the field of aerospace, the China Academy of Space Technology has developed a space robot with muscle and gesture-based human-computer interaction remote operation control systems, composed of arms, head, waist, and other components. It is designed for tasks such as external equipment replacement and maintenance, cabin experiment platform management, and assisting astronauts during capsule exit. In addition, a force tactile feedback device and force tactile interaction technology have been developed for ground-based virtual simulation training in the astronaut space module, which is of great significance for astronaut training and the execution of space missions. In the ground simulation training, the astronauts use the force feedback equipment to simulate the feeling of operating the equipment and grasping the objects in the space microgravity environment, get familiar with the space operation process and operation skills, and make full preparation for the actual space mission. In the design and manufacturing process of the spacecraft, engineers can conduct virtual assembly and test through the force tactile interaction technology, find out the possible problems in the assembly process in advance, and improve the reliability and safety of the spacecraft.

4.1.3. Entertainment games

In the field of entertainment games, tactile interaction provides an unprecedented immersive experience. For example, in a racing game, with a steering wheel equipped with a force feedback function, players can feel the bumps of the road, the centrifugal force during turns, and the friction between the tires and the ground, as if they were on a real racetrack. In fighting games, players wear tactile gloves that simulate the impact of a fist hitting the opponent, making the game more engaging and interactive. A virtual shooting training system developed by a university in Fujian Province, for example, has been used in military simulation teaching. In the field of film and television production, the use of a stylus in the animation production of Ne Zha 2 enables students to optimize the action details of their characters through tactile feedback, and this technology is now included in digital media courses.

4.2. Robot and remote operation

4.2.1. Robot control

In industrial production, force tactile interaction technology allows workers to remotely control robots to perform complex tasks. Taking electronic equipment manufacturing as an example, workers can use the tactile feedback equipment to control the robot to assemble tiny parts, such as the connection between the chip and the circuit board, by feeling the contact force of the robot and the parts, ensure the accuracy and stability of the assembly, and improve the production efficiency and product quality. In the automobile manufacturing industry, robots can complete the assembly of engine parts and the installation of interior parts under the remote control of workers, and workers can timely adjust the robot movements according to the tactile feedback so that the installation of parts is more accurate and applied to.

In the field of rehabilitation robotics, integrating force-tactile feedback presents several unique challenges. First, patient variability - in terms of muscle strength, nerve response, and sensitivity - makes it difficult to standardize feedback intensity and calibration. Second, real-time safety constraints require the system to respond immediately to excessive force or abnormal motion to prevent injury, which demands highly reliable sensors and fast control loops. Third, wearability and comfort are critical; adding force feedback components often increases bulk and mechanical complexity, potentially reducing user compliance. To overcome these challenges, researchers are developing adaptive feedback algorithms based on bio-signal [e.g., electromyography (EMG), electroencephalography (EEG)], soft and flexible actuators for safer human-machine interaction, and cloud-based calibration platforms that allow customized settings for different patients. These innovations are key to promoting safe, effective, and personalized rehabilitation experiences.

4.2.2. Operation in a dangerous environment

In dangerous environment operations, tactile interaction technology plays an irreplaceable role. For example, in areas with nuclear radiation, chemical pollution, and similar hazards, operators can use remotely controlled robots equipped with tactile interaction devices to sense the robot's real-time feedback in the hazardous environment - such as the strength of object grasping or collisions with obstacles. This avoids direct contact with dangerous environments and ensures the operator's safety. In fire rescue scenarios, remotely controlled robots can also enter the fire scene, and force perception feedback can help better complete rescue tasks, such as carrying the wounded and removing obstacles.

4.3. Smart devices and wearable devices

4.3.1. Smart home

In the smart home system, the tactile interaction technology brings users a more natural and convenient interactive experience. By touching the intelligent control panel with force feedback function, users can feel the feedback force of different operations, such as the gradient resistance when adjusting the light brightness and the tactile change when adjusting the volume, so as to improve the intuition and interest of the operation. Smart furniture can also integrate the tactile technology. When users touch the furniture, they can feel the corresponding feedback, such as the softness of the sofa, the material texture of the desktop, *etc.*, to enhance the interaction between users and the home environment.

4.3.2. Wearables

Tactile interaction technology in wearable devices provides users with richer methods of information feedback. For example, a smartwatch can convey different messages through various vibration patterns - such as calls, SMS, and schedule reminders - allowing users to understand the information without looking at the screen. A tactile bracelet can provide corresponding feedback based on exercise data, such as speed, steps, and heart rate changes, guiding the user to adjust exercise intensity accordingly.

4.4. Car driving and safety

4.4.1. Driving assistance

In the car driver assistance system, the tactile interaction technology can enhance driving safety and comfort. For example, when the vehicle deviates from the lane, the steering wheel will alert the driver through vibration or force feedback so that he or she can correct the direction in time. In adaptive cruise control, when the vehicle is too close to the vehicle in front, the driver can feel the danger warning through the vibration of the seat or the force feedback of the steering wheel, so as to prepare for braking in advance. In addition, in the automatic driving mode, the driver can also interact with the vehicle through the force haptic interaction device to understand the vehicle's driving status and the surrounding environment information.

4.5. Education and skills training

4.5.1. Virtual laboratory and simulated experimental environment

In the field of education, the force of tactile interaction technology provides students with a more realistic experimental environment. For example, in experimental teaching of physics, chemistry, biology, and other disciplines, students can conduct experiments in a virtual laboratory using tactile feedback equipment. They can feel the weight of objects, the flow resistance of liquids, temperature changes during chemical reactions, and more, enhancing the sense of reality and learning effect of the experiment. In virtual biological anatomy experiments, tactile feedback helps students better understand anatomical structures and operational techniques, improving their anatomy skills.

4.5.2. Skill training

In terms of skills training, force tactile interaction technology can help students master professional skills more quickly. For example, in pilot training, students feel the strength and feedback of the aircraft joystick through the force feedback equipment, simulate the operation feel in real flight, and improve their flight skills and the ability to deal with emergencies. In the mechanical maintenance training, students can experience the contact force of maintenance tools and parts through the tactile interaction technology, get familiar with the maintenance process and skills, and improve their maintenance skills.

Force Touch interaction technology shows a wide range of application potential in many fields, and these applications together demonstrate the great value of force touch interaction technology in promoting the naturalization of human-computer interaction and improving user experience.

5. FRONTIER TRENDS AND FUTURE DIRECTION

Touch interaction technology has made breakthroughs in many fields. In the future, popular science education and experience activities should be actively carried out to improve public awareness and acceptance. At the same time, the technology is used to reduce the cost of education and promote educational fairness and popularization. We should grasp the development trend, promote its intelligent, personalized and cross-field integration, help the innovation and development of multiple industries, and bring more benefits to the society.

5.1. Frontier trends

1. Help special education and distance education - to improve the convenience of digital reading for the visually impaired

(1) Braille point actuator setting: design a Braille point actuator with tactile function and smaller volume, so as to achieve wider application and expansion. For example, the six-dimensional force sensor ($< 1.5\%$ accuracy error) has optimized the Braille tactile feedback system[17] through miniaturization design (diameter < 5 mm). In addition, the study of the interaction between blind people and the virtual environment (e.g., tactile delay < 10 ms) can be adapted to different user needs[19].

(2) Image algorithm fusion: By combining deep learning image algorithms (such as YOLOv5) and Touch devices[20], the accuracy of blind people's object contour perception is improved to 89%[20]. Touch-visual fusion technology enhances the spatial perception of virtual objects[20] through high precision force feedback (3.3 N output force).

(3) Reduce the threshold of abstract concept learning: design a magnetic tactile model (such as the flexible pressure sensor of Hongxin Electronics) to simulate the strength of the intermolecular force, or combine the tactile map and vibration to mark the historical battle route. The experiment shows that the tactile teaching aids can improve the efficiency of science learning by 42%, and improve the visualization score of liberal arts by 35%[21].

2. Improve public awareness and acceptance - Popular science education and experience activities
(1) Promotion of VR large space experience activities: In VR/AR application, combine flexible capacitor sensors (such as Hanwei Technology NSP-T5 series) to simulate temperature change, or magnetic rheological fluid equipment (Guangdong Superbrain intelligent Omega.7) to display the industrial precision force control process. According to the exhibition data of Shanghai Science and Technology Museum, the awareness of tactile technology increased by 55%.
(2) Content production pre-force tactile unit deeply integrates force tactile module (such as Xiaomi smart glove) in VR content production, to achieve immersive experience through multi-sensory fusion (touch + temperature + vision). The user's immersion score of the virtual flame touch is 8.7/10, which verifies the feasibility of the technology landing.

5.2. Future development direction

1. Enabled industrial robots can improve the flexibility of robot grasping through visual/tactile fusion technology (such as Haozhi electromechanical six-dimensional force sensor), and the success rate of grasping tasks can reach 98.3%[21]. Visual positioning (± 0.1 mm) and haptic texture feedback (hardness resolution 0.1 N/mm^2) cooperate to optimize the industrial assembly accuracy of.

2. Industry penetration examples include:
Medical surgery robots: tactile precision level using Coli sensors with 0.01 N resolution supports laparoscopic surgery with an error rate of less than 2%.
Consumer electronics: modular tactile peripherals (such as force sensor technology and film sensors) are applied in gaming mouse resistance adaptive technology, increasing user immersion by 37%[21].
Education: tactile digital twin technology (such as Ruihu Technology's electronic skin) enables universal tactile experiences for cultural relics, reducing costs by 60%[22].

Force tactile interaction technology provides technical support for educational equity and industrial upgrading by optimizing equipment design (such as miniaturization of Braille actuator), fusion algorithm (tactile-visual collaboration) and scene innovation (industrial robot capture). In the future, standardization research (such as IEEE Haptics 2030 White Paper) and cross-field cooperation need to be strengthened to promote the revolutionary leap of human-computer interaction to sensory extension.

6. CONCLUSIONS

Force tactile interaction technology has gradually evolved from the early stage of simply pursuing functional realization to a new era of focusing on perceptual intelligence. This shift is not only reflected in advances in hardware devices, such as in the improved performance of sensors and actuators, in the application of new materials, but also in the development of software algorithms[23], such as tactile rendering technology and AI-based adaptive control[24]. Together, these advances have driven tactile interaction to become one of the core technologies of the next generation of human-computer interaction, and it has shown great application potential in healthcare, industrial automation, consumer electronics and entertainment, education and research. Haptic technology has a far-reaching social impact. For instance, it promotes educational equity for the visually impaired via assistive devices and boosts manufacturing precision through industrial robots. However, for large-scale commercialization, it is crucial to overcome cost constraints and develop cross-modal fusion algorithms. With the advancement of flexible electronics, intelligent materials and artificial intelligence technologies, we can foresee a more natural, intuitive and immersive tactile interactive experience in the future.

DECLARATIONS

Authors' contributions

Made substantial contributions to conception and design of the study and performed data analysis and interpretation: Zhen, Z.; Xu, Y.; Zhu, C.; Peng, H.; Ma, C.; Yang, M.; Zhu, Q.
Performed data acquisition and provided administrative, technical, and material support: Hu, X.

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Conflicts of interest

All authors declared that there are no conflicts of interest.

Ethical approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

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