BUILDING A CLOSED-LOOP FOR CHILD EMOTIONAL INTERVENTION: INTEGRATING OPTICAL SENSING, MOTION CAPTURE, AND MULTIMODAL ANALYSIS

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Abstract: Aiming at the core pain points in emotional management intervention for children aged 4-12, namely "intrusive physiological data collection, insufficient motion capture accuracy, and disconnection between motion and physiology," this paper relies on a multimodal interactive somatosensory emotional management platform. It integrates optical quantum non-contact sensing, ToF high-precision motion capture, and multimodal motion analysis as three independent technical dimensions to construct a five-element data source system of "physiology-motion-analysis-environment-quantum wave" and optimize the closed-loop of "dimension identification-digital human action-social application." Optical quantum non-contact sensing enables non-invasive collection of heart rate variability (HRV) and electrodermal activity (EDA) with a sampling frequency of 10Hz and data transmission delay below 10ms, increasing the success rate of physiological data collection for special needs children from 60% to 95%. ToF high-precision motion capture, utilizing a 13-megapixel depth camera and self-developed algorithms, supports real-time tracking of 342 human skeletal points with motion accuracy of 0.1mm and response delay under 25ms. Multimodal motion analysis independently processes optical quantum physiological data and ToF motion data through spatiotemporal alignment, feature fusion, and correlation modeling to establish a mapping between motion features, physiological responses, and emotional states, achieving an analysis accuracy of at least 92% and addressing the research gap in motion-physiology integration. Practical application involving 1,500 children across 12 cities in East, North, and South China demonstrates that the collaboration of these three technical dimensions increases the accuracy of children's emotional recognition to 90% (80% for children with autism), improves intervention effectiveness by 29 percentage points, and achieves a skill transfer rate of 80%. This study provides a comprehensive pathway of "non-intrusive collection, high-precision capture, scientific analysis, and full-scene application" for children's emotional management.

Keywords: Children's emotional management; Optical quantum non-contact sensing; ToF high-precision motion capture; Multimodal motion analysis; Closed-loop intervention; Intervention for special needs children

1 INTRODUCTION

1.1 Research Background and Technical Pain Points

Children's emotional management ability is a core indicator of mental health, directly affecting their social adaptation and personality development. The "China Children's Mental Health Development Report (2024)" shows that the incidence of emotional problems among Chinese children aged 4-12 reaches 22.8%, with the incidence of emotional regulation difficulties among children with autism spectrum disorder exceeding 65%. Children with attention deficit hyperactivity disorder (ADHD) have an emotional outburst frequency 2.3 times that of ordinary children. Due to the lack of intervention resources, the non-intervention rate of emotional problems among children in rural areas and migrant worker families reaches 58%, significantly higher than that of urban children (23%). Meanwhile, the "Healthy China 2030 Planning Outline" clearly proposes "building a children's mental health service system and improving the accessibility of grassroots services", highlighting the urgency and policy orientation of children's emotional management intervention[1].

Scientific intervention in children's emotional management relies on a complete chain of "physiological state - behavioral motion - emotional meaning". However, the existing technical system has three independent pain points that need to be addressed separately:

1. Lack of Optical Quantum Non-Contact Sensing: Traditional physiological data collection relies on wearable devices (wristbands, patches), with a resistance rate of over 60% among special needs children. Moreover, the data transmission delay exceeds 50ms, failing to reflect emotional dynamics in real time (e.g., sudden EDA surge during anxiety).

2. Insufficient Accuracy of ToF Motion Capture: Existing 2D visual motion capture can only track < 15 skeletal joints with an accuracy of 1-3mm, unable to capture subtle motion features such as "jumping amplitude and grasping force" of children, leading to distorted identification of dimensions like "hand-eye coordination" and "social collaboration".

3. Blank in Multimodal Motion Analysis: The lack of an independent analysis link results in the sole use of physiological or motion data, failing to establish the correlation between "motion → physiology → emotion". For example, a child's "fist-clenching motion" may indicate anger (elevated EDA) or tension (reduced HRV), and single data is prone to misjudgment.

The multimodal interactive somatosensory emotional management platform takes the three technologies as independent

dimensions to address the problems of "intrusive collection, insufficient accuracy, and correlation analysis" respectively: optical quantum non-contact collection avoids resistance, ToF high-precision capture captures motion details, and multimodal analysis establishes the correlation between the two[2]. The three technologies collaboratively provide complete technical support of "data - capture - analysis" for the closed-loop.

1.2 Research Objectives and Core Logic

Core Objectives (Objectives Clarified by Technical Dimension)
Optical Quantum Non-Contact Sensing: Achieve non-contact, high-real-time collection of HRV and EDA for children aged 4-12 (especially special needs children), with a collection success rate $\geq 90\%$ and data delay $< 25ms$.
ToF High-Precision Motion Capture: Realize real-time tracking of 342 skeletal points with a motion accuracy $\leq 0.1mm$, supporting simultaneous capture of multiple people (2-4 people) to adapt to group intervention.
Multimodal Motion Analysis: Independently construct a correlation model of "optical quantum physiological data + ToF motion data", with a correlation degree of $\geq 92\%$ between "motion - emotion", providing a scientific basis for dimension identification and real-time adjustment logic for digital human intervention.
The three dimensions are collaboratively integrated into the closed-loop, increasing intervention accuracy by 30% and achieving a skill transfer rate of 80%[3].
Core Logic (Closed-Loop Disassembled by Technical Dimension)
Construct a closed-loop with "three technologies as independent supports and the platform as a collaborative link":
1.2.1 Dimension identification stage
Optical quantum sensing collects HRV/EDA (identifying hidden anxiety and emotional regulation needs);
ToF captures motion accuracy/social frequency (identifying hand-eye coordination and social collaboration problems);
Multimodal motion analysis independently correlates the two types of data (e.g., "stiff motion + elevated EDA = social anxiety"), outputs the correlation result of "motion - emotion", and screens core dimensions combined with environment and quantum wave data[4-5].
1.2.2 Digital human intervention stage
Optical quantum real-time monitors emotional changes (e.g., elevated EDA indicates anxiety);
ToF real-time captures task execution motions (e.g., jumping amplitude and collaboration degree);
Multimodal motion analysis independently outputs the dynamic correlation of "motion - physiology" (e.g., "meeting jumping standards + HRV recovery = emotional calming"), driving digital humans to adjust intervention strategies (e.g., motion difficulty and feedback methods)[6].
1.2.3 Social application stage
Optical quantum sensing adapts to multiple scenarios (high-precision for institutions / simplified version for families);
ToF motion capture adapts to cross-terminals (large screens for institutions / touch screens for communities);
Multimodal motion analysis provides scenario-specific versions (full version for institutions / simplified versions for families and communities), ensuring the collaborative implementation of the three technologies in all scenarios[7].

2 THEORETICAL BASIS: SEVEN SUPPORT SYSTEMS FOR CLOSED-LOOP CONSTRUCTION (THEORIES SUPPLEMENTED BY TECHNICAL DIMENSION)

2.1 Theory of Dimension Identification in Children's Emotional Intervention

Erikson's Psychosocial Development Theory of Children: Children aged 4-6 are in the "initiative vs. guilt" stage, needing to establish confidence in emotional expression through concrete role-playing (e.g., "biological emotional rescue" in Octonauts). The core dimensions are "emotional recognition and vocal expression". Children aged 7-12 are in the "industry vs. inferiority" stage, needing to enhance self-worth through group role-playing (e.g., collaborative "environmental material sorting" at Yamdrok Lake in Tibet). The core dimensions are "social collaboration, emotional regulation, and hand-eye coordination". This theory provides an age-adaptive basis for dimension prioritization and role-playing task design, avoiding "over-age intervention"[8-10].
DSM-5 Diagnostic Criteria for Emotional and Behavioral Disorders: Clarify the core emotional problems of different special needs children and their adaptability to role-playing: children with autism spectrum disorder need to prioritize "social collaboration and emotional recognition", adapting to "low social pressure" role-playing (e.g., "single-person rescue mission" in Octonauts); children with ADHD need to prioritize "emotional regulation and impulse control", adapting to "goal-clear" role-playing (e.g., "material classification specialist" at Yamdrok Lake in Tibet); children with Down syndrome need to prioritize "hand-eye coordination and basic emotional recognition", adapting to "simplified motion" role-playing (e.g., "prop messenger" in Octonauts). This standard ensures the clinical adaptability of dimension identification and role-playing tasks[11].
Embodied Cognition and Role-Playing Integration Theory: Children's emotional cognition is closely related to physical experience and role immersion. In digital twin scenarios, children can strengthen the memory chain of "role behavior - emotional cognition - scenario correlation" through embodied motions such as "playing Captain Barnacles to identify marine creature emotions" and "playing environmental volunteers to collaboratively sort materials", increasing the skill transfer rate by 40%-60%. This provides a theoretical basis for the intervention logic of IP/natural scenario role-playing[12].
Technical Support System:

Optical quantum sensing support: Identify "emotional regulation" needs through HRV low-frequency/high-frequency ratio < 1.0, and "hidden anxiety" through EDA fluctuation > 5μS, avoiding missing physiological signals only through behavioral observation.

ToF capture support: Identify "hand-eye coordination" needs through motion accuracy (e.g., prop placement error > 1cm), and "social collaboration" needs through social cooperation times < 2 times / 10 minutes.

Multimodal analysis support: Independently verify the consistency of "physiology - motion" (e.g., "emotional regulation needs" must meet both low HRV + irregular motion with an analysis correlation degree ≥ 85%).

2.2 Theory of Digital Human Action Intervention

Digital Human-Role-Playing Collaborative Response Theory: Digital humans can play classic roles in IP scenarios (e.g., Peso the Medic in Octonauts, environmental guide at Yamdrok Lake in Tibet). Their characteristics of "stable expression (60FPS rendering), predictable motion (<10ms delay), and voice consistent with role settings (e.g., Captain Barnacles' decisive tone)" make the acceptance of role-playing by special needs children 35% higher than that of real-person guidance. Studies have shown that when digital humans play "Peso the Medic", the active participation duration of children with autism increases from 5 minutes to 15 minutes[13-14].

Applied Behavior Analysis (ABA)-Role-Playing Integration Theory: Decompose complex emotional skills into "small-step role-playing tasks": for example, "emotional regulation" is decomposed into "role immersion (discovering crises) → role motion selection (deep breathing under Peso's guidance) → role task execution (calming marine creature emotions) → role feedback (obtaining rescue medals)". Digital humans provide immediate feedback to reinforce positive role behaviors, shortening the skill acquisition cycle of special needs children by 30%[15-16].

Multimodal Interaction-IP Scenario Adaptation Theory: Young and special needs children have higher acceptance of "IP scenarios + multi-sensory stimulation": the sensitivity of children with autism to multimodal feedback such as "tactile vibration (simulating ocean currents) + role voice (Peso's soothing words)" in Octonauts scenarios is 2.5 times that of abstract scenarios; the attention duration of children with ADHD in Yamdrok Lake scenarios with "3D spatial audio (sound of prayer flags fluttering) + visual effects (light and shadow of mani piles)" is extended by 50%. The multimodal feedback design of the platform needs to be deeply integrated with IP/natural scenario characteristics[17].

Technical Support:

Optical quantum sensing support: Digital humans adjust interaction tone according to HRV/EDA changes (e.g., switching to a soothing tone when EDA rises).

ToF capture support: Digital humans improve interaction naturalness through motion synchronization (delay < 10ms) (e.g., raising hands synchronously with children).

Multimodal analysis support: Digital humans adjust task difficulty according to analysis results (e.g., increasing difficulty if "motion meets standards + physiological calming", and simplifying otherwise).

3 THEORY OF SCENARIO MIGRATION AND SIMULATION

IP/Natural Scenario Migration Theory: The higher the similarity between the intervention scenario and children's familiar IP content and natural cognition, the higher the skill transfer rate. When the scenario similarity ≥ 80% (e.g., replicating the console layout of Octonauts' Octopod and the details of prayer flags and mani piles at Yamdrok Lake in Tibet), the skill transfer rate reaches over 75%[18]; otherwise, the transfer rate of abstract scenarios is less than 30%. Digital twin technology can realize 1:1 replication of IP/natural scenarios, solving the problem of "disconnection between virtual and reality"[19].

Ecosystem Theory: Children's emotional management is a systematic project of "micro (family) - meso (school/community) - macro (social policy)": families are responsible for "parent-child role-playing consolidation" (e.g., replicating Octopod emotional rescue), schools promote "group role-playing migration" (e.g., carrying out Yamdrok Lake environmental protection themed activities), communities provide "inclusive role-playing services" (e.g., IP-themed public welfare sessions), and the government ensures system operation through policies and funds. The collaboration of the four can increase the coverage efficiency of social services by 60%[20].

Sustainable Development Theory: Social intervention needs to balance "public welfare and market": the government purchases community terminals with IP/natural scenarios (subsidizing 80% of the cost) to cover public welfare scenarios; enterprises obtain revenue through institutional-side "IP role customization services" (e.g., designing exclusive Octonauts roles for special needs children), and then feedback public welfare (e.g., providing free IP role-playing accounts for low-income families), forming a virtuous cycle of "public welfare supporting inclusiveness and market ensuring sustainability".

Technical Support:

Optical quantum sensing support: Embed "physiology - emotion" correlation rules during high-fidelity scenario replication (e.g., switching scene lights to warm light during anxiety).

ToF capture support: 1:1 restore motion interaction during scenario replication (e.g., the physical space of "raising hands to grasp toys" in family scenarios).

Multimodal analysis support: Embed "motion - analysis" trigger mechanisms in scenarios (e.g., triggering emotional regulation tasks when "toy snatching motion + EDA rise").

3.1 Theory of Closed-Loop Social Application

Optical Quantum Sensing Support: Community terminals adopt simplified sensors (only collecting EDA trends) to reduce operational thresholds.

ToF Capture Support: Family mobile-screen interaction simplifies motion capture (only tracking core joints such as raising hands and jumping).

Multimodal Analysis Support: Community/family terminals only analyze the correlation between "core motions - physiology" (e.g., "raising hands + stable EDA = active social interaction"), adapting to non-professional users.

3.2 Optical Quantum Non-Contact Sensing Theory

3.2.1 Principle of optical quantum wave reflection imaging
Using near-infrared optical quantum waves (wavelength 650nm) to penetrate the surface of human skin, HRV (Heart Rate Variability) and EDA (Electrodermal Activity) are calculated through changes in the phase and amplitude of reflected signals:

HRV: The reflection frequency of optical quantum waves changes with heart rate, and the HRV low-frequency/high-frequency ratio (reflecting autonomic nerve activity and correlating with emotional stability) is obtained through frequency analysis.

EDA: Changes in skin sweat gland secretion affect the reflection intensity of optical quantum waves, and EDA data (reflecting anxiety level) is obtained through intensity fluctuations.

This principle realizes non-contact collection, avoiding resistance to wearable devices, with a collection distance of 0.3-2m, adapting to children's activity range[21].

3.2.2 Theory of non-invasive collection of children's physiological data
Children have delicate skin and a high resistance rate to wearable devices. Optical quantum non-contact sensing conforms to "child-friendly" design:

No Physical Contact: Avoids discomfort (e.g., allergies, itching) caused by sensors adhering to the skin.

Low-Power Safety: The optical quantum power is < 1mW, complying with the "Safety Standards for Children's Electronic Products".

High Real-Time Performance: 10Hz sampling frequency + < 25ms delay, capturing instantaneous emotional changes (e.g., sudden EDA surge during anxiety).

3.3 ToF High-Precision Motion Capture Theory (Newly Added, Independently Supporting Capture Dimension)

3.3.1 Principle of Time-of-Flight (ToF) depth imaging
ToF cameras emit modulated light signals (near-infrared light), calculate the distance between objects and the camera by measuring the time difference between the emission of light signals and their reflection back to the sensor, and construct 3D depth images[22]:

Skeletal Tracking: Based on 3D depth images, 342 human skeletal points (e.g., wrists, elbow joints) are identified through self-developed algorithms, and joint coordinates and angles are calculated to obtain motion amplitude, frequency, and accuracy data.

Accuracy Guarantee: 13-megapixel camera + sub-picosecond time measurement, with motion recognition accuracy up to 0.1mm and response delay < 25ms, capturing fast motions of children such as "jumping and grasping" without motion blur.

3.3.2 Theory of wearable-free motion capture adaptation
Children (especially special needs children) have a resistance rate of over 60% to wearable devices (e.g., motion capture gloves). The wearable-free design of ToF adapts to children's operating habits:

No Equipment Restraints: Children can move naturally (e.g., barefoot jumping, grasping with hands) without learning wearing procedures.

Environmental Adaptability: Resistant to ambient light interference (supporting indoor and outdoor low-light environments), adapting to scenarios such as family living rooms, school playgrounds, and community parks.

Multi-Person Collaboration: Supports simultaneous motion capture of 2-4 people, adapting to group intervention (e.g., school group collaboration tasks).

3.4 Multimodal Motion Analysis Theory

3.4.1 Theory of spatiotemporal alignment of heterogeneous data
Optical quantum physiological data (time-series, such as HRV curves) and ToF motion data (spatial, such as joint coordinates) are heterogeneous data, and "spatiotemporal alignment" is required to ensure the validity of correlation:

Time Alignment: Unify hardware clocks (accuracy 100 nanoseconds), and attach timestamps to each frame of optical quantum data and ToF motion data to ensure the matching of "motion occurrence time" and "physiological change time" (error < 1ms).

Spatial Alignment: Correct the optical quantum collection distance (0.3-2m) through ToF depth data, avoiding physiological data errors caused by distance changes (e.g., HRV measurement deviations due to excessive distance).

3.4.2 Theory of motion-physiology feature fusion
Analysis is realized through three steps: "feature extraction - feature fusion - correlation modeling":

Feature Extraction:

Optical quantum features: HRV low-frequency/high-frequency ratio, EDA fluctuation amplitude, physiological event markers (e.g., EDA surge).

ToF motion features: Joint angles (e.g., raising hand angle ≥ 45°), motion amplitude (e.g., jumping amplitude ≥ 10cm), motion frequency (e.g., jumping once / 2 seconds).

Feature Fusion: Adopt an attention mechanism, assigning high weights (30%) to "emotion-sensitive features" (e.g., EDA fluctuations, irregular motions) and regular weights (20%) to ordinary features (e.g., motion amplitude).

Correlation Modeling: Based on a CNN-LSTM hybrid network (CNN extracts motion spatial features, LSTM extracts physiological time-series features), output the correlation degree between "motion - emotion" (e.g., "fist-clenching + elevated EDA" with a correlation degree of 92% = anger).

3.4.3 Theory of real-time analysis response

Children's emotions are characterized by "instantaneous outbursts - rapid changes", requiring multimodal motion analysis to meet "low latency - high real-time performance":

Edge Computing Support: Adopt RK3588S edge chips (computing power 8TOPS) to complete "data preprocessing - feature extraction - correlation calculation" locally, avoiding cloud transmission delays.

Analysis Process Optimization: The full-process delay is < 50ms (collection 10ms + preprocessing 15ms + correlation calculation 15ms + output 10ms), ensuring timely intervention response (e.g., driving digital humans to adjust within 50ms when emotions are agitated).

4 MULTIMODAL INTERACTIVE SOMATOSENSORY EMOTIONAL MANAGEMENT PLATFORM: INDEPENDENT AND COLLABORATIVE ARCHITECTURE OF THREE TECHNICAL DIMENSIONS

The platform adopts a four-level architecture of "hardware interaction layer (divided by technical modules) - software core layer (divided by technical modules) - scenario adaptation layer (divided by technical adaptation) - safety guarantee layer (divided by technical protection)", ensuring that optical quantum sensing, ToF capture, and multimodal analysis operate independently and collaboratively support the closed-loop[23-24].

4.1 Hardware Interaction Layer: Independent Hardware Modules of Three Technologies

Hardware design focuses on "wearable-free, low resistance, and high precision", adapting to the role-playing behaviors of children aged 4-12 (including special needs children). The core module parameters and functions are as follows (Table 1-3):

Table 1 Technical Architecture of the Multimodal Sensing System for Affective Computing

Technical Dimension	Hardware Module	Core Parameters and Functions (Independent Technical Indicators)	Supported Closed-Loop Links (Independent Roles)
Optical Quantum Non-Contact Sensing	Multimodal Physiological Sensor	1. Collection principle: Optical quantum wave reflection imaging (wavelength 650nm, power < 1mW); 2. Collection indicators: HRV (40-180ms), EDA (0-50μS); 3. Performance: Sampling frequency 10Hz, data transmission delay < 25ms, collection distance 0.3-2m; 4. Adaptation: Compatible with children's watches, community terminals and other devices	Intervention dimension identification (identifying hidden anxiety and emotional regulation needs); Digital human intervention (real-time monitoring of emotional changes, such as triggering adjustments when EDA rises); Social application (high-precision collection for institutions / simplified collection for families)
ToF High-Precision Motion Capture	ToF Motion Capture System	1. Camera: 13-megapixel ToF depth camera (frame rate 30fps); 2. Skeletal tracking: Real-time tracking of 342 skeletal points, motion accuracy 0.1mm, response delay < 100 picoseconds; 3. Functions: Wearable-free capture, supporting simultaneous interaction of 2-4 people, resistant to ambient light interference; 4. Adaptation: Institutional large screens, school all-in-one machines, community terminals	Intervention dimension identification (collecting motion accuracy and social collaboration data); Digital human intervention (real-time motion synchronization to judge task progress); Social application (institutional group intervention / simplified capture for family mobile-screen interaction)
Multimodal Motion Analysis	Multimodal Analysis Processing Unit (Newly Added)	1. Hardware: FPGA chip (timing control accuracy 100 nanoseconds) + edge computing unit (RK3588S); 2. Functions: Realizing spatiotemporal alignment and feature fusion of optical quantum and ToF data; 3. Performance: Analysis delay < 25ms, correlation accuracy ≥ 92%; 4. Adaptation: Outputting analysis results to digital human drive and dimension identification modules	Intervention dimension identification (verifying physiology-motion consistency to avoid misjudgment); Digital human intervention (driving dynamic adjustment of intervention strategies); Social application (full-version analysis for institutions / simplified-version analysis for families)
Auxiliary	Multi-Scenario	1. Institutional terminal: 43-inch 4K screen	Social application (cross-scenario

Hardware	Terminal Equipment	(integrating optical quantum sensors and ToF cameras); 2. Family terminal: Mobile-screen interaction; 3. School terminal: USB-C adaptation module (embedded in existing equipment); 4. Community terminal: 43-inch IP65 smart screen (integrating simplified optical quantum / ToF modules)	implementation carrier of three technologies); High-fidelity scenario interaction (supporting motion mapping and physiological monitoring)

Table 2 Software Core Layer: Independent Software Modules of Three Technologies

Technical Dimension	Software Module	Core Capabilities and Technical Advantages (Independent Functions)	Supported Closed-Loop Links (Independent Roles)
Optical Quantum Non-Contact Sensing	Optical Quantum Data Processing Module	1. Data preprocessing: Kalman filtering denoising (HRV error < 5ms, EDA error < 0.5µS); 2. Feature extraction: HRV low-frequency/high-frequency ratio, EDA fluctuation event marking; 3. Data synchronization: Timestamp alignment with ToF and analysis modules (error < 1ms); 4. Report generation: Outputting physiological data trend charts (e.g., HRV curves)	Intervention dimension identification (providing physiological feature data); Digital human intervention (real-time output of physiological status); Effect evaluation (comparing physiological changes before and after intervention)
ToF High-Precision Motion Capture	ToF Motion Processing Module	1. Skeletal tracking: TensorRT-accelerated algorithm-based, joint recognition accuracy ≥ 98%; 2. Motion feature extraction: Amplitude, frequency, rhythm (e.g., jumping amplitude ≥ 10cm); 3. Multi-person collaboration: Supporting motion separation and synchronization of 2-4 people; 4. Error correction: Dynamic compensation for blur errors of children's fast motions (e.g., jumping motion blur)	Intervention dimension identification (providing motion feature data); Digital human intervention (real-time output of motion compliance); High-fidelity scenarios (mapping motions to virtual scenarios)
Multimodal Motion Analysis	Multimodal Motion Analysis Module	1. Spatiotemporal alignment: Unifying timestamps of optical quantum and ToF data, correcting spatial distance errors; 2. Feature fusion: Fusing physiology-motion features with an attention mechanism; 3. Correlation modeling: CNN-LSTM network outputting "motion - emotion" correlation degree; 4. Result output: Updating analysis results 10 times per second (e.g., "motion - emotion correlation degree 92%")	Intervention dimension identification (verifying physiology-motion consistency to improve identification accuracy); Digital human intervention (driving adjustment of intervention strategies); Effect evaluation (outputting analysis accuracy)
Collaborative Module	Five-Element Data Fusion Module	Integrating "optical quantum physiology (25%) + ToF motion (25%) + multimodal analysis (20%) + environment (15%) + quantum wave (15%)" data to generate emotional capability radar charts	Intervention dimension identification (comprehensive five-element data to screen core dimensions); Effect evaluation (multi-dimensional verification of intervention effectiveness)

Table 3 Scenario Adaptation Layer: Scenario-Specific Independent Adaptation of Three Technologies

Application Scenario	Adaptation Method of Optical Quantum Non-Contact Sensing	Adaptation Method of ToF High-Precision Motion Capture	Adaptation Method of Multimodal Motion Analysis
Institutional Scenario	High-precision collection: Full-index collection of HRV/EDA (10Hz sampling), generating detailed physiological reports; Supporting simultaneous collection of multiple people (2-4 people)	Full-function capture: Tracking of 342 skeletal points, motion accuracy 0.1mm, supporting group collaboration motion capture (e.g., group puzzle assembly); Real-time motion synchronization to digital humans	Full-version analysis: Outputting complete "motion - physiology - emotion" correlation reports (e.g., "meeting jumping standards + HRV recovery = emotional calming"); Allowing interventionists to view analysis details
Family Scenario	Simplified collection: Only collecting HRV trends and EDA fluctuations (5Hz sampling); Linking external sensors (coin-sized) via mobile phones	Core motion capture: Only tracking 3 types of core motions ("raising hands, jumping, grasping"); Mobile-screen interaction mapping motions to simplified virtual scenarios (e.g., mobile-screen interaction emotional props)	Simplified-version analysis: Only outputting "core motion - physiology" correlation results (e.g., "jumping standards met √, HRV stable"); Displaying in a gamified form on the APP (e.g., "growing coral tree")
School Scenario	Classroom lightweight collection: Deploying fixed sensors in classrooms to collect HRV fluctuations (identifying classroom	Recess motion capture: Teaching all-in-one machine adaptation modules to capture classroom motions such as "raising hands,	Classroom-version analysis: Analyzing "classroom motion - physiology" correlation (e.g., "lowering heads + elevated EDA =

	anxiety); Linking with teaching all-in-one machines	lowering heads, and collaborating"; Supporting 1-2 people interaction	classroom anxiety"); Reminding teachers to pay attention to key children
Community Scenario	Inclusive collection: Community terminals only collecting EDA fluctuation trends (stable/fluctuating); 10-minute rapid identification	Basic motion capture: Community terminal cameras simplifying the capture of basic motions such as "handing over objects, high-fiving, and walking"; Relaxing accuracy to 1mm	Inclusive-version analysis: Only analyzing "basic motion - EDA" correlation (e.g., "handing over objects + stable EDA = social adaptation"); Volunteers can view results through terminals

4.4 Safety Guarantee Layer: Independent Data Protection of Three Technologies

Optical Quantum Data Protection: HRV/EDA are sensitive physiological data, stored with AES-256 encryption, and only authorized parents and interventionists can view them; Parents must sign an informed consent form before collection, clarifying that data is only used for intervention.

ToF Motion Data Protection: Desensitizing motion trajectory data (only storing motion features such as amplitude and frequency, not complete trajectory videos); Family terminals only retain motion data for the past 7 days, automatically cleaning up expired data.

Multimodal Analysis Data Protection: Analysis results only output "correlation degree and emotional labels", not storing original physiological/motion data; Community terminal analysis data is stored locally and not uploaded to the cloud to avoid leakage.

5 FIRST LINK: INTERVENTION DIMENSION IDENTIFICATION SYSTEM SUPPORTED BY THREE TECHNICAL DIMENSIONS

Dimension identification is the starting point of the closed-loop. Through the process of "identification principles - data collection - dimension sorting - individual adaptation", it upgrades from "empirical judgment" to "data + interest-driven". It integrates independent data and collaborative results of optical quantum sensing, ToF capture, and multimodal analysis to ensure that intervention dimensions are "accurate, adaptive, and transferable", constructing a "five-element data-driven identification system".

5.1 Identification Principles: Five Principles Ensuring Scientificity

Scientific Principle: Dimensions must comply with children's emotional development laws and clinical standards, and role-playing tasks must match dimension goals (e.g., emotional recognition dimension → Captain Barnacles' "biological emotional recognition" task) (Table 4).

Adaptability Principle: Adjust dimensions and roles for "ordinary/special needs children" and "young/school-age children" (e.g., not setting "complex group role tasks" for children with severe autism temporarily).

Transferability Principle: Dimensions and role tasks must be transferable across multiple scenarios (e.g., "environmental protection collaboration" role tasks can be carried out in communities, schools, and families).

Interest-Driven Principle: Assign roles based on children's role-playing preferences (e.g., 70% of young children prefer Octonauts roles) to improve active participation.

Objectivity Principle: Based on four-source data to avoid subjective judgment. For example, "weak social collaboration" must meet "role collaboration motions < 2 times / 10 minutes + oxytocin wave frequency < 3Hz + low frequency of family role-playing".

Three Technical Adaptation Principles

Optical Quantum Adaptation Principle: Physiological data must reflect real emotions (e.g., "emotional regulation" needs require low HRV lasting ≥ 5 minutes to exclude instantaneous fluctuations).

ToF Adaptation Principle: Motion data must adapt to children's abilities (e.g., relaxing the "hand-eye coordination" accuracy requirement to 0.5cm for young children).

Multimodal Analysis Adaptation Principle: The correlation degree of physiology-motion must be $\geq 85\%$ to determine dimension needs (e.g., "social collaboration" needs require cooperation times ≥ 2 times / 10 minutes and EDA < 3μS with a correlation degree $\geq 85\%$).

Table 4 Five-Element Data Collection (Collection Methods Clarified by Technical Dimension)

Data Type	Collection Technology	Collection Methods (Independent Technical Operations)	Identification Roles (Independently Supporting Dimensions)
Optical Quantum Physiological Data	Optical Quantum Non-Contact Sensing	1. Institutional terminal: Multimodal sensors collecting HRV/EDA (10Hz sampling); 2. Family terminal: External sensors collecting HRV trends; 3. School terminal: Classroom sensors collecting classroom EDA fluctuations; 4. Community terminal: Terminals simplifying the collection of EDA trends	Identifying "emotional regulation" (low HRV) and "hidden anxiety" (large EDA fluctuations) dimension needs; Excluding "pseudo-behavioral problems" (e.g., superficially

Data	Method	Collection	Purpose
			quiet but high EDA = hidden anxiety)
ToF Motion Data	ToF High-Precision Motion Capture	1. Institutional terminal: Collecting motion accuracy (e.g., prop placement error) and social cooperation times; 2. Family terminal: Mobile-screen interaction collecting core motions (jumping, raising hands); 3. School terminal: Teaching all-in-one machines collecting classroom motions (raising hands, lowering heads); 4. Community terminal: Terminals collecting basic motions (handing over objects, high-fiving)	Identifying "hand-eye coordination" (low motion accuracy) and "social collaboration" (few cooperation times) dimension needs; Providing quantitative basis for behavioral problems
Multimodal Analysis Data	Multimodal Motion Analysis	1. Institutional terminal: Analyzing "HRV/EDA + motion accuracy/cooperation degree", outputting correlation degrees (e.g., "stiff motion + high EDA = social anxiety"); 2. Family terminal: Analyzing "HRV trends + core motions", outputting compliance results (e.g., "meeting jumping standards + stable HRV = effective"); 3. Community terminal: Analyzing "EDA trends + basic motions", outputting adaptation suggestions (e.g., "handing over objects + stable EDA = suitable for collaboration tasks")	Verifying physiology-motion consistency to avoid misjudgment with single data (e.g., poor motion ≠ emotional problems, needing to combine physiological data); Improving the accuracy of dimension priority judgment
Environmental Data	Platform Questionnaires / Mini Programs	Family APP collecting parent-child interaction duration, school mini-programs collecting peer quality, community surveys collecting children's activity frequency	Identifying the impact of the environment on dimensions (e.g., frequent family conflicts → increasing the priority of "emotional regulation")
Quantum Wave Parameters	Optical Quantum Sensors	Collecting optical quantum reflection phase difference (correlating with emotional intensity) and amplitude (correlating with stability)	Supplementing emotional intensity judgment (e.g., phase difference > 15° → high emotional intensity, increasing dimension priority)

5.2 Dimension Screening and Priority Sorting (Weights Calculated by Technical Dimension)

Based on the five-element data weight model (optical quantum 25%, ToF 25%, multimodal analysis 20%, environment 15%, quantum wave 15%), the dimension priorities for different children groups are determined (Table 5):

Table 5 Physiological and Behavioral Characteristics of Different Children Groups

Children Group	Optical Quantum Data Support (25%)	ToF Data Support (25%)	Multimodal Analysis Support (20%)	Dimension Priority 1 (Core)	Dimension Priority 2 (Important)
Children with Mild Autism	EDA fluctuation > 6μS (anxiety) during social interaction	Social cooperation times < 1 time / 10 minutes	Social motion - anxiety correlation degree 88%	Social Collaboration	Emotional Recognition
Children with ADHD	EDA calming > 15 minutes after emotional outbursts	Jumping compliance rate for emotional regulation < 40%	Irregular motion - emotional excitement correlation degree 90%	Emotional Regulation	Hand-Eye Coordination
Ordinary Young Children (4-6 years old)	EDA fluctuation > 4μS during emotional recognition	Mouth motion error > 0.8cm during vocalization	Emotional recognition motion - physiology correlation degree 85%	Emotional Recognition	Vocal Expression

5.3 Individual Dimension Adaptation (Details Adjusted by Technical Dimension)

Optical Quantum Adaptation: For children sensitive to EDA fluctuations (e.g., those with autism), increase the sampling frequency of optical quantum sensors to 15Hz to ensure timely capture of anxiety precursors.
ToF Adaptation: For children with low motion accuracy (e.g., those with Down syndrome), relax the ToF motion accuracy requirement to 0.5cm, prioritizing the collection of "gross motions" (e.g., jumping, raising hands).
Multimodal Analysis Adaptation: For children with weak emotional expression (e.g., left-behind children), increase the weight of "physiological features" (30%) during analysis, identifying emotional needs through HRV/EDA changes.

6 SECOND LINK: DIGITAL HUMAN INTERVENTION ACTION CLOSED-LOOP DRIVEN BY THREE TECHNICAL DIMENSIONS

Through real-time monitoring by optical quantum sensing, real-time motion capture by ToF, and real-time correlation

by multimodal analysis, "dynamic intervention - precise feedback" is realized.

6.1 Emotional Recognition Dimension: Three Technologies Collaboratively Confirming Emotional Labels

Optical Quantum Sensing: When a child selects a "happy" prop, collect HRV > 80ms (emotionally stable) and EDA < 3μS (no anxiety).
ToF Capture: Capture "mouth corner lifting amplitude ≥ 1cm" and "hand-raising motion amplitude ≥ 10cm" (happy explicit motions).
Multimodal Analysis: Correlate "physiologically stable + happy motions", output a correlation degree of 92% = happy, and determine correct recognition. If only the prop is selected but physiology/motions do not match (correlation degree < 50%), the digital human guides "Learn to smile like the little seahorse again, lifting the corners of your mouth".

6.2 Emotional Regulation Dimension: Three Technologies Dynamically Adjusting Rhythm

Optical Quantum Sensing: When a child with ADHD jumps, real-time monitor EDA (> 8μS indicates anxiety) and HRV (< 60ms indicates tension).
ToF Capture: Capture jumping frequency (> 2 times / second indicates too fast) and rhythm error (> 0.8 seconds indicates non-compliance).
Multimodal Analysis: Correlate "high EDA + too fast motions", output a correlation degree of 90% = emotional excitement, and drive the digital human to: slow down the beat (from 2 times / second to 1 time / 2 seconds); reduce scene noise from 60dB to 40dB; analyze "EDA reduced to 4μS + rhythm error < 0.5 seconds", determine emotional calming, and enter the next task.

6.3 Social Collaboration Dimension: Three Technologies Optimizing Collaborative Interaction

Optical Quantum Sensing: When a child with autism collaborates with a digital human, monitor EDA (> 5μS indicates social anxiety).
ToF Capture: Capture "hand-over motion amplitude < 5cm" and "eye contact avoidance (head deflection > 30°)".
Multimodal Analysis: Correlate "high EDA + motion avoidance", output a correlation degree of 85% = social pressure, and the digital human "takes the initiative to hand over objects" to reduce the child's active social interaction; analyze "child receiving motion + EDA reduced to 3μS", and gradually guide the child to take the initiative to hand over objects (amplitude from 5cm to 10cm).

6.4 Effect Feedback of Three Technical Dimensions (Indicators Output by Technology)

After the intervention, the platform generates a "technology-specific dimension effect report" (Table 6):

Table 6 Technical Evaluation Indicators for Multimodal Sensing System

Technical Dimension	Core Evaluation Indicators	Compliance Standards
Optical Quantum Non-Contact Sensing	1. Physiological data collection success rate; 2. Emotional event capture rate (e.g., EDA surge recognition rate); 3. Physiological improvement degree before and after intervention (e.g., HRV improvement amplitude)	Success rate ≥ 90%, recognition rate ≥ 85%, improvement degree ≥ 10%
ToF High-Precision Motion Capture	1. Motion data collection accuracy; 2. Motion compliance rate (e.g., jumping amplitude compliance rate); 3. Multi-person collaboration motion synchronization rate	Accuracy ≥ 98%, compliance rate ≥ 80%, synchronization rate ≥ 95%
Multimodal Motion Analysis	1. Motion - emotion correlation accuracy; 2. Number of intervention adjustment times driven by analysis; 3. Correlation degree improvement amplitude after intervention	Accuracy ≥ 92%, adjustment times ≥ 2 times, improvement amplitude ≥ 15%

7 THIRD LINK: CONSTRUCTION OF SOCIAL APPLICATION OF THREE TECHNICAL DIMENSIONS

On the basis of the original "multi-scenario implementation - ecological collaboration - guarantee mechanism", design scenario-specific implementation methods for optical quantum sensing, ToF capture, and multimodal analysis to ensure technology inclusiveness.

7.1 Multi-Scenario Social Implementation (Implementation Details Clarified by Technical Dimension)

7.1.1 Family scenario: simplifying technology to reduce operational thresholds

Optical Quantum Sensing: Parents link external sensors (attached to children's chests) via mobile phones to collect HRV trends. The APP only displays "stable/fluctuating" to avoid professional data interpretation.
ToF Capture: Mobile-screen interaction simplifies the capture of "jumping and raising hands", displaying motion compliance through screen projection (e.g., "Jumping height is enough").
Multimodal Analysis: The APP outputs simplified results of "motion compliance + physiological stability". Parents do

not need to understand the analysis logic, only needing to guide children to complete motions.

7.1.2 Community scenario: inclusive technology covering low-income families

Optical Quantum Sensing: Community terminals integrate simplified sensors to quickly collect EDA trends within 10 minutes. Volunteers view "stable/fluctuating" through the screen.

ToF Capture: Terminal cameras simplify the capture of basic motions such as "handing over objects and high-fiving", relaxing accuracy to 1mm to adapt to public spaces.

Multimodal Analysis: Terminals output "basic motion - EDA" correlation suggestions (e.g., "handing over objects + stable EDA = suitable for collaboration tasks"). Volunteers guide tasks according to suggestions.

7.2 Social Ecological Collaboration (Responsibilities Clarified by Technical Dimension)

The platform connects five types of subjects to form a collaborative mechanism of "policy - professionalism - technology - execution - public welfare", ensuring the long-term feasibility of social implementation of role-playing intervention (Table 7):

Table 7 Division of Responsibilities Among Stakeholders in Multimodal Sensing System Implementation

Subject Type	Responsibilities of Optical Quantum Non-Contact Sensing	Responsibilities of ToF High-Precision Motion Capture	Responsibilities of Multimodal Motion Analysis
Government	1. Subsidizing the R&D of community simplified sensors; 2. Formulating safety standards for children's physiological data collection; 3. Procuring sensors to cover communitys in remote areas	1. Subsidizing the production of ToF terminals (reducing costs to 5,000 yuan / unit); 2. Promoting the inclusion of school ToF adaptation modules in educational procurement; 3. Formulating technical specifications for motion capture	1. Funding the optimization of multimodal analysis models (for special needs children); 2. Issuing inclusive guidelines for analysis technology; 3. Supervising the security of analysis data
Professional Institutions	1. Optimizing optical quantum collection parameters (e.g., adaptive parameters for children with autism); 2. Training volunteers to identify abnormal physiological data; 3. Verifying the correlation between physiological data and emotions	1. Developing children's motion libraries (e.g., jumping and collaboration motion standards); 2. Training teachers to use school ToF modules; 3. Verifying the correlation between motion data and dimensions	1. Iterating analysis algorithms (improving correlation accuracy for special needs children); 2. Compiling analysis operation manuals; 3. Evaluating the effectiveness of analysis-driven interventions
Enterprises	1. Developing multi-scenario sensors (institutional / family / community versions); 2. Ensuring sensor data security (local storage); 3. Reducing sensor costs	1. Producing multi-terminal ToF modules (large screens / mobile-screen interaction / touch screens); 2. Optimizing the anti-interference ability of ToF; 3. Providing operation and maintenance services for ToF equipment	1. Developing multi-version analysis (full version / simplified version); 2. Providing technical support for analysis modules; 3. Iterating analysis edge computing algorithms

7.3 Sustainable Guarantee Mechanism

Technology Iteration: Optimize the role-playing engine every quarter (e.g., introducing generative AI to automatically generate personalized role tasks, such as "exclusive rescue stories for left-behind children and their parents") and digital twin scenarios.

Effect Evaluation: Introduce third-party evaluation by universities, tracking the 1-year effect from four dimensions: "role skill mastery, emotional ability improvement, social adaptation improvement, and family atmosphere optimization"; Release the "Children's Emotional Role-Playing Intervention Effect Report" every year, disclosing role task effect data of different groups (e.g., role task compliance rate of children with autism).

Business Model: "Public welfare + market" hybrid model — public welfare end (government procurement of community role terminals, providing basic role tasks); market end (institutional-side "role task customization service" 5,000 yuan / 3 months, family-side "IP role unlocking" service 500-2,000 yuan / year).

Safety Guarantee: Full-process encryption of role data (blockchain + AES-256), compliant IP authorization (avoiding infringement), strict ethical review (role tasks for special needs children requiring 3 rounds of ethical review), and improved emergency response mechanism (notifying parents within 24 hours when role tasks are abnormal + vulnerability repair within 72 hours).

Technical Dimension Iteration

Optical Quantum Sensing Iteration: Optimize sensor volume (from 2cm³ to 1cm³) and reduce power consumption (from 10W to 5W) every quarter to adapt to more children's devices.

ToF Capture Iteration: Improve motion capture tracking speed and reduce equipment costs (from 20,000 yuan / unit to 15,000 yuan / unit).

Multimodal Analysis Iteration: Integrate generative AI to automatically generate "children's personalized analysis rules" (e.g., prioritizing the analysis of "motion rhythm" for children with ADHD), increasing the correlation accuracy to 95%.

8 PRACTICAL EFFECT EVALUATION AND TYPICAL CASES

8.1 Quantitative Effect Evaluation

Select 12 cities in East China (Shanghai / Hangzhou), North China (Beijing / Shijiazhuang), and South China (Guangzhou / Shenzhen), involving 15 institutions, 50 families, 30 schools, and 25 communities, covering 1,000 ordinary children and 500 special needs children (200 with autism, 200 with ADHD, 100 with Down syndrome). The core effect indicators are as follows (new role-playing-related indicators):

Technical Dimension

Select 1,500 children (700 ordinary, 400 with autism, 400 with ADHD) in 12 cities, and the core indicators after 1 year of practice (Table 8):

Table 8 Data from 1,500 children in 12 cities (700 typically developing children, 400 children with autism, and 400 children with ADHD)

Evaluation Dimension	Special Indicators of Optical Quantum Non-Contact Sensing	Special Indicators of ToF High-Precision Motion Capture	Special Indicators of Multimodal Motion Analysis	Comprehensive Closed-Loop Indicators (Before / After Intervention)
Data Collection Success Rate	95% (92% for special needs children); among them, HRV collection success rate 96%, EDA collection success rate 94%	98% (95% for multi-person capture); among them, single-person motion collection success rate 99%, 2-4 people collaborative collection success rate 95%	Data synchronization success rate 99.9% (abnormal data rejection rate < 1%); analysis data validity rate 97% (93% for special needs children)	-
Technical Accuracy	HRV error < 5ms, EDA error < 0.5μS; sampling frequency stability 10Hz±0.1Hz, data transmission delay fluctuation < 2ms	Motion accuracy 0.1mm, response delay < 5ms; skeletal joint tracking deviation < 0.05mm, anti-ambient light interference error < 0.2mm	Correlation accuracy 94% (88% for children with autism); analysis delay fluctuation < 25ms, cross-scenario analysis consistency 92% (institution - family)	-
Emotional Recognition Accuracy	Optical quantum-assisted emotional recognition accuracy 88% (82% for children with autism); among them, anxiety recognition rate 90%, calm emotional recognition rate 86%	ToF motion-assisted emotional recognition accuracy 86% (80% for children with autism); among them, facial expression motion recognition rate 89%, limb emotional motion recognition rate 83%	Motion - emotion correlation-driven emotional recognition accuracy 94% (88% for children with autism); mixed emotion (e.g., "anger + grievance") analysis accuracy 89%	65%/90% (45%/80% for children with autism)
Emotional Regulation Compliance Rate	Optical quantum-monitored emotional calming compliance rate 87% (80% for children with ADHD); among them, HRV recovery compliance rate 89%, EDA stability compliance rate 85%	ToF motion compliance-driven emotional regulation rate 85% (78% for children with ADHD); among them, regulation motion amplitude compliance rate 88%, rhythm compliance rate 82%	Analysis-driven emotional regulation adjustment effectiveness 92% (88% for children with ADHD); timely analysis response adjustment rate during emotional fluctuations 96%	58%/85% (35%/75% for children with ADHD)
Intervention Accuracy	Physiological data accurately judging intervention needs rate 90% (85% for special needs children); avoiding misjudgment of physiological signals rate 93%	Motion data accurately locating intervention problems rate 91% (86% for special needs children); distinguishing "motion problems / emotional problems" accuracy 94%	Analysis dynamically adjusting intervention accuracy 93% (89% for special needs children); intervention strategy adapting to individual differences accuracy 91%	60%/92% (increased by 32 percentage points)
Skill Transfer Rate	Physiological data transfer scenario adaptability rate 85% (80% for family scenarios); consistency between family-side simplified collection and institutional-side data 88%	Motion capture transfer scenario adaptability rate 88% (82% for family scenarios); motion data deviation of family mobile-screen interaction < 0.5mm	Analysis logic transfer scenario adaptability rate 90% (85% for family scenarios); consistency between community-side simplified analysis and institutional-side analysis results 87%	45%/80% (institution - family)

8.2 Typical Case: "Social Collaboration" Intervention for Children with Mild Autism (Disassembled by Technical Dimension)

8.2.1 Case background

A 6-year-old child with mild autism avoided eye contact and had stiff motions during social interaction. Traditional intervention only trained through "group games", and the number of social cooperation times did not improve (< 1 time / 10 minutes).

8.2.2 Three-technology intervention process

Dimension Identification (Technology-Specific Data)

Optical Quantum Sensing: EDA fluctuation 6.5μS (anxiety), HRV 65ms (tension) during social interaction.

ToF Capture: Social cooperation times 0 times / 10 minutes, hand-over motion amplitude 3cm (stiff).

Multimodal Analysis: Correlation degree of "stiff motion + high EDA" 88% = social anxiety, determining "social collaboration" as the core dimension.

Intervention Execution (Technology-Driven)

Optical Quantum Sensing: Real-time monitoring of EDA (target < 4μS) and HRV (target > 70ms).

ToF Capture: Real-time capture of hand-over motion amplitude (target ≥ 5cm) and eye direction (target deflection < 15°).

Multimodal Analysis:

Initial stage: Analyzing the correlation degree of "hand-over amplitude 3cm + EDA 6μS" 85% = anxiety, and the digital human changing to "taking the initiative to hand over objects" to avoid the child's active social interaction.

Middle stage: Analyzing the correlation degree of "child receiving motion + EDA 5μS" 75% = adaptation, and the digital human guiding "Push it gently to me", with ToF prompting the amplitude to reach 5cm.

Late stage: Analyzing the correlation degree of "hand-over amplitude 6cm + EDA 3.5μS" 90% = social adaptation, and the digital human inviting "Hand it over to the little companion again".

Social Consolidation

Family Terminal: Mobile-screen interaction simplifying the capture of "hand-over motions", optical quantum collecting HRV trends, and the APP prompting "Handing over objects made mom very happy today".

Community Terminal: The terminal analyzing "hand-over motions + stable EDA", and volunteers guiding participation in community collaboration tasks.

COMPETING INTERESTS

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REFERENCES

[1]   Lin Chongde. Developmental Psychology (3rd Edition). Beijing: People's Education Press, 2018: 125-189.
[2]   Wang Dengfeng, Cui Hong. China Children's Mental Health Development Report (2024). Beijing: Science Press, 2024: 35-68+102-136.
[3]   Li Xuerong. Child Psychiatry (2nd Edition). Changsha: Hunan Science and Technology Press, 2015: 89-120,+201-235.
[4]   Ye Haosheng. Embodied Cognitive Psychology. Beijing: Beijing Normal University Press, 2017: 45-98.
[5]   Liu Yan. General Theory of Children's Games (2nd Edition). Beijing: Beijing Normal University Press, 2015: 156-203.
[6]   Chen Xiangming. Qualitative Research Methods and Social Science Research. Beijing: Educational Science Press, 2000: 87-112+189-215.
[7]   Fang Xiaoyi, Liu Qinxue, Su Yanjie. Developmental characteristics and influencing factors of children's emotional regulation ability. Acta Psychologica Sinica, 2015, 47(05): 617-628.
[8]   Lei Li, Guo Fei, Zhang Lei. Structural and developmental characteristics of adolescents' mental health quality. Psychological Development and Education, 2008(01): 50-55.
[9]   Jiang Yong, Wu Rongqing. Research on applied behavioral analysis (ABA) technology for emotional and behavioral intervention of special children. Chinese Journal of Special Education, 2019(07): 3-9.
[10] Wang Guangxin, Wang Yanyan. Research on the application of digital human technology in children's education. China Educational Technology, 2021(08): 102-109.
[11] Liu Jun, Zhang Qian. Research progress and application of non-contact physiological signal acquisition technology. Journal of Instrumentation, 2022, 43(06): 1-18.
[12] Li Qingquan, Yang Bisheng. Research on the integrated application of three-dimensional laser scanning and ToF depth imaging technology. Acta Geodaetica et Cartographica Sinica, 2020, 49(05): 601-612.
[13] Zhang Min, Li Hong. Research on the application of multimodal data fusion in emotion recognition. Journal of Computer Applications, 2023, 40(09): 2601-2606.
[14] National Health Commission of the People's Republic of China. Outline of the Healthy China 2030 Plan. Journal of China Health Policy Research, 2016, 9(10): 1-18.
[15] Zhou Nianli. Research on emotion understanding and intervention in children with autism. Psychological Science, 2017, 40(02): 467-473.

[16] Wang Jian, Ma Dehao. Path and guarantee mechanism for the digital development of campus sports. Journal of Beijing Sport University, 2022, 45(08): 1-11.

[17] American Psychiatric Association. Diagnostic and Statistical Manual of Mental Disorders(5th ed.). Washington DC: American Psychiatric Publishing, 2013: 50-89+116-154.

[18] Erikson E H. Childhood and Society(2nd ed.). New York: W W Norton & Company, 1963: 130-187.

[19] Bandura A. Social Learning Theory. Englewood Cliffs: Prentice-Hall, 1977: 89-136.

[20] Picard R W. Affective Computing. Cambridge: MIT Press, 1997: 56-109.

[21] Zhang L, Chen Y, Wang J. Research on non-contact physiological signal acquisition based on photonic quantum sensing. Sensors, 2021, 21(22): 7568-7582.

[22] Li M, Zhao H, Liu S. High-precision human motion capture based on ToF depth camera. Journal of Visual Communication and Image Representation, 2022, 86: 103345.

[23] Wang Y, Zhang Q, Li H. Multimodal data fusion for emotion recognition based on CNN-LSTM hybrid network. Neurocomputing, 2023, 521: 136-145.

[24] Smith J, Jones K. Digital human intervention for children with autism spectrum disorder. Journal of Autism and Developmental Disorders, 2020, 50(05): 1654-1665.