Technical Progress and Challenges of a New Type of Pediatric Oral Monitoring System

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Abstract

With the rapid development of 5G communication technology, 3D structured light vision technology and micro-sensors, the demand for children's oral health monitoring is increasing. Traditional oral monitoring methods have problems such as low efficiency, poor accuracy and complex operation, but the fusion application of new technologies can significantly improve the accuracy and efficiency of monitoring, and improve children's experience in the monitoring process. This paper first describes the application of 5G communication technology, 3D structured light vision technology and sensors in children's oral monitoring, and analyzes their working principles, challenges and breakthroughs, and finally discusses their clinical application prospects.

Keywords

5G communication; 3D structured light vision; Sensor; Children oral monitoring.

1. INTRODUCTION

Childhood is a key stage in the development of oral health. Dental caries, gingivitis, malocclusion and other oral diseases, if not detected and treated in time, may affect children's chewing, pronunciation, maxillofacial development and physical and mental health[1].According to the Fourth National Oral Health Epidemiological Survey Report, the prevalence of caries in children at 3 years old was 50.5%, at 4 years old 63.0%, and at 5 years old was as high as 70.9%. The incidence of caries in children showed an increasing trend, but the treatment rate was only 4.1%[2].The traditional monitoring system has some problems, such as low monitoring efficiency, poor accuracy and complicated operation, and the resistance of children to oral monitoring and treatment is one of the important reasons for the low cure rate. In order to ensure the oral health of children, an integrated cloud oral monitoring system that integrates 5G communication technology, multi-sensory interaction mechanism, high-precision 3D scanning and advanced visual recognition technology is urgently needed to realize remote monitoring of children at home.

2. 5G COMMUNICATION TECHNOLOGY

2.1. Application of 5G communication technology in oral monitoring

The fifth generation of mobile phone mobile communications standards (5G) features: Fast speed (low latency 1 ms), wide range (high broadband 10Gbps), network slicing (differentiated service requirements), MEC can achieve mobile edge computing, submeter-level high-precision positioning. The iteration of 5G communication network has expanded the implementation scope of "5G+ smart medical"[3].

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In recent years, many domestic medical institutions have applied implantable sensors more and more widely. However, according to the monitoring of various physiological movement signs, it is found that the function of sensors is limited by obvious problems such as slow and discontinuous communication of 4G network at the present stage[4]. In addition, some patients in remote areas or with mobility difficulties who cannot obtain timely diagnosis and treatment have a demand for telemedicine. When 4G communication networks transmit patient information and medical data, information transmission is often asynchronous and visual field clarity is low, resulting in lower diagnostic efficiency and even misdiagnosis[5].

In contrast, the 5G communication network has the characteristics of high speed, low delay and large connection, which can transmit the patient's oral status data and intra-oral HD images collected by the sensor to the monitoring terminal in the first time, and the low delay can ensure the timely interaction of remote medical staff. At the same time, the large connection capability supports the simultaneous access of multiple low-energy and low-delay monitoring devices, sensors and auxiliary devices to continuously collect patients' medical data and build a comprehensive monitoring data collection network, so as to facilitate medical staff to provide timely medical services for patients and provide more accurate personalized medical solutions[6].

2.2. Challenges and Breakthroughs of 5G Communication Technology

Behind the convenience brought by 5G technology, the leakage problems of personal data and privacy are more obvious. As a group in special need of protection, the security of children's oral health data is particularly important[7].When monitoring or telemedicine collection of relevant data, 5G technology can help doctors quickly diagnose and treat, but there may be problems of personal privacy disclosure in the process of data uploading, collection, and sorting. When implementing telemedicine services, medical personnel need to ensure not only that patient privacy is adequately protected, but also that patients give informed consent. At the same time, the telemedicine platform must establish a secure information transmission mechanism to strictly maintain data security and prevent any unauthorized access[8].Through cooperation in different fields, patients' privacy can be effectively protected[9]， At the same time, the compliance of data storage and management should also be considered, and relevant laws and regulations should be observed.

In addition, the high energy consumption of 5G networks cannot be ignored. In telemedicine, there is a need to balance network performance and energy consumption, develop more energy-efficient 5G equipment and network optimization schemes. At the same time, the high cost of 5G equipment may affect its popularity in grassroots medical institutions, and more economical solutions need to be explored.

3. 3D STRUCTURED LIGHT VISION TECHNOLOGY

3.1. Working principle of 3D structured light vision technology

3D structured light scanning technology has fast speed, high accuracy and clear imaging, which is more intuitive and accurate than two-dimensional measurement. As shown in Figure 1, 3D structured light scanning technology is based on the principle of triangulation. The projector projects the structured light on the surface of the tooth and soft tissue, and the camera observes the deformity. When the position of the projector and the camera is fixed, the image coordinates of the child's deformed maxillofacial region and its teeth can be obtained according to the known structured light pattern, and the three-dimensional structure virtual model can be constructed. For the basic principle of structured light projection, please refer to the paper on teaching structured Light written by Geng et al.[10].

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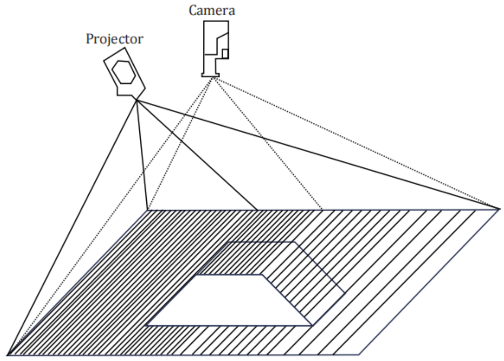

Figure 1. The Principle of Structured Light 3D Vision

In Figure 2, it is assumed that the upper surface of the measured point is parallel to the horizontal plane, the light beam is illuminated diagonally downward, reflected by the object to be measured and then emitted vertically and received by the CCD camera module, point A B is the central position of the spot on the point surface of the laser beam at different heights,A',B' are respectively the image point of A,B on the CCD target surface, the horizontal plane where point A is the reference plane (the displacement of the workpiece to be measured is zero), the distance AO from the reference plane to point O is known; The point is the center of the camera lens, and the length of A 'B' can be read out by the measuring system through geometric calculation:$A'B' = \frac{\mathrm{OA\prime \times H \times tanT}}{AO}$.

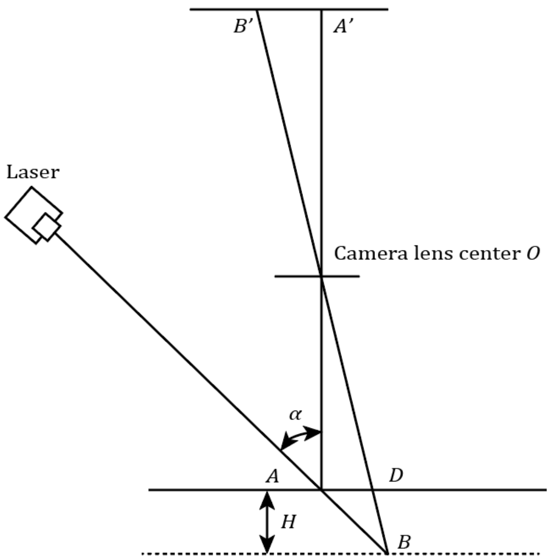

Figure 2. The Principle of Triangulation Ranging

3.2. Application of 3D structured light vision technology in oral monitoring

Yi-jiao Zhao et al.[11]evaluated the actual accuracy of a "structured light" face scanner (FaceScan) by using data registration and "3D error" as a new measurement calculated by Geomagic Studio. In this study, 10 patients with clinical oral facial deformities were studied. The accuracy of 3D facial reference models obtained by high-precision industrial "line laser" scanner (Faro) and the errors of models obtained by "structured light" face scanner were

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evaluated, and the conclusion was drawn that the "structured light" face scanner met the clinical requirements of oral medicine.

In recent years, researchers have also compared the near and distal diameters, buccolingual diameters and clinical crown heights measured by electronic calipers measuring plaster models and handheld 3D structured light scanner digital models, and found that there is no difference in dental measurement between the two methods [12] .Peng Juxiang et al.[13]also used structured light 3D scanning technology to measure and reconstruct facial soft tissue in 3D direction before and after orthodontic orthomandibular combined treatment, which intuitively and accurately reflected the changes of soft tissue. It shows that 3D structured light scanning technology has broad application prospects in orthodontic and prosthodontic fields.

The camera group of the head of the autonomous detection hardware is used to collect oral images, which should meet the characteristics of small size and clear shooting. The 8mm diameter HD endoscope module mentioned by Liu Jiahu[14] can be selected, which has a high resolution of 640×480, with 6 LED lamp beads on the lens to provide lighting and reduce the interference of external light sources for monitoring, and the image transmission rate can reach about 30 frames per second.

3D structured light vision technology has good feasibility in oral clinic, and can be applied to new types of children.

3.3. Challenges and breakthroughs of structured light scanning technology

Structured light scanning technology has shown great application potential in the field of stomatology, but it still faces many challenges in practical clinical application, among which the problem of scanning blind areas is particularly prominent[15].The complexity of the oral environment, including anatomical limitations, interference with light reflection, and dynamic changes in soft tissues, often results in parts of the oral cavity that cannot be captured effectively, thus affecting the integrity and accuracy of the 3D reconstruction model. Specifically, the lingual and palatal areas of the teeth are often difficult to cover completely due to the physical limitations of the device probe, becoming a common scanning blind area. In addition, the slight movement of the patient's soft tissues such as the tongue and cheek during the scan may cause significant interference with the projection and collection of light. At the same time, the high reflectivity of tooth surfaces (especially metal restorations or areas with high gloss) and light absorption problems in dark or wet areas such as gums further exacerbate the difficulty of data acquisition, resulting in the absence of valid data in some areas.

To solve these problems, the researchers put forward a variety of solutions. For example, in response to device size limitations, the development of smaller and more flexible scanning probes has become an important research directionto better cover complex areas such as the fossae and margins of the oral cavity.[16] At the same time, interference in highly reflective areas can be effectively reduced by treating the tooth surface with an anti-reflective coating or spray before scanning, thus improving the accuracy and integrity of data acquisition.

4. MICRO SENSOR/MULTI-PERCEPTION INTERACTION TECHNOLOGY

4.1. Application of flexible sensor in oral monitoring system

The micro-sensor in the oral monitoring system should have the function of monitoring tooth force, temperature, electrophysiological muscle movement and obtaining partial chemical signals. The flexible sensor has a flexible base that is closely fitted to the human surface, and can stretch the electrode and the active layer material[17]. It can adapt to the oral environment of the human body, with light weight, small size, deformable and wearable[18], and can be widely used in oral prevention and examination of children.

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4.1.1. Optical sensor

The optical sensor is based on the characteristics changes of substances such as absorption, reflection and scattering of light for real-time monitoring, including the monitoring of physiological signals such as blood oxygen saturation and biomarkers, with high sensitivity, rapid response and anti-electromagnetic interference[19].

Surface Plasmon Resonance (SPR) sensors are a type of optical sensor that can enhance the local electromagnetic field by using the interaction between metal nanostructures and incident light at a specific frequency. Thus, marker-free optical detection of target bioanalytes can be achieved[20]. According to the working principle of the SPR sensor, Li et al.[21]further utilized the local reaction between gold-silver core-shell nanorods and volatile sulfur compounds to change the plasmon resonance on the surface of the nanorods, resulting in color changes, thus achieving accurate location of caries[17].

4.1.2. Electrochemical sensor

In the study on the application of flexible sensors in oral monitoring, Huang Jingwen et al. [17]mentioned that electrochemical sensors can well prevent children's periodontal diseases by providing oral data.The principle is to convert the information of the target analyte into measurable electrical signals through REDOX reaction[22], which are monitored by amperometry, potentiometric method and voltammetry.

The microchip of electrochemical biosensor studied by Zhang et al.[23]can quickly and accurately measure lactic acid concentration in saliva, providing preliminary data for periodontitis. The electrochemical sensor coated with cellulose acetate membrane developed by Arakawa et al.[24]can also detect glucose in saliva in real time, indirectly reflect the risk of dental caries and periodontal disease, and at the same time monitor the blood sugar level of diabetes, thus controlling diabetic periodontitis. Electrochemical sensors can perform point-of-care (POCT) in the mouth to measure various indicators of the mouth briefly and quickly.

4.1.3. Biosensor

Biosensor is an analytical device that uses biometric elements and physicochemical transducers to convert biological signals into detectable physical or chemical signals, so as to detect biological molecules or biorelated substances. Therefore, it is also a complex electrochemical and optical sensor[17]。

In recent years, with the increasing demand for POCT detection technology, the innovative application of microfluidic chips has gradually become a research hotspot. POCT is of great significance for the detection of oral diseases such as periodontal disease[25]. Researchers such as Li et al. [26]have successfully developed an integrated microfluidic device that can quickly diagnose periodontal pathogens in gingival crevicle fluid, and only a small amount of samples are needed for detection. Effective data from relevant experiments fully prove that the microfluidic chip is an efficient and accurate tool for diagnosing pathogens.

Brann et al.[27]combined the self-developed microfluidic visualization chip with white-light interferometry (WLI) to monitor the structural changes of subgingival plaque biofilm at real time. The experiments showed that the images generated by the chip were able to capture small changes in the early stages of biofilm development and fine features of mature biofilm structures. This technique also provides a new perspective for the detection of periodontal disease.

At present, with the continuous development of various technologies, researchers have become more and more perfect in the study of oral biomarker identification technology, and the application potential of microfluidic chips in periodontal disease prevention and treatment has been continuously tapped, which is expected to cover the entire oral and even various fields of the medical industry in the future[28].

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4.2. Challenges and breakthroughs faced by oral sensing technology

In order to monitor the complex oral environment in real time, the sensor of the oral monitoring system should adapt to the oral environment, improve the biocompatibility and improve the portability.

Due to the moist environment of the mouth and the flow of saliva, the enzymes in the sensor are easy to lose their biometric function[29]. Packaging or protective film can effectively prevent moisture and improve stability. Artificial receptors that collect target signals can also be used, which is simple to process and reduces cost[30]. In addition, the accumulation of biological pollutants in the mouth and the temperature change during activities will also affect the stability of the sensor and its instrument materials. Protective film can prevent biological pollution and reduce unnecessary wear, and the addition of compensation elements such as temperature sensors can reduce or avoid the impact of temperature changes on the sensor[31].

The frequent movement of the mouth and the complex biological environment make it difficult for flexible electronic devices to realize real-time monitoring of target signals. For accurate measurement of chemical/biological signals, selective sensor arrays can be used to identify different analytes and enable analysis of mixture components[32]. A conductive hydrogel with excellent adhesion properties is used as the base material[33], and ionic additives are introduced to enhance the stretchability and conductivity of the material while reducing its Young's modulus, thus effectively improving the measurement accuracy of the sensor[34].

The sensitivity level of the sensor affects the accuracy of oral and craniofacial status monitoring. In order to improve the sensitivity of the sensor, it is possible to (1) explore new high-concentration biomarkers with strong correlation with target diseases to expand the detection target range[35]; (2) Optimizing the sensitivity performance of the sensor itself, in which the use of signal amplification transistors to enhance the signal transduction efficiency, or the introduction of fluorescent protein labeling technology, are effective methods[36].

Miniaturization is another development trend that promotes the advancement of flexible sensing technology. Precision manufacturing of miniaturized flexible electronic devices can be achieved by integrating 3D printing and thin film sputtering technology, and using semi-solid/solid electrolyte materials[18]. At the same time, new sensors developed using flexible semiconductor materials (such as crystalline silicon carbide nanofilms) can break through traditional design limitations and achieve more miniaturized and ultra-thin sensor structures[37].

5. SUMMARY AND PROSPECT

The deep integration of 5G multi-sense interaction technology and 3D optical vision technology has brought significant technological breakthroughs for children's oral monitoring systems. This innovative combination not only improves the accuracy and efficiency of monitoring, but also significantly enhances the comprehensiveness and reliability of the data. In clinical application, the system has shown important value in the early diagnosis of dental caries in children, orthodontic treatment planning and periodontal disease monitoring, and has effectively improved the accessibility and popularization of oral health care services for children.

Despite the significant advantages of the technology, it still faces some challenges in practical application, such as the high cost of equipment, complex operational processes, and data privacy protection issues, which may limit its large-scale adoption. However, with the continuous optimization and iteration of relevant technologies, this new monitoring system is expected to achieve a wider range of applications in the field of pediatric stomatology, so as to provide more efficient and accurate support for children's oral health management.

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