Rehabilitation system for children with cerebral palsy based on body vector analysis and GMFM-66 standard

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Abstract. This paper mainly proposes a rehabilitation training system that uses motion recognition technology to help children with cerebral palsy complete the evaluation of gross motor functions. This article makes a comprehensive introduction to this product with regard to the system functional architecture, application technology principles and its application scope.

1. Introduction to rehabilitation training and product for children with cerebral palsy

According to statistics, the total number of cerebral palsy patients in China exceeds 8 million, of which 40,000 to 50,000 new cases of cerebral palsy are added each year, and the treatment and rehabilitation process of children with cerebral palsy will bring huge economic pressure to families and society.

Due to the complexity of the disease in patients with cerebral palsy, currently, the rehabilitation training of cerebral palsy patients generally needs to be completed in the hospital by means of comprehensive guidance from medical staff. For example, the evaluation of the gross motor function of children with cerebral palsy concerned in this article requires the doctor to guide and give the action score to complete. In the face of a large patient population, domestic hospitals and related research institutions do not provide sufficient medical resources. The figure below shows the proportion of hospitals in the specialized cerebral palsy treatment and rehabilitation training departments in the medical institutions in the provinces. It can be seen that the current medical resources for cerebral palsy patients are far from sufficient [1].

In recent years, the development of artificial intelligence technology has made it possible for us to realize the evaluation of automated rehabilitation training for children with cerebral palsy. We extract the coordinates of the key points of the human body through OpenPose, and establish a rehabilitation system for children with cerebral palsy based on body vector [2] analysis and GMFM-66 [3] medical evaluation standard. This system assigns the GMFM rating that originally required professional physicians to the computer, which can greatly save the assessment cost. The system is low in cost and easy to use, which not only solves the problem that must be handed over to the doctor to judge the evaluation result, but also enables the family of cerebral palsy patients with more economic conditions to enjoy the automatic rehabilitation training service.
2. Introduction of system

2.1. Overview of system architecture

The system mainly includes three parts: Raspberry Pi client-side, remote database and server. Users primarily interact with the Raspberry Pi client and the web-side. The Raspberry Pi client-side is responsible for collecting the user's original action data and uploading it to the server. After the server extracts the key points of the human body using OpenPose, the body vector is generated, and the action standard evaluation algorithm is used to compare the subject motion with the standard GMFM-66 action to obtain the final test score. The score is finally inserted into the remote database. After the data is processed, the user can log in to the web to view the evaluation data of the child. Among them, the data set of the standard GMFM-66 action was taken by the author of the paper.

2.2. Overview of function

The guardian of the child can operate the graphical interface on the Raspberry Pi client-side and select the action that needs to be trained. The camera will then be turned on to record the action data of the child in real time, while the standard action will be displayed on the screen for the reference of the subject.
Figure 3. GMFM evaluation interface (standard action video on the upper right and video recorded by the real-time camera on the lower right)

After the evaluation is completed, the user can log in to the supporting website to view the GMFM's score and visual data of the limb movement ability.

Figure 4. Evaluation interface

2.3. Product composition
Camera, camera stand, yoga mat and Raspberry Pi client-side (including display screen).

3. Principle and realization of system technology
We use OpenPose to extract the coordinates of the joint points of the human body and convert them into body vector, and then use the body vector based motion standard evaluation algorithm to compare with the standard GMFM-66 action and get the final test score, in which the data set of the standard GMFM-66 action was taken by the author of the paper.

3.1. Extraction of key points on human body
3.1.1. This system use the open source project.
OpenPose to extract key points on the user's body. Traditional multi-person motion recognition generally adopts the "top-down" method [4], which first identifies the person's position and then looks for the limb. Therefore, the amount of calculation will increase as the number of people increases. OpenPose adopts the “bottom-up” method, which first searches for the position of the human body part and the Part Affinity Field (PAF) of each part, and then classifies the limbs into different people
one by one according to the graph algorithm. This not only ensures the efficiency of the operation, but also ensures the accuracy of feature extraction [5].

3.1.2. For each WxH pixel image.

OpenPose's neural network outputs two matrices: The matrix S: the shape is S=(S1, S2, ..., SJ), containing J vectors, each vector has WxH elements, J vectors correspond to J confidence maps, and each key point of the human body corresponds to one of the confidence maps, each of which is used to record the probability that each pixel in the original image belongs to a certain type of human key point. The matrix L: the shape is L = (L1, L2, ..., LC), containing C vectors, each vector has WxHx2 (vector) elements, and stores the direction and intensity of the vector field for each pixel in the original image. C vectors correspond to the C body part affinity vector field, and each type of limb corresponds to a Part Affinity Field (PAF).

3.1.3. OpenPose processes the image in an iterative manner.
First, the original image is processed using a 10-layer CNN network to obtain a feature map, which then enters the iterative processing stage. In each iteration, an S matrix and an L matrix are generated. The two matrices plus the previous feature map will be used as input to the next iteration, and so on until the iteration is completed. Finally, the Hungarian algorithm is used to classify the key points into the human body. As shown in the figure, each iteration has two parallel processing branches to generate the key matrix and the vector field matrix, and the output of this iteration will be used along with the initial feature map as the output of the next iteration.

![OpenPose workflow](image)

3.2. Evaluation of standard degree of action

The core of the system is to assess the degree of agreement between the subject's motion data and the standard GMFM action. If the Euclidean distance corresponding to the human key point between the subject and the standard action is simply used as the basis for the evaluation of the action standard, the evaluation result will be related to the height of the child and the distance from the camera. We use the concept of “body vector” [6] to assess the standard of motion of the child. This evaluation is only related to the angle between the corresponding limbs, not the height and the distance between the subject and the camera.
In the form of the vector, we calculate the similarity between the records of the body key points of each adjacent ordered pair during the movement of the child. Where \((x_{st}, y_{st})\) and \((x_{re}, y_{re})\) represent the vector between the same nodes in the two images before and after movement.

\[
\cos \alpha = \frac{x_{st}x_{re} + y_{st}y_{re}}{(x_{st}^2 + y_{st}^2)^{1/2} + (x_{re}^2 + y_{re}^2)^{1/2}}
\]  

(1)

After obtaining the angle of similarity, we can use the inverse trigonometric function to get the specific value of the angle. We can use the specific value of the angle to score it.

\[
D = f_{\alpha_1}(\alpha_1) + f_{\alpha_2}(\alpha_2 + \alpha_3) + f_{\alpha_4}(\alpha_4 + \alpha_5) + f_{\alpha_6}(\alpha_6 + \alpha_7)
\]  

(2)

Where \(\alpha_i\) represents the comparison between two adjacent maps, and then the calculated degrees of the eight angles are obtained, and \(f_i\) represents the weight of the different limbs, which is calculated by the following formula:

\[
f_i = \frac{1}{\text{Avg}_i} \cdot \frac{1}{\sum_{i=1}^{4} \text{Avg}_i}
\]  

(3)

Among them, \(\text{Avg}_i\) represents the arithmetic mean of the value of angles between the eight vector pairs of the left and right upper arms, the left and right lower arms, the left and right thighs, and the left and right lower legs.

We can think that when the difference between the subject's action angle similarity and the standard action is greater than a certain value, the score should be sharply reduced, so that the score can more accurately describe the subject's motion ability. So our deviation limit function:

\[
f(\alpha_{\text{max}}) = 1 - \frac{0.2}{M} \cdot \alpha_{\text{max}}^2
\]  

(4)

\(M\) is equivalent to the threshold. If the difference between the front and rear movements exceeds the threshold, \(f(\alpha_{\text{max}})\) will quickly drop to 0, causing the similarity score to decrease rapidly. After obtaining the score \(D\), we can use the following formula to calculate the similarity score of the subject and the standard GMFM action.

\[
\text{Score} = f(\alpha_{\text{max}}) \cdot \left[D_{st} - D \times \frac{50 - S_{st}}{D_{st}} + S_{st}\right]
\]  

(5)

Both \(S_{st}\) and \(D_{st}\) are user-defined. The role of \(S_{st}\) is to let the user define the range of values. The role of \(D_{st}\) is to let the user set the standard of action similarity. The smaller the value of \(D_{st}\) is set, the stricter the score will be.

Figure 6. Comparison of subjects and GMFM standard actions

At \(S_{st}=30\), \(D_{st}=30\), \(M=5\), we invite normal adults to perform the 57th action of GMFM-66 for a score of 96 points.
4. Survey on similar products
We investigate the current rehabilitation training devices for the motor function of children with cerebral palsy, which are classified into the following three categories according to the complexity of the instrument.

4.1. Simple rehabilitation instrument without modern technology
Single traditional cerebral palsy rehabilitation instrument: Pap ball, balance bar, etc.; 
Compound rehabilitation room: For example, the child integration training room of Jiusheng Rehabilitation Medical Equipment Co., Ltd. integrates single rehabilitation items. However, it covers a large area and does not combine modern technology to achieve automated data analysis and program development, but only integrates rehabilitation props.

4.2. Rehabilitation instrument combined with modern technology
This type of rehabilitation equipment does not specifically target the integrated training of children with cerebral palsy. Some of them are only specialized rehabilitation equipment for various parts. The cost is expensive, and it is more suitable for hospitals or high-end rehabilitation centers. It is not suitable for most cerebral palsy populations.

For example, Huakang Hongli's multi-functional limb rehabilitation workstation uses physical shock to pull muscle tissue to promote recovery. Such instruments have limited significance for patients with cerebral palsy, because the rehabilitation of cerebral palsy patients can only achieve the best rehabilitation effect by combining brain movements and achieving coordination between the brain and the limbs.

4.3. GMFM evaluation scoring software
Currently existing motion evaluation software, such as GMAE scoring software, requires specific scores to be given by the medical staff during the testing process and manually entered into the software. It can be seen that the software is just a simple scoring software and cannot be called a rehabilitation system.

In summary, there is currently no practical rehabilitation system for cerebral palsy patients on the market.

5. Conclusion
This paper proposes a system that uses artificial intelligence technology to automate the evaluation of GMFM-66 in children with cerebral palsy. Compared with traditional rehabilitation methods, this system does not require the participation of professional physicians and reduces the cost of performing an assessment while satisfying the accuracy requirement for training and evaluation of children, which is a medical device for families of ordinary patients.

The project has opened up new service areas and filled the gap in the family rehabilitation platform for patients with cerebral palsy. At the same time, the cost is low and it is easy to promote and serve the majority of patients and families. Whether in innovation or in the social sense, this rehabilitation system is a good enough product.

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