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COMPUTATIONAL TOOL TO SUPPORT HAND POSTURE FOR DIAGNOSING CARPAL TUNNEL SYNDROME

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Abstract: The article discusses the use of computational tools to support the diagnosis of Carpal Tunnel Syndrome (CTS), a common peripheral neuropathy caused by compression of the median nerve in the wrist. This syndrome primarily affects individuals who perform repetitive hand and wrist movements, such as office workers, factory assemblers, and musicians. In Mexico, the prevalence of CTS is estimated to be between 3% and 6% of the population, with a higher incidence among women aged 30 to 60 years. CTS represents a significant burden on the healthcare system and the economy due to the costs associated with treatment and lost productivity. Traditionally, CTS is diagnosed through clinical tests such as Tinel's sign and Phalen's sign, supplemented by electrodiagnostic studies. However, these techniques can be invasive and costly. The article highlights the growing interest in the use of computer vision technologies for medical diagnosis, specifically Google's Mediapipe, which facilitates real-time detection and tracking of hand key points.
Keywords: Carpal Tunnel Syndrome, Medical Diagnosis, Computer Vision, Hand Tracking, Non-Invasive Technologies.

INTRODUCTION

Carpal Tunnel Syndrome (CTS) is a common peripheral neuropathy caused by the compression of the median nerve in the wrist, which can result in pain, numbness, and weakness in the hand and fingers. It is particularly prevalent among individuals who perform repetitive hand and wrist movements, such as office workers, factory assemblers, and musicians. Early diagnosis is crucial to prevent the progression of the disease and avoid invasive surgical interventions. Traditionally, CTS is diagnosed through clinical tests such as Tinel's sign and Phalen's sign, supplemented by electrodiagnostic studies. However, these techniques can be invasive, costly, and sometimes inconclusive in the early stages of the disease.

In Mexico, this syndrome has gained significance in both occupational and public health contexts due to its impact on the quality of life of affected individuals and on workplace productivity. Some recent data and statistics include:

1. **Prevalence**: It is estimated that between 3% and 6% of the Mexican population suffers from CTS, with a higher prevalence in women than in men. Women are three to five times more likely to develop this condition, especially those aged between 30 and 60 years.
2. **Risk Factors**: In Mexico, the risk factors for developing CTS include:
   - **Repetitive Manual Work**: Occupations requiring repetitive hand and wrist movements, such as sewing, factory work, prolonged use of keyboards and mice, and construction.
   - **Medical Conditions**: Diseases such as diabetes, rheumatoid arthritis, and hypothyroidism increase the risk of CTS.
   - **Pregnancy**: Pregnant women are at higher risk due to fluid retention and other hormonal changes.
3. **Economic Impact**: CTS represents a significant burden on the Mexican healthcare system and economy. Treatment can include physical therapies, medications, and in severe cases, surgery. The costs associated with CTS treatment and lost productivity are estimated to amount to hundreds of millions of pesos annually. Additionally, it is one of the leading causes of temporary work disability, directly impacting household economies and business productivity.

4. **Healthcare Attention**: Public health services in Mexico, such as IMSS (Mexican Social Security Institute) and ISSSTE (Institute for Social Security and Services for State Workers), report an increase in the number of consultations related to CTS. In 2023, over 50,000 medical consultations for this syndrome were recorded at IMSS, representing a 15% increase compared to the previous year.
5. **Preventive Measures**: In response to the growing prevalence of CTS, various preventive measures have been implemented in the workplace, such as ergonomics programs and education on proper postures and work techniques. Some companies have begun introducing regular breaks for stretching exercises and modifying workstations to reduce the incidence of this condition.

In recent years, there has been a growing interest in the use of computer vision technologies for medical diagnosis, leveraging their ability to analyze large volumes of data quickly and accurately. Various studies have explored the use of image analysis for diagnosing a range of medical conditions.

For hand posture analysis specifically, technologies like Google's MediaPipe have facilitated the real-time detection and tracking of key points on the hand. MediaPipe has been used in applications ranging from gesture control to physical rehabilitation. However, its application in diagnosing CTS is an emerging and highly interesting area, as it can provide a non-invasive, accessible, and low-cost tool for preliminary diagnosis. MediaPipe can detect and track 21 landmarks on each hand, enabling detailed analysis of hand postures and movements. Recent research has explored its application in CTS diagnosis by combining motion capture with classification algorithms to identify patterns associated with median nerve compression.

Another innovative approach is the use of deep learning techniques for gesture recognition. Studies have shown that convolutional neural networks (CNNs) can be trained to distinguish between normal hands and those affected by CTS based on video images captured during specific movements. This method not only improves diagnostic accuracy but also allows for continuous and real-time evaluation, which is particularly useful for monitoring treatment progress.

Combining these technologies with wearable devices has also shown promise. Motion sensors and accelerometers integrated into devices like smartwatches can capture detailed data on wrist and hand dynamics. These data, analyzed through machine learning algorithms, can provide early indications of CTS, facilitating preventive interventions.

Additionally, the use of augmented reality (AR) platforms for visualizing hand tracking data has been explored as an educational tool for patients and healthcare professionals. This technology allows intuitive visualization of hand movements and nerve positions, enhancing understanding of the pathology and the effectiveness of diagnosis and treatment.

Developing a computational program for hand posture analysis to preliminarily diagnose CTS offers several significant advantages. Firstly, it allows for a quick and non-invasive assessment that can be performed in various settings, from medical offices to mobile applications. This increases diagnostic accessibility, especially in rural areas or populations with limited access to specialized medical care. Secondly, by utilizing machine learning algorithms, the system can improve its accuracy over time as more data is collected and analyzed, potentially surpassing the limitations of traditional clinical tests. Finally, this technology can serve as a screening tool, identifying individuals who require more detailed evaluation and reducing the burden on medical resources.

Such a computational tool could revolutionize the diagnosis and management of Carpal Tunnel Syndrome, providing healthcare professionals with an accurate and accessible solution for evaluating their patients. Therefore, some of its characteristics are:

- Real-Time Analysis: The ability to detect and analyze hand postures and movements in real-time.
- Non-Invasive: A non-invasive diagnostic method that avoids the discomfort and cost of traditional tests.
- Accessibility: Can be used in a variety of settings, including remote and rural areas with limited access to specialized healthcare.
- Machine Learning Integration: Utilizes machine learning algorithms to continually improve diagnostic accuracy over time.
- Wearable Device Compatibility: Can integrate with wearable devices to collect and analyze data on wrist and hand dynamics.
- Early Detection: Facilitates early detection of CTS, allowing for timely intervention and prevention of disease progression.

METHODOLOGY

Computer vision technologies have advanced significantly, enabling detailed capture and analysis of hand movements. Recent research has shown that computer vision algorithms, combined with high-resolution cameras, can identify movement patterns characteristic of CTS with high precision.

The approach employed involves using libraries such as OpenCV for image capture and MediaPipe for hand tracking. OpenCV was used to capture video from a webcam, and MediaPipe was utilized to detect and track hand movements. In a loop, each video frame was captured, processed to detect hands, and tracking landmarks were drawn. To analyze hand movements, the coordinates of the landmarks provided by MediaPipe were accessed; 21 landmarks on each hand were accessed, and the distance between certain landmarks was calculated to determine gesture recognition.

Figure 1 shows a hand in a specific position used to assess the function of the median nerve in diagnosing Carpal Tunnel Syndrome. This syndrome is a condition where the median nerve, which passes through the carpal tunnel in the wrist, becomes compressed, causing pain, numbness, and weakness in the hand and fingers.

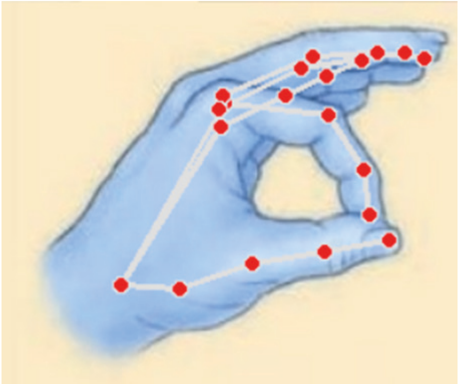

Figure 1. Hand Movement Tracking Using Mediapipe in the Diagnosis of Carpal Tunnel Syndrome

In the Figure 1, the hand is shown with the index and middle fingers raised and the thumb extended upwards, while the ring and little fingers are bent towards the palm. This posture is known as Tinel's sign and is one of the tests used to diagnose Carpal Tunnel Syndrome. During this test, the doctor may lightly tap over the median nerve in the wrist to see if it provokes a tingling sensation in the fingers, which is a positive indicator for Carpal Tunnel Syndrome. Tinel's sign is useful for identifying irritation or damage to the median nerve. A positive result, where the patient feels tingling or an electric-like sensation when the nerve is tapped, can suggest the presence of median nerve compression in the carpal tunnel.

Figure 2 shows a hand in a specific position used for the diagnosis of Carpal Tunnel Syndrome. This syndrome is a condition that occurs when the median nerve, which runs from the forearm to the hand, becomes compressed or pressed at the wrist.

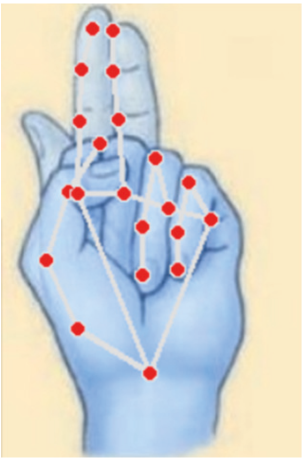

Figure 2. Hand Movement Tracking Using Mediapipe in the Diagnosis of Carpal Tunnel Syndrome

Figure 2 shows a hand in a specific position used for the diagnosis of Carpal Tunnel Syndrome. This syndrome is a condition that occurs when the median nerve, which runs from the forearm to the hand, becomes compressed or pressed at the wrist.

The pose shown in the figure 2 is used in a test known as the Phalen's test. To perform this test, the patient is asked to flex the wrist maximally, maintaining the position for about a minute. The hand in the image is in a position that simulates this flexion, although the test is usually performed with both hands flexed and the dorsal sides touching each other. If this posture provokes symptoms such as tingling, numbness, or pain in the fingers (particularly the thumb, index finger, middle finger, and part of the ring finger), it is considered a positive indicator for Carpal Tunnel Syndrome.

This test is a useful tool in the clinical evaluation of Carpal Tunnel Syndrome as it reproduces the pressure on the median nerve and helps identify nerve compression. However, a complete diagnosis of Carpal Tunnel Syndrome typically includes a combination of clinical history, physical examination, and, in some cases, electrodiagnostic tests such as electromyography (EMG) and nerve conduction studies to confirm the presence and severity of the compression.

RESULTS

Figure 3 shows an example of using computer vision technology for tracking and analyzing hand movements, specifically using the Mediapipe library. In the image, a person is seen making a hand gesture, positioned within a reference frame that allows for the detection of key points or landmarks. These points are marked in blue, and green lines connect these points to illustrate the connections between the different parts of the hand.

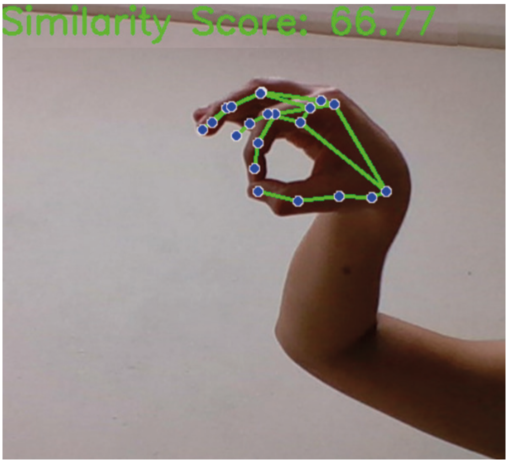

Figure 3. Hand posture analysis for diagnosis of CTS with similarity score

The system has calculated a "Similarity Score" of 66.77, indicating the similarity of the detected gesture with a previously defined reference gesture. This type of scoring is useful for applications requiring precise gesture recognition, such as diagnosing Carpal Tunnel Syndrome (CTS), where certain hand movements and positions can indicate the presence of the syndrome.

The technology used in this image allows for real-time capture and analysis of hand movements. OpenCV is used for video capture, while Mediapipe handles the processing and tracking of hand landmarks. The combination of these tools enables the detection, tracking, and analysis of hand movements with high precision, facilitating the recognition of patterns associated with specific medical conditions like CTS.

The "Similarity Score" displayed in the image results from machine learning algorithms that compare the current gesture with a database of known gestures. This approach is particularly useful in medical applications, where high accuracy and consistency in diagnosis are needed. The use of this technology not only provides a non-invasive and accessible evaluation but also can be utilized in remote settings, benefiting patients in rural areas or with limited mobility.

Figure 4 shows a hand with points and lines overlaid in green, representing the detection of key points; these points and lines are used to track the position and movement of the fingers. In the context of diagnosing Carpal Tunnel Syndrome, this technique is employed to assess the mobility and posture of the hand and fingers. The "Similarity Score" of 64.25 indicates how accurately the hand posture matches a predetermined model or standard.

This type of technology can help identify incorrect or abnormal postures that could be related to Carpal Tunnel Syndrome, a condition affecting the nerves in the wrist and causing pain, numbness, and weakness in the hand. By analyzing hand posture and movements, doctors can gain valuable insights for diagnosing and treating this condition.

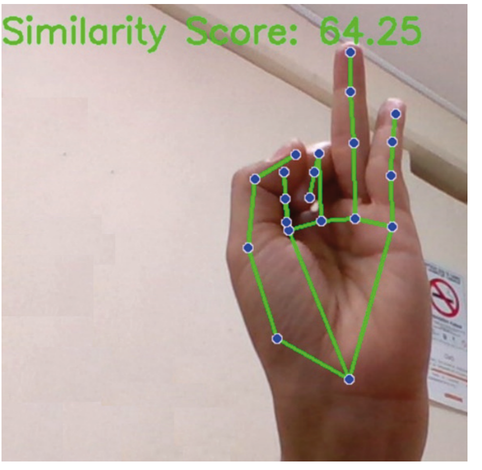

Figure 4. Analysis of the flexed hand posture for diagnosis of CTS

In Figure 5, the hand is marked with blue points at the joints and green lines connecting these points to form a model of the hand's structure. The hand is in a closed fist position. This type of posture can be analyzed to detect issues in the flexion of the fingers and wrist. In Carpal Tunnel Syndrome, the nerves in the wrist may be compressed, affecting the ability to fully close the hand or maintain a fist without pain.

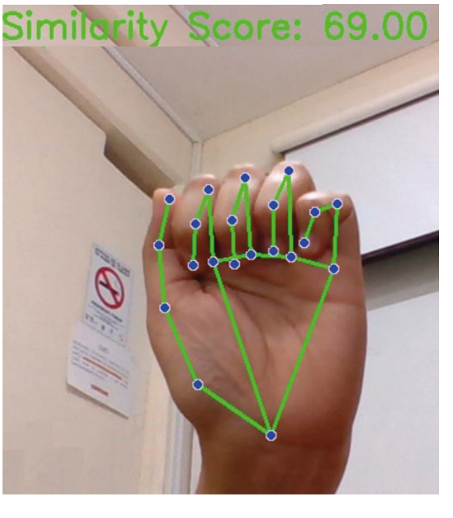

Figure 5. Hand close fist position for diagnose of CTS

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The "Similarity Score" of 69.00 in this image indicates how similar the patient's hand posture is compared to a reference model. A higher score suggests that the posture is closer to the ideal, while a lower score might indicate problems. For the evaluation of Carpal Tunnel Syndrome, the following parameters are considered:

Finger Flexion: This evaluates how the fingers bend towards the palm. Incomplete or asymmetric flexion could indicate the presence of Carpal Tunnel Syndrome.

Wrist Position: The position of the wrist is also critical. In Carpal Tunnel Syndrome, compressed nerves can limit the ability to bend the wrist properly.

Pain and Numbness: If the patient experiences pain, numbness, or weakness while holding this posture, it could indicate that the median nerve is affected.

CONCLUSIONS

Carpal Tunnel Syndrome (CTS) is a condition that significantly affects the Mexican population, especially women and workers who perform repetitive manual tasks. Timely attention and preventive measures are crucial to reduce its prevalence and the associated economic impact. Collaboration between the healthcare sector, employers, and workers is essential to address this growing public health concern in Mexico. Preliminary diagnosis of CTS through hand posture analysis can be a useful tool to detect this condition in its early stages. Early identification and proper management of Carpal Tunnel Syndrome are essential to prevent permanent nerve damage and ensure full recovery of hand function.

The use of advanced computer vision technologies for hand posture analysis represents an innovative and promising approach for the preliminary diagnosis of CTS. This approach not only has the potential to improve the accuracy and speed of diagnosis but also can democratize access to advanced diagnostic tools, benefiting a wide range of the population.

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