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Application of Improved PSO in Augmented Reality for Dental Healthcare

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ABSTRACT

Augmented Reality (AR) is a unique technological innovation that seamlessly blends virtual and real worlds. Regarding dental healthcare, AR can be used for enhancing the visualization of dental structures, and treatment planning. AR overlays digital information onto the real-world dental environment, allowing dentists to see virtual dental models, treatment simulation on a patient's teeth in real-time. The feature extraction process based on geometric features is the most crucial step in oral image registration. In the presented study, Particle Swarm Optimization algorithm (PSO) is advanced in order to increase the accuracy of the extracted features descriptor by adding Anti-aliasing technique and utilizing the Hamming distance metric to enhancing the performance of PSO-based feature extraction in AR for dental healthcare. Firstly, applying anti-aliasing techniques to the virtual dental models and AR visualization, the edges of the virtual objects can be softened and blended more smoothly with the real dental structures. This, in turn, enhances the reliability of the feature extraction process by providing clearer and more accurate data points for subsequent analysis and treatment planning. Secondly, the Hamming distance metric is utilized to quantify the similarity among various feature vectors derived from dental images, this metric optimizes the feature extraction process in PSO, leading to more accurate and reliable dental health care applications.

1. Introduction

Augmented reality (AR) is a type of technology that enhances the environment through the process of layering computer-generated virtual content onto the structure of the real world, thereby enhancing our sensory perception of reality [1-3]. An AR platform is currently described as a system that mixes virtual and real items in a single actual environment, operates interactively in real time, and reciprocally records virtual and real objects.

To create a successful AR system, the following fundamental functions must be used and tightly integrated: tracking, registration approaches, visualization processing, display kinds, perception locations, and feedback mechanisms [4,5]. Dentistry encompasses various features common to other medical subspecialties, but also possesses unique characteristics. It is an additional field that can greatly benefit from the successful utilization of AR technology to enhance outcomes in diagnosis,

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treatment, and education [6]. The AR system in oral medicine must precisely calculate the camera's position by conducting a comprehensive analysis of feature information derived from the authentic surgical scene. This system must then proceed to acquire the transformation matrix of the oral virtual model and visual plane and accurately locate the superimposed position of the oral virtual model in real-time, in a timely and efficient manner [7]. In order to mitigate the occurrence of inordinate registration errors during surgical procedures, it is imperative that the comprehensive augmented reality system possesses the ability to effectively employ an identification tracking algorithm for precise identification and determination of the registration location of the virtual model. In practical applications, however, AR surgical system technology exhibits highly precise and stable registration capabilities [8]. Doctors exhibit a heightened sensitivity toward visual errors. Even a minor tracking registration error can have a substantial impact on the actual surgical results generated by the doctor, leading to a decrease in surgical efficiency. Therefore, registration represents the most crucial technical component in the implementation of AR technology, as its success or failure directly determines the effectiveness of AR systems. Enhancing the accuracy of tracking and registration in AR has consistently been a core focus and challenge in AR technology research [9]. Based on hardware, sensors, track registration algorithms, and identification points, registration technology effectively places virtual objects or sceneries in the physical world. The use of the technology of registration is mostly based upon hardware registration technology, sensors, and registration technology that depends on machine vision [10]. The user's current location is recorded using sensors or hardware-based registration technology, which includes mechanical tracking registration technology, GPS tracking registration technology, magnetic field tracking registration technology, optical tracking registration technology, and acoustic tracking registration technology. [11]. The registration issue has three crucial technical indications that can be used for evaluating the impact of AR: real-time (no delay), high error rate registration stability (jitter-free, accurate), and robust (unaffected by object motion and occlusion) [7].

1.1 Related Works

In 2018, Seid M. and Vera C. Presented an algorithm that has the potential to provide superior solutions compared to conventional and other improved PSO schemes in relation to target tracking in AR remote laboratories. In order to disclose supplementary data, an object tracking scheme assumes a pivotal role in presenting formerly imperceptible concerns in a discernible manner. The elevated-PSO is utilized to enhance the diversity of particles, particularly when all particles are constrained in close proximity to the best predicted solution accompanied by adequate similarity. The proposed algorithm presents a superior solution for target tracking in AR remote labs as compared to classic and other improved PSO methods. [12].

In 2019, Martín M. and Alejandro P. Presented a novel augmented reality assistant that employs a colour segmentation approach to detect security signs. The proposed method utilizes linear equations that are dependent on the RGB space and are subsequently optimized using a PSO algorithm. Through the use of this method, the system can effectively recognize and label colour information signs, which are then transmitted to the user [13].

In 2021, Behnaz M. and M. Soleyman. Introduced a framework for its performance across a diverse range of synthetic, real-life, and higher dimensional datasets. The optimizer module initially employed four distinct binary optimization algorithms. Experimental observations suggest that the proposed solution is highly efficient and compact clusters while maintaining a consistent level of distortion across most datasets. Similarity between data points belonging to the same category, such as those found in remote sensing, crowdsourced multi-view video uploading, and augmented reality, is responsible for the correlation within a dataset [14].

In 2022, Long S. and Shuo Y. Proposed a new type of AR calibration framework is introduced that combines a Microsoft HoloLens device with a single camera registration module for surgical navigation purposes. In order to adjust the size of the reconstructed model, a shape feature matching-based search method is suggested. Additionally, there are also suggestions for a double clustering-based 3D point cloud segmentation method and a 3D line segment detection method to extract the corner points of the image marker [15].

In 2023, Hai l. and Hongjia Z. Proposed a system that uses single Microsoft HoloLens 2 that equally to the one sensor and display device. The system achieved a high-precision models and accomplish accurate registration. In addition, it can be easily to combine the dental diagnostic and therapeutic procedures, for example bracket placement guidance [16].

1.2 Real-Time Medical Registration Method

Recent years have seen many studies on real-time registration [7], which frees doctors from preoperative planning restrictions. Additionally, AR real-time registration could enhance the operating room atmosphere for the doctors and enable them to provide appropriate intraoperative guidance. The dentist could arbitrarily zoom in or out or rotate the inside of the mouth using augmented reality [17,18]. The real-time registration technique of AR could be classified into two types based on the kind of registration object, in accordance with the medical image registration approach [19].

1.2.1 Manual marker registration

The manual marker registration approach involves using certain artificially placed objects or natural scenes as identification points in the actual environment [5,20]. The identification in the image is then detected using the camera, and the registration and tracking of virtual information are finished simultaneously using the camera calibration technique [21]. The placement of the marker has an impact on the authenticity and naturalness of the real world, which is one of this registration's limitations. Additionally, throughout the tracking registration procedure, there are problems with drift and flag occlusion [7].

1.2.2 Natural feature registration

The natural feature-based registration technology exploits the innate characteristics of the physical environment to generate relevant reference points [22]. Thus, the extraction of natural features is a fundamental and crucial technology for the registration method [23]. These feature points represent certain pixels in the real world with unique characteristics and distinctive shapes. However, the application of this registration type is limited by its high computational complexity and system delay [7].

The algorithm responsible for completing the task of feature point extraction and matching is none other than the feature point extraction and matching algorithm. The algorithms that are frequently employed can be categorized into three types: spot detection, corner detection, and feature point description algorithms. The overall operation time and quality of AR-guided oral surgery are significantly impacted by the optimization and processing speed of these algorithms [1].

For the purpose of increasing students' understanding, object tracking, and image processing could be used to render a virtual image in the field of view accurately and flawlessly. As a result, it is necessary to find and follow the target that has been chosen to supplement further information. Additionally, swarm intelligence algorithms have caught the attention of numerous academics in a variety of engineering applications due to their capacity to identify the optimal approach to reduce processing time for images. One of the most effective heuristic algorithms for object tracking is PSO. A diverse variant of PSO for object tracking has just been suggested [24].

1.3 Traditional PSO Algorithm

PSO is a swarm intelligence (SI) method that Kennedy and Eberhart first suggested in 1995 [25,26]. The PSO technique is utilized in various domains, including machine learning and pattern recognition. The PSO algorithm is utilized for the optimization of numerical parameters required for the tuning of equations used for colour classification. The inspiration for the algorithm is derived from the collective behaviour of bird flocks. The algorithm commences with the random initialization of i particles' Xi positions around the search space. To begin with, Vi, the velocity of each particle, is set to zero in all D dimensions of its search space. The PSO algorithm comprises two primary components, namely personal and social. The personal component relies on Pi, which denotes the best position known for each particle. Conversely, the social component relies on PG, which denotes the best position known by the entire swarm [14].

However, like any algorithm, it has its limitations. Some of the limitations of applying PSO for feature extraction are:

i. Noisy or inconsistent data: PSO assumes a smooth and continuous fitness landscape. If the data is noisy or exhibits inconsistent patterns, PSO may not be able to identify robust and meaningful feature subsets [27].
ii. Feature Redundancy: PSO may not effectively address the issue of feature redundancy, where some selected features may carry similar information, leading to an unnecessarily large feature subset [28].
iii. Limited Handling of Categorical Data: PSO has been designed for continuous optimization problems, and it may not handle categorical features directly. Special encoding schemes or additional preprocessing steps are required to use PSO with categorical data [29-31].

To overcome these limitations, researchers often combine PSO with other techniques, such as local search methods, hybrid approaches, or feature ranking techniques, to enhance its performance and robustness in feature extraction tasks. It's also essential to carefully pre-process the data, perform feature selection and engineering, and validate the results using appropriate evaluation metrics.

2. Methodology

The proposed methodology involves a series of eight crucial parts that are practical to implement in Python and have the objective of deploying AR systems in dental healthcare. The method utilizes natural feature-based tracking registration technology, wherein the extraction of distinctive features for both real and virtual frames is accomplished by amalgamating PSO with Anti-Aliasing and Hamming distance metric (PSO-AH). These extracted features are subsequently utilized for completing the process of matching virtual and real image features is an essential task in image processing. The proposed methodology involves a series of significant steps, which are clearly depicted in Figure 1 as shown below.

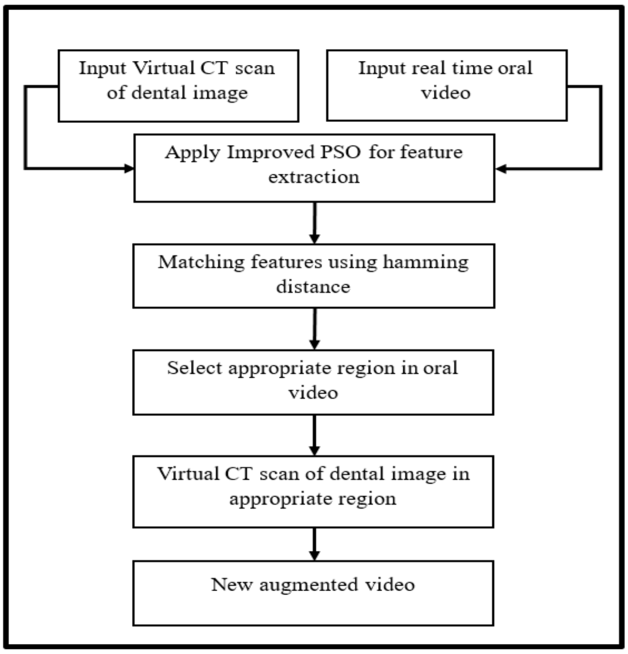


Fig. 1. The Block diagram of the proposed approach

The main steps of the proposed method are shown below:

i. 1st Stage: Input AVI files of real oral video & virtual 3D model of a dental image.
ii. 2nd Stage: The real-time video and CT scan of the dental image were partitioned into frames. Relevant data, comprising the overall number of frames, height, and width, were gathered from the AVI header. Following this, the videos were segmented into individual frames.
iii. 3rd Stage - Resizing the Frames: To make sure of the frame size, algorithm 1 is used to resize the frames.

Algorithm 1. Frame Resize Algorithm

Algorithm Name: Frame Resize.
Input: Frame, H(frame _height), W(frame _width).
Output: New Frame, New H(frame _height), New W(frame_width).
Start
1. Initialize U // U represent the block height. Initialize V // V represent the block width.
2. Set M as the total No. of blocks in the height (U).
M= Int (H/U).
3. Set N as the total No. of blocks in the width (V) N= Int (W/V).
4. New H=U*M.
5. NewW=V*N.
6. NewFrame=Resize (frame, NewH, NewW).
END.

iv. <u>4th Stage - Feature Extraction:</u> This stage includes 2 significant processes which include the extraction of features for both real-world frames & virtual frames by using improved PSO. As shown below, Figure 2. Presents the primary phases of the proposed Enhanced Particle Swarm Optimization (PSO).

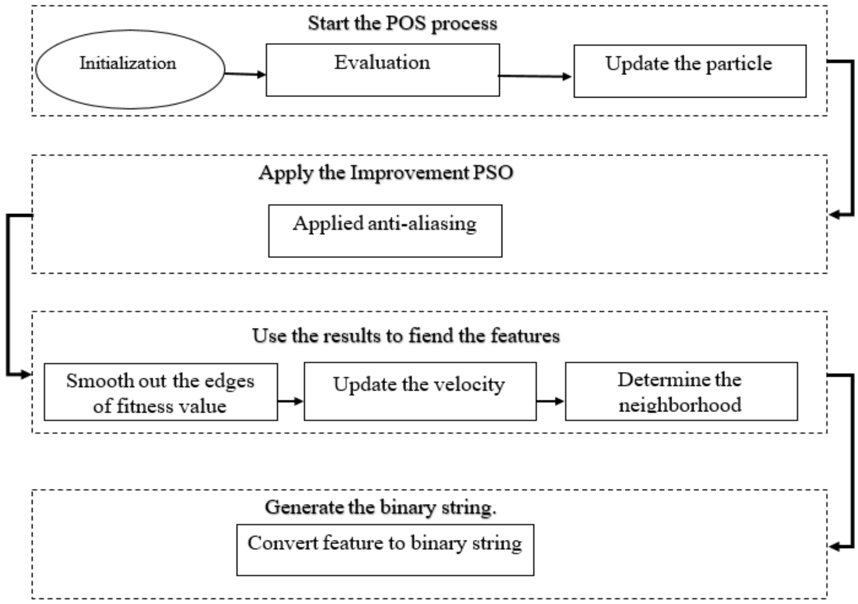


Fig. 2. Block diagram of the Suggested Improved PSO process

The steps below illustrated the Improved PSO:

a. Initialize a particle population:
   - The number of particles is a parameter of the algorithm.
   - The initial positions of particles are randomly generated in the search space.
   - The initial velocities of the particles are also randomly generated.
b. Assess the fitness of every particle:
   - The fitness function is evaluated for each particle.
   - The fitness value of a particle is a measure of how good the solution represented by the particle is.
c. Apply an anti-aliasing filter to the fitness values: The anti-aliasing filter smooths out the edges of the fitness values, therefore it helps to prevent the algorithm from being stuck in local minima.
d. The velocity and position of each particle need to be updated according to the equation below [14]:

$$V_i\,(t) = w.V_i\,(t-1) + c1.r1[P_i - X_i\,(t-1)] + c_2.r_2[P_G - X_i\,(t-1)] \tag{1}$$

The velocity of particle i at time t is denoted by v i (t), while the weight of the inertia is represented by w. Additionally, cognitive and social learning coefficients are denoted by c1 and c2, respectively. Random numbers between 0 and 1 are represented by r1 and r2. The best position of particle i at time t is represented by p i (t), whereas the best position of the swarm at time t is represented by g i(t). Finally, the current position of particle i at time t is represented by x i (t). Each particle's positional update is determined by the equation below:

$$X_i\ (t) = X_i\ (t-1) + V_i\ (t) \tag{2}$$

e. Repeat 2-4 until the stopping criteria is met. The stopping criteria can be a maximal number of the iterations, a minimal fitness value, or a combination of the two.

v. 5th Stage: Converting Features to Binary Strings.

vi. 6th Stage: Matching Features: this stage measures the similarity between the binary strings of both the real object of patient mouth and virtual CT scan of dental image by using Hamming distance Figure 3. Depicts the main steps of Hamming distance metric:

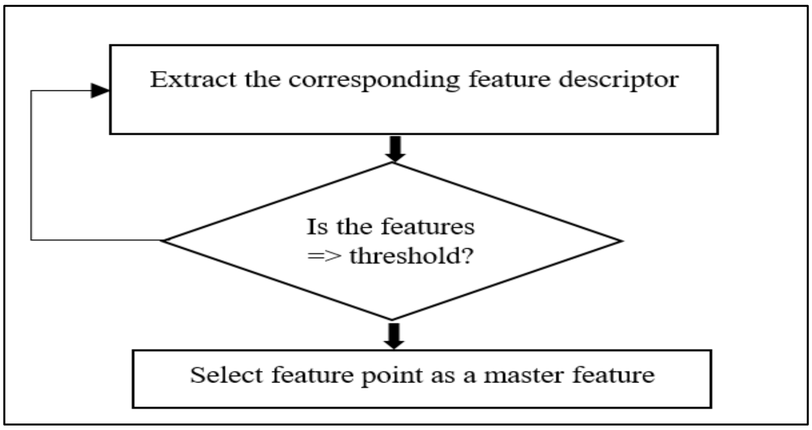


Fig. 3. The Process Matching Features Using Hamming Distance

a. Calculate the Hamming distance between any two particles (feature subsets) in the PSO swarm. The Hamming distance can be determined as the number of bit positions in which the two binary strings differ.
b. Find similar feature subsets based on their Hamming distances. Particles (feature subsets) with lower Hamming distances are considered more similar, as they have more common features.
c. Choose a maximum value of Hamming distance as Threshold value for matching process.
d. Take a union of the features from matched subsets in order to merge the similar features.
e. Training the model by using Hamming distance matching with PSO, we have effectively combined the advantages of PSO for feature extraction and Hamming distance for feature subset comparison, leading to potentially improved model performance and more efficient feature selection.

vii. 7th Stage: Insertion Process: the final stage is steering Virtual CT scan dental image in Real-oral video. In the process of insertion, a virtual dental model in 3D is aligned within the corresponding framework of real-life video through the utilization of the equations presented below [3]:

Cor_row = (dr - (cr – row)) (3)

Eq. (3) has been utilized for the calculation of the corresponding row in the suitable area to the present Virtual CT scan dental image pixel that place in row less than centre point row of the Virtual CT scan dental image.

$$Cor\_row = (dr + (row - cr)) \quad (4)$$

Eq. (4) has been utilized for the calculation of corresponding row in the suitable area to the current Virtual CT scan dental image pixel which place in row greater than centre point row of the Virtual CT scan dental image.

$$Cor\_col = (dc - (cc - col)) \quad (5)$$

Eq. (5) has been utilized for the calculation of corresponding col in the suitable area to the Virtual CT scan dental image pixel which place in col less than centre point col of the Virtual CT scan dental image.

$$Cor\_col = (dc + (col - cc)) \quad (6)$$

Eq. (6) has been utilized for the calculation of corresponding col in the suitable area to Virtual CT scan dental image pixel which place in col greater than centre point col of the Virtual CT scan dental image. Where (dr,dc) represent the required centre point of the suitable area, (cr,cc) denote centre point of virtual 3D dental image, (Cor_row, Cor_col) denote the corresponding point in suitable area to the current Virtual CT scan dental image pixel.

viii. 8^{TH} Stage: Appropriate -Region [cor_row, cor_col] = Virtual CT scan dental image [row,col].

ix. 9^{th} Stage - Objective Measurements: The aim of the objective measurements is designing the mathematical models which have the ability for the accurate and automatic prediction of the quality of an image or algorithms. To obtain more accurate percentages, we implement the feature extraction system, train and test it on a dataset, and then evaluate its performance using Confusion Matrix and Evaluation Metrics as illustrated in (Table 2 and Table 3) and (Figure 4 and Figure 5).

3. Results and Discussion

The proposed improved PSO-AH methodology was evaluated through simulation using various software programs, including Python, MATLAB 2018, and Microsoft Excel 2010. These software programs possess unique properties and tools that have demonstrated efficacy in facilitating the desired outcomes of the proposed method. The sample videos and images were gathered from a database online. Two sample videos and two sample CT scan images were utilized with various age groups in the maxilla and mandibular regions. AVI is a type of real-world video input format. Table 1 presents a depiction of the fundamental procedures proposed in this approach. The process commences with the utilization of oral real video files and virtual CT scan images as input, whereby the video is subjected to frame transformation, and subsequently, all the frames are converted to grey-level. The distinctive features of both real and virtual dental frames are extracted by applying an improved PSO-AH algorithm that incorporates PSO, anti-aliasing, and hamming distance techniques. Subsequently, the size and border of geometrical shapes within both virtual and real objects are evaluated. Lastly, insert the virtual scan of the dental image into real oral frames by tracing the path of a virtual object's trajectory.

Table 1
Maxilla area Results

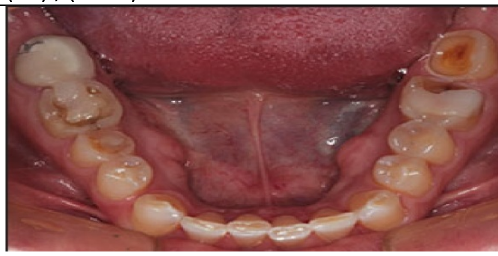
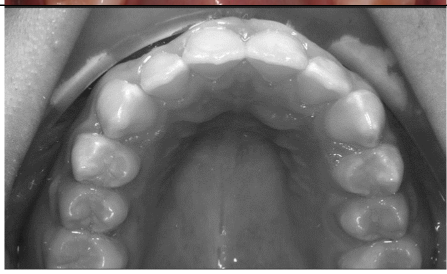
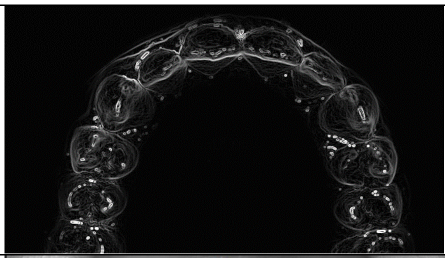
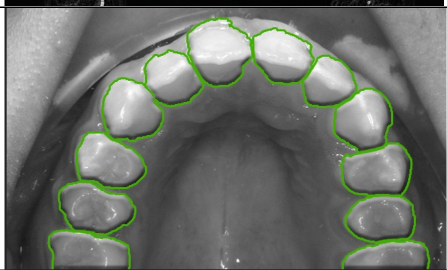
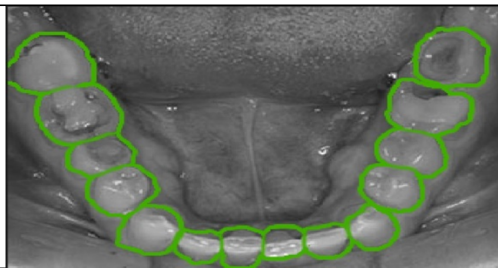
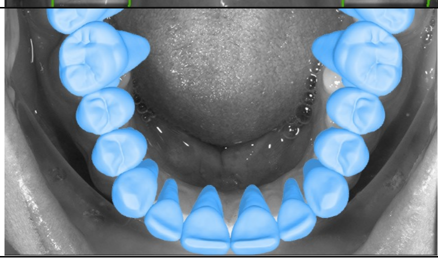
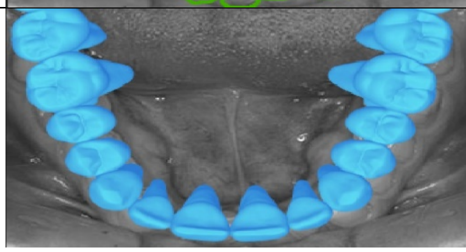
1st Sample Details: Upper Front Teeth, Age (25), (Male)		Frame rate	2nd Sample Details: lower Front Teeth , Age (40) , (Male)	Frame rate
Original Video		25fps		25fps
Gray-level		25fps		25fps
Corner Detection		25fps		25fps
Feature Extraction by PSO-AH		25fps		25fps
Augmented video		25fps		25fps

Table 2
Confusion Matrix 1st maxilla sample for each method by comparing the predicted labels with the ground truth labels

Metric	Only PSO	PSO-A	PSO-AH
True positives	55	88	92
True negatives	70	87	95
False positives	10	8	4
False negatives	15	9	3

Where:

i. Only PSO: refers to the traditional PSO.
ii. PSO-A: refers to the PSO with Anti-Aliasing.
iii. PSO-AH: refers to the PSO with Anti-Aliasing and Hamming Distance.
iv. True Positives (TP): No. of positive instances that were correctly have been as positive.
v. True Negatives (TN): No. of negative instances that were correctly have been as negative
vi. False Positives (FP): No. of negative instances that were incorrectly have been as positive.
vii. False Negatives (FN): No. of positive instances that were incorrectly have been as negative.

Table 3
Confusion Matrix 2nd mandible sample for each method by comparing the predicted labels with the ground truth labels

Metric	Only PSO	PSO-A	PSO-AH
True positives	54	86	95
True negatives	71	89	93
False positives	10	7	4
False negatives	17	8	3

The Evaluation Metrics results of both maxilla and mandible samples are discussed in (Figure 4 and 5) which obtained values from Confutation Matrix as shown below:

i. Obtain a sample image dataset with ground truth labels for dental health care.
ii. For each PSO feature extraction method, apply the AR system to the sample images and classify them.
iii. Create confusion matrices for each method by comparing the predicted labels with the ground truth labels.
iv. Determine the evaluation metrics (precision, accuracy, F1-score, and recall) for each approach using the confusion matrices.

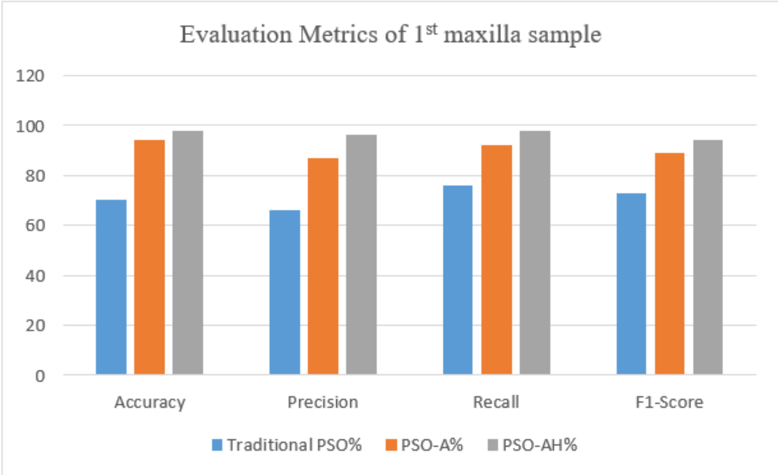


Fig. 4. The Evaluation Metrics of 1st maxilla sample (accuracy, precision, recall, and F1-score) from the confusion matrices for each method

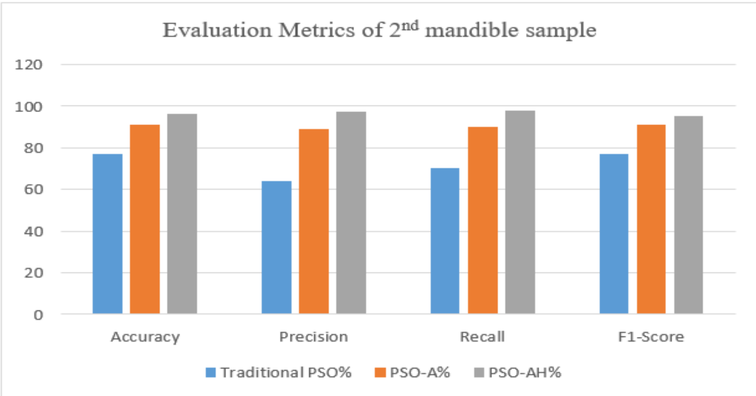


Fig. 5. The Evaluation Metrics of 2nd mandible sample

4. Conclusion

The experimental results validate that the Anti-aliasing and Hamming play a critical role to improving the PSO algorithm. Firstly, the application of anti-aliasing in the PSO feature extraction process benefits mitigate the effects of aliasing artefacts that commonly occur when transforming analogue dental images into digital formats. By reducing aliasing, the algorithm can more accurately capture and represent the fine details of dental structures, leading to improved precision and reliability in dental health analysis. This, in turn, enhances the overall quality of augmented reality visualizations in dental health care applications. Secondly, incorporating the Hamming distance as a similarity metric within the PSO-A feature extraction process enables better comparison and matching of dental patterns, making it particularly useful in aligning dental models and images in augmented reality overlays. The combined benefits of anti-aliasing and the Hamming distance in PSO feature extraction contribute to an improved augmented reality experience for dental health care. Dentists and dental professionals can leverage these advancements to precisely visualize dental conditions, and accurately assess treatment requirements. Patients, on the other hand, can better comprehend their oral health status and make informed decisions about their dental care, leading to improved patient outcomes and overall satisfaction. However, AR environments can be noisy and prone to errors, such as occlusions of dental structures, varying lighting conditions, and patient movements. Anti-aliasing and Hamming distance calculations may not always perform optimally in such conditions, leading to false positives or negatives.

In future work, we propose to develop robust error-handling mechanisms and consider using sensor fusion techniques (e.g., combining data from multiple sensors like cameras and depth sensors) to improve accuracy and reliability, even in noisy environments.

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