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Towards IoT-Enabled Technologies: Foot-Type Classification Based on Artificial Intelligence Methods

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ABSTRACT

The Internet of Things (IoT) is a promising technology used for several connectivity applications to enable technologies. IoT includes connectivity protocols, sensors, communication technologies, and data processing methods that will allow IoT devices to collect, process, and analyze large amounts of data. Many types of foot distortion, such as bunions, hammer toe, flatfoot, and others, can either be congenital or acquired. These deformities are considered significant contributors to body imbalance, leading to fatigue and discomfort during everyday activities. Timely identification of flatfeet and the development of treatment plans are very important to mitigate or eliminate complications. Thus, IoT technology can enhance patient care, improve diagnostic accuracy, increase efficiency, and support connected doctors and clinical staff in caring for their patients. Therefore, the objective of the present manuscript is to design and implement an IoT application that can detect and diagnose the flatfeet types. It is a user-friendly application that can be managed by both patients and physicians to record the stages of flatfeet and perform a preliminary check for possible gait problems in daily life. The proposed work uses a segmentation method that partitions and analyzes a digital image into discrete clusters of pixels. This method assigns a label to each segment based on shared characteristics (i.e., colors). Thus, all segments that belong to the same cluster are treated as identical. The proposed method classifies foot distortion types into flatfeet, concave, and normal, and finds hidden patterns in the dataset. The finding of this study is to enable early disease detection, enable real-time patient monitoring, and thus personalized treatment plans.

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1. INTRODUCTION

In recent decades, the healthcare sector has faced many challenges related to accurate, rapid diagnosis. These issues contribute to diagnostic errors, which can result from problems with clinical reasoning, inadequate diagnostic tools, or inconsistencies in information collection [1]. Thus, developing the healthcare field and integrating modern technology into it has become essential. Flatfeet, or pes planus, is a common condition and a congenital problem of foot shape, in which people have no visible arch in one or both feet, or the arch is very low [2, 3]. See Figure 1 [3]. This problem causes pressure on the ground in specific areas of the foot, which may lead to permanent deformation of the foot and result in knee joint pain, back pain, or both [2]. Additionally, the feet can easily distort due to torn or stretched tendons, poor walking posture, and the use of unsuitable shoes; this distortion can cause fatigue, deform the spine, and lead to pain while walking [4]. Therefore, a rapid and accurate diagnosis of foot deformity is required. The healthcare field has changed dramatically because of technological developments [5]. Recently, there has been a significant rise in interest in the Internet of Things (IoT). IoT is a network of physical objects that are connected to collect, transmit, receive, and exchange data. These systems are embedded with actuators, software, sensors, and other technologies that allow them to communicate with other intelligent systems over the internet [6]. So, IoT automation systems can provide many benefits to homeowners. It can reduce costs, enhance efficiency, and improve convenience by automating repetitive tasks and enabling remote monitoring of objects. These systems are used indoors and outdoors to provide comfort and energy savings [7].

In the healthcare sector, the benefits of IoT include enhanced patient care and outcomes through early disease detection, remote patient monitoring, reduced costs through operational efficiency, and improved operational efficiency via real-time tracking, etc. [6].

Figure 1: Foot deformation [3].

Several researchers have demonstrated the combination of the IoT and the healthcare field, especially in the flatfeet detection. According to [8], the authors designed an IoT monitoring system for the healthcare field. The proposed study aims to check pulse rate, diabetes, heart rate, and kidney functioning. The data is obtained by sensors that are attached to the patient and then uploaded to the cloud via the internet to the authorized person. Similarly, authors in [9] introduced an IoT-based reliable healthcare system that utilizes an ATmega 328 microcontroller to measure temperature, heart rate, and accelerometer data, along with a Global System for Mobile Communications module. The proposed system transfers patient data to the parents and the patient's doctor in the event of an emergency. These related works focus only on IoT technology.

Thus far, several studies have reported cooperation between IoT-based AI technologies. As highlighted by [10], unsupervised learning has many applications in medical treatment, including group segmentation, image and video analysis, and anomaly detection. This has led the authors to label their data after grouping and insightful conclusions for further study. In the medical treatment field, the analysis and detection of anomalies are gaining significance for making precise decisions [11]. Several studies have been conducted on unsupervised machine learning approaches for identifying abnormalities, particularly focusing on the collaboration between AI and IoT technologies. The study by [12] examined the classification image by using one of statistical routines commonly called clustering, where categories of pixels are classified based on their properties. This method is used in medical treatment to discover and analyze hundreds of different data then get the useful information and offer timely risk scores. By one of ML algorithms can process these data in order to improve decision-making and patient care.

In different study [13], authors developed a classification foot types using image and numerical foot pressure data. This work is set 192 of data for the left and right feet and used to create a refined visual geometry K-nearest neighbor (k-NN) and group-16 (VGG16) models, respectively. The study is improved the accuracy and robustness of diagnosis results. However, the plantar pressure measurement device used for this study is a bit expensive and did not support IoT technology. This means that the data can collected locally. In another study [14], authors introduced flatfoot detection and history of delay walking for 5 to 6 years old. In this study, the foot arch is evaluated by wet footprint test. The study is tested for 120 children aged 5-6 years old and applied in three playground areas. So, the study did not apply IoT technology and the data is collected locally.

Unfortunately, few studies have been executed on the integrating IoT with AI technique in the healthcare field. Therefore, in this study, the technical novelty of this work focuses on the integration of AI and IoT application in order to automate objects. In this study, a device is manufactured to diagnose foot deformities, specifically flatfeet or concave. The proposed device is employed to capture the images of everyone standing on the device and then process these images and showed results, and finally transmitted it to final destination through internet for further analyses. The study uses one of the popular segmentation algorithm is called K-means method. This method an unsupervised machine learning technique applied for clustering images into a pre-defined number (k) of clusters or groups. Thus, the present work has the potential to enhance the precision and dependability of diagnostic results while maintaining objectivity, which makes it particularly suitable for the analysis and design of foot healthcare products derived from foot deformation diagnosis outcomes.

The remainder of this work is presented as follows: The proposed system and algorithm is described in Section. This section also introduced data gathering, pre-processing, and explains in details the measurement of foot arch index method. Section III reveals the experimental results and comparisons. Last, section IV summarized the work.

2. System Model

This part introduces the architecture of the proposed method and demonstrates its algorithmic process. Then, the process and setup of the proposed device are provided to capture participants' feet, gather data, and transmit the results to the ultimate receiver for further analysis. After that, the image segmentation is performed using a clustering method, and the final results are shown.

2.1 The Proposed Method Architecture

As we mentioned above, this paper aims to design and implement an IoT remote monitoring system for flatfeet detection. This device is integrated with a microcontroller and communications units for connectivity. The research consists of three main parts: 1) Hardware design. 2) Algorithm implementation. 3) Testing the performance system and evaluation. Figure 2 demonstrates the overview of the proposed device. Figure 3 explains how the device is set up, data is collected and analyzed, and the results are transmitted from the device to the user via the internet, alerting the user.

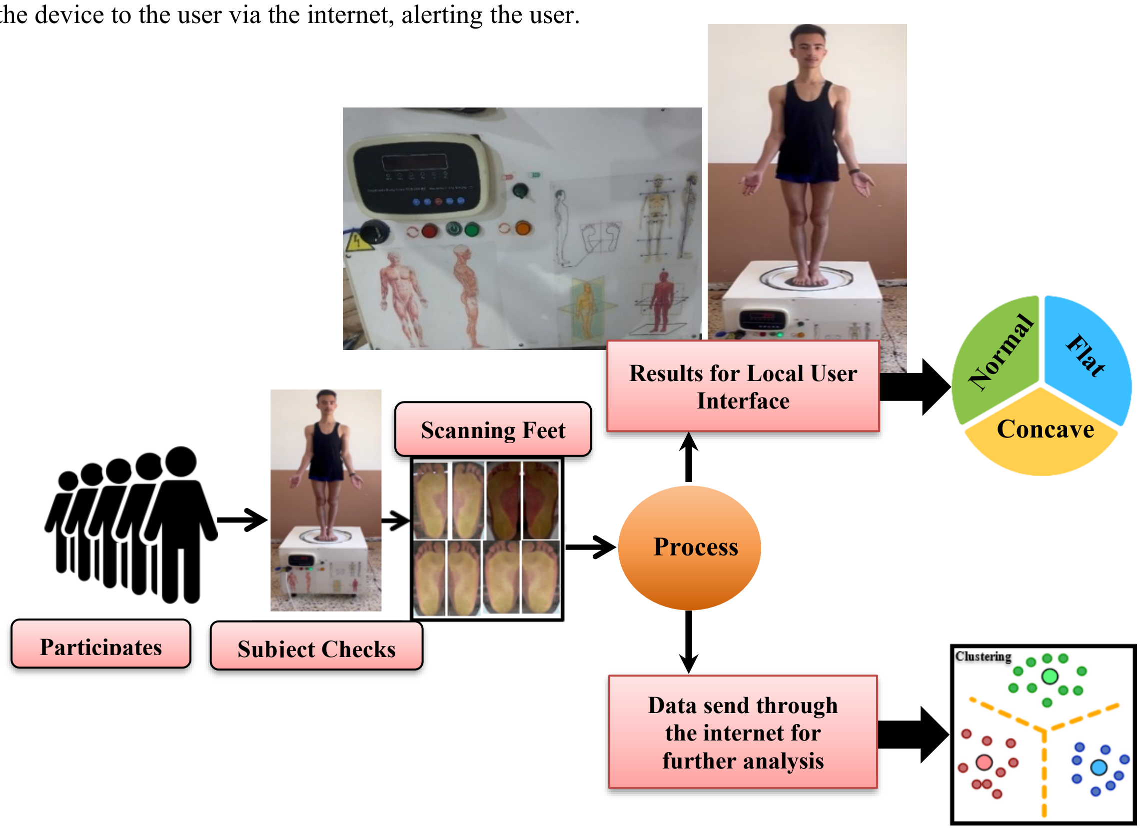

Figure 2: The proposed IoT device.

2.1.1 Hardware Design

The proposed IoT monitoring system reveals the foot-types and gathers dataset by capturing the images and then deliver them to the proposed segmentation method. The recent work aims to design and develop foot healthcare product for general public people and is placed in remote area such as market, university, street or shops in order to diagnose and classify walking-related diseases. The proposed device can be included into four main parts: aluminum box, raspberry pi 4 (RasPi), digital camera, and toughened glass. The aluminum box is a small container and made of aluminum, which means it is very low weight in relation. The dimensions of the box are written as width * height * length, (50 * 60 * 50). The RasPi is one of the best IoT platforms. It includes complete operating systems (i.e., Raspbian Linux) in a tiny platform for a very economical [6], and is utilized as an IoT-device for this present work. The job of this device is to collect, process the collected data and then dispatch it to the cloud platform over the internet for further analyses. The digital camera is an input device that is connected to the RasPi and captures the digital images. The features of this camera are full HD 1080P coloured, 2-megapixel resolution, and USB driver-free (plug and play). The image dimension is an intensity colour image of size (640 * 480) pixels, (horizontal * vertical) respectively. The camera is provided with USB cabled that is linked to the RasPi. The RasPi and digital camera are linked and built-in inside the aluminum box.

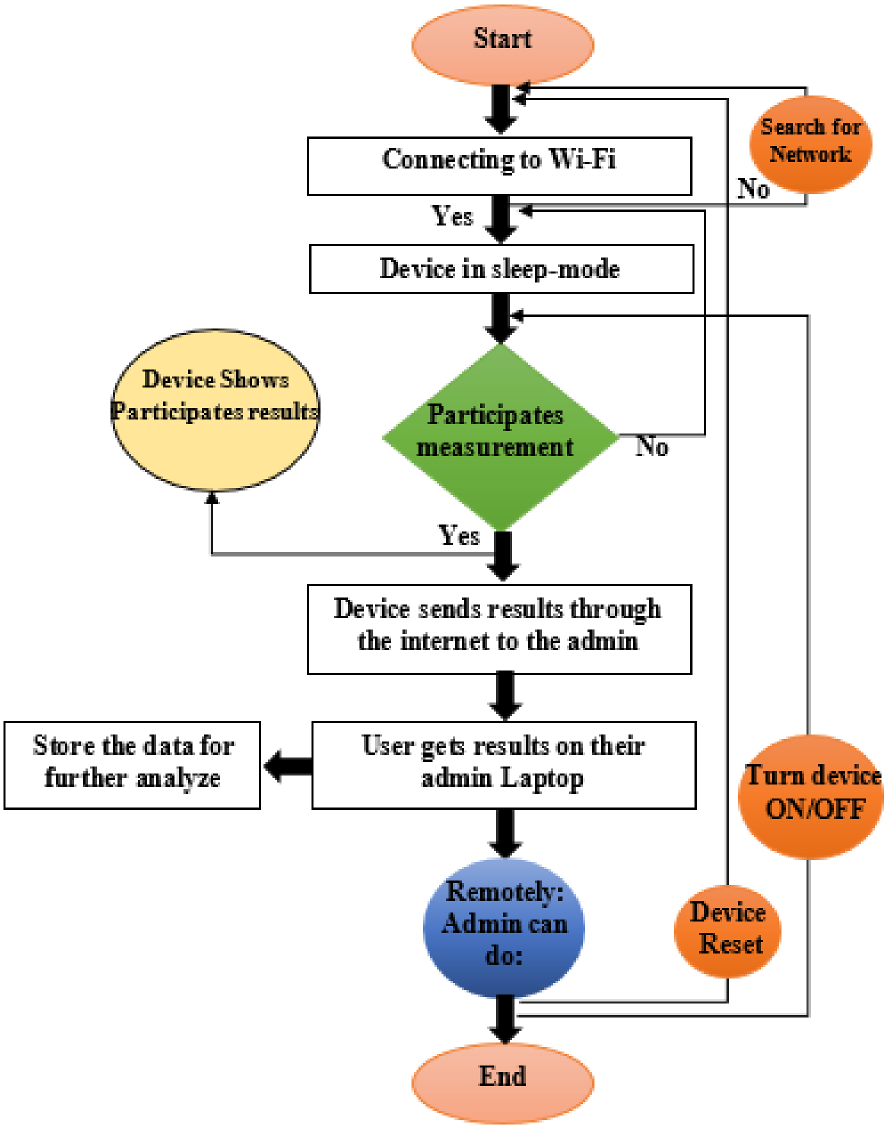

Figure 3: The proposed IoT device architecture system.

While the toughened glass is referred to as tempered is very simply a stronger version of the standard glass that is used on the top of the proposed device. The dimension of the toughened glass height * weight is (4 * 6) mm respectively. The measurement device has a detection area of (300mm * 600mm). Thus, the object can stand barefoot on this detection area (toughened glass). Figure 3 demonstrates the experimental method structure for the proposed device.

2.1.2 Algorithm Implementation

The objective of the proposed algorithm is to analyze the data and classify foot deformities into normal, flat, and concave categories using an unsupervised machine learning method. So, the developed model gathers data on foot shape (specifically, arch foot) and the concavity of the foot color. Thus, the proposed algorithm uses only the critical data from the analysis image to diagnose and determine the type of foot. This means the proposed algorithm removes unnecessary and redundant data to improve processing and obtain results quickly and with high accuracy. Figure 4 presents the proposed method using a flowchart. In this study, 250 males and females participated voluntarily in the experiment through public recruitment. The subjects are split into two groups based on their ages (15-30) and (31-50) years old. The subjects were told about the purpose of the pre-experimental test, and they ratified the contract before taking part in the experiment. The test was done under the leadership of the research team. Subjects stood one by one on the standing area of the device, which was indicated by both feet on the measurement device, to obtain the footprint. The proposed scheme is divided into three main parts: data collection, measurement of the foot arch index, and feature extraction.

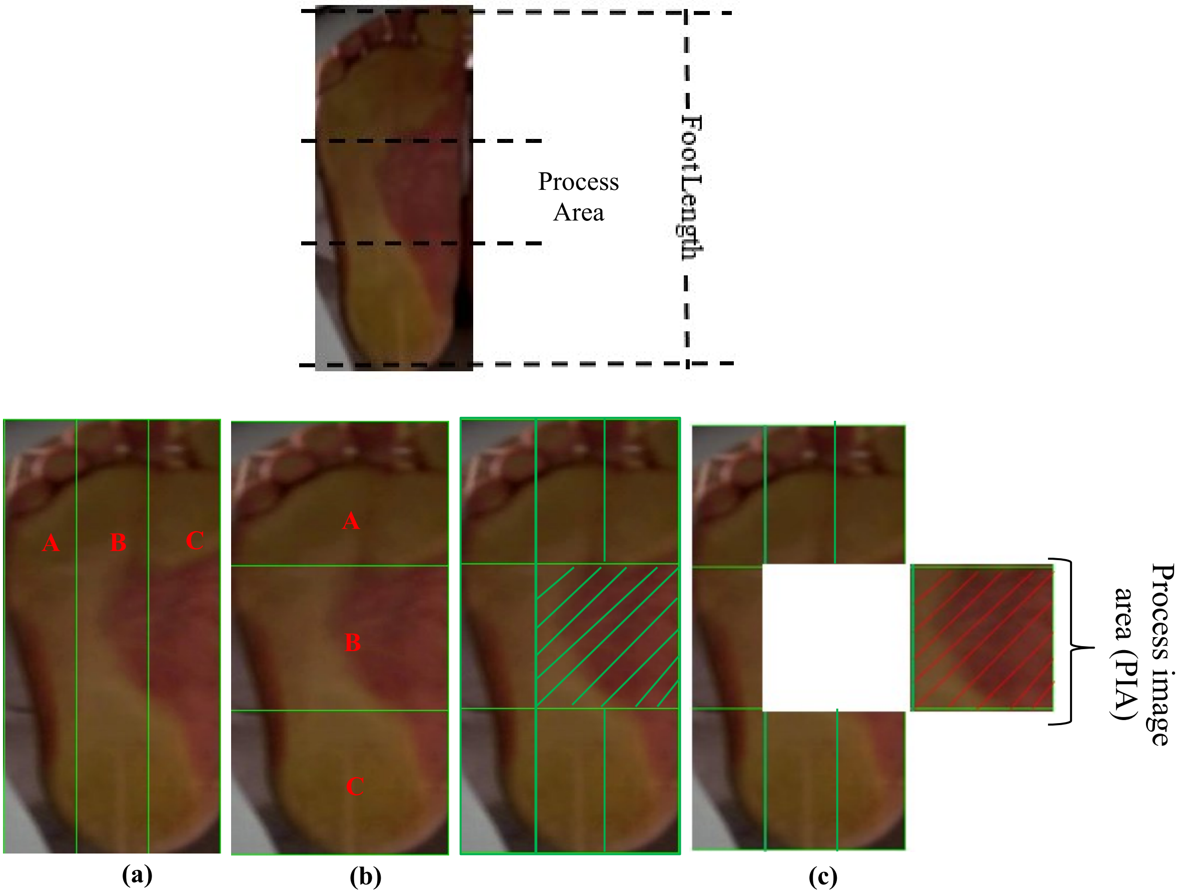

Figure 4: The flowchart of a proposed method.

- ## The Measurement of Foot Arch Index

In this research, we used an image segmentation method to detect and diagnose the distorted foot. The segmentation method is a computer vision process that split the image into groups of pixels and regions [15, 16]. The arch index is defined as the ratio of the area of the central footprint to the overall area of the footprint. The segmentation method is influenced by the quality and size of the image, due to the significant reliance on factors such as the type of disease and the image's characteristics. Thus, the measurement of the foot arch index is performed by dividing the foot area both vertically and horizontally, with each division further segmented into three equal sections. The horizontal division section is computed by dividing the total length of the foot (the length between two points, the end of forefoot and heel of the foot) into three equal areas, which are indicated as (A, B, and C) and calculated by Equation 1 and shown in Figure 5 (a). Yet, the vertical division section is also measured by dividing the total length of the foot into three equal areas, which are indicated as (A, B, and C) and calculated by Equation 1 and shown in Figure 5 (b). This calculation aims to measure the affected area only and remove unnecessary information in order to accelerate the process and get accurate results, and also to determine the type of foot, whether it is normal, flat, or concave. The image data includes both necessary and unnecessary data, where unnecessary data may distort the actual information, yield inaccurate results, and slow down the entire process. Thus, to achieve high-accuracy measurements, the proposed system removes unnecessary parts of the image and analyzes only the process image area (PIA), which can detect foot types. Figure 5(c) shows the PIA chunk for diagnosing and detecting the foot type. Therefore, the dataset is a group of small slices of the feet (right and left) for each participant that are prepared for diagnosis. Figure 6 explains how the dataset is collected before we analyze.

$$\text{Division (d)} = \frac{B}{A+B+C} \tag{1}$$

Figure 5: The feet arch index measurement method: (a) Demonstration of the vertical foot division, (b) Demonstration of the horizontal foot division, (c) Reveals the real dataset which is stored and processed for further analyses.

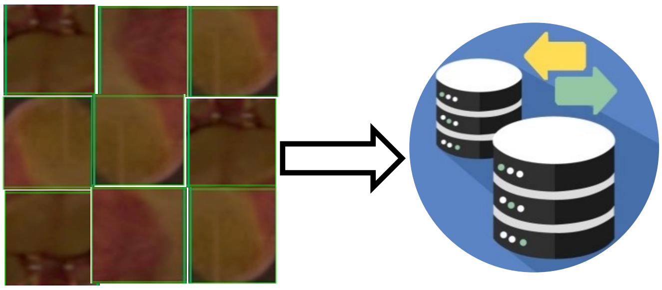

Figure 6. Dataset process.

- **Pre-Processing of Image Information**

In this context, the following pre-processing steps are implemented to enhance the accuracy of data images and reduce the time required for diagnosing fallen arches. In this paper, we use one of the popular unsupervised learning algorithms that is called K-means method. Such method enrolls to analyze and cluster unlabeled datasets based on similar and dissimilar objects. It also deals with big amounts of data and makes the results faster and more accurate without problems. Here the K is the number of clusters of equal variance. Based on proposed clustering method [17, 18], the dataset is assuming as $x = \{x_1, x_2, …., x_n\}$ in a d-dimensional Euclidean space R_d and $A = \{a_1, a_2, …, a_c\}$ as the cluster centers (c). While $z = [Z_{ik}]_{n*c}$, the $Z_{ik} \in \{0,1\}$is a binary variable value that shows if the dataset x_i belongs to k-th cluster, $k = 1,\cdots,c$. So, the K-means objective function is J(z,A), as:

$$\text{AI} = \frac{area\ of\ PIA}{total\ area\ of\ PIA} * 100\% \quad (2)$$

The k-means method is repeated through necessary conditions in order to decrease the J(z, A) with updating equations for (*c*) clusters and memberships, respectively, as the follow:

$$J(z,A) = \sum_i^n = 1 \sum_k^c = 1 \ Z_{ik} \, || x_i - a_k||^2 \quad (3)$$

$$a_k = \frac{\sum_i^n{=}1\ zikxij}{\sum_{i=1}^n zik} \ \text{and}$$

$$Z_{ik} = \begin{cases} 1 & if \ \ ||xi - ak||2 = \min_{1\le k\le c} \ ||xi - ak||2 \\ 0 & otherwise \end{cases} \quad (4)$$

Where $|| x_i - a_k||^2$ means the R_d between data point (x_i) and the cluster center (a_k).

Generally, normal people have an arch that is Obvious when they stand barefoot on the toughened glass. This arch is caused by the normal slight pull of the tendons in the objects feet. This creates a gap between the foot and the glass. So, the proposed method takes a picture of the both feet (right/left) using a camera mounted on the bottom of the toughened glass and the foot appear mostly with two colors (red and yellow). But, in some cases, the tendons do not pull at all. Thus, the soles of the participate touch the toughened glass and unseen arch is presented. Therefore, the foot is mostly cover with yellow color only, see Figure 5. Thus, the proposed algorithm measures the percentage of yellow and red colors to the whole area of PIA in order to categorize the foot types based on the segmentation algorithm. Equation 5 is employed to detect the foot deformity based on the ratio of red region to other. In this equation, the AI is the ratio of the red color of the PIA to the total area of PIA. This measures the red color and divides it by the total area of PIA multiple by 100%. The equation is showed the foot is normal when the AI value is between 85 – 36. However, the foot is concave when the AI value is larger or equal to 86. While, the foot is flat when the AI value is less or equal to 35. These results are almost the same as showed by [19]-[21] references. Thus, we can summaries the types of feet as (85 <= AI <= 36), (AI < = 35), (AI < = 86), normal, flat and concave feet respectively.

$$\text{AI} = \frac{area\ of\ PIA}{total\ area\ of\ PIA} * 100\% \quad (5)$$

3. Results and Discussion

The present paper is integrated work between IoT technology and AI technique. So, this section presents the analyses and outcomes of a comparative study with the research papers [13, 14] based on IoT technology. This section also introduces a brief description of the segmentation method for image partitions with real dataset to demonstrate the performance of the proposed study. The K-means method is used to group the interest area based on similar colors and features [22].

Table 1: Comparison between existing work with the different methods.

Parameters	Ref [13]	Ref [14]	Proposed Method
Implemented IoT technology	No	No	Yes
Energy consumption	More	-	Less
Cost efficiency	No	Yes	Yes
Implemented AI analysis	Yes	Yes	Yes
No. of participates	192	120	250

Table 1 displays the comparison of various properties of different methods based on IoT technology. The results, as shown in Table 1, indicate that the proposed method is outperformed than other for various parameters. This is because the proposed IoT device is generally cheaper and economy and highly accurate results due to real-time data collection, using AI method based on IoT technique and thus elimination of human errors. One of the primary challenges in this study is that data collection involves personal health information, which is highly sensitive and necessitates specific permissions. Therefore, there is a hesitance to disclose such information, even for research purposes. Furthermore, the quality of images presents a problem that may lead to erroneous decision-making and inaccurate outcomes. This study also analyzed some preliminary results using AI technology based on K-means algorithm and presented these results to the reader. However, in future work, we will analyze the data collected by the IoT device more extensively using the employed AI algorithm.

The K-means technique aims to group the data into (n) observations in order to get the best (k) clusters. As we mentioned above, the data was collected from 250 participates from different ages. The proposed algorithm is performed in the python language. After the participate stands on the toughened glass, the administrator runs the code by using PyCharm platform. The application automatically scans both feet and shows the main page as explained in the figure 7. The page contains four fields such as subject name, age, right and left feet. The name and age fields are filled manually by the administrator and others are filled automatically by foot pressure scanning using the digital camera on the bottom of the device. After this step, the administrator presses the "Save" button to insert the data into database as shown in the Table 2. This data is also transmitted and stored in the monitoring server over the internet for further analyses. After that, the software initializes the form for the next subject.

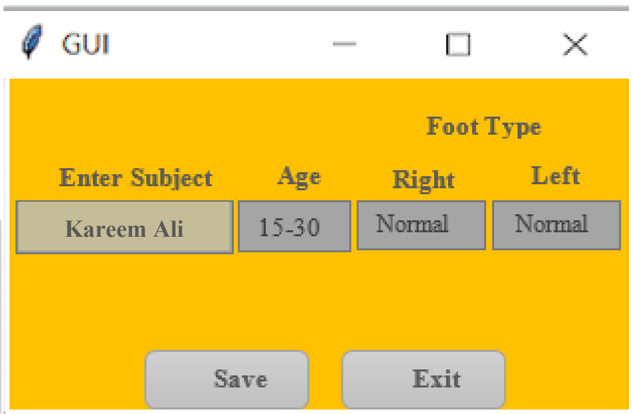

Figure 7: User interface results for foot type.

Table 2: Users dataset measurements.

Subject Name	Age	Gender	Right Foot	Left Foot	Classify Right Foot	Classify Left Foot
Ahmed Farhan	Age(15-30)	Male	24.33	23.90	Flat	Flat
Fatima Mohamed	Age(31-50)	Female	25.41	21.81	Normal	Normal
Zaneb Ali	Age(15-30)	Female	71.18	67.31	Normal	Normal
Adel Jalal	Age(31-50)	Male	72.49	68.22	Normal	Normal
Mustafa Kadhim	Age(15-30)	Male	91.5	90.21	Concave	Concave

Figure 8 provides a pie chart comparing two gender groups, males and females, respectively. The pie chart shows that there are extremely more males than females due to a higher selections of males for this study. This finding provides that the male group are about 3.5 times larger than the female group. The k-means method is employed to our dataset in order to choose the number of clusters and optimal clusters (k) data points as initial centroids. We also use the elbow plot technique to calculate the optimal k and find the total within the sum of squares for each k. As highlighted in the figure 9 introduces an elbow plot and the total sum of squares distance decreases as k increases. This figure shows that the k value at the location of bend (elbow joint) is accounted as the optimal value of k. At the point of k=3, there is a significant drop in the appearance of an elbow. Thus, k=3 is considered as the optimal number of clusters.

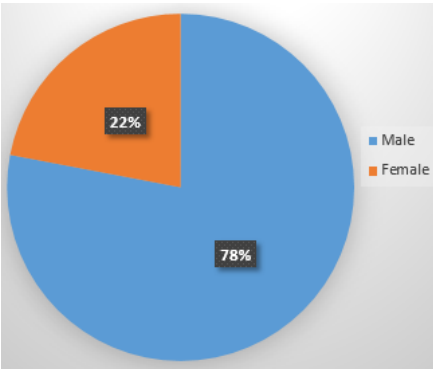

Figure 8: Distribution of males vs females.

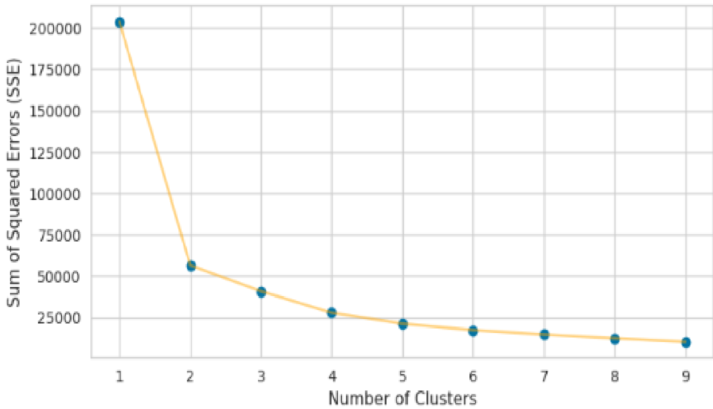

Figure 9: The optimal number of clusters (k).

Figure 10 introduces a scatter plot, with the right feet on the x-axis and left feet on the y-axis. From this figure, it can be seen that three clusters of feet are formed. There are several groups of coloured data points, possibly representing different clusters. These clusters are (0, 1, 2), normal, flat, concave respectively.

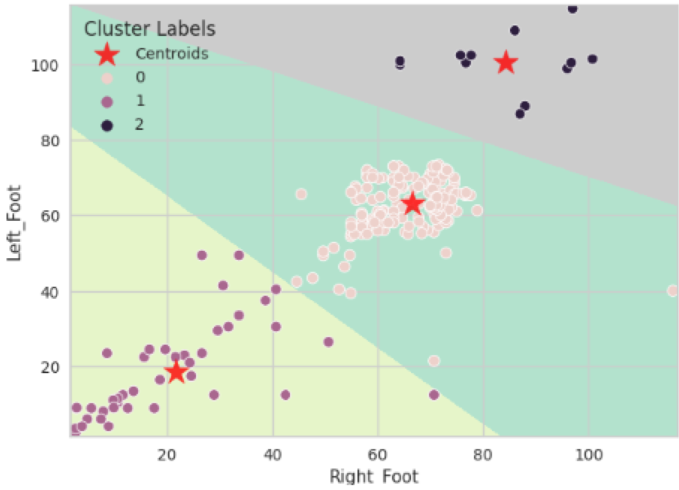

Figure 10: Labelled Clusters.

Interestingly, Figure 10 also observes that the normal cluster is divided into two types of clusters, namely normal and critical normal. This means that the critical normal and normal are both same type of foot. Therefore, in the following figures, both clusters are represented as normal cluster. Figure 11 shows the proportion of different categories of foot deformities types for 250 subjects. From this figure, it is clear that the largest segment, representing the majority of subjects had normal feet with 84.2%, and 13.2% had flat feet. Only a small minority subjects had concave feet with 2.6%. However, in the present dataset above, unique cases found for a few subjects, which indicated that the subjects had a normal foot and other is concave foot.

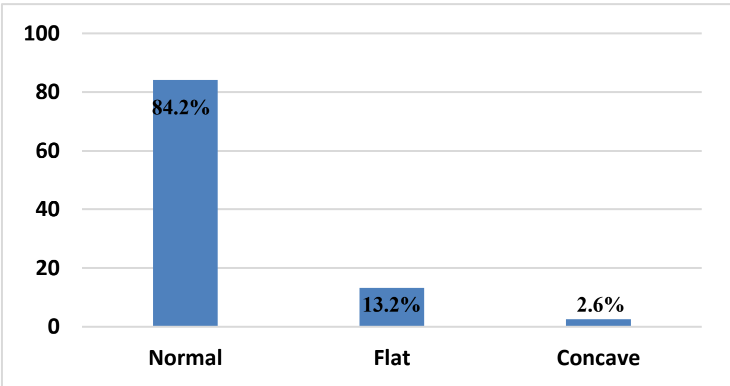

Figure 11: Chart with the percentage of Foot-types.

4. Conclusion

In recent years, the Internet of Things (IoT) has become a crucial technology, particularly in automation systems. In healthcare field, the IoT is used in numerous and diverse applications in order to improve patient outcomes, earlier disease detection, accurate results, increased performance, etc. Therefore, the proposed system involves to design and implement a specialized medical device for the early detection of fallen arches. This system is designed the The proposed algorithm is detected congenital foot anomalies e.g. normal, flatfoot, and concave. The function of this method is to gather, process the collected data and then transmitted it to the ultimate destination through internet for further analyses. The proposed study is collected the data from 250 participates where they stand on the foot-types Internet of things device one-by-one and then the result classifies the foot type based on the segmentation method. This method is partition each image into multiple groups of pixels. Then, it assigns a label to each pixel based on shared characteristics in order to simplify these images for task such as object detection. The present work also provides a remote monitoring system for the end-user that can diagnose and check the performance of this IoT product during real-time communication.

Future studies should focus on more analyze by using one of unsupervised machine learning algorithm. This research has thrown up many questions in need of further investigation. Further work needs to be done to develop a new convolutional neural network (CNN) to classify patterns in foot data and ascertain whether the individuals in question exhibit foot deformities. Additionally, further research is necessary to enhance accuracy by creating more robust algorithms that leverage various features, which could prove advantageous.

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