An Image Processing Based Approach for Assessing Wheelchair Cushions

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***Abstract*—**Wheelchair users spend long hours in a sitting position, and selecting the right cushion is highly critical in preventing pressure ulcers in that demographic. Pressure Mapping Systems (PMS) are typically used in clinical settings by therapists to identify the sitting profile and pressure points in the sitting area to select the cushion that fits the best for the users. A PMS is a flexible mat composed of arrays of distributed networks of pressure sensors. The output of the PMS systems is a color-coded image that shows the intensity of the pressure concentration. Therapists use the PMS images to compare different cushions fit for each user. This process is highly subjective and requires good visual memory for the best outcome. This paper aims to develop an image processing technique to analyze the images of PMS and provide an objective measure to assess the cushions based on their pressure distribution mappings. In this paper, we first reviewed the skeletal anatomy of the human sitting area and its relation to the PMS image. This knowledge is then used to identify the important features that must be considered in image processing. We then developed an algorithm based on those features to analyze the images and rank them according to their fit to the user's needs.

***Keywords*—**Cushion, image processing, pressure mapping system, wheelchair.

I. Introduction

ONE of the secondary health complications that individuals with impaired physical mobility, such as wheelchair users, suffer from is the development of pressure ulcers (PU) in their seating area. The main reason for PU development is prolonged sitting that causes the hardening of the tissue overlying bony prominences such as ischial tuberosities (IT), resulting in blood flow obstruction to the neighboring skin area [1]. Other external factors such as friction, sheer, and moisture accumulation exacerbate skin breakdown and ulcer development [2], [3]. Recovering from PU is a long process and may even lead to death [1], [4]. It also imposes a significant financial burden on healthcare systems [5], [6]. Depending on PU's stage, the cost for managing one PU can be as much as $100k [7].

The standard technique for PU recovery includes occasional moving the patient and relieving pressure from the affected area, which entails the continuous engagement of healthcare professionals [8]. Selecting the right cushions for wheelchair users is also considered an effective approach in prevention and recovery from PU [9]. PMS are distributed networks of sensors that are widely used by occupational therapists and healthcare professionals for cushion selection [10]-[12].

A PMS consists of a flexible pressure sensing mat placed between the user's buttock and a cushion to show the pressure distribution of the seating area. The PMS output can be displayed as a color-coded contour map. Areas with the highest pressure concentration are typically represented in red, while areas with low-pressure are shown in blue. Red zones are typically formed under IT [1].

Generally speaking, a good cushion has an even pressure distribution. As a common practice, wheelchair cushions are ranked based on their pressure distribution by visual assessment of the color-coded PMS images [13]. This process can become more objective by considering parameters such as peak pressure value (represents the highest individual sensor value in mmHg) and the average pressure value (the mean of all the pressure sensor values) [13]. Alternatively, image processing can be employed for the assessment of the PMS images to rank cushions based on their performance for each user.

Image processing has been used in the past to segment a PU's image and has improved the accuracy and efficiency of the ulcer assessment in health care systems [14]. In addition, high-risk bedsores have been detected by image segmentation of pressure images recorded by PMS [15].

This paper employed an image processing approach to develop an objective tool for assessing wheelchair cushions. The rest of the paper is organized as follows: Section II discusses pressure map images from sitting on a cushion and using a machine learning algorithm for easier processing of these images. The user's posture, which affects the PMS output, is determined from analyzing the images, and its consistency is preserved for accurate assessment. A standard clinical test for data collection is conducted in Section III. Finally, in Section IV, two different approaches for assessing cushions based on image processing of PMS images are introduced. The results are compared with the occupational therapist's assessment in Section V.

II. Pressure Map

A pressure map (Fig. 1 (a)) is a color-coded image generated by PMS representing the pressure interaction between buttocks and a cushion. This map contains distinct regions that are formed because of the buttock's anatomy. Generally, the parts of the sitting area under the hard tissue produce higher pressure concentration regions (red). In reality, the formation of those regions will increase the chances of PU and thus have to be

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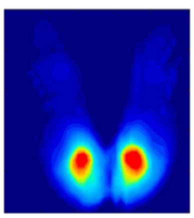
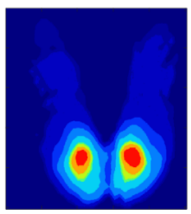
avoided by selecting the right cushion. It can be concluded that a good cushion has more extensive regions in the blue spectrum. Such cushion takes the pressure off the bony areas and transfers them to other regions. The selection of the right cushion highly depends on the buttocks' anatomy, which varies among different users. Physiotherapists use PMS images as a tool in their assessment; however, in principle, that can be highly subjective. In this paper, image processing techniques and pressure mapping images are used to develop an objective method for assessing cushions.

A. Image Segmentation

A pressure mapping image contains a wide range of colors. Those images are represented by a three-dimensional matrix, and the dimension of this matrix corresponds to the size of the image. An original pressure map has 256 RGB colors, and the matrix elements corresponding to this image pixels contain a range of values between 0 to 255, which can generate a maximum of 16,777,216 colors. To make the process easier for processing, we employed color segmentation to reduce the number of colors.



(a)



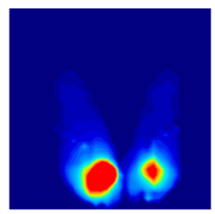
(b)

Fig. 1 (a) The original pressure map from PMS; (b) the segmented image with ten dominant colors (k = 10)

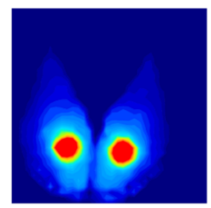
Here, the pressure maps are segmented by replacing a cluster of colors with a dominant color. An unsupervised machine learning technique known as the k-means algorithm is used to determine dominant colors in an image. By implementing this algorithm, each pixel color is encoded to the RGB channel and can be considered a point in a three-dimensional coordinate system. The algorithm chooses k points randomly as cluster centers or centroids, and by adding the points in each iteration to a cluster which is a group of similar points, the cluster center changes. As the processing of different images results in different centroids, the k centroids from one pressure map image are considered the k random points for processing other images; therefore, the centroids of all images rank in the same order. The color located on the centroids of each cluster is considered the dominant color, and all of its pixel colors are replaced with the RGB code of the dominant color. In this paper, ten clusters were identified by the algorithm, and all the pixel colors are replaced with the ten dominant colors (Fig. 1 (b)). Using this clustering method segments the image and enables our image processing algorithm to distinguish different colors faster.

B. Posture Recognition

Sitting posture can affect the pressure distribution of a cushion; therefore, to increase the accuracy of our assessments, we need to implement a posture recognition module to ensure consistent sitting patterns. This module considers the pressure maps on the right and left buttocks areas to recognize the posture. This is achieved by scanning the corresponded matrix of an image to find adjacent elements with different values. Then the element values and the indexes of the adjacent elements are used to identify colors of the areas and distinguish between the identified colors of the areas, respectively. The dark blue region between the thighs clearly shows the division between the right and left sides of the pelvis and is used to discriminate between the two sides. Finally, the number of pixels on high-pressure regions (red and orange colors) is counted for each area to determine the sitting posture. For instance, in Fig. 2 (a), the larger red and orange area on the left side shows the user has leaned toward the left side while the equal right and left areas of red and orange in Fig. 2 (b) represent an upright user's posture. By recognizing the user's postures on different cushions, similar posture maps are selected in our assessment process.



(a)



(b)

Fig. 2 (a) A leaning on the left posture showed on a pressure map; (b) an upright posture

C. Cushion Assessment

Wheelchair cushions are intended to prevent PU development in users. Despite similarities in the patterns, the pressure mapping images from sitting on a cushion has some differences from solid surfaces. That is because cushions expand the sitting area and reduce the mean pressure by better distributing it. The pressure distribution can be quantified by considering the number of pixels for each region in the sensing area (all pixels except dark blue). Since the PU typically develops in the high-pressure regions, peak pressure can also be considered as a factor for assessing cushions. The peak pressure is calculated by counting the pixels on the area with maximum pressure. To compare different cushions based on their pressure distributions, we defined "Cushion Index" as,

$$Cushion\ Index = \frac{Peak\ pressure\ area}{\text{Sensing area}} \quad (1)$$

In this equation, the peak pressure area is obtained from the segmented image by counting the number of pixels in the higher pressure color-coding.

III. Cushion Test Method

The same standard cushion assessment protocol in a clinic setting was considered in our test. We used a manual tilt-inspace wheelchair with a metal seat pan and a commercial PMS (LX100, XSensor) with an 18x18 inch mat (Fig. 3 (a)). Five cushions with different materials and designs, i.e., Jay Union, Synergy, Vicair Vector X, Ride Forward, and Stimulite, were chosen based on our physiotherapist's recommendation (Fig. 4). Jay Union is a contoured foam-based cushion with lateral pelvic support. Synergy is a dual-layer foam cushion designed for pressure management. The Vicair Vector X is designed to manually adjust the small air-filled packages inside a cover to offload the pressure from the vulnerable areas such as IT and coccyx. Ride Forward is composed of a visco-elastic foam over a base polyurethane foam and is designed to reduce pressure under the hard tissue. Stimulite (Slimline) is a cushion with honeycomb cells designed to relieve pressure and shearing forces.


(a)

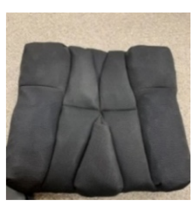

(b)

Fig. 3 (a) The wheelchair used in our test; (b) The participant posture on the wheelchair

Our protocol required a participant to sit in a neutral pelvic alignment with hips and knees flexed at 90 degrees and forearms placed on the wheelchair's armrests (Fig. 3 (b)). The PMS records each test for 1 minute that is set in sitting protocol. We also collected the participant's feedback as well as physiotherapist assessment.


(a)


(b)


(c)


(d)


(e)

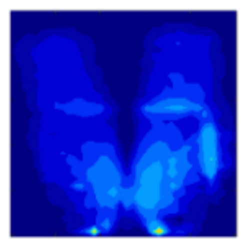
Fig. 4 All the tested cushion: (a) Jay Union, (b) Synergy, (c) Vicair, (d) Ride Forward, (e) Stimulite

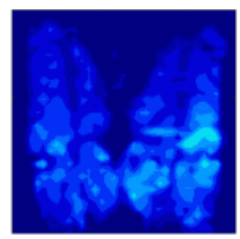
IV. Cushion Assessment by Image Processing

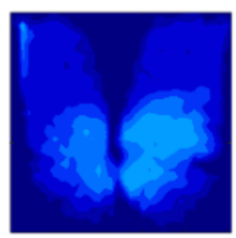
The participant's pressure maps on five cushions were ranked based on the minimum risk of developing PUs. Five PMS images from sitting on five cushions that showed similar posture were selected for assessment. Two approaches were considered for the cushion index calculation. In the first approach, the pixels that represent the peak pressure were counted over the total sensing area to calculate the cushion index. In the second approach, we considered the pressure concentration on high-risk areas to rank the cushions. The first approach is mainly applicable for general cushion selection, while the second one is more needed for identifying the best cushion with the history of PU development or those who are recovering from PU.

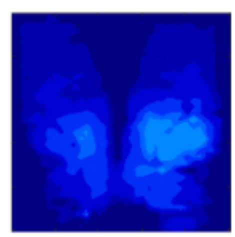
A. First Approach

The segmented images of pressure maps from sitting on the five cushions are shown in Fig. 5. Although the sitting protocol was to ensure an upright posture, the posture recognition module showed that the user has slightly leaned toward the right. Since this pattern is constantly repeated in all the images, we did not repeat the tests. At first, four levels based on pressure concentration are defined as follows: red to orange (level 1), yellow (level 2), green (level 3), and light blue (level 4). The cushion index in level 1 was calculated by dividing the number of red and orange pixels by the total sensing area. The index for other levels is calculated by adding the pixels from the same and all previous levels and dividing the total by the total sensing area. These four indices are then used to rank the cushions.


(a) Synergy


(b) Vicair


(c) Jay


(d) Ride Forward


(e) Stimulite

Fig. 5 The participant's segmented pressure map images on five cushions

B. Second Approach

In this approach, we define the pressure concentration on the buttocks' bony area as the criteria for cushion selection. Although the bony area can be clearly distinguished in images for sitting on hard surfaces (Fig. 1), those are hardly recognizable from the images for sitting on a cushion (Fig. 5). To find the approximate location of the bony area, we used the images of sitting on a solid surface as the reference. Here, we used the PMS images of 24 participants sitting on a solid surface with the same sitting protocol in Section III. We generated a statistical model for determining the distances between the centers of the red areas. The model also identifies the distance between the center of the bony prominence and the posterior end part of the seating area, as well as the approximate size of the red area. Based on this model, two squares of 130 x 130 pixels are used to represent the critical bony area on PMS images (Fig. 6). A software code is developed to identify the location of the high-risk areas in all PMS images of the cushion tests.

V. Result

The criteria for ranking the cushions are the smaller index value in each level that represents the larger pressure distribution area and the smaller high-pressure area (Table I). In the cushions assessment, a small colored area was considered as the existence of an extra object like a coin or key inside the back pocket; therefore, this area was not considered in the calculation. In the First Approach, Level 1 and 2 Cushion Indexes are zero because there were no red, orange, and yellow colors in the images. Having said that, except Vicair, all other maps did not even have the green color, and the indices were calculated only for level 4.

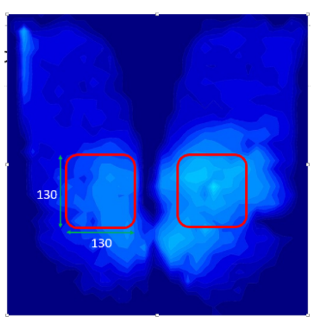


Fig. 6 The participant's sitting pressure map images on five cushions

TABLE I
Ranking the Cushions by the Therapist and the Two Approaches of Image Processing

Cushion Order	Ranked by Therapist	Ranked by First approach		Ranked by Second approach	
		Rank	Cushion Index	Rank	Cushion Index
Synergy (spectrum)	1	1	5.6% (level 4)	1	3%(level 4)
Vicair Vector X	2	5	1.4% (level 3) 7.9% (level 4)	2	3.1% (level 4)
Jay Union	3	3	9.5% (level 4)	4	6.2%(level 4)
Ride Forward	4	2	5.9% (level 4)	3	3.3%(level 4)
Stimulite (Slimline)	5	4	25% (level 4)	5	16%(level 4)

VI. Discussion

As it can be seen in Table I, the ranking done by the therapist and our first approach has a few inconsistencies. We think it might be due to the fact that some cushions are contoured, and the edges of the contoured area sometimes apply a higher pressure than normal to the sides of the sitting area. The higher pressure in this area that is not under the hard tissues maybe be ignored by the visual assessment. Moreover, some colors in the PM images are not distinguished and neglected by the visual assessment; therefore, the subjective assessment may affect the ranking of the competitive cushions. The green pixels in the Vicair cushion are located on the right side of the right thigh. This area is 1.4% of the seating area, which shows the maximum pressure between all five cushions; therefore, it dropped Vicair's rank to the last.

The cushion ranking by the second approach is closer to the therapist's ranking. The only difference in this comparison is between the Jay and Ride cushions, which can be justified as a visual assessment error.

Overall, choosing either of these two image processing approaches for a patient depends on the location of the ulcers in their seating area. The first approach can be useful if a habitual sitting posture is the cause of ulcer development on the sides of the buttocks, while the second approach can be used for the hard tissue area. Both results from the image processing approaches represent objective approaches for assessing cushions that can be an alternative to the subjective approach used by therapists.

VII. Conclusion

Using image processing approaches can improve the objectiveness of wheelchair cushion selection. We assessed five cushions by this approach. The next step in this research is to include more cushions and consider other parameters such as mean pressure in a sitting map that might help to improve the effectiveness and accuracy of the assessment process.

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