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Research Article

Design of Sesame Peeling Machine and Performance Analysis with Threshold-Based Image Segmentation Technique

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ABSTRACT

In this study, peeled sesame seeds were analyzed using a threshold-based image segmentation technique. Peeled sesame seeds were obtained from a sesame membrane peeling machine whose design and production was carried out within the project's scope. By applying the image segmentation technique to the samples taken from the machine, the machine's sesame peeling performance and sesame peeling percentage were determined. Automatic calculation of the peeled sesame weights in the image is presented by the threshold-based image segmentation technique, which is one of the basic operations of digital image processing and is extensively employed in many application areas, including extraction, detection, and identification of features. This technique aims to divide an image into meaningful regions according to a particular operation. Based on the results obtained using the threshold-based image segmentation technique, the success achieved in the peeling process is 48%, 56%, 60% for periods of 60 min, 120 min, 180 min respectively. By using the designed machine, the processing time of peeling sesame has been reduced by 75%, water consumption has been reduced by 90%, and salt use has been eliminated. Moreover, operating, personnel, and energy costs have been minimized.

1. INTRODUCTION

Sesame seeds, whose motherland is India, Indonesia, Nigeria, China and Burma in the world, are found in yellow, white, red and black colours, also have geometrical dimensions such as 2,26-3,01 mm in height, 1,55-1,86 mm in width and 0,75-0,97 mm in thickness [1,2]. Sesame, which is used widely in dough products such as fat, tahini, halvah, bread, pastries, pies, is an oily seed that contains minerals such as Ca, Fe, Mn, Zn, Mg, Cu, and Se, as well as fat, carbohydrate and protein with high nutritive properties [3]. However, it also contains substances that are harmful to human health, especially in the thin membrane surrounding the grains, as well as oxalic acid, phytic acid and cellulose. Sesame membrane contains a large amount of oxalic acid, phytic acid and cellulose, which form a structure that disrupts human health by reacting chemically with Ca, Mg, Zn and Fe in sesame grains [2]. Moreover, the membrane on sesame seed has undesirable outcomes in the food industry like the dark colour and sour flavour. Therefore, before the sesame is consumed, it is a necessity to peeling of the membrane on the seed [1].

Sesame seeds contain a thin membrane around them. Approximately 15-20% of sesame seeds consist of this thin membrane. The ratio of oxalic acid, which is approximately 2.53% in a sesame seed, in the membrane can reach 15%. Oxalic acid combines with calcium in the environment to form oxalate, which can cause health problems such as kidney stones. Phytic acid and Cellulose ratio in the membrane is around 5% separately. These substances can cause digestive problems by combining magnesium, zinc, calcium, and iron found in sesame [2, 4]. In order to purify the sesame of these harmful active substances and make them suitable for consumption in the food industry, the membrane must be peeled. The amount of oxalic acid in a peeled sesame seed can decrease up to 0.25%.

In the food industry, the membranes of sesame seeds are peeled by mechanical methods, using different chemical disinfectants and solvent salts. Disinfectants and salts, used in the peeling processes of the sesame membrane, cause environmental pollution and require high water consumption. Therefore, environmental pollution and a large amount of water consumption establish a crucial problem. In order to reduce water consumption and shortened the process duration, sesame grains are kept in salt and chemical disinfectants such as NaCIO and H_2O_2 before the mechanical peeling process [1]. In another decorticating process, the sesame grains were kept at 60°C for 5 to 10 hours in NaOH and Na_2CO_3 saline solutions and then subjected to the mechanical stirring. After the stirring process, the sesame seed from the saline solution was dried at 120°C for 2 hours. Thus the peeling processing time can be reduced to 40 minute [5]. In another method, while sesame seeds are in the water, they simultaneously stir with rotating the tank, driving by the engine. After the stirring process, the sesame grains were taken into the boiler and transferred to the saline solution with higher density. The peeled grains from the saline solution were washed in another medium and then dried [6].

In order to peel the sesame membrane, the mixer rods in A, I and L profiles were fixed on the rotating shaft. Moreover, during the mixing process, the sharp edges of the bars are rounded to prevent the breakage and deformation of the sesame seeds. Better results were obtained in the peeling process with L-shaped stirrer bars at 500 rpm rotating speed [7]. In another method, sesame grains, which are water in the sesame grains and put into the water heated simultaneously with the electrical resistance, were kept at a temperature of 60ºC-70ºC for 1 to 1.5 hours. During the holding process, the moistened sesame grains were stirred with the rotational speed of 1800 rpm in the acidic bath. Then the sesame grains were separated from the membrane with the effect of the centrifugal movement inside the sieve [7]. In the existing sesame membrane peeling methods, chemical disinfectants and salts, causing environmental pollution, are used. Furthermore, large amounts of water are consumed during the solution waiting and subsequent washing.

Programmable Logic Controller-PLC is widely used in many industrial applications such as driving AC servo motors used in robotic manipulators [8], automatic liquid filling systems [9], solar power generation systems [10], hydraulic positioning systems [11], and machine automation. In [12], the liquid level control process was carried out automatically without human observation and using a buoy. A neural network-based PID controller has been designed in [13]. Speed control of an asynchronous motor is realized by using this controller and PLC together. An electrical energy generation system has been established in [14] by using a thermoelectric generator. The current and voltage values of this system are monitored instantaneously by using a PLC-SCADA system. In [15], the control of a water pump has been experimentally provided using a PLC. The most important advantage of this study is that the wireless communication application has been implemented in the system controlled by PLC. Thus, observation and control operations could be made farther from where the water pump is located. In [16], a system with a Stirling engine (providing thermal energy), electric generator, and secondary heat exchanger were controlled by an automation system using PLC in a solar energy conversion system. This automation system aims to ensure the operating safety of the system and monitor its parameters during operation. At the same time, the solar concentrator is positioned towards the sun to obtain maximum power. In [17], the engine oil production process was carried out using PLC automation. Instead of star-delta starting, a motor driver is used. Worker safety has been increased by taking high-security measures. Apart from that, many studies have been done on image processing in industrial applications. In a vegetable chopping automation, by using image processing, human labor was reduced, and various parameters related to vegetables such as texture, hardness, color, size, and shape were analyzed. Appropriate knife selection was made [18]. In another study, sesame oil quality was determined using Hyper Spectral Image-HSI analysis [19]. Industrial orange grading is done manually and using expensive technologies. A more efficient orange selection system has been developed in a very recent study using artificial intelligence and image processing [20].

Segmentation (border detection) is one of the most significant steps in image-processing stage because of that (a) it ensures major information for example: border shape, border disorder, and asymmetry (b) it helps extraction of features depending on the accuracy of the border detection [21]. Considering the literature studies, a large number of segmentation methods have been suggested to segment related object from the background. [22] and [23] employed the common and simple image segmentation method, which is the Otsu thresholding (adaptive thresholding). In segmentation, obtaining the outline of the object from the noisy image is one of the most important difficulties. To manage this problem, a technique called active contour is often used to outline an object from an image [24, 25]. The precision of the segmentation can be advanced by combining multiple segmentation techniques, which is also known as fusion based segmentation [26]. In addition, alternative segmentation methods are used for object segmentation, for example, neural network-based [27], edge-based [28] and cluster-based [29]. In this study, the threshold-based segmentation process was preferred, which gives extremely easy and fast results. After the segmented image of the object is obtained, the next step is to calculate the pixel-based area of the relevant object. The reason for calculating the segmented object area is that finding percentage of it in whole image. In literature, a few studies have been done on the calculation of the relevant object area by image segmentation methods. These studies are summarized respectively. [30] investigated the segmentation of the brain tumor using brain MR images and computed the area of the segmented tumor regions employing two algorithms: K-mean clustering and Fuzzy C-Mean algorithms. [21] suggested a new approach for skin lesion detection. Moreover, they computed the diameters of the segmented lesions. In this study, the properties (coordinates, area etc.) of the segmented image regions were calculated to determine the area of the peeled sesame in each image.

This study, it is aimed to test the performance of a sesame skin peeling machine designed and manufactured within the scope of the project numbered TUBITAK / SAN-TEZ. Thus, the peeled sesame samples obtained from the machine were analyzed using the threshold-based image segmentation technique. This study contributed to the literature on both machine design and automation, and image processing. Since machine design is not the subject of this article, detailed mechanical calculations are not included. The paper is divided into four sections. In section II machine design, machine automation and threshold-based image segmentation technique is presented. In section III, the simulation results obtained from the threshold-based image segmentation technique are given. Section IV describes conclusions.

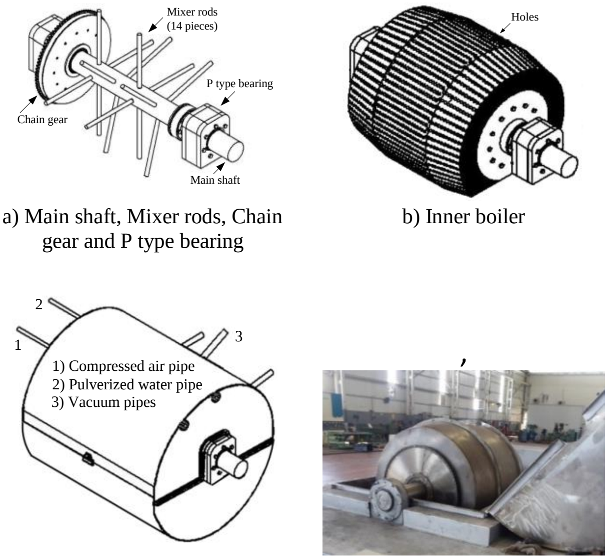
2. MATERIALS AND METHOD

When looking through the literature, it is clear that the salty water method is commonly used to peel sesame skins. This procedure is carried out in two stages: For the first stage, 1 ton of sesame is kept in 5 tons of water for 6-12 hours at a maximum temperature of 600°C. The sesame seeds softened in the first stage are preserved in a solution of 5 tons of water and 1 ton of salt for 6-12 hours in the second stage, after which they are washed with approximately 12 tons of water to desalinate, and finally dried and peeled off. Similarly, peeling sesame skins with different mechanisms using water and salt have been developed in the sources numbered [31, 32, 33]. The intensive use of inputs such as water and salt, high labor, time, energy, and operating costs, large area coverage, and wastes they leave in the environment are all drawbacks of these techniques. Furthermore, since sesame is a delicate and oily seed, it can be deformed by the skin peeling process's impact and friction. Fat, carbohydrate, protein, and other useful minerals and the peeled membranes are discarded as trash. A sesame skin peeling machine was developed and a prototype produced to remove these drawbacks and to be distinct from the brine method. Sections 2.1 and 2.2 describe the mechanical and electrical characteristics of the designed machine.

2.1. Machine Design

Fig.1 shows the main components of the sesame skin peeling machine, which includes 1) the main shaft, stirring rods, chain gear, and P-type bearings, 2) the sieve perforated inner vessel, and 3) the external boiler [34]. One of the most important machine components is the main shaft, as shown in Fig.1a. A 15 kW motor can drive it in both directions. It has a 100 mm diameter and is held in place by two P-type bearings. It comes with 14 detachable mixing rods. During rotation, these stirring rods are intended to avoid damaging sesame seeds. Also, the main shaft has a chain gear mechanism that rotates the sieve hole inner tank. P-type bearing bearings can support approximately 600 kg of weight, including the weight of the inner tank. The inner tank with the sieve hole is shown in Fig.1b as another key component of the machine. It can hold 500 kilograms of sesame seeds. It has a 560 mm radius, 1120 mm length, and a 1 mm wall thickness. It has 1 mm diameter holes with a 2 mm spacing between centers and a filling and discharges opening. With the assistance of hinges, this mouth can be opened and closed. A 15 kW motor powers the screen hole inner boiler. The inner bowl can rotate independently from the main shaft thanks to its chain gear assembly. Depending on demand, the main shaft and inner bowl may rotate in the same direction or the opposite direction.

Peeling sesame skins is easier when you rotate in the opposite direction. The outer boiler, shown in Fig.1c, has a pulverized water pipe, compressed air pipe, and vacuum pipe. External boiler; the perforated inner vessel also acts as a casing, keeping the main shaft and stirring rods safe from the elements. Evaporated water is sprayed from the pulverized water pipe to moisten the sesame seeds in the inner boiler at regular intervals. The peeled sesame membranes are vented using compressed air pipes, and the ventilated sesame membranes are transferred to the outside using vacuum pipes. An external compressor provides compressed air. Sesame membranes that have been vacuumed into the outside environment are preserved in a separate environment for various purposes. Fig.1d [34] shows a real image of a sesame skin peeling machine made of A304 stainless steel.



a) Main shaft, Mixer rods, Chain gear and P type bearing — b) Inner boiler — c) Outer boiler — d) Sesame peeling machine

Fig 1. Main parts of sesame peeling machine [34].

2.2. Machine Automation

The machine is operated by a PLC-based automation system, which was designed and manufactured. The main shaft carrying the mixing rods was driven by a 15 kW drive motor, while the inner bowl was driven by a 15 kW drive motor. Each motor is an asynchronous type motor with a Delta-VFD150E43A model industrial type motor driver controlling its speed. Direct torque control-DTC and field-oriented control-FOC are two advanced control techniques used by this driver. In practice, an open-loop control was conducted. The central processing unit is a DVP-14SS211R CPU, and the touch panel is a Delta-DOP-B07S410 model HMI panel. All control operations on the HMI panel are carried out by touch, thanks to software designed for machine automation. The HMI panel was used to adjust the motor rotation direction, and the speed settings were made on the drivers. Excessive currents and the dangers that can occur when the direction of rotation changes during idle and load are protected by software. Fig.2a depicts the machine's control and control panel, while Fig.2b depicts the established HMI panel interface.

a)Automation panel — b)HMI user interface

Fig 2. Machine Automation.

2.3. Practise

The sesame skin peeling process, made with the machine manufactured, was carried out as in practice.

Practise : 400 kg of untreated dried sesame seeds were submerged in 280°C water for 3 hours. After the sesame seeds had softened in the skin, they were loaded into the machine and peeled. The inner bowl with sesame seeds was rotated at 45 rpm during the peeling process, while the main shaft with stirring rods was rotated at 25 rpm. The cauldron's rotation period has been determined to be 180 minutes. Fig.3 shows the photographs taken every 60 minutes from peeled sesame seeds. An operator using a high-resolution camera captured these images. The image acquisition unit has not yet been integrated into machine automation because the machine is a prototype. However, during the mass production phase, the machine will be equipped with image acquisition and a processing unit. As a result, it is expected that the sesame skin peeling process will be improved in terms of energy and time.

During the application, the effect of the rotational movement separated the sesame seeds from their membranes after they had been moistened by soaking in water. Vacuuming was used to transfer the split sesame membranes to the outside world. The process was completed by removing the peeled sesame seeds from the discharge cover at the bottom of the inner boiler.

For peeling, 500 kg of sesame, 20 tons of water, and 1 ton of salt are used in the conventional saltwater peeling process. It will take about 24 hours to complete the task. The use of salt was eliminated with this machine's development, and only 1 ton of water was used to peel 500 kg of sesame in each application. The peeled sesame images in Fig.3 were subjected to the threshold-based image segmentation technique to test the machine's performance. In section *D*, the results of the study are reviewed.

Unprocessed Sesame | Image1-Processed Sesame for 60 min. | Image2-Processed Sesame for 120 min. | Image3-Processed Sesame for 180 min.

Fig 3. Machine-processed sesame images

2.4. Image Processing

2.4.1 Sesame Image Dataset

The dataset used in our study during the image-processing phase consists of 16 sesame images, which belong to three groups of images (Group-1: 60 minutes; Group-2:120 minutes and Group-3: 180 minutes). These images were obtained from the mobile phone cameras as shown in Fig.3.

2.4.2 Image Pre-Processing and Segmentation

In this stage, each sesame image was resized to 1/4 original image size. The resized images were then converted to 8-bit gray scale images via MATLAB-2016. After that, these images were turned into binary images based on thresholding. Region filling morphological algorithm were then applied to the thresholded binary images in order to fill image holes and regions.Later, image segmentation approach was implemented to the preprocessed sesame images to determine connected label components in the binary images. Lastly, the properties (coordinates, area etc.) of image regions were computed to find the collected area of the peeled sesame in the each image. These stages were considered in the following sections in details.

A) Image Thresholding

The threshold approach is the simplest method of image segmentation, which can be used to create a binary image from a gray scale image by selecting a single threshold (T) value. It is also used to divide the image into smaller sections using at least one color or gray scale value to determine its boundaries. The advantage of attaining a binary image is the simplification of the recognition and classification process, together with reducing the data complexity. In the threshold operation, input is generally a gray or color image *f(x, y)* and output is a segmented binary image *g(x, y)*, where black pixels match with the background and white pixels comply with the foreground (or vice versa). Moreover, a single criterion is implemented to all pixels in the image at the same time. The steps of threshold-based image segmentation are simply given in below:

- *The image is partitioned into pixel sets or continuous regions for segmentation.*
- *The partition is made according to intensity value of pixel sets.*
- *Then, the image is segmented as the background, g(x, y)=1, while the pixels of input image f(x, y) smaller than the threshold (T) value;*
- *Image is segmented as the foreground, g(x, y)=0, while the pixels of input image f(x, y) bigger than the threshold (T) value.*

$$g(x,y) = \begin{cases} 0 \; if \; f(x,y) < T \\ 1 \; if \; f(x,y) \geq T \end{cases} \quad (1)$$

B) Region Filling Morphological Algorithm

Region filling is one of the most frequently used morphological algorithms in image processing and it endeavor filling the image regions with specific colors. The algorithm is built on the complementation, dilations and intersection operators. In this algorithm, all non-boundary pixels are first categorized as 'white' and a value of black is then assigned to p. Region filling with 'black' is carried out by the following equation.

$$x_m = (x_{m-1} \oplus S) \cap I^C \qquad m = 1,2,3 \ldots \quad (2)$$

Here $x_0 = p$, S is the symmetric structuring matrix, $\oplus$ is dilation operator, $\cap$ is intersection operator, I is image matrix and I^C is the complement of I matrix [35].

2.4.3 Calculation of the Area of the Peeled Sesame

After pre-processing and segmentation stage, the pixels that form the outer boundaries of the peeled sesame were determined automatically and the area of these boundaries was calculated using Matlab R2016a commands such as ‘regionprops’. This command calculates the object measurements like area, bounding box, centroid …etc. [36].

2.4.4 The Proposed Threshold-Based Image Segmentation Approach

The proposed approach consists of five stages as indicated in Fig.4.

1) A dataset consisting of 16 different sesame images was obtained from the mobile phone cameras over the machine we designed.
2) These images were resized to 1/4 original image size and turned into 8-bit gray scale images.
3) Resized gray scale images were converted to binary images based on thresholding.
4) Morphological algorithm was implemented to the binary images.
5) The weights of the peeled sesames were computed thanks to segmented areas.

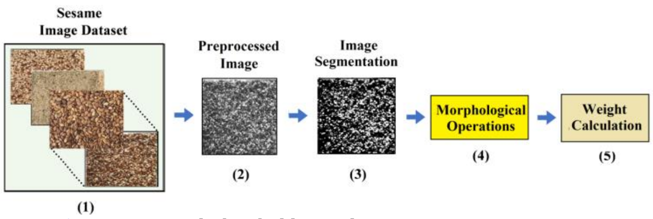


Fig 4. Proposed Threshold-Based Image Segmentation system

3. EXPERIMENTS RESULTS AND DISCUSSION

In this section, the attained 16 Sesame images (3 different Groups) were resized in 25% of original image size and they were converted to 8-bit resolution gray scale images. The original and resized 8-bit gray scale image samples for Group-1 are shown in Fig.5 (a) and (b). After that, segmentation of the peeled sesames was made based on thresholding, which was chosen according to the pixel value of peeled sesame in the image. Moreover, region filling morphological algorithm was applied to the segmented binary images as shown in Fig.5 (c). Finally, the approximate weights of the peeled sesames were computed by using the Equation-3 and tabulated in Table-1.

$$Weights(\%) = \left(\frac{Pixel\ areas\ of\ the\ segmented\ sesames}{Total\ pixel\ area}\right) \times 100 \qquad (3)$$

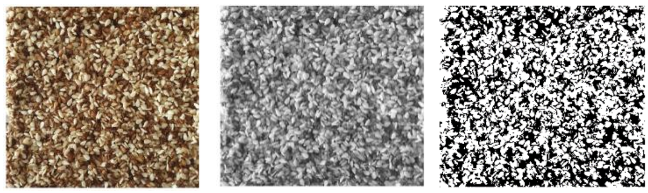
The same methodology used for Group-1 images above was implemented to the other groups (Group-2 and Group-3) and the output images for these groups were shown in Fig.6 and Fig.7, respectively. Moreover, the ratio of peeled sesame for each image groups was given in Table-2 and Table-3, respectively.

a) b) c)

Fig 5. The output images for a sample Group-1 image after 60 minutes: (a) Original Image (b) Resized Gray Scale Image (c) Segmented Binary Image based on Thresholding and morphological algorithm

TABLE I
THE APPROXIMATE WEIGHTS OF THE PEELED SESAMES FOR A SAMPLE IMAGE OF GROUP-1

Pixel areas of the Segmented Sesames	328862
Total Pixel areas	689500
Ratio of Peeled Sesame in Whole Image	**48 %**

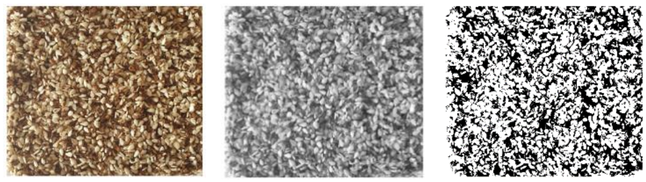


a) b) c)

Fig 6. The output images for a sample Group-2 image after 120 minutes:(a) Original Image (b) Resized Gray Scale Image (c) Segmented Binary Image based on Thresholding and morphological algorithm

TABLE II
THE APPROXIMATE WEIGHTS OF THE PEELED SESAMES FOR A SAMPLE IMAGE OF GROUP-2

Pixel areas of the Segmented Sesames	361239
Total Pixel areas	650655
Ratio of Peeled Sesame in Whole Image	**56 %**



a) b) c)

Fig 7. The output images for a sample Group-3 image after 180 minutes: (a) Original Image (b) Resized Gray Scale Image (c) Segmented Binary Image based on thresholding and morphological algorithm

TABLE III
THE APPROXIMATE WEIGHTS OF THE PEELED SESAMES FOR A SAMPLE IMAGE OF GROUP-3

Pixel areas of the Segmented Sesames	373978
Total Pixel areas	630591
Ratio of Peeled Sesame in Whole Image	**60 %**

Taking everything into account, it can be said that. The threshold-based image processing technique provides an advantage because it has a much easier structure compared to architectures such as U-Net, in terms of both time and processing complexity. However, in architectures such as U-Net, threshold-based image processing technique will be disadvantageous in this respect, as much better training can be achieved by marking the area to be segmented beforehand.

4. CONCLUSIONS

In this study, in order to test the performance of the sesame-peeling machine, which designed within the scope of the project before, the images of the peeled sesame samples obtained from the machine were analysed by threshold-based image segmentation technique. The proposed system consists of several stages. In the first stage, sesame images obtained from three different groups were pre-processed as well as these images were reduced in size and transformed into grayscale images. In the second stage, the pre-processed images were converted to the binary images thanks to threshold-based image segmentation approach. In the last stage, morphological operations were implemented to the binary images and the weights of the peeled sesames were calculated via segmented pixel areas. Considering the results obtained with the proposed threshold-based image segmentation technique, it was observed that a great success was achieved in peeling sesame grains.

When the results of the threshold-based image segmentation technique were investigated, the success achieved in the peeling process is 48%, 56%, 60% for periods of 60 min, 120 min, 180 min respectively. In terms of fictionalized processing time, these results are satisfactory. With this machine, the time it takes to peel sesame seeds is reduced by 75%, and the amount of water used is reduced by 90%, eliminating the use of salt. Furthermore, operating, staffing and energy costs have all been reduced. Image acquisition and processing unit will be mounted on the machine in future experiments. With various applications to be made, the machine's rotation time and rotation speed are optimized, aiming to improve the machine's performance. Reducing the amount of water used in the sesame peeling process may be a interesting research topic for other researchers.

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