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Procedia Computer Science 00 (2024) 000–000

Procedia Computer Science

www.elsevier.com/locate/procedia

6th International Conference on Industry 4.0 and Smart Manufacturing

Exploring the Role of Artificial Intelligence for Pattern Recognition of Textile Sorting and Recycling for Circular Economy

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Abstract

In an era where sustainability is a vital concern, the textile industry is a major obstacle that stands in the way of addressing environmental challenges, climate change, pollution, and biodiversity loss. The integration of Artificial Intelligence (AI) into the textile recycling process holds significant promise for advancing the circular economy agenda. AI technologies offer innovative solutions for automating pattern recognition tasks, thereby enhancing the efficiency and accuracy of textile sorting and recycling processes. This paper endeavors to explore AI algorithms specifically tailored for soiled cloth detection in textile products. Through a comprehensive analysis of existing literature studies, the paper aims to propose an approach that addresses the unique challenges associated with identifying and classifying soiled cloth. This research focuses on investigating and developing unsupervised computer vision techniques for the initial detection and segmentation of stains on textile materials. The paper focuses on the capabilities of two methods, (1) Otsu's thresholding and (2) K-Means clustering, which do not require extensive training data or deep learning models. Practical conditions are examined for complex backgrounds and uneven lighting conditions and capability for accurate separation of stains from fabrics with similar colors or textures. The results show that for both methods to work efficiently, they require even and bright lighting conditions on the textiles. Moreover, the paper has discussed the challenges faced for real implementation of models for textiles being sorted on factory line.

Peer-review under responsibility of the scientific committee of the 6th International Conference on Industry 4.0 and Smart Manufacturing

Keywords: Textile Industry; Artificial Intellegence; Sorting & Recycling; Patter recognition; Otsu's thresholding; K-Means clustering.

Nomenclature

AI	Artificial Intelligence
NIR	Near Infrared Spectroscopy

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1877-0509
Peer-review under responsibility of the scientific committee of the 6th International Conference on Industry 4.0 and Smart Manufacturing

PCA	Principal Component Analysis
PLS	Partial Least Squares
RMSEP	Root Mean Squared Error of Prediction
ROI	Region of Interest
SWIR	Shortwave Infrared Range
VNIR	Visible Near Infrared Ranges
WCSS	Within cluster sum of squares

1. Introduction

Artificial Intelligence (AI) is the most revolutionary technology since the invention of paper and the potential to empower every aspect of our modern lives [1,2]. The current situation of the world is one where various solution in all industries are powered by AI, including the textile industry. This paper explores the impact AI currently has and can have in the textile industry for soiled cloth detection and sorting. In an era where sustainability is a vital concern, the textile industry is a major obstacle that stands in the way of addressing environmental challenges – climate change, pollution, and biodiversity loss [3,4]. This paper endeavors to explore AI algorithms specifically tailored for soiled cloth detection in textile products. Through a comprehensive analysis of existing methodologies, the paper aims to propose an approach that addresses the unique challenges associated with identifying and classifying soiled cloth. By integrating machine learning techniques, image processing algorithms, and sensor technologies, the proposed AI algorithm seeks to achieve a high level of accuracy and reliability in detecting soiled areas within textile products.

In automating the detection of soiled cloths, AI can significantly expedite the process saving time while simultaneously reducing labor costs which would allow for more efficient sorting of larger volumes of textiles [5]. This also aligns with the principles of the circular economy by promoting the reuse, manufacturing, and recycling of textile materials. It would also ensure that only clean and reusable materials are recycled, hence improving the quality of recycled textile products which would in return increase consumer confidence and demand in sustainable products and promote a circular business model [6]. This paper explores the effectiveness of two image processing techniques – Image thresholding and K-Means clustering based on different use cases and different textiles to recommend the most accurate and reliable techniques for specific use cases. This paper aims to develop an artificial intelligence algorithm tailored for the detection of soiled cloth in textile products, with the overarching goal of enhancing sorting efficiency and promoting recycling in the context of the circular economy. The secondary research aim is to investigate methods to optimize the accuracy and the reliability of the AI algorithm in identifying soiling while considering factors such as color and surface irregularities. Furthermore, the goal of the research is to recommend the best image processing algorithms depending on the use case after a thorough analysis of all the algorithms is conducted to determine where it would be the most effective and reliable.

2. Literature review

The integration of Artificial Intelligence (AI) into the textile recycling process holds significant promise for advancing the circular economy agenda [7]. As the textile industry grapples with sustainability challenges, efficient sorting and recycling methodologies are imperative [8]. AI technologies offer innovative solutions for automating pattern recognition tasks, thereby enhancing the efficiency and accuracy of textile sorting and recycling processes. This literature review examines the current state of research on the role of AI in pattern recognition for textile sorting and recycling within the context of the circular economy.

2.1. Textile Recycling and Circular Economy

Textiles are essential to humans in a variety of ways, especially clothing. However, the speed at which they end up in landfills is astonishing (one garbage truck per second), posing severe risk to the environment, if the trend continues [9]. To this day, only a tiny fraction of discarded textiles is recycled. While the clothing industry has doubled production in the last 15 years, the time garments are worn has fallen by more than 30 percent. At the same time, the rising demand for low-cost fast fashion is driving a decline in the quality of materials, which makes them more difficult to re-use or recycle. It is estimated that a 114 million tonnes of textile waste are generated every year – out of which 12 percent is downcycled into lower-value applications such as insulation material, and less than 1 percent is used to make new clothing in closed-loop circular economy [10].

Moreover, as of 2023, the fashion industry produced a startling 97 million tonnes of waste annually, of which 18 million were leftover textiles, 2.5 million tonnes were chemical waste, and 3 million tonnes were packaging materials [11,12]. It is clear from these statistics that a huge proportion of the waste is leftover textiles – which would make it plausible for most efforts into textile waste management be allocated to this specific area. The prevention of waste throughout a product life cycle and the elimination, or at least minimization, of the percentage of waste ending up in landfills are one of the biggest challenges that the textile and clothing industry will have to confront while transitions into the circular economy. Effective waste management will significantly influence all the 3Rs (reduce, reuse and recycle) by reducing virgin raw materials, reusing textile and clothing waste and recycling them [13,14]. In theory, 95% of the waste textiles can be recycled, but in practice the recycling rate is very low, such as only 10-15 percent in China, 15.2 percent in the United States, and 25 percent in the European Union. At present, the sorting of waste textiles mainly relies on manual operation, and the labour cost of manual sorting process account for 30 percent of the entire recycled textile cost [15,16]. The need for an efficient and cost-effective solution is needed – this is where an AI powered solution would be pivotal in moving a step closer to achieving a circular economy.

The alarming rate at which textiles are discarded, coupled with the staggering amount of waste generated by the fashion industry, underscores the urgent need for comprehensive waste management strategies. Focused efforts on reducing, reusing, and recycling textiles can mitigate environmental risks and promote a transition towards a circular economy.

2.2. Role of Artificial Intelligence in textile sorting and analysis and recycling in the circular economy

A wide variety of methods currently exist to investigate the characteristics of a textile sample. Near infrared (NIR) spectroscopy can distinguish different fiber materials of textiles and is suitable for large datasets. Visible and near infrared spectroscopy (VIS-NIR spectroscopy) has been used in automated sorting of used clothing based on material composition and was successful in separating textiles by color and material. One shortcoming of the mentioned sorting technologies mentioned above is their inability to analyze other characteristics, especially finishing and contaminants [17]. Near infrared spectrometry can be used to categorize textile waste streams into different material fractions easily and efficiently. However, some of the limitations include only surface analysis of textiles, the thicker the layer facing the sensor the harder the recognition, and multi-layered samples may hide other materials at their core or under the visible surface [18].

One other attempt in developing an optical sorting technology for textile waste involved using an identification method with NIR spectroscopy. The sorting technology proved to be capable of differentiating between unblended cotton, wool, and polyester. In this method developed, NIR could even separate fabrics with a substantially similar chemical composition, however this required correct feature enhancement and identification parameters. The divergence in NIR spectra between cotton, wool, and polyester would make it possible to identify these materials with just simple scatter correction, smoothing operation, and broad-tolerance correlation analysis. Based on the study, it can be stated that NIR spectroscopy can identify textile materials quickly and accurately based on their characteristic spectra. The identification method required a standardized measurement distance, corrections for varying physical properties among the samples and identification tolerances that allow natural spectra variation [19].

In addition, one other similar method for textile sorting implemented “Hyperspectral imaging for textile sorting in the visible-near infrared range”. The study was conducted using a variety of pure textile materials (cotton, viscose, polyester, wool, silk, and polyamides) and blends (cotton and polyester; viscose and polyester). The results were promising, and it was found that material discrimination can be performed in the VNIR range, and for a more robust sorting system for all textile varieties a more extensive sample set was needed in the training phase. Being able to sort textiles in the VNIR range brings many advantages since it offers higher spatial resolution, cheaper and more compact cameras than the traditional SWIR range. Moreover, the VNIR range sorting of blue denim, and abundant and relevant component of textile waste that could be difficult to sort in the SWIR range [20].

Moreover, studies have also been conducted for optical dirt detection using image analysis as an approach. An algorithm for detection was constructed for detection of any particulate soiling on woven cloth, without prerequisite knowledge about colours or brightness or the weave's dimensions. When there is contrast between particles and cloth, the algorithm detects single particles and classifies the entire cloth unclean. This was achieved by subtracting the background from the original image using the "rolling ball method" which pronounced small differences such as particle deposits. The next step was performing the Haar transform and then finally the actual detection is performed on the filter response [21]. One other study proposed a machine vision system for color sorting of multi-colored waste textiles. The proposed system consisted of three parts: (1) an object detection algorithm to define the boundary of the entire textile. (2) a discretization and color determination algorithm which divides the textile area into a number of cells, and attributes a color to each cell using color descriptors. (3) a categorization algorithm which uses a decision tree to sort the textiles based on their color distribution, using only a few sorting criteria. The proposed system was tested on a set of pre-sorted textiles, and it was able to reach an accuracy of 88.3% with a mean computational time of 0.77 seconds for each textile. While a fixed area sampling method had an accuracy of 74.0%, it is concluded that the proposed system performs better, especially for multi colored textiles [22].

2.3. Research gap analysis

The primary objective of this research is to develop computer vision techniques for detecting soiled or stained regions on textile materials and clothing items. Despite advancements in textile analysis and sorting technologies, accurately identifying stains against diverse textile backgrounds remains a challenge due to variations in stain types, colours, textures, and complex fabric patterns. Specific challenges in textile soiled cloth detection include variations in stain types, colours, and textures, as well as the complexity of fabric patterns. Existing technologies may struggle with accurately identifying stains against diverse textile backgrounds. Otsu's thresholding separates and K-Means clustering offer distinct approaches to address these challenges. Otsu's thresholding is the preferred method of thresholding that was used for this research mainly due to its ability to automatically determine an optimal threshold value in an image, its simplicity, and no requirement for training data. Images are first converted into grayscale and then after thresholding into a binary image. The expected outcome is that stains and soils would be separated from the textile fabric using the automatically calculated threshold value. However, its performance may degrade when dealing with complex backgrounds or uneven lighting conditions.

K-Means clustering was the preferred method of image segmentation for this research. Images were processed and portioned using the algorithm into multiple distinct regions. The expected outcome is that the stains and soils would be isolated in separate clusters from the textile fabric or material to allow for ease in the later stages of detection. K-means clustering partitions an image into clusters based on similarity, potentially isolating stains, and soils into distinct regions. By iteratively optimizing cluster centroids, K-means clustering aims to minimize the within-cluster variance, which could aid in separating stains from textile fabric. The motivation for selecting these unsupervised methods is to investigate whether AI or machine learning techniques can detect stains or soiled textiles without the need for extensive training or human input.

3. Investigation of AI models for soiled cloth detection in textile industry sorting processes

This research focuses on investigating and developing unsupervised computer vision techniques for the initial detection and segmentation of stains on textile materials. The chosen methods, Otsu's thresholding and K-Means clustering, do not require extensive training data or deep learning models. While these methods may provide valuable insights and techniques for stain detection, they have inherent limitations. Otsu's thresholding may struggle with complex backgrounds and uneven lighting conditions, while K-Means clustering may not accurately separate stains from fabrics with similar colours or textures. The results of this experiment could provide valuable techniques for image pre-processing and serve as a foundation for more comprehensive AI models for textile soiled cloth detection. Additionally, the findings could contribute to enhancing the accuracy of convolutional neural networks for object detection tasks in this domain.

3.1. Proposed configuration

For each of the above-mentioned methods, a sensitivity analysis will be conducted to assess the algorithms' effectiveness, accuracy, and reliability with various textile colours, fabrics, and textures. The sensitivity analysis will involve the following steps:

- Prepare a diverse dataset of textile images covering a wide range of colors, patterns, materials, and stain variations.
- Apply the method (either Otsu's Thresholding or K-means clustering) to the dataset.
- Analyze how the performance metrics change as the input parameters are varied.
- Evaluate the robustness and limitations of each method by examining their sensitivity to different textile characteristics, stain types, and lighting conditions.

The results of the sensitivity analysis for each method will be presented and discussed in their respective sections. Challenges during the evaluation process may include ensuring a representative dataset, addressing algorithmic biases, and optimizing parameters for different textile types and stain variations.

Experiment 1: Otsu's Thresholding

1. Obtained images of textiles were converted into grayscale.
2. Apply Otsu's thresholding algorithm to determine the optimal threshold value.
3. Create a binary image using the calculated threshold, separating stained/soiled regions from the fabric background.
4. Repeat steps 1-3 for different types of textiles in different conditions for the sensitivity analysis.

Experiment 2: K-Means Clustering

1. Apply the K-Means clustering algorithm starting at K=0.
2. Increment K after every iteration until optimum K is found.
3. Once optimal K is found analyse the resulting clusters to identify the cluster(s) representing stained/soiled regions.

3.2. Using Otsu's Thresholding for Textiles

The idea of using Otsu's thresholding for textile soiled cloth detection is that the algorithm will determine an optimal threshold value that will effectively separate the foreground of the textile from the background. The foreground obviously being the stains or dirt and the background being the textile material itself. As mentioned before Otsu's thresholding technique is used to separate and image into foreground and background – where foreground pixels are assigned a value of 255 and background pixels are assigned a value of 0. In this experiment, Otsu's thresholding technique for image segmentation was used on 2 different textile materials. Each textile material had two samples – one with a stain and one without a stain. The results of the experiment are illustrated in Fig. 1.

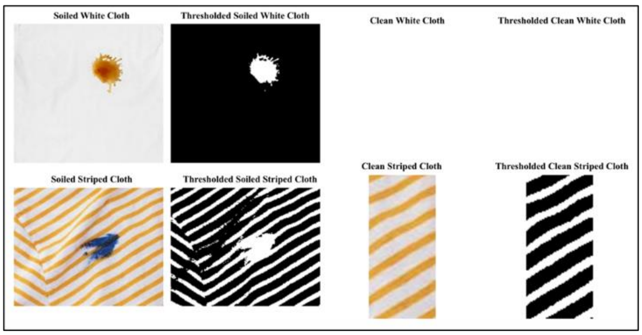

Fig. 1. Results of experiment with Otsu's Thresholding.

Fig. 1. shows that the stain in the white cloth was detected using the algorithm as can be seen in the *"Thresholded Soiled White Cloth"* image – where the cloth was with threshold into the background and the stain was with threshold

into the foreground. It also worked well with the *"Clean White Cloth"* as can be seen from the figure above where only foreground was detected – in other words, no stains were detected. *(The "Clean White Cloth" appears invisible because it is white).* However, Otsu's thresholding has its limitations as can be seen from the *"Striped Cloths"*. In both the *"Soiled Striped Cloth"* and *"Clean Striped Cloth"* Otsu's method detected a foreground and a background which is as expected but given this result Otsu's method cannot be used to detect soiled cloths with patterns as it is inaccurate and unreliable with textiles that have patterns or multiple colours. To conduct the sensitivity analysis for Otsu's thresholding in soiled cloth detection, above experiment was repeated with multiple different kinds of textiles with the goal of analysing the sensitivity of Otsu's thresholding in efficiently separating stains from a textile. The results of the experiment can be found in Fig. 2.

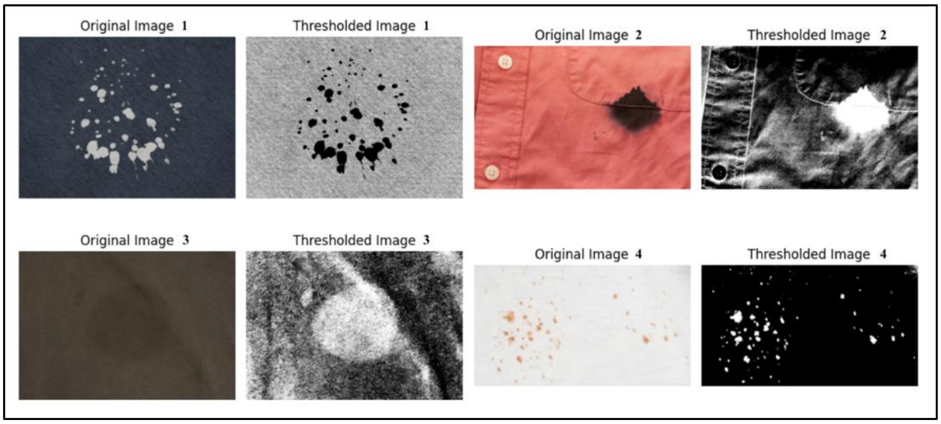

Fig. 2. Sensitivity analysis for Otsu's Thresholding.

As illustrated in Fig. 2, Otsu's thresholding is efficient in segmenting multiple stains in a textile product from the textile– this is evident from image 1 and 4. Especially in image 1, where the textile has a sheer texture and still managed to segment the stains from textile product. In image 4, Otsu's thresholding proved to be effective in segmenting very small multiple stains in a textile fabric. However, the algorithm failed to accurately segment stains in image 2 and 3. In image 3, the uneven lighting conditions and the faded nature if the textile affected the algorithms accuracy and ability in accurately segmenting the stains, this resulted in multiple foreground and background regions that were scatters all over the textile fabric while the intended outcome was only one foreground region and one background region. In image 2, the layers of the shirt (the shirt and the button seam), the stitches, and the wrinkles (which also causes micro shadows) affected the algorithms ability to accurately segment the stain from the shirt (which was both a different colour and a different intensity level). To further investigate the impact the button seam had on the algorithm the algorithm was run again with the button seam cropped out. The results can be seen in Fig. 3. In Fig. 3, the results are significantly better than in image 2 in Fig. 2. In Fig. 3, the stain was accurately segmented; however, the wrinkles were also inaccurately segmented along with the stain. However, the results in Fig. 3 prove that the button seam or multiple layers in the same textile fabric isn't an ideal situation where Otsu's thresholding should be used. It also highlighted that the threads or the stitching affected the reliability of the results.

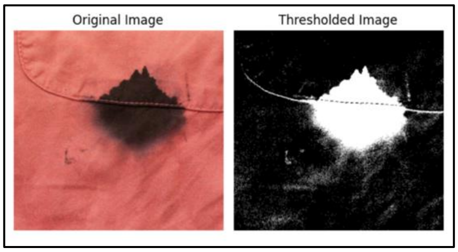

Fig. 3. Cropped version for Sensitivity Analysis.

3.2.1. Conclusion for Otsu's Thresholding

Given the results of the experiment we can conclude that Otsu's Thresholding is efficient for Textile Soiled Cloth Detection but only for plain textiles. It is inaccurate and unreliable for textiles that have patterns, multiple colours, multiple layers and works best in even lighting conditions – it is extremely sensitive to lighting conditions. This research also further explores solutions to soiled cloth detection in textiles for patterned textiles or multi-coloured textiles. One such method that was explored was K-Means clustering.

3.3. Using K-Means for soiled cloth detection

Cluster analysis is a technique used in machine learning to group similar objects into clusters. K-Means clustering is a widely used method for cluster analysis where the aim is to partition a set of objects into K clusters in such a way that the sum of the squared distances between objects and their assigned cluster is minimized [23]. The 'K' in K-Means clustering stands for the number of clusters which also must be determined. In this case the goal is for K-Means to cluster the stains from the textile and the textiles patterns so that the stains can not only be observed but also be separated from the textiles in attempts to address the limitations of Otsu's Thresholding. In this experiment, the K-Means clustering algorithm was used on 2 different textile materials. Each textile material had two samples – one with a stain and one without a stain. The results of the experiment can be seen in Fig 4 and Fig. 5.

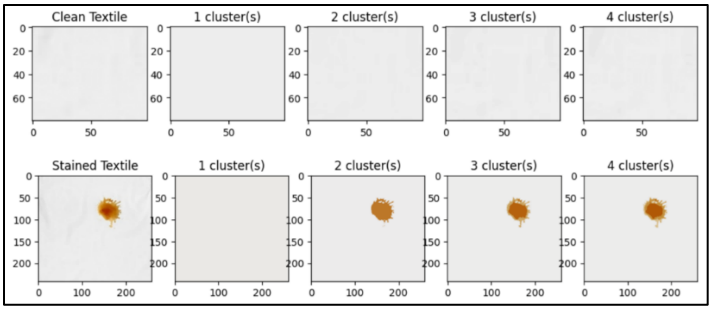

Fig. 4. K-Means clustering with plain textile.

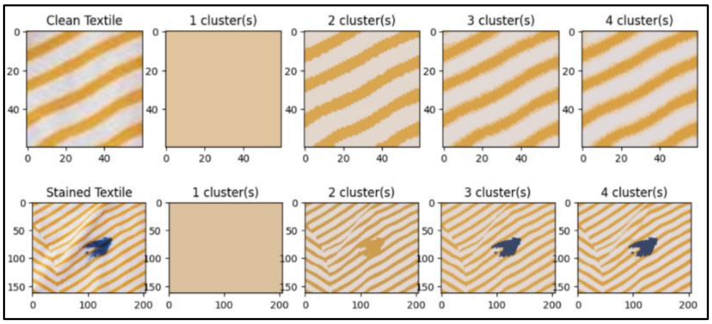

Fig. 5. K-Means clustering with striped or patterned textile.

As illustrated in Fig. 4 and Fig. 5, K-Means clustering works for soiled cloth detection where the stain was perfectly clustered for plain textiles with a K value of 2 and the same for striped or patterned textiles with a K value of 3. However, the challenge of determining the optimum number of clusters still remains as can be seen from the results above that different textiles require different number of clusters to accurately detect *stained clusters.* Using less than required clusters would mean that the stain cluster blends in or appears in the same cluster as one of the textiles original colours or patterns. Also, using more than the required or optimum number of clusters would lead to longer processing times and as a result make the process computationally expensive which is not a desired outcome. In addition, observing the results of K-Means clustering for the clean striped or patterned textile it is evident that by selecting different values of K a different challenge arises. It can be observed that 2 is the optimum number of clusters – one cluster for the white stripes and one cluster for yellow stripes. However, increasing the number of clusters to three or even four forces new unnecessary clusters to be processed which could potentially lead to inaccurate stain clusters being detected and more computationally expensive detection.

In summary, it is evident that automatic method of selecting the optimum number of clusters, similar to how the optimum threshold in Otsu's thresholding is calculated, is required since different variations of textiles require different optimum values of K for reliable soiled cloth detection. Two such methods for determining the optimum number of clusters in K means clustering are – the Elbow Method, Silhouette Analysis and Hierarchical clustering. This research further explores the effectiveness of the Elbow Method and the Silhouette Analysis.

3.3.1. Elbow Method and Silhouette Analysis for obtaining an optimal number of clusters.

The Elbow Method is a graphical method for finding the optimal K value in K-Means clustering algorithm. The elbow graph shows the within-cluster-sum-of-square (WCSS) values on the y-axis corresponding to the different values of K (on the x-axis). The optimal K value is the point at which the graph forms an "elbow" [24]. In Silhouette Analysis a silhouette coefficient or silhouette score is calculated to measure how similar a data point is within-cluster (cohesion) compared to other clusters (separation). The values of the coefficients lie between [-1, 1] – a higher score denotes that a data point is very compact within the cluster to which it belongs and far away from other clusters [25]. For both these methods a range of K-values are selected, usually from 1 to 10, and then the Silhouette Coefficient and WCSS are plotted for each value of K.

To determine optimum K for K-Means clustering, both methods (Silhouette Analysis and Elbow Method) were used to determine optimum K for K-Means clustering. For this experiment the K-values used ranged from [1,10]. Two graphs were obtained in the result one for the Elbow Method and one for Silhouette Analysis. Both these methods were used in unison to obtain a more confident answer for optimum K. For the Elbow Method the WCSS that was calculated for all K-values was plotted against their K values likewise for Silhouette Analysis the Silhouette Coefficient that was calculated for every K value was plotted against its respective K value. The results of this experiment are illustrated in Fig. 6.

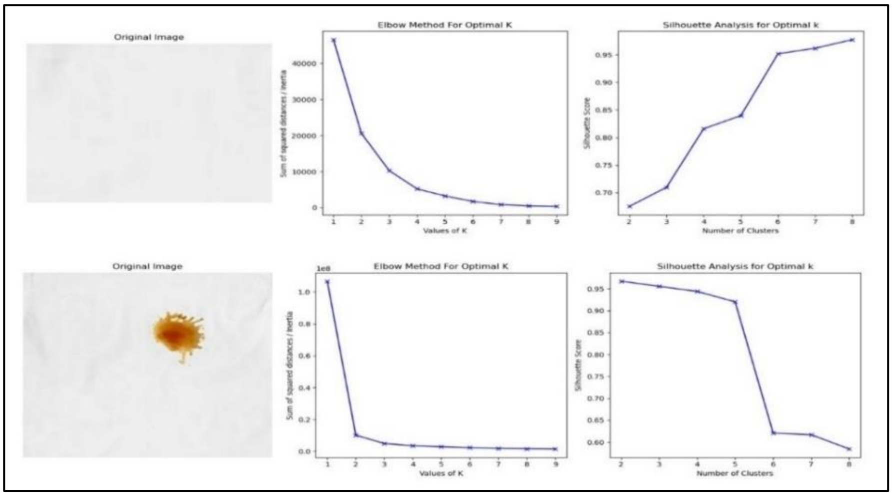

Fig. 6. Elbow Method and Silhouette Analysis for Plain Textiles.

The elbow method for the first image in Fig. 6 depicts an optimum K value between 2 to 3 - the values were obtained visually for the sake of simplicity. The silhouette analysis for the first image in Fig. 6 predicted an optimum K value of 8 – since this was the value with the highest silhouette score. Neither value is ideal for our analysis since the desired K is 1 because the textile product is plain. In contrast, for the second image in Fig. 6, both the silhouette score and the elbow method provided a value of 2 which is exactly what is desired or expected. This is because the stain is both a different colour and intensity level from the textile product. This could also explain why the methods gave different results for image 1 in Fig. 6 since the textile fabric had different intensity levels around the fabric which the silhouette analysis algorithm detected as different clusters and hence provided results that were not desired.

Considering Fig. 7, both the elbow method and Silhouette analysis can be used to determine an optimal K for the K means clustering algorithm. These two methods are usually used in conjunction with each other to provide a more confident K for the clustering algorithm. In the first image in Fig. 7, the striped textile was accurately determined to be in two clusters by both the elbow method and silhouette analysis. This was because the stripes are both of different colours and intensity levels. Similarly, for the second image in Fig. 7, the stripes and the stains were both of different colour and intensity levels, which is why the elbow method and silhouette analysis accurately predicted the number of clusters.

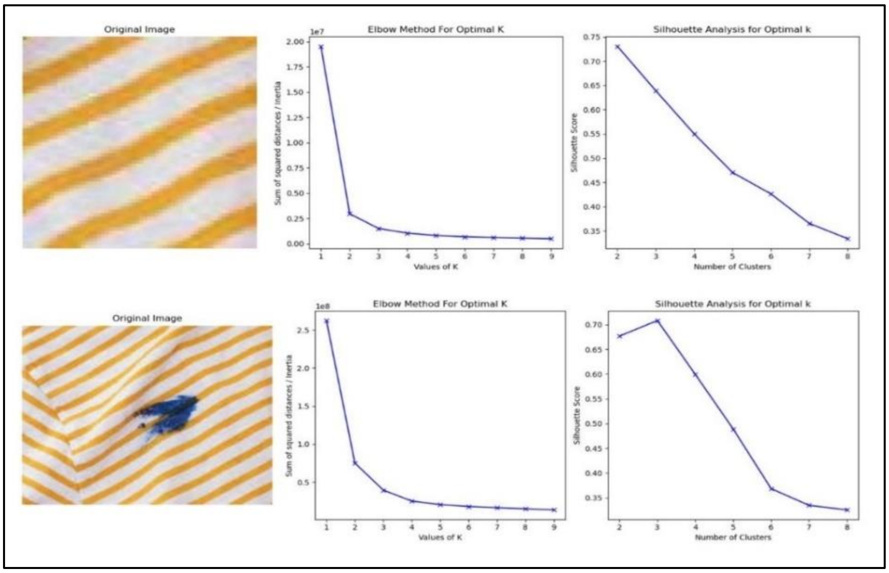

Fig. 7. Elbow Method and Silhouette Analysis for Striped or patterned textiles.

To conduct the sensitivity analysis for K-Means Clustering experiments were repeated with multiple different kinds of textiles with the goal of analyzing the sensitivity of K-Means clustering in efficiently clustering stains from a textile. The results of the experiment can be found in Fig. 8. It can be observed that the accurate number of clusters for separating between stains and textiles was predicted by both the elbow method and silhouette analysis in images 1, 3 and 4. In contrast, both the elbow method and silhouette analysis failed to predict a number of clusters that would separate the textile fabric from the stain in image 2. This is because of the uneven lighting conditions, the faded nature of the textile and similar colours and intensity levels between the textile fabric and the stain. Further investigation is necessary to see if these challenges can be overcome.

3.3.2. Conclusion for K-Means Clustering

The elbow method and silhouette analysis work extremely well in predicting the correct number of clusters except for cases with plain textiles under uneven lighting conditions. It was very effective in cases with multiple stains and multicoloured textiles all of which aided in the performance of the K-Means clustering algorithm. The best use case for the algorithm to work efficiently would be with multi-coloured or patterned textiles to prevent the detection of unnecessary clusters. The algorithms also failed to work efficiently with faded textile – which is as expected since faded textiles add a new colour or shade to the textile which then get identified as separate clusters. Moreover, the K-Means clustering algorithm provided better and more reliable results in textiles with threading lines, multiples layers, and buttons.

4. Conclusion and discussions

By automating the detection of stains or soiled clothing, the sorting process in recycling facilities or second-hand clothing markets could become more efficient. This efficiency can lead to faster processing times and reduced labor costs, which are beneficial for the circular economy by making the recycling or reusing process more economically viable. Detecting stains or soiled clothing accurately can increase the reusability of garments. Clean garments can be sorted for resale or donation more effectively, extending their lifespan and reducing the need for new clothing production. This aligns with the circular economy principle of maximizing the use of existing resources. This paper has investigated the efficiency of unsupervised computer vision techniques for the initial detection and segmentation of stains on textile materials. The chosen methods based on the literature review were Otsu's thresholding and K-Means clustering.

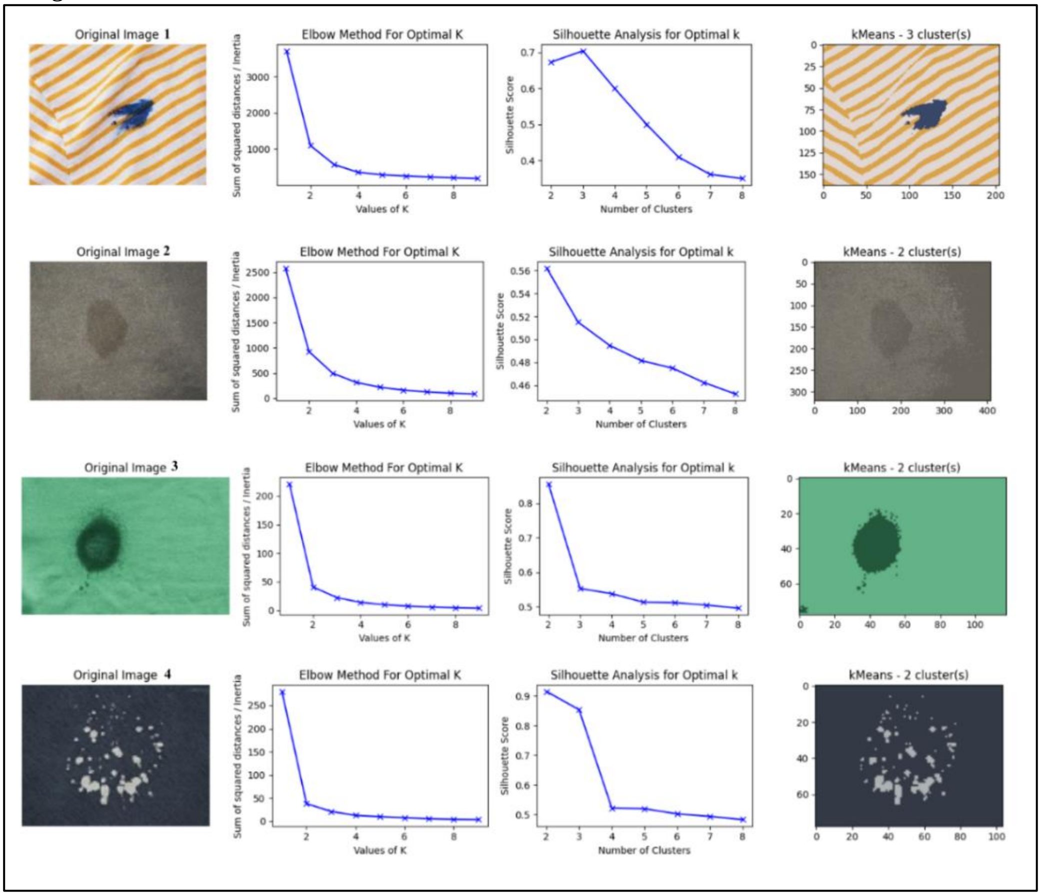

Fig. 8. Sensitivity Analysis for K-Means clustering.

Both Otsu’s thresholding and K-Means clustering have their drawbacks and strengths, but for both to work efficiently they require even and bright lighting conditions on the textiles to avoid unnecessary clustering or segmentation. Both Otsu’s thresholding and K-Means clustering provided inaccurate and unreliable results in cases with faded textiles which is expected since threshold values and number of clusters would both be difficult to accurately compute in unsupervised learning. Moreover, the elbow method and silhouette analysis are both computationally expensive and take too long to run which might not be ideal for textiles being sorted on factory line. However, despite their drawbacks it was found that Otsu’s thresholding works best to segment stains from textile fabrics in cases where the textile has one uniform color regardless of texture or material composition and proved to be successful while detecting multiple stains of different sizes effectively. The most efficient use case for K-Means was one with textiles that had uniform patterns. In these cases, any stains would be accurately clustered into their own clusters. All of which is evident from the multiple experiments conducted. In addition, textile with layers posed to be challenge for both Otsu’s thresholding and K-Means clustering, however if the end goal was simply detecting if stains existed on the textile, then the results from K-Means could be taken as reliable and accurate.

Solutions around the realm of image pre-processing could prevent the challenges faced with faded textiles which would further aid in attempts at recycling denim – which is a challenge. Lastly, the methods used in this paper could be paired with more sophisticated methods like CNN or RNN to yield more accurate and more reliable results with the needed expediency on a factory line. By ensuring accurate detection of stains, the model can increase consumer confidence in purchasing second-hand or pre-owned clothing items. This can lead to a shift in consumer behavior towards more sustainable consumption patterns, favoring reuse over disposal. Identifying stains accurately can streamline the recycling process by ensuring that only clean and usable materials are included. This can lead to higher-quality recycled fibers, which in turn can be used to produce new clothing items of better quality. Improved recycling processes contribute to closing the loop in the circular economy by reducing the need for virgin materials.

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