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Design and analysis of shadow detection and removal scheme in real-time still images

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ABSTRACT

This research's main objective is to study and evaluate the detection and removal of undesired shadows from still images since these shadows might mask important information caused by light sources and other obstructions. A variety of methods for detecting and eliminating shadows as well as object tracking approaches based on movement estimation and identification are investigated. This includes shadow removal methods like background subtraction, which are intended to improve obstacle recognition of the source item and increase the accuracy of shadow removal from objects. When new items enter the frame, they are first distinguished from the background using a reference frame. The tracking procedure is made more difficult by the merging of the shadow with the foreground object. The approach highlights the difficulties in object detection owing to frequent occurrences of obstacles by using morphological procedures for shadow identification and removal. The proposed approach uses feature extraction is also discussed, highlighting its importance in image processing research and the use of suggested methods to get over obstacles in image sequences. The proposed method for shadow identification and removal offers a novel approach to improve image processing when dealing with still images. The purpose of this technique is to better detect and remove shadows from images, which will increase the precision of object tracking and detection. Depending on the type of images being processed, the process begins with initializing a background model, which is based on a static image background.

Keywords: background modelling and subtraction; human motion detection; shadow removal; object tracking; still images

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1. Introduction

Numerous computer vision applications managing to detect the shadows and to unhide the actual object is being research focus and tracking moving objects or in still images. At the point when the objects of nature have an all-around characterized shape, format coordinating or classifiers that are more refined can be utilized specifically in edge detection the regions from the image. These procedures function admirably for all measuring and to characterize the color intensity in the still images, for example, vehicles yet are hard to execute for non-inflexible questions, for example, human bodies[1].

Shadows are visual sensations, which may occur when a region in an image is occlude by the primary light source; it may be artificially light of bulb, sodium lights or the natural light of sun. Shadows can be everywhere surrounding us, and no one can be confused due to their presence. If a shadow would, be review then

more information can be extracted from the original object but often these shadows may disturb the original object due to its darkness or intensity of light source. The information can contain geometry of the scene, light sources position are also included and formation of the object. However, shadows have been proved like a challenging problem for the computer vision algorithms to detect the original object's shadow and then to remove it by segmentation procedure. A thorough procedure and process flow is illustrated in the **Figure 1**. Detection of any object, segmentation process, tracking and the stereos are all over the confusing items by object shadows due to the changing appearance of the scene and to move with real objects[2].

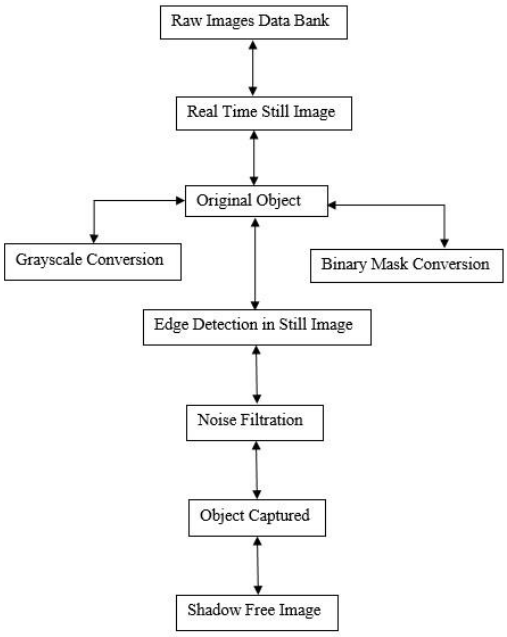

Figure 1. A framework of shadow detection and removal process.

If we talk about the past literature reviews, we can see that there is a lot of work has already done over such type of projects, detecting moving cast and self-shadows in different digital still images especially at surveillance and monitoring applications. A more basic methodology for distinguishing individuals in a feature arrangement is to recognize front area pixels, for instance through Gaussian blend models. Then again, current methods regularly have one noteworthy drawback: shadows tend to be namely piece of the closer view. This happens because shadows have the same development designs and have a comparable size of force change as that of the forefront objects[3].

Along with a sequence of images, the same action does perform over the moving objects like detecting the objects in videos, when the objects may become interest of research, which may have a shape of well-defined objects. There are various kinds of classifiers available that can be used in the processing of these objects likewise matching of templates or also there are classifiers that are more sophisticated and available for utilization of direct segmentation of objects in images. The well-defined objects work well with these techniques with the objects such as vehicle information, but it is very complicated task to implement for the non-rigid objects such that human bodies. The foreground pixel detection is very common approach while processing images or videos for object tracking like Gaussian mixture model[3,4].

2. Related work

Image segmentation process can be used to separate the still image in between foreground and the background of the still image. Digital image segmentation process is commonly being utilized because it highlights the homogeneity attributes or characteristics of shadow. While the digital image segmentation process, versatile thresholding procedure has been utilized to separate the umbra regions and estimate

histogram investigation is associated to the resultant digital image to evacuate the penumbra region. The worldwide thresholding procedure has applied to the resultant still image with a specific end goal to get the shadow's blob then it will get the resultant picture as to work out through the whole shadow process and create the histogram for the visual competency and nature of image segmentation[5,6].

The shadow detection technique has then applied to gray scale digital images taken by a digital handy camera. The Canny edge detection will have to utilize both the foreground and background still images. After which, image segmentation is performed on the foreground edges and on the background edges to remove the object's edges. For recovery of actual shapes of still images, object recovery procedure has been used to the object's edges. There are three very important guidelines or properties of shadow as characterized by several other authors. The first one is the foreground pixels should be vivid to see as that they are difficult to fit in with shadows. Furthermore, foreground pixels with characteristics unique in relation to the properties of the shadow may be observed to remove the penumbra region such as multi-gradient analysis and projection histogram analysis and the third one is that foreground pixels of the image can observe the nearly located object by preserving its edges[7–9].

The Color Image Feature works as the shadowed pair is relighted based on pairs of histogram matching. The methodology they use is fully unsupervised based entirely on color image features. The methods and the results are evident in this paper that the need of a complex deep learning-based solution is not needed[10]. A new method was devised for shadow detection shadows were highlighted by improved shadow index (ISI). the study provides methods when applied it accurately detect shadow from high resolution remote images[10]. The G2R shadownet uses 3 sub networks for shadow generation for both shadow removal and refinement. while performing extensive experiments on the ISTD dataset and the Video Shadow Removal dataset provides significant better results than the method proposed by ECCV 2020[11]. The Shadow Elimination Algorithm Using Color and Texture Features focuses on urban video surveillance. This algorithm proposes an improved shadow detection and removal algorithm. These methods obtain the moving targets with texture features. The shadow is then detected and removes the shadow interference. These methods then embed the algorithm into a C/S framework and a HTML5 socket protocol[12]. The study works on a new dataset named SOBA named after shadow object association with around 1000 photos. They then designed LISA which as an abbreviation for Light-guided Instance Shadow-object Association it is an end-to-end framework that automatically predicts shadow and object. In the final results they formulate a new matric named shadow-object average to measure the performance of their result[13].

These kinds of techniques most widely be used for human motion objects that can be upon the previous knowledge, which is to verify the original object for shadow detection. To removing smoothly segment, the extra-unwanted edges in shadows, which provides a projection of histogram technique to separate and recognize the edges in still images.

2.1. Edge detection in still images

Still images are often difficult to calculate right edge information from their internal attributes and due to color and intensity information, therefore translation of picture substance is one of the targets in computer vision particularly in still image processing. In this period, it has gotten much consciousness of research specialists and scientists. In image elucidation, the segmentation of the picture into objects and backgrounds is an extreme stride. Dissection isolates an image into its segment partitions or small objects. Still image subdivision, which needs to be, fragmented the actual object from the groundwork to inspect the image appropriately and recognize the contents of the images very carefully through a sequence of steps can be seen in the **Figure 2**. flowchart. In this unique circumstance, the edge detection is a key contraption for image processing[14,15].

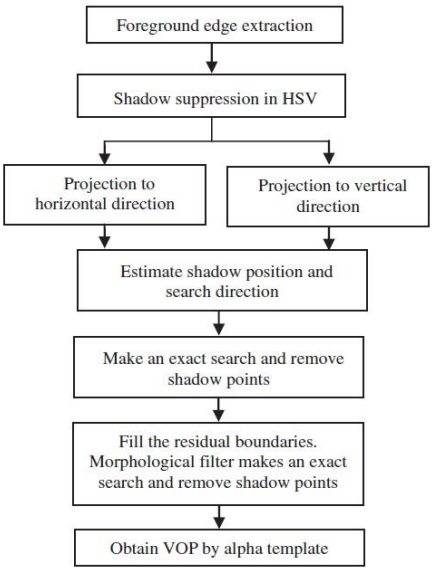

Figure 2. Flowchart of the proposed shadow removal method[5].

In this paper, an endeavor is made to analyze about the execution of most regularly utilized edge detection methods using software tools for image processing furthermore we have correlated of these strategies by utilizing MATLAB programming software with code behind of C++ language. Image extraction is a crucial stride in digital image processing. Segmentation isolates a picture into its unit partitions or in objects. The extent on which the segmentation can carried out relies on upon the problem being resolved. At the point when the objects of interest for an application have been difficult to reach the segmentation must stop. Image segmentation algorithm for digital images largely in view of the brokenness and uniformity of image intensity values. Irregularity approach is to segment a picture considering sudden changes in intensity and resemblance depends on segmenting an image into regions that are comparable as per an arrangement of predefined criteria. Subsequently the decision of image extraction structure is relying on upon the problem being reflected. Edge detection is a part of image processing. The feasibility of numerous image processing similarly computer vision tasks rely on upon the excellence of identifying significant edges. It is one of the classifications for detecting intensity cutoffs in a digital still image[16,17].

The proposed method for shadow identification and removal as depicted in **Figure 3**. offers a novel approach to improve image processing when dealing with still images. The purpose of this technique is to better detect and remove shadows from images, which will increase the precision of object tracking and detection. Depending on the type of images being processed, the process begins with initializing a background model, which may be based on a static or dynamic background. To streamline the image data and lower noise, the algorithm processes each image sequentially via a set of operations that include blurring and grayscale conversion. The foreground elements are then highlighted using a binary threshold after background subtraction to separate them from the background. To maintain effective foreground recognition in dynamic settings, the background model is updated continually to consider changes over time.

Algorithm 1 Shadow Detection and Removal in Still Images

Input: Sequence of images $\{I_t\}$, $t = 1$ to T
Output: Sequence of shadow-free images $\{I'_t\}$
1: Initialize Background Model (B)
$B = I_1$ for static OR $B = median(\{I_1, \ldots, I_n\})$ for dynamic backgrounds
2: For each image I_t in $\{I_t\}$
2.1 : *Grayscale and Blur:* $I_t^g = Blur(Grayscale(I_t))$
2.2 : *Foreground Detection:* $F_t = |B - I_t^g| > \theta ? 1 : 0$
2.3 : *Update B for dynamic scenes:* $B = \alpha B + (1 - \alpha) I_t^g$
2.4 : *Edge Detection:* $E_t = EdgeDetect(F_t)$
2.5 : *Morphology:* $M_t = Open(Close(E_t))$
2.6 : *Shadow Segmentation:* $S_t = Segment(M_t)$ // Use intensity & color criteria
2.7 : *Shadow Removal:* For each pixel (x, y) in S_t, adjust $I_t(x, y)$
2.8 : *Post-process & Integrate:* $I'_t = Integrate(F_t, B, Adjustments)$
3: Return $\{I'_t\}$

Figure 3. The proposed shadow detection and removal algorithm.

After applying edge detection to the foreground, objects' outlines are identified. Morphological techniques are then used to improve the outlines of the objects, removing noise, and filling in gaps. This sets the image up for the critical process of shadow segmentation, which separates shadows from objects using parameters related to color and intensity. After being identified, shadows are eliminated by adjusting brightness, keeping the objects' underlying features intact. The algorithm concludes with post-processing stages that create a smooth, shadow-free image by integrating the modified foreground with the background. This succinct yet effective method for detecting and removing shadows shows a novel approach to advancing image processing and provides a robust solution to the common problem of shadow interference in still images.

Image segmentation

Segmentation of still images is the way toward partitioning a still image into different regions or pixel-based sets. Usually, the image processing are various substances that can have a similar texture or color intensity. The image extraction results are an arrangement of regions that may plot the entire image organized and a preparation of contours separated from that image. The greater part of the pixels in a region are comparative as for a few qualities, for example, color, intensity, or the image texture. Bordering regions are significantly unique concerning a similar individuality. The diverse methodologies, which are as follows:

(a) The discovery of region-based boundaries over the cutoffs in the level of image intensity,
(b) Distribution of the pixel properties based on image edges, like the values of intensity,
(c) Direct region discoveries based on image edges and light source.

Region based techniques in still images are construct upon endurance. These methods separate the whole image into sub-regions relying upon a few beliefs as if every one of the pixels in one region must have a similar gray level. Region based systems depend considering normal examples in the values of intensity inside a bunch of neighboring pixels. The bunch can point to be as the region however to group of the regions as indicated by their structural or the functional roles are the objective of the image segmentation. Threshold is the least complex method for image segmentation. Utilizing thresholding method regions, which must be classified on the premise and in range values, application of which can be to the intensity values of the image pixels. Thresholding is the procedure of transforming an input image to an output in which binary image can perform segmentation. Segmentation procedure considering finding the regions specifically finding for unexpected changes in the intensity value of image. These strategies can recognize as boundary or edge-based techniques. Detection of the edge is the issue of crucial significance in image inspection. Edge detection systems for utilizing to ascertaining discontinuity as a part of grayscale images. To identify considerable discontinuity in

the gray level image is the key regular method in edge detection. In the image, extraction strategies for distinguishing discontinuity are the boundary-based techniques.

2.2. Object tracking in still images

In the process of shadow detection and removal, the object tracking may perform central role because of the core originality of the actual object can be extracted for further information exploration. Object tracking in the sequence of digital images may have been applied with different frames of image pixels using contour segmentation algorithm. In the process the segments of edges should have to group that are most likely to be one from the actual object. The results from this process can be very vivid due to clarity of pixel values in digital images. This method can be inappropriate, from which the results of contours from the similar object are most often broken or separated. This limitation using the same algorithm can overcome by applying the contour merging algorithm, from which the results may show with identifiable contours of objects[18,19].

The key landscapes of the objects are extracting in each frame of digital image and the object values calculated centrally, which is the mean position to the sum of key elements of the contour object and these elements may now tracked with the same algorithm. There is a prediction can be made upon the position of the centroid object position in the followed-up frame while seeking the region of the interest around the centroid for looking out about the key elements and the process be followed-up with by matching the key elements to the contour object groups within that region. By applying this method will provide paths located point of the object. The validation can occur for every path to check the grouped contours in every frame of image sequences[20,21].

2.3. Applications and motivation

Either detection or tracking of the moving object in video sequences or in the still images can be very complicated task in computer vision. There are various applications of this type of research. Applications can be included visual surveillance: This type of surveillance is aimed to monitor the human action or to capture the crowd activities at the very sensitive areas such as Banking sectors, departmental super store, parking areas and country border to observe that whether one or more than one human which engaged are doing suspicious activities or under criminal activity. Content based video retrieval: In this type of application a human conduct, recognizing system can detect an input video, and an activity or event, which may have to specify as high-level language output[22,23].

2.4. Noise filtering in still images

Noise is the most important factor in digital images while processing for the object detection as it can be the result of errors occurring in image acquisition process, which also may produce output because of pixel values become in efficient intensities of the actual object. Noise reduction techniques are using as the greatest methods for reducing the noise from the digital images. These methods are abstractly very similar irrespective of the signal being observed though, from the earlier learning of the attributes of an expected signal can mean the usage of these procedures very incredibly relying upon the kind of signal[24]. The digital image captured by the sensor experiences separating by various smoothing filters and the resultant still images. The devices of recording, both simple and advanced in the terms of digital and analogue have characteristics, which make them defenseless to noise. The principal issue of still image processing is to shorten noise from a computerized color image. The two most regularly happening sorts of noise are: Impulse noise and Additive noise[25,26].

Sources of the noise in still digital images can be exist due to color intensities and other malfunction factors in still images. The noise commonly can be measure by the percentage of pixels that are corrupted or in not a normal form. The corrupted pixels may set to its maximum values or can have single bits. The noise interruption in still images by several ways, depending upon the creation of the still image. For example:

a) One of the reasons is that the image has scanned from a film made photograph and the noise may be in

the film grain. Noise may also be the resultant damage to the film or can be scanner itself.

b) The image will be acquired directly as a digital format and the procedure by which the data has gathered such as CCD detector, which can produce noise.

c) The transmission of the still image data via electronic signal transmission.

2.5. Objective and work scope

The fundamental objective of this research is to develop and dedicate an analyzed model of the techniques used to detect shadows and then to remove them from still images. The smart model that can be able to remove shadow of the concerned object, there are many tasks carried out likewise background modeling and subtraction, edge and motion detection in still images and foreground detection. With the help of different operations such as morphology and to recognizing obstruction. There are very rare cases over such type of research that can detect and then remove the shadow from the original object. There may be several approaches those methods on properties of undersigned shadow of the original object. Here we are going to show some the important approaches that can work for detecting the shadow and then to remove it from the still images[27].

2.5.1. Model based method

In this type of method there must be known these factors to calculate and in term of accuracy of the geometry and the illumination of the scene localization and the direction of the light source and the geometry of the observed objects. The Shadow-aware dynamic convolution for shadow removal promotes awareness towards large gap between color mapping for shadow and non-shadow. The SADC takes in the non-shadow areas and provides a bit more complex version of the module which enables and ensures the quality of quality of image construction. they perform extensive experiments on the ISTD and SRD datasets which proves that the methods the authors implemented gave better results compared to state of the art methods[28].

2.5.2. Texture based method

The texture-based model is somehow work differently because of texture of foreground model object is entirely different from the original background texture where shadow can be casted over that original background. There are more techniques have been developed from this model of texture-based implementation. This method is over all the best method found working with the satisfactory ratio and the observation that the shadow regions can present over the same textual attributes with each frame of the grayscale images. The Color aware background extraction network (CBENet) has a shadow removal network that further has two stages where stage 1 consists of a background-constrained decoder that promote a coarse result and refined it to maintain a consistence appearance. While stage 2 enhance the texture details[29].

2.5.3. Image based method

This method deals with the image attributes like color or chroma key and intensity with the shadow structures that are “umbra” and “penumbra”, boundaries and there may not be assumption about the scene structure. Image based method examines if there is availability of the information which can be utilized to enhance and optimize the process of detection and edge calculation performance. The shadow is not smart to change the surface texture, which can mark to be continue across the boundary of a shadow. In image-based technique there are color combination or the color components of the same may not observe the change that whether the regions have shadows or not due to the invariant to shadows[30].

The Shadow Removal methods for high resolution images are not highly affective due to image shadow removal. The network is trained in pyramid stages which enhances the global information processing. The result ensures the validity and effectiveness of the methods used[31]. The Moving Target Shadow Detection consists of background modeling and shadow detection based on intensity information and neighborhood similarities (BIIANS). BIIANS states that when a target is moving the contrast of its shadow is lower[32]. The problem of shadow removal resulting in low resolution images and the usages of heavy network architecture

which cannot run limited resources. SHARDS, which is a shadow removal method for high resolution images, solve these problems in two stages; a LSRNet and a DRNet[33].

3. Experimental results

In this section of the research paper, we have formulated the overall research process, which worked from scratch to the end until results and have shown some of the results from the outcomes of research methodology. The data has processed in MATLAB r2014a tool by using C++ as code behind. The problem is formulated using background subtraction method for detection and removal of shadows in digital still images.

There are different purposes to remove shadows from still images such that due to security vulnerable, accurate object capturing, intelligence institutes working for security purposes and for spy detection. There are several departments working for investigation purposes like Criminal Investigation Department (CID) and in Federal Investigation Agency (FIA) may use in the context of cyber-crimes. Therefore, existence of shadows may cause different problems to find out the accurate object and to extract the useful information especially in traffic analysis and in surveillance systems that aims to monitor crowd activities specifically at banking sectors. These shadows can be really a major obstacle while segmenting and tracking the objects in real time still images so, due to shadows and light-source the object can merge to hide the actual shape. For this purpose, shadow detection techniques may trace the regions of shadows in images and separate shadow from the objects of foreground. There are rare cases in which detection of shadows can exploit to conclude geometric properties of the objects causing the shadow. Despite the various determinations, perpetually the algorithms are the same and may be extended to any of these applications[34–36].

We have addressed the problem in this paper that there is foreground intervention to segment the background still image to extract the shadow from the object. There is scarcity of foreground segmentation algorithms are available that rely over the strong digital image gradients to find the strong boundaries of shadow in that still image. As an output, they may be prone to be confusion by these shadows due to irregularity of shadow nature to appear clearly to its object. The shadow may corrupt the segmentation and interrupt the overall process by two ways; firstly, interpretation of cast shadow in the segmentation process and secondly, a self-shadow may cause the object to be the under segmentation.

3.1. Background subtraction

The background subtraction is the most widely used technique for segmentation of the shadow from the actual still image in interested frame object. This technique is very useful while comparing the differences of the still image and its background image to detect the edge region for accurate calculation of shadow. The key feature of background subtraction technique is it initializes and updates the background of the images by itself. There are also several procedures to initialize background image with first frame as the background directly or by taking the average brightness of pixels in each frame at the background or using different sequences of still images without moving the actual object.

This proposed algorithm can verify effectiveness of the background subtraction technique; we have selected different still images and processed them to detect the background shadow and then to remove it from the original object. In **Figures 4** and **5** the output of the processed images can be seen like the first images is the having the original shape after which it has been converted into grayscale. Then for detecting the object edges and to calculate them for accuracy the image has been converted into binary mask invariant image by which it is very easy to sharpen the edges, capturing accurately and then to remove the shadow. The last image can be seen as the shadow free image which is the overall process result.

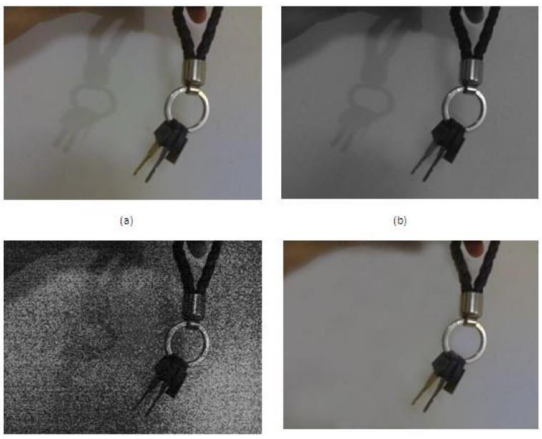

Figure 4. A key object is processed, and the results can show here the grayscale conversion, binary mask image invariant and the shadow free object.

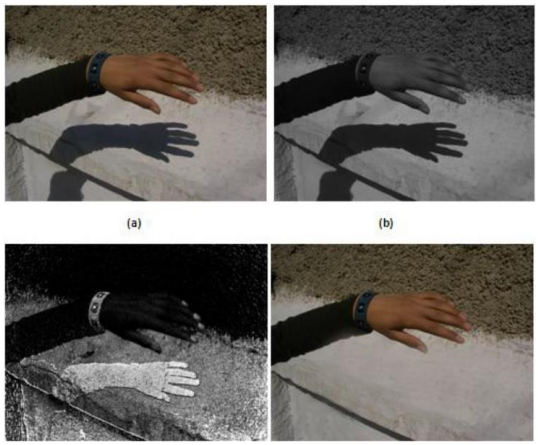

Figure 5. A human hand processed as of result can show here with different stages of shadow detection and removal.

3.2. Discussions

At our peak of this research work, the shadow removal method of background subtraction is present based on pixel values. The pixel value cannot fall into the intensity gamut of the color defined by the response of the pixel. At where two illumination light sources which the primary or natural light are “the sun” and the “artificial light of sodium or bulb” the algorithm has prone to failure while an actual scene change can occur in still images at the new object’s color intensity level within the gamut. The performance of segmentation can bound by the contents of noise in the original image, which can set the size of the threshold for the region of shadow with turning round the curve of shadow.

4. Conclusion

This paper proposed a novel approach, the methodology to detect and remove shadows for different still images. It is an approach, proficient to detecting motion in video sequencing or in still images and extracting object information, which involves any substance or object that may derive the use of improving and extract the required results. The algorithm, which has been used, is background subtraction method, which involves modeling of the desired background as a reference model for later used in background subtraction to produce foreground pixels which is the deviation of the current frame from the reference frame. The deviation, which represents the moving object within the analyzed frame, that is further processed to localize and extracts the information. This shows that it is possible to remove shadow from image without losing a large amount of pertinent data. We had conducted analysis for object tracking that how an object can be tracking out from motion detection to the still images; the algorithm involves modeling of the desired background as a reference model for later used in background subtraction to produce foreground pixels, which is the deviation of the

current frame from the reference frame. This algorithm efficiently removes the shadow of any object, and for future reference, this work will have to be an extension to designing a framework model to improve extracted information from shadows in the still images.

Author contributions

Conceptualization, SA and JA; methodology, SA; software, MAK; validation, SA, JA and MAK; formal analysis, TAK; investigation, SKM; resources, URS; data curation, BAA; writing—original draft preparation, SA; writing—review and editing, SA; visualization, TAK; supervision, SA; project administration, NAB; funding acquisition, MAK, SKM and NAB. All authors have read and agreed to the published version of the manuscript.

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Conflict of interest

The authors declare no conflict of interest.

References

1. Lakhotiya SA, Ingole MD, Joshi MS. Human Object Tracking using Background Subtraction and Shadow Removal Technique. International Journal of Computer Science And Applications. 2013; 6(2): 117-121.
2. Sanin A, Sanderson C, Lovell BC. Shadow detection: A survey and comparative evaluation of recent methods. arXiv. 2013; arXiv:1304.1233.
3. Sanin A, Sanderson C, Lovell BC. Shadow detection: A survey and comparative evaluation of recent methods. Pattern Recognition. 2012; 45(4): 1684-1695. doi: 10.1016/j.patcog.2011.10.001
4. Valanarasu JMJ, Patel VM. Fine-Context Shadow Detection using Shadow Removal. 2023 IEEE/CVF Winter Conference on Applications of Computer Vision (WACV). Published online January 2023. doi: 10.1109/wacv56688.2023.00175
5. Audet S, Cooperstock JR. Shadow removal in front projection environments using object tracking. In: Proceedings CVPR, IEEE Computer Society Conference on Computer Vision and Pattern Recognition; 17-19 June 1997; San Juan, PR, USA.
6. Guo L, Wang C, Yang W, et al. ShadowDiffusion: When Degradation Prior Meets Diffusion Model for Shadow Removal. 2023 IEEE/CVF Conference on Computer Vision and Pattern Recognition (CVPR). Published online June 2023. doi: 10.1109/cvpr52729.2023.01350
7. Liu W, Wang B, Zheng J, et al. Shadow Removal of Text Document Images Using Background Estimation and Adaptive Text Enhancement. In: ICASSP 2023-2023 IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP); 4-10 June 2023. pp. 1-5.
8. Mengel T, Steffanic P, Hughes C, et al. Interpretable machine learning methods applied to jet background subtraction in heavy-ion collisions. Physical Review C. 2023; 108(2): L021901.
9. Yücel MK, Dimaridou V, Manganelli B, et al. Lra&ldra: Rethinking residual predictions for efficient shadow detection and removal. In: Proceedings of the IEEE/CVF Winter Conference on Applications of Computer Vision. 2023. pp. 4925-4935.
10. Zhou T, Fu H, Sun C, Wang S. Shadow Detection and Compensation from Remote Sensing Images under Complex Urban Conditions. Remote Sens. 2021, 13, 699.
11. Li X, Wang W, Li Q, Zhang J. Spatial-temporal graph-guided global attention network for video-based person re-identification. Machine Vision and Applications. 2024; 35(1): 8.
12. Wu M, Chen R, Tong Y. Shadow elimination algorithm using color and texture features. Comput. Intell. Neurosci. 2020, 2020, 2075781.
13. Wang Q, Wu B, Zhu P, et al. ECA-Net: Efficient channel attention for deep convolutional neural networks. https://openaccess.thecvf.com/content_CVPR_2020/html/Wang_ECA-Net_Efficient_Channel_Attention_for_Deep_Convolutional_Neural_Networks_CVPR_2020_paper.html (accessed on 12 February 2024).
14. Koutsiou DCC, Savelonas MA, Iakovidis DK. SUShe: simple unsupervised shadow removal. Multimed Tools Appl.2024; 83, 19517–19539.
15. Vasluianu FA, Seizinger T, Timofte R. WSRD: A Novel Benchmark for High Resolution Image Shadow

Removal. 2023 IEEE/CVF Conference on Computer Vision and Pattern Recognition Workshops (CVPRW). Published online June 2023. doi: 10.1109/cvprw59228.2023.00181
16. Jiang H, Drew MS. Tracking objects with shadows. Vasudev B, Hsing TR, Tescher AG, Ebrahimi T, eds. Image and Video Communications and Processing 2003. Published online May 7, 2003. doi: 10.1117/12.476458
17. Kumar A. SEAT-YOLO: A squeeze-excite and spatial attentive you only look once architecture for shadow detection. Optik. 2023; 273: 170513. doi: 10.1016/j.ijleo.2023.170513
18. Xu L, Qi F, Jiang R, et al. Shadow detection and removal in real images: A survey. Shanghai JiaoTong University, PR China; 2006.
19. Vasluianu FA, Seizinger T, Timofte R, et al. NTIRE 2023 image shadow removal challenge report. In: Proceedings of the IEEE/CVF Conference on Computer Vision and Pattern Recognition. 2023. pp. 1788-1807.
20. Muthukrishnan R, Radha M. Edge Detection Techniques For Image Segmentation. International Journal of Computer Science and Information Technology. 2011; 3(6): 259-267. doi: 10.5121/ijcsit.2011.3620
21. Jiao L, Zheng M, Tang P, et al. Towards Edge-Precise Cloud and Shadow Detection on the GaoFen-1 Dataset: A Visual, Comprehensive Investigation. Remote Sensing. 2023; 15(4): 906. doi: 10.3390/rs15040906
22. Mythili C, Kavitha V. Efficient technique for color image noise reduction. The research bulletin of Jordan ACM. 2011; 1(11): 41-44.
23. Chang HE, Hsieh CH, Yang HH, et al. TSRFormer: Transformer Based Two-stage Refinement for Single Image Shadow Removal. 2023 IEEE/CVF Conference on Computer Vision and Pattern Recognition Workshops (CVPRW). Published online June 2023. doi: 10.1109/cvprw59228.2023.00148
24. Irie K, McKinnon A, Unsworth K, Woodhead I. Shadow removal for object tracking in complex outdoor scenes. Image and Vision Computing New Zealand. 2007.
25. Audet S, Cooperstock JR. Shadow Removal in Front Projection Environments Using Object Tracking. In: 2007 IEEE Conference on Computer Vision and Pattern Recognition. Published online June 2007. doi: 10.1109/cvpr.2007.383470
26. Singh H, Verma DM. A Novel Hierarchical Geometric Feature Fusion Learning for Robust Lightweight Video Salient Shadow Detection. Mridula.
27. Lakhotiya SA, Ingole MD, Joshi MS. Human Object Tracking using Background Subtraction and Shadow Removal Technique. the International Journal of Computer Science and Applications. 2013; 6(2): 117-121.
28. Xu Y, Lin M, Yang H, et al. Shadow-aware dynamic convolution for shadow removal. Pattern Recognition, 2024; 146: 109969.
29. Zhang L, He Y, Zhang Q, et al. Document Image Shadow Removal Guided by Color-Aware Background. In: 2023 IEEE/CVF Conference on Computer Vision and Pattern Recognition (CVPR); 2023; Vancouver, BC, Canada. pp. 1818-1827.
30. Zhu S, Guo Z, Ma L. Shadow removal with background difference method based on shadow position and edges attributes. EURASIP Journal on Image and Video Processing. 2012; 2012(1). doi: 10.1186/1687-5281-2012-22
31. Cui S, Huang J, Tian S, et al. Pyramid Ensemble Structure for High Resolution Image Shadow Removal. In: 2023 IEEE/CVF Conference on Computer Vision and Pattern Recognition Workshops (CVPRW), Vancouver, BC, Canada.
32. Zhang Z, Shen W, Xia L, et al. Video SAR Moving Target Shadow Detection Based on Intensity Information and Neighborhood Similarity. Remote Sensing, 2023; 15(7). doi:10.3390/rs15071859
33. Sen M, Chermala SP, Nagori NN, et al. SHARDS: Efficient SHAdow Removal using Dual Stage Network for High-Resolution Images. In: 2023 IEEE/CVF Winter Conference on Applications of Computer Vision (WACV), Waikoloa, HI, USA. pp. 1809-1817. doi: 10.1109/WACV56688.2023.00185
34. Shahade AK, Patil GY. Efficient shadow removal technique for tracking human objects. 2014 International Conference on Power, Automation and Communication (INPAC). Published online October 2014. doi: 10.1109/inpac.2014.6981150
35. Liu L, Prost J, Zhu L, et al. SCOTCH and SODA: A Transformer Video Shadow Detection Framework. 2023 IEEE/CVF Conference on Computer Vision and Pattern Recognition (CVPR). Published online June 2023. doi: 10.1109/cvpr52729.2023.01007
36. Nigam S, Singh R, Singh MK, Singh VK. Multiview human activity recognition using uniform rotation invariant local binary patterns. Journal of Ambient Intelligence and Humanized Computing. 2023; 14(5): 4707-4725.