facilitating better communication and avoiding duplication of efforts. Web GeoSIS also recognizes the inherently location-based nature of soil information and therefore provides both geographic as well as non-geographic perspectives for data access, analysis and visualization. Such a strategy can facilitate participatory research for revising the database for monitoring soil health relative to land-use change[1,7].

The role of soils in maintaining ecosystem and climate regulation is increasingly gaining recognition. This demands relevant and useful information on soils throughout the world. The need for relevant and pertinent datasets to develop a SIS at the country, state, and farm level is a dynamic process. This is more so since the soil has many dynamic parameters which control its health affecting crop performance. Digital soil maps have been useful in providing information on dynamic soil properties. These can be generated for the Indian scenario as well following the scheme discussed in the present communication. Linking datasets of natural resources for web-based solutions requires team-work. With the changing global scenario at present we need expertise with sufficient knowledge on agriculture and allied sciences. Such experts would find GeoSIS and the proposed DSS useful to analyse issues like land degradation, soil diversity, agricultural land-use planning in different AESRs, and change in soil and land quality parameters as influenced by land-use and/or climate change.

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An efficient method for digital imaging of ancient stone inscriptions

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Ancient stone inscription is one of the most important primary sources to know about our ancient world such as age, art, politics, religion, medicine, etc. Image acquisition is the first stage for digitizing and preserving the stone inscriptions for further reference. The traditional method of wet paper squeezes is still being used, that will be digitized and preserved for recognition. In this communication, we propose a novel image acquisition method called Shadow photometric stereo method for upgrading the image for recognition. The efficiency of the proposed acquisition method has been proved in image thinning process. Improving the thinning quality of the characters facilitates better feature extraction for character recognition. An experiment has been performed on two stone inscriptions that were in different places, one placed inside laboratory and other in its original place, i.e. outside the laboratory. Analyses were performed in terms of performance measures such as hamming distance and peak signal-to-noise ratio. Comparisons with the best available results are given in order to illustrate the best possible technique that can be used as a powerful image acquisition method.

Keywords: Ancient stone inscriptions, image processing, shadow photometric stereo method, thinning algorithms.

DIGITAL images play an important role in epigraphy which is a study of inscriptions on rocks, copper plates, temple walls and pillars that are important for tracing the cultural and historical heritage of a countrey[1]. Ancient stone inscriptions are one of the most important primary sources for getting information about the ancient world. These inscriptions preserve writings from ancient times and give us direct access to the past. The main difficulties in studying and interpreting the stone inscriptions are that they are inaccessible due to location or damage by various natural climatic conditions such as wind, rain, lighting and thunder. The traditional methods of wet paper squeezes, wax rubbings and scale drawings for image acquisition are still used in many countries.

Presently epigraphists take the impressions of stone inscriptions on wet paper called 'squeezes' by beating them using a brush against the rock surface[2]. The squeezes with inadequate legibility are scanned for digital preservation, dissemination and transcription. It is both time-consuming and laborious. The digitized image of a sample squeeze is given in Figure 1, which is not legible.

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The second method of wax rubbing is the manual reproduction of the texture of a surface on paper using wax or charcoal. It shows the character in white on black/wax colour background. Dents and cracks are also shown in levels of grey[2]. The drawback is that manually applied pressure while rubbing causes variations in the contrast. The third method is scale drawing. Such drawings require time, skill and expertise. As technology advances, an alternate method is digital photograph which is also not of required quality because of varied rock surfaces and illumination conditions.

Whenever an image is acquired and converted into digital form, some amount of degradation will occur in the output[3]. Once acquisition has been completed, various methods of processing can be applied to the image to perform the different vision tasks required today. If the image has not been acquired satisfactorily, then the intended tasks may not be achievable. Thus, enhancement is required and should be made during image acquisition itself. The main objective of the present study is non-invasive acquisition of digital images of good visual quality directly from the stone inscriptions using a high-resolution camera with intelligent lighting. Then the output image of the proposed shadow photometric stereo method is fed into the thinning process. The results are analysed in terms of hamming distance and peak signal-to-noise ratio (PSNR) by comparing with their ground truth images to demonstrate the efficiency of acquisition techniques. In summary, our main contributions are the following: (i) Developing a highly accurate image acquisition method based on shadow photometric stereo for stone inscriptions. (ii) The issues of non-uniform rock surface reflection, self inter-reflection and various illumination conditions are addressed using Shadow, which is independent of the correspondence problem and surface reflectance characteristics.

Figure 1. Sample Stone inscription squeeze. (Courtesy: Department of Archaeology, Government of Tamil Nadu).

In conventional photography method, the images produced are two-dimensional, i.e. they illustrate the illusion of depth. An ordinary digital camera is used to capture the image under surrounding ambient light source for illumination and the camera is set at the middle of the object. Figure 2 *a* show the set-up for conventional photography. The images of stone inscriptions captured using conventional photography when used for recognition of ancient characters result in lower accuracy. This is because of the unwanted shadow effects due to varied, non-uniform rock surface. Image enhancement methods are employed by many researchers to overcome the above problem[4]. In the proposed method, such effects are greatly reduced at the image acquisition stage itself using shadow photometric stereo method.

Shadowing is almost unavoidable in any image. Technique based on shadows have the advantage that they do not rely on correspondences or on a model of the surface reflectance characteristics, and they may be implemented using inexpensive lighting and/or imaging equipment. A number of cues such as stereoscopic disparity, contours, shading and shadows have been shown to carry valuable information on surface shape[5].

Woodham[6,7] introduced a technique called photometric stereo in which multiple images are captured by varying the direction of incident illumination between successive images, while holding the camera position constant. Einarsson *et al.*[8] developed a fast and robust system for acquiring high-resolution geometry and reflectance properties using photometric stereo. It addressed the challenges of photometric stereo such as surface anisotropy and distance from source to surface point by taking ten images with a remotely mounted camera flash at a different position pointed towards the stone inscription.

Nayar *et al.*[9,10] addressed the shape from inter-reflection problem using photometric stereo. The pseudo (erroneous) shape extracted by this algorithm was overcome by iteratively refining the shape. Zhang *et al.*[11] categorized them as minimization approaches, propagation approaches, local approaches and linear approaches.

In our proposed work, shadows are considered for obtaining the shape of the engraving letters on stones by capturing only two images separately for the same object taken from a fixed, single camera, illuminated with known light source placed to the left and right of the normal vector of the object with fixed angle θ. In this work, the camera is mounted with a transmitter which wirelessly triggers the flash whenever the images are captured. Hence the flash alone will be shifted from the left-side to rightside while capturing the stereo images without disturbing the position of the camera. Generally, shadows are generated on the inscribed letters due to depth of curve cut on the stones.

Figure 2 *b* and *c* shows the hardware set-up for proposed method. By studying the changes in shadows over a surface, shape information for characters can be

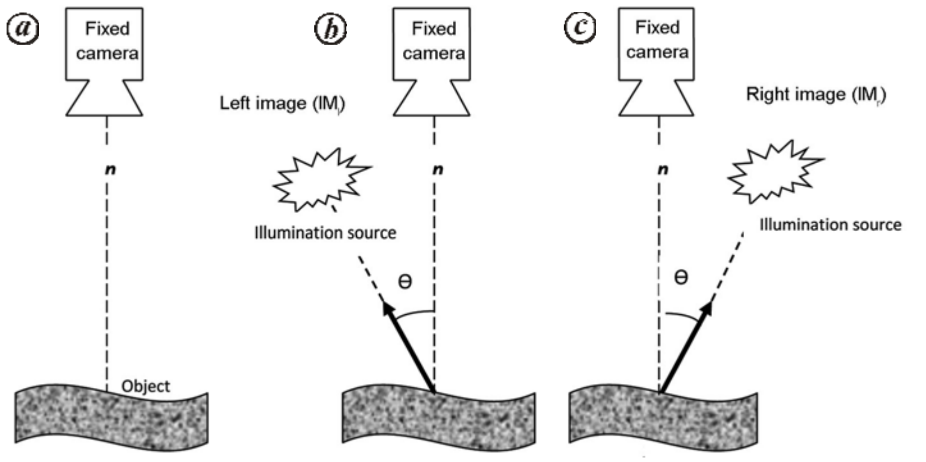


Figure 2. ***a***, Conventional photography system. ***b***, ***c***, Proposed shadow photometric stereo system that captures (***b***) left image (IM_l) and (***c***) right image (IM_r).

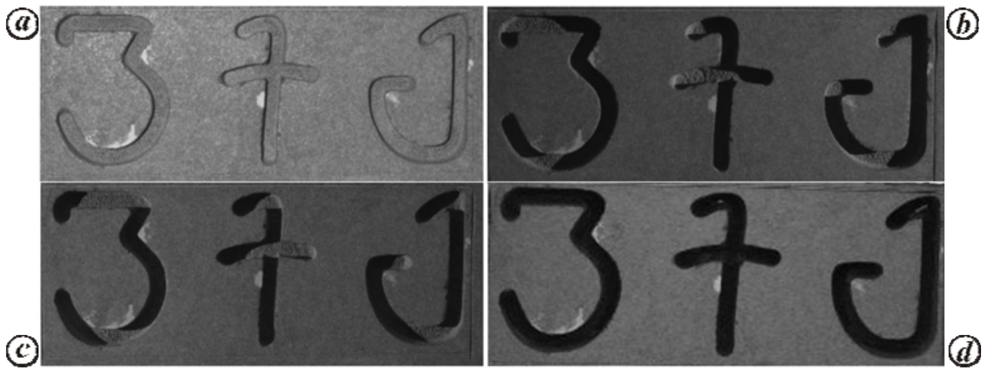


Figure 3. ***a***, Image of conventional photography method. (***b***) Left image and (***c***) right image of proposed shadow photometric stereo method. ***d***, Enhanced image.

Figure 4. ***a***, Indoor stone inscription; ***b***, outdoor stone inscription.

calculated by taking minimum value (shadow) for each pixel between two images. Shadow photometric stereo method ensures the stereo correspondence between two images where points in one image can correspond only to points along the same scan line in the other image. Then the enhanced image will be used in the thinning process and will produce better result.

Algorithm for shadow photometric stereo method: Input: Two images namely left image (IM_l) and right image (IM_r) of size $n \times n$. Output: Enhanced image S. (i) Convert RGB images to grayscale images. (ii) For $i \leftarrow 0$ to n; For $j \leftarrow 0$ to n; $S[i, j] = \min\{IM_l[i, j], IM_r[i, j]\}$.

Initially we performed and the experiments on stone inscriptions under controlled illumination in the laboratory. The output is shown in Figure 3. Then the experiments were extended to the actual locations of stone inscriptions.

Figure 4 *a* and *b* shows the stone inscriptions used for indoor and outdoor shooting experiments. The outdoor shooting was done at Sri Dhenupuriswara temple in

Manimangalam near Tambaram, Tamil Nadu. This stone inscription belongs to the 16th century.

Image thinning is one of the preprocessing steps in character recognition, particularly in the areas of feature detection and feature extraction, which simplifies the subsequent task of interpreting the information content in the original image. In this study, two well-known thinning methods morphological thinning and Zhang–Suen methods – are used for thinning the acquired images. Figure 5 shows the flow diagram of the image thinning process.

The first step of this process is binarization, which converts the input image into binary image containing only 0s and 1s to represent the details. If the input is RGB image, then first it is converted to grayscale image that in turns converted into binary image by thresholding[9]. The output image replaces all pixels in the input image with luminance which is greater than the specified threshold by the value 1 (white) and replaces all other pixels with value 0 (black).

$$b(x, y) = \begin{cases} 1, & \text{if } s(x, y) > th \\ 0, & \text{otherwise} \end{cases}$$

$$0 \le x < R,\ 0 \le y < C,$$

where $b(x, y)$ is the binary image, $s(x, y)$ the input image, th the threshold value, and R, C are the dimensions of the image.

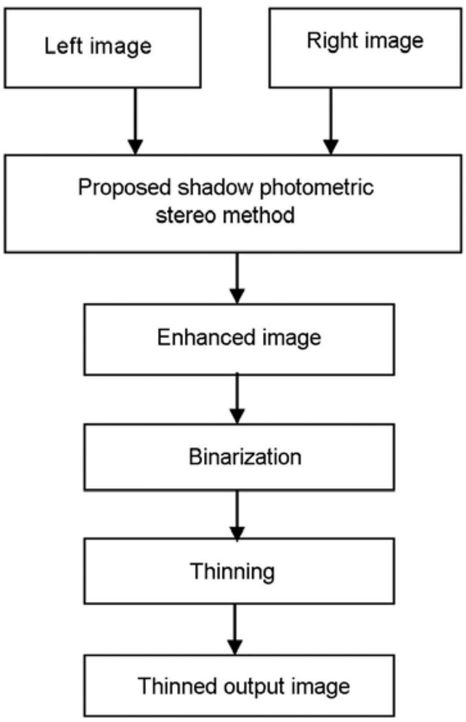


Figure 5. Flow chart for the thinning process.

Image thinning is the process of reducing the thickness of the image into one pixel width images. There are several algorithms available among which the following two methods are considered here.

(i) Morphological thinning: The morphological operation of 'thin' divides the image into two distinct subfields in a checkerboard pattern[12]. In the first sub iteration, delete pixel p from the first subfield, if and only if the conditions $G1$, $G2$, and $G3$ are all satisfied. In the second sub iteration, delete pixel p from the second subfield, if and only if the conditions $G1$, $G2$, and $G3$' are all satisfied.

$$\text{Condition } G1: \quad X_H(p) = 1, \tag{1}$$

where $X_H(p) = \sum_{i=1}^{4} b_i$,

$$b_i = \begin{cases} 1, & \text{if } x_{2i-1} = 0 \text{ and } (x_{2i} = 1 \text{ or } x_{2i+1} = 1) \\ 0, & \text{otherwise} \end{cases}$$

$x_1, x_2, ..., x_8$ are the values of the eight neighbours of p, starting with the east neighbour and numbered in counter-clockwise manner.

$$\text{Condition } G2: \quad 2 \le \min\{n1(p), n2(p)\} \le 3, \tag{2}$$

where

$$n1(p) = \sum_{k=1}^{4} x_{2k-1} \vee x_{2k}$$

$$n2(p) = \sum_{k=1}^{4} x_{2k} \vee x_{2k+1}$$

$$\text{Condition } G3: (x_2 \vee x_3 \vee \bar{x}_8) \wedge x_1 = 0, \tag{3}$$

$$\text{Condition } G3': (x_6 \vee x_7 \vee \bar{x}_4) \wedge x_5 = 0. \tag{4}$$

The two sub-iterations together make up one iteration of the thinning algorithm. When we specify an infinite number of iterations, they are repeated until the image stops changing.

Zhang–Suen method: Another efficient method for thinning which is easy to implement is the Zhang–Suen thinning algorithm[13]. This requires that the pattern be thinned has a proper shape; otherwise; the skeleton produced may contain several branch points and unwanted small/trifling matters. It comprises of two sub-iterations.

P9	P2	P3
P8	P1	P4
P7	P6	P5

Figure 6. Structural element.

Table 1. Comparison results

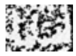
Tamil character	Acquisition method	Thinning method	PSNR	Hamming distance (%)	Output–thinned image
உ	Conventional	Morphological thin	62.84	3.4	
Vu (indoor)		Zhang	62.98	3.3	
	Proposed	Morphological thin	59.07	8.1	
		Zhang	60.09	6.4	
ல	Conventional	Morphological thin	50.82	54.2	
La (outdoor)		Zhang	–	–	–
	Proposed	Morphological thin	56.18	15.8	
		Zhang	56.60	14.3	
ம	Conventional	Morphological thin	50.56	57.6	
Ma (outdoor)		Zhang	–	–	–
	Proposed	Morphological thin	56.47	14.8	
		Zhang	57.05	12.9	
ய	Conventional	Morphological thin	49.88	67.2	
Ya (outdoor)		Zhang	–	–	–
	Proposed	Morphological thin	56.22	15.6	
		Zhang	57.14	12.7	
எ	Conventional	Morphological thin	62.86	3.4	
Ea (indoor)		Zhang	63.21	3.1	
	Proposed	Morphological thin	58.86	8.5	
		Zhang	58.8	8.6	
இ	Conventional	Morphological thin	61.84	4.3	
EE (indoor)		Zhang	62.39	3.8	
	Proposed	Morphological thin	57.05	12.9	
		Zhang	56.72	13.9	

Figure 6 shows the structural element used by this algorithm.

In the first iteration, a pixel *P*1 is marked for deletion if the following conditions are satisfied: (1) If the sum of pixels in a 3 × 3 structural element, excluding the pixel *P*1 is 1. (2) If the sum of black pixels in the neighbourhood of *P*1 is greater than 2, but less than 6. (3) If the product of pixels in *P*2, *P*4 and *P*6 equals zero. (4) If the product of pixels in *P*4, *P*6 and *P*8 equals zero.

In the second sub-iteration the conditions in steps 1 and 2 remain the same, but steps in 3 and 4 are as follows: (3) If the product of pixels in *P*2, *P*4 and *P*8 equals zero. (4) If the product of pixels in *P*2, *P*6 and *P*8 equals zero.

At the end, pixels that satisfy these conditions will be deleted. At the end of either sub-iteration if there are no pixels to be deleted, then the algorithm stops and produces the skeleton of the image. The output image of the thinning process may be sent as input to the next process of feature extraction and classification.

The experiment was conducted on two sets of stone inscriptions placed at two different locations. A part of an stone inscription was placed inside the laboratory and image was acquired conventionally and stereoscopically. Then the same acquisition process was done outdoor, i.e. acquiring the image directly from the temple wall. We used a DSLR camera and speedlite transmitter (both Canon), for providing synchronized auxiliary light flash. This set-up captured both left and right images as mentioned earlier. We then implemented these processes in Matlab 11b and the output images were compared with their ground truth images. Performance was analysed in terms of PSNR and hamming distance. The hamming distance is used to measure the number of positions at which the corresponding pixels are different[14]. It is mainly used to determine the similarity between ground truth image and output image; lower the value, higher the similarity. PSNR is another well-known measure of image quality. If the PSNR value is high, it provides higher image quality. A small PSNR value implies high numerical difference between images.

Table 1 gives the results for three indoor and three outdoor images. The conventional photographic system works better for indoor images. However, shadow photometric stereo method eliminates the problem of outlier bright points in outdoor images. Hence the accuracy of outdoor images is better with shadow photometric stereo method.

As we have most of the stone inscriptions on temple walls, rocks or pillars, it is not possible to bring them to the laboratory for digitization. Our proposed method gives better results for both thinning algorithms. The Zhang–Suen method was not working well for conventional photography incase of outdoor. For example, the character 'La' gives PSNR values of 56.18 and 56.60 and hamming distances of 15.8% and 14.3% for morphological thinning and Zhang–Suen algorithms respectively. Higher PSNR value and lower hamming distance value give greater similarity. As observed the proposed method works well outdoor using additional hardware such as wireless transmitter to synchronize the flash with the camera.

Thus we propose an acquisition method for digitizing ancient Tamil stone inscriptions. It produces shadow images containing the shape information which will become the best input image, especially for the stone inscription recognition process. The method was tested with image thinning process as it is one of the pre-processing steps in character recognition that helps in extracting the features on images for classification and recognition. Our proposed method requires photometric stereo image pairs which give better accuracy in similarity than conventional photography. In conclusion, the proposed image acquisition method helps reveal the shadow information for further processing in character recognition. Further, it will be used to study ancient stone inscriptions of other languages as well.

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