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Automatic time detection from image using a Gnomon and determining sun's elevation from shadow length

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Abstract

In this project we explore the problem of shadow detection and interpretation. As a part of interpretation we try to infer useful information such as direction of light source and time of the day from the shadow in given image. Shadow detection is a foundation step in this project. In order to facilitate accurate results we use a special construct called a 'Gnomon'. This device is traditionally used to calculate time from the object shadows. We used our algorithm to interpret the shadow cast by gnomon and calculate the time using given formula [5]. In order to evaluate our method for automatic time detection, we used data with temporal spread provided with ground truth value for experiment.

Main aim of project is to gain confidence in shadow detection, time measurement and calculating sun's elevation at specific time in a day. Once gained confidence and accurate results using this approach we can extend these ideas to estimate geographical location of the given set of images.

Keywords
Shadow detection, intensity statistics, gnomon, angle of elevation, time

Introduction

Automatic interpretation and inference on real world images manipulation remains one of the most challenging areas in the field of computer vision. In this project we aim at shadow detection and interpretation. To perform shadow detection, we used various approaches and implemented the one which was well suited and most feasible for our project. Next step, we constructed an instrument called 'Gnomon' which is a triangular shaped device whose shadow moves as day goes along and can be best used to determine the time provided it is positioned in appropriate direction. In order to ensure success, Gnomon should be pointed to true celestial north [12]. As day progresses angle the slanted edge makes with the vertical line also changes which is an indication of change in time. By calculating angle at each temporal interval and using formula [5] we determine the time at which photograph was taken.

Once we succeed in shadow detection and time estimation from shadow, in the next step we moved with calculation of sun's elevation and from the object length and its shadow. The accuracy in sun's elevation will be used in future implementation for Geo-location estimation.

Shadow detection

In order to detect the shadow of the object in the image, we used various approaches. However detection approach that can be used is highly dependent on the image. There are various issues related to the selection of appropriate method for given image of the scene. Shadow detection helped us to determine lighting direction and orientation of shadow which is used as input to time detection algorithm. In the following section, we describe some of the shadow detection approaches that we implemented as a part of our project.

Intensity Statistics [1] [2]

This method is based upon the fact that the shadowed areas in the image tend to be darker and more uniform than rest part of the image. In this approach we traverse through the image and calculate the average intensity of pixels in the image. In the second run we set the shadow sensitivity parameter 't' and visit each pixel to check whether value of that pixel is below particular 't' percentage of the average intensity value image scene. If the pixel value is below the considered threshold, then the pixel is declared as shadow pixel. Rest of the pixels having value above threshold is marked as non-shadow.

To avoid false positives and true negatives, we again scan through the shadow mask we got and apply intensity statistics on the clusters of shadow and non-shadow point space in order to rectify result of incorrect classification. Results of shadow detection using intensity statistics for specific value of sensitivity parameter t, are shown below,

C **D**

Fig. 1.1 *shows the result of shadow detection using intensity statistics approach.*
Fig. C *shows failure due to lightening condition and texture under observation. Failure caused due to inability of algorithm to distinguish between shadow and non-shadow parts.* ***Fig D*** *shows successful result. Threshold't' may range from 0.7 to 0.95 depending on the image*
(All Images [3] above with 640 X 425 resolution)

Image differences

As the name suggests in this approach we use set of two images one, original scene without shadow and second with only shadow of the object. We match two images pixel by pixel. Pixels for which intensity difference is greater than some threshold‘t’ are marked with shadow. Rests of the pixels are marked with non-shadow label.

As with the previous approach, selecting threshold t plays an important role in final shadow detection result. Since this is the pixel matching technique, sometimes it necessitates applying translation on images if pixels from both images are not exactly mapped.

Results of shadow detection using image differences are as follows

A

B

Fig. 2.2 *shows the result of shadow detection using image difference approach.*
In both ***Fig. A*** *and* ***Fig. B*** *shows introduction of salt and pepper noise due to false positives and true negatives. Images can be corrected later by applying morphological closing and opening operation. (Images [3] above tested with 640 X 425 resolution)*

Intensity matching

Intensity matching approach works on comparing two images taken at two different intensity settings, one with light and other by obstructing light. Object and shadow remain at same place in both images. By intensity analysis of pixels we mark those pixels for which intensity is close to match (as determined by threshold 't') as shadow pixels in first image and all the pixels in second image will have almost same intensity value in both images.

This approach works on images having both shadow and object. Similar to previous, this approach also requires set of two images for comparison and selection of appropriate threshold.

Results of shadow detection using intensity matching are as follows

C

D

Fig. 2.3 *shows the result of shadow detection using intensity matching approach.*
In both ***Fig. C*** *and* ***Fig. D*** *above introduction of salt and pepper noise can be seen in the last image. Image can be corrected using closing and opening operations when applied externally using inbuilt morphological operations in Matlab.*
(Images [3] above with 640 X 425 resolutions)

Comparison of shadow detection approaches

Method	Advantages	Disadvantages
Intensity Statistics	Works on single image	Unimpressive results on images with dark object
	Good results on images with shadow and object	Sometimes results in noise introduction due to false positives and true negatives
Image difference	Gives better results than Intensity statistics	Necessitates the translation if image pixels are not matching exactly
	Robust to presence of dark objects in the image scene	Works on shadow only images
Intensity Matching	Robust to presence of dark objects in the image scene	Requires two images
	Works well on images with shadow and object	Requires that camera position and orientation should be fixed

Table 2.4 *Comparison of shadow detection approaches*

Since we performed our experiment on single images, intensity statistics method was most appropriate and robust for our experiment. In addition, this approach helped us to save time and memory requirement as it demanded use of only one image. Also due to unavailability of fixed cameras the result from last two approaches would not be suitable for final measurement.

Calculating time from shadow

Gnomon [4] [5]

Detecting time from shadow requires use of other instruments where the position of shadow can be used to tell time at a particular location at particular moment.

Gnomon is a triangular device as shown in figure whose face is kept pointing towards north. As sun progresses throughout the day, shadow of slanted edge also undergoes transition from one side to another construction of gnomon is determined by the latitude of the location at which such estimation to be made. Latitude of location determines the principle angle of gnomon.

Following is the picture of gnomon we constructed and shown is the angle of slanted edge which is 39.26 which is the latitude of Bloomington.

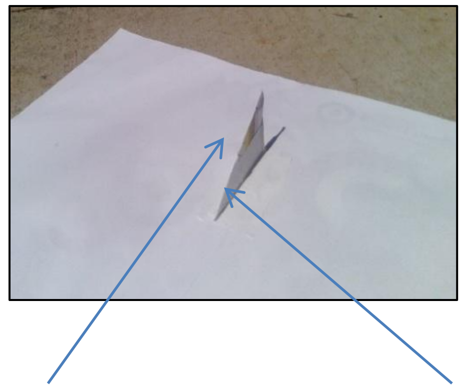


Fig. 2.1 *Shows gnomon created for Bloomington.*

Shadow detection and interpretation

By applying intensity statistics [1] [2] methods we created the mask of gnomon shadow and then applied shadow interpretation algorithm to determine position of the sun in sky and slanted edge orientation.

By calculating the inclination of slanted edge with respect to vertical line and then using formula mentioned below we estimate the time at which photograph was taken. The time of the day whether it is before noon or after noon can be determined by position of the tip of gnomon. If the tip is on the left hand side then it is before noon otherwise it is after noon.

Given formula [5] expresses time in terms of 24 hour clock schedule

$$\textbf{Timesolar} = -\left(\left(\left(180\right)/\left(\pi * 15\right)\right) * \tan^{-1}(\tan(\text{theta}))/(\sin(\text{beta}))\right) + 12 \qquad \textbf{(1)}$$

All angles are in radians and,

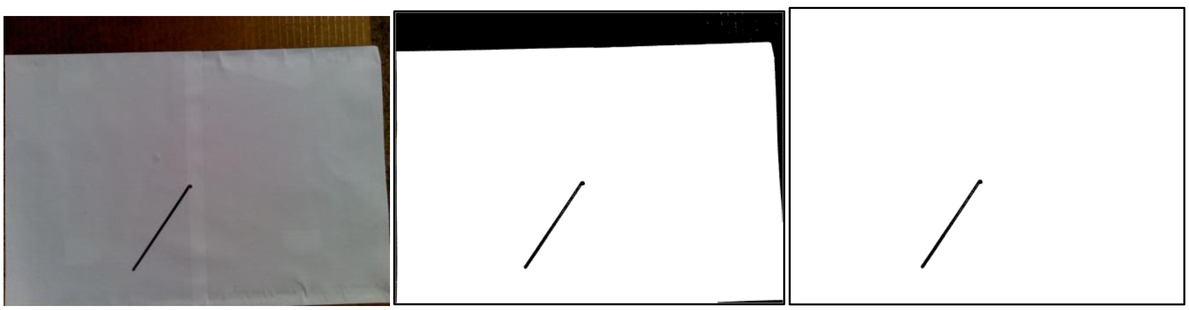
theta: Angle that shadow of slanted edge of gnomon makes with vertical line
beta: Latitude of current location (Also angle of gnomon)
Timesolar: Current time as estimated by gnomon in terms of 24 Hour clock

Calculating elevation of sun from object shadow

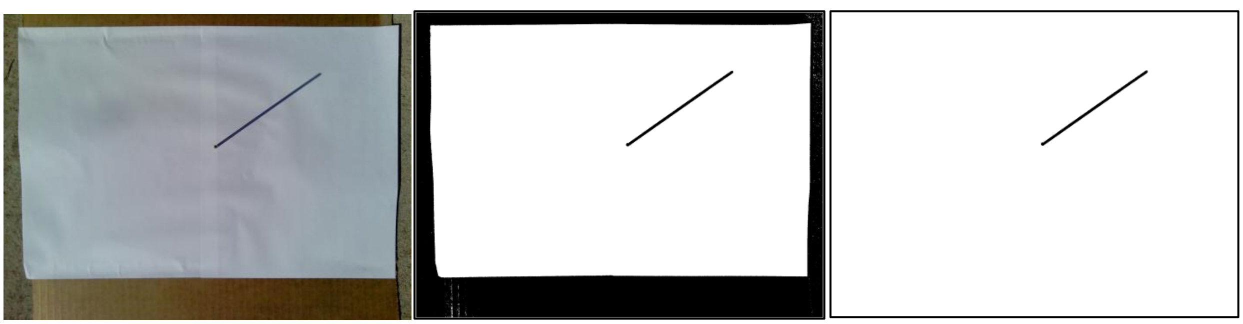
Determining shadow length and sun's elevation

We use the same intensity statistics [1] [2] method that was used in the time detection from shadow. Following images represent the result of shadow detection algorithm. However the shadow thus detected is not perfect and contains noise especially at the boundary. So we apply noise removal algorithm to clear this.

Result is as follows



E



F

***Fig. 4.1** shows the result of noise removal algorithm for elevation measurement.*
*In both **Fig. E** and **Fig. F**, First one is an original image, second image is the result of shadow detection algorithm in which redundant pixels are clearly visible on the boundary and third image shows the result of noise removal algorithm.*
(Images above with 2048 X 1536 resolutions)

Once we get rid of boundary and other noisy pixels in the image, image is given to algorithm which calculates the length of the shadow from given shadow mask. Once obtained shadow length, we use actual length of the object to determine the sun's elevation [6]. Where length of the object is manually calculated from the image in terms of the number of pixels. We feed object and shadow length to following formula [6] which calculates the sun's elevation using simple trigonometry equation.

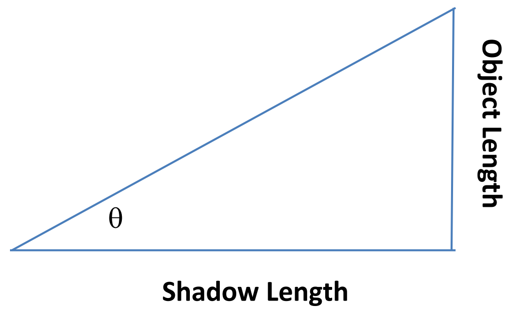


Fig. 4.1.1 *Angle of elevation =* θ

Angle of Elevation = $\tan^{-1}(\frac{Object\ Length}{Shadow\ Length})$

Estimating latitude from sun's elevation

Though method we present for latitude estimation is not very advanced and cannot be generalized for all times at a particular location. However by measuring sun's elevation at particular time we used following formula [7] for latitude estimation.

$$\mathbf{L = \pi /2 - E + D} \qquad \textbf{(2)}$$

Where all values are in radian.

L=Latitude of location
E=Elevation of sun
D=declination of sun at particular day (Can be found in astronomical almanac) [6] [8]

Dataset

In order to evaluate shadow detection algorithm we used a dataset from internet which belonged to UIUC test dataset collection [3]. We gathered different types of images and evaluated different shadow detection techniques on that image set. Where each image contains at least one shadow. Images we chose contained different shades of shadow and also contained textured and plain surfaces.

For evaluation of time detection algorithm we used our own dataset where gnomon images were captured at different time of the day. We gathered images in the morning, around noon as well as during afternoon. For the elevation estimation we gathered test images at different time and ran our algorithm to estimate the elevation of sun at particular time and latitude of current location as well.

Evaluation

Shadow detection evaluation

Evaluation of shadow detection algorithm was done by visual evaluation for the mask returned by an algorithm. No actual shadow mask was provided for shadow detection algorithm evaluation. Result of various shadow detection approaches is shown in **fig. 7.1**

Time detection evaluation

Evaluation of time detection algorithm was done by comparing the actual time at which image was taken and The time returned by an algorithm. Results of various time detection experiments are shown in **Table 6.3** below.

It was found that at the particular time there is error in observed time and actual time. This error can be attributed to the position and orientation of the camera while taking a gnomon images. Small movement or slightest tilt in camera angle can introduce error in shadow angle.

Sun elevation calculation evaluation

To evaluate sun's elevation calculation we took measure of the length of object and shadow and calculated sun's elevation manually. After getting practical data, we estimate the length of shadow using out algorithm and feed the shadow and object length to elevation measuring algorithm. We compared the actual and calculated value to determine the difference in measurement. Result of Sun elevation calculation experiment is shown in following **Table 7.2**

Similar to time detection approach, this error can be attributed to the position and orientation of the camera while taking shadow images.

Latitude estimation evaluation

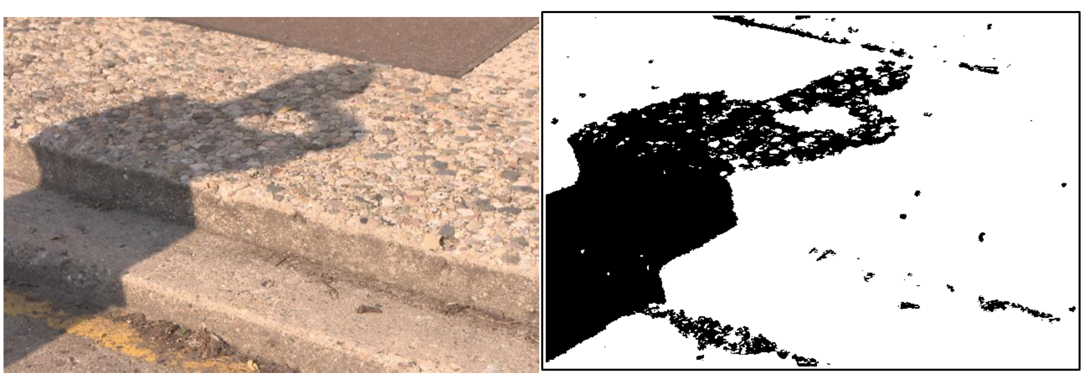
We use sun's elevation to estimate latitude of the location at which image was taken. However the technique we used though accurate was not robust enough. Accuracy of method is highly dependent on the time at which images are taken. At a specific time of day, this method gives fair estimation of latitude. However fails on other occasions. We evaluate our method with the current value of Bloomington's latitude which is 39.26. Result of Latitude estimation approach is shown in following figure. It was found that latitude estimation gives good results at the time close to noon. Latitude evaluation results are shown in the **Table 7.2**

Results

Results on image Dataset:

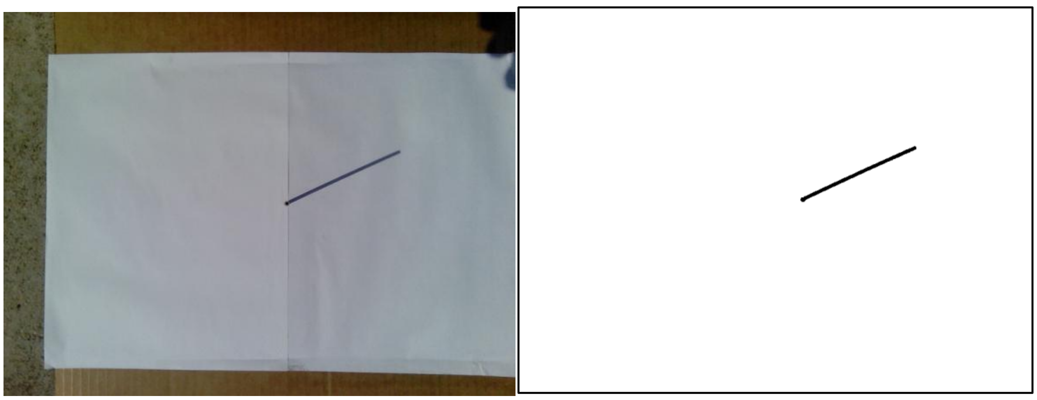
A

B

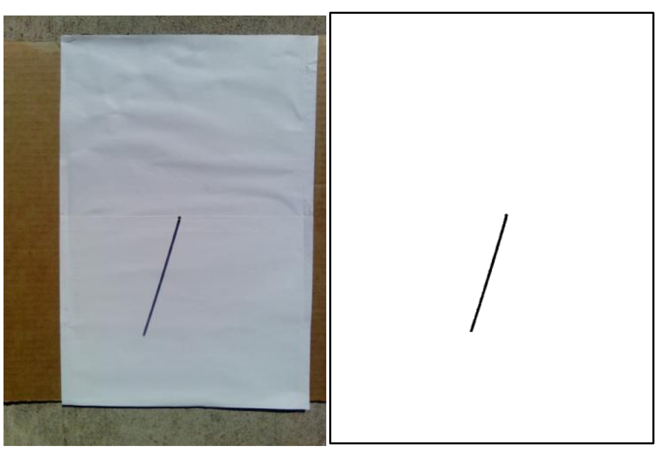


C

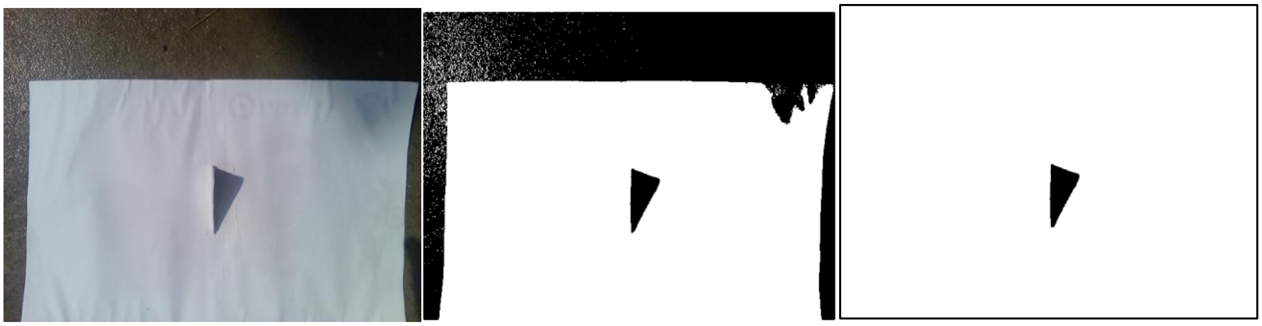
D



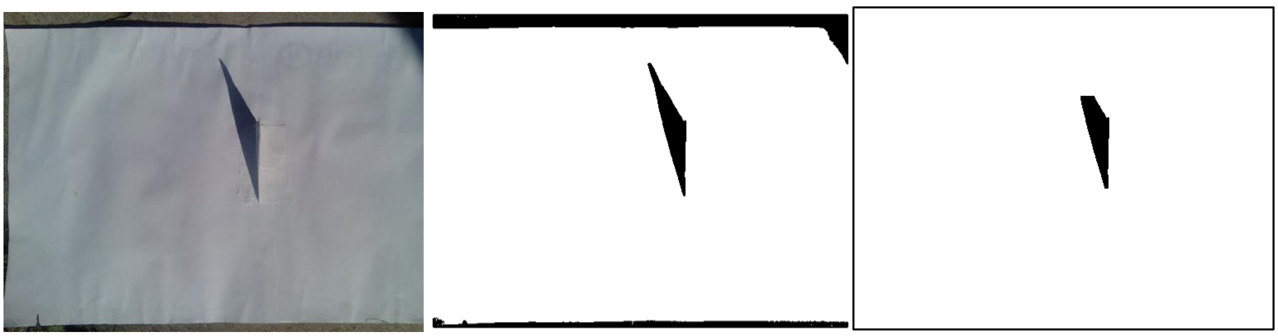
E



F



G



H

I

Fig. 7.1*: The result of various shadow detection and noise removal algorithms on experimental images.* ***Fig. A*** *shows result of image difference approach,* ***Fig. B*** *for intensity matching,* ***Fig. C*** *successful intensity statistics,* ***Fig. D*** *failed intensity statistics due to presence of dark objects in scene*

Fig. E and F *shows shadow detection result for elevation measurement experiment. Leftmost image is original one and rightmost image is the result of shadow detection and noise removal algorithm.*

Fig. G, H and I *show result of shadow detection combined with boundary noise removal.* ***Fig. H*** *is cropped on the right hand side due to uneven illumination formed by the sun position.*

Test images presented above taken with resolutions 640 X 425, 480 X 640 and 600 X 800.Images in Fig. A, B, C, D imported from [3].

Comparison of Theoretical and experimental values for sun's elevation

Image Name	Object length Actual	Shadow Length (Actual)	Actual Elevation	Object Length (Theoretical)	Shadow Length (Theoretical)	Experimental Elevation	Experimental Latitude	Actual Latitude	Elevation Error
r1.png	14.3	6.6	65.22	250	121.433	64.1	40.14	39.23	1.12
r2.png	14.3	11.3	51.68	241	197.385	50.68	54.34	39.23	1
r3.png	14.3	13.3	47.07	183	177.85	48.06	57.09	39.23	1.01

Table 7.2: Shows comparison sun's elevation actual vs. experimental. Last column shows error between actual and experimental value. Latitude thus calculated is populated in third last column of the table. Latitude matches with actual value only at particular time and for every other times causes large deviation.

Comparison of Theoretical and experimental value of time at different periods of the day

Observation Number	Name of Image File	Ground Truth	Actual	Absolute Error (In minutes)
1	Pic_0501_277.png	15.42	15.41	1
2	Pic_0501_278.png	15.43	15.47	3
3	Pic_0501_281.png	16.04	16.13	9
4	Pic_0501_282.png	16.04	16.1	6
5	Pic_0501_283.png	16.05	16.08	3
6	Pic_0502_291.png	10.14	10.39	25
7	Pic_0502_293.png	10.34	10.42	8
8	Pic_0502_299.png	11.02	11.01	1
9	Pic_0502_319.png	12.2	11.51	30
10	Pic_0502_304.png	11.3	11.33	3
11	Pic_0503_323.png	10.54	10.59	5
12	Pic_0502_316.png	11.43	12.03	20

Overall Deviation from ground truth: 9.5 minutes

Deviation eliminating outliers: 6.4 minutes

Table 7.3*: It was found that whenever time approaches to 12 noon, shadow becomes narrower, as it tries to align with vertical line. Sometimes shadow detection algorithm fails to detect this scenario and captures any random point close to vertical line which might be slightly deviated from central line.*
From above table, minimum error is 1 minute and maximum error is 25 minutes which occurs at approximately 10:14 in the morning. Error can be attributed towards moved camera position.
Overall deviation is 9.5 minutes. Eliminating outliers number 9 and 12, occurring at the noon due to gnomon design error, we get fairly less deviation of 6.4 minutes.

Assumptions

As we figured out, our gnomon model and algorithm are not perfect. Model we built is based upon many constraints and assumptions. Results we provided are the outcome of these assumptions.

When shadow detection and recognition model is constructed, it is placed on the white paper in order to avoid introduction of noise that can be caused by other elements as we are not performing multiple shadow recognition on given image. However noise introduced at the border of the image does not affect the working and accuracy of algorithm as it is easy to detect and eliminate this noise from images. These assumptions hold valid for both time detection and sun elevation measurement experiment.

Also our algorithm works only on Portable network Graphics (PNG) images. However this is because we use the base code provided by Prof. Crandall for providing input and output cue for the images and can be improved when more general base code will be deployed for purpose. But this is not the weakness of method itself.

Below are some specific assumptions made for time and elevation measurement.

Time detection algorithm

As a part of time detection algorithm we used the device called gnomon. However to construct gnomon [4] [5] [8] [9] [10] we need to know the latitude of the location beforehand. Camera is positioned exactly vertical and kept almost in the plane on which gnomon is fixed to avoid any parallax effect on the captured image which would have resulted in false shadow lengths. During experiment we had to change time calculation formula [5] to run 1 hour faster to adapt to our location and gnomon thus constructed.

Elevation and latitude estimation algorithm [6] [7]

Elevation is calculated with the help of data of shadow and object length. Shadow length is calculated by our algorithm. Length of the object is calculated manually in terms of number of pixels from object images.

Images of the shadow and object are taken from the same height and with the same orientation in order to avoid any error in elevation calculation. Similar to time detection approach, camera lies in the same plane in which reference rod is fixed.

Latitude calculation presented [7] in this project is very much arbitrary and reflect the actual value only at particular time as shown in the table below. For the time away from noon accuracy of latitude calculation decreases. We introduce some parameters other than elevation for latitude estimation such as declination angle of the sun as well as time at which image was taken.

Conclusion

In this project we presented the methodology for detecting time and elevation of the sun from the object shadow. First of shadow detection algorithm was used for detecting shadows from the image and result of detection was presented to the time and elevation detection algorithm separately.

Our approach is constrained as it keeps conditions on the camera position, object structure, object background etc. However when compared with actual result, as shown in the above tables we get fairly good results. From the given test data, maximum deviation for time detection algorithm is 9.5 minutes and for elevation detection it is 1.25 when images were taken with proper camera orientation and position. We also succeeded in calculating latitude although constrained in terms of time of the day and got fairly good detection results as well.

Future Work

In the future we can implement better shadow detection methods so as to grab shadows from the natural images. We can also think on implementing our algorithm on the wide range of images to see if errors are getting introduced as a part of future course of action.

We can extend our understanding and results that we obtained from this project for more sophisticated experiment to calculate Geo-location attributes of the location from the set of shadow images. As long as this project is concerned, we succeeded in time detection and sun elevation measurement from the shadow. We can feed these results to Geo-location estimator algorithm along with other parameters such as declination of the sun and the time of image capture.

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