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Image-Based Geographical Location Estimation Using Web Cameras

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***Abstract*—This paper describes a method for estimating the location of an IP-connected camera (a web cam) by analyzing a sequence of images obtained from the camera. First, we classify each image as Day/Night using the mean luminance of the sky region. From the Day/Night images, we estimate the sunrise/set, the length of the day, and local noon. Finally, the geographical location (latitude and longitude) of the camera is estimated. The experiment results show that our approach achieves reasonable performance.**

***Keywords*-latitude, longitude, sunrise/sunset, environmental monitoring, web camera**

I. Introduction

Thousands of sensors are connected to the Internet [1], [2]. The "Internet of Things" will contain many "things" that are image sensors [3], [4], [5]. This vast network of distributed cameras (i.e. web cams) will continue to exponentially grow. We are interested in how these image sensors can be used to sense their environment. In particular in this paper we investigate simple methods for how one can determine metrics of a location (e.g. sunrise/sunset, length of day) and the location of the web camera by observing the camera output.

The location of a point on the Earth is described by its latitude and longitude (and perhaps by its altitude above sea level). Latitude is measured in degrees north or south of the Equator, 90° north latitude is the North Pole and -90° south latitude is the South Pole. Longitude is measured in degrees east and west of Greenwich, England. 180° east longitude and -180° west longitude meet and form the International Date Line in the Pacific Ocean [6], [7], [8]. The definition of sunrise and sunset is when the geometric zenith distance of the center of the Sun is $90^\circ 50'$ [9]. That is, the center of the Sun is geometrically 50 arcminutes below a horizontal plane. There are various definitions for sunrise/set and daylength [10].

Several approaches have been reported with respect to finding a location from images. The sunrise and sunset were determined by classifying images taken from a webcam and the location was then estimated in [11]. For determining the sunrise and sunset, the intensity of the image was used to classify day or night and then determine the midday (or local noon) time to identify the longitude and latitude. In [12] the sky region is identified by using image data taken under various weather conditions, predicting the solar exposure using a standard sun path model, and then tracing the rays from the sun through the images. In [13] vehicle detection and tracking is used to detect road conditions in both day and night images by using images and sonar sensors. A method to retrieve the weather information from a database of still images was presented in [14]. The sky region of image was detected by using the difference of pixel values from successive image frames, morphological operations were then used to obtain a sky region mask. The weather condition was recognized by using features such as color, shape, texture, and dynamics.

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II. The Proposed Method

A. Sunrise/Sunset Estimation

Sunrise and sunset can be obtained by classifying each image from the camera with the label "Day" or "Night." One of the factors that can be used for detecting Day/Night is the brightness of the image. In [11], the mean of the combined RBG components were used to detect Day. In our work, we used the luminance to measure the brightness of the image. We first convert from the RGB to $YCbCr$ color space and use the Y component to obtain the average luminance. We assume that an image with large luminance tends to be Day. We have ignored camera AGC effects. We recognize that this introduces error in our estimates for sunrise and sunset due the fact that the images will be "brighter" than normal. In our operational scenario we have no control of this in that we cannot turn off the camera AGC.

The color of the sky is mostly sensitive to whether it is Day or Night while other objects in the scene can have various colors. To make use of this fact in determining Day/Night, we can define into two spatial regions–the sky region and the non-sky region. We are assuming that some part of the field of view of the camera "sees" the sky. The set of pixels in an image belonging to the sky is defined as the sky region, and the rest of the pixels which do not belong to the sky are defined as the non-sky region. Day/Night detection based on the luminance of the entire image could be incorrect due to factors in the non-sky region, e.g. lights from a building at night, the dark objects or shadows that appears during the day. Therefore, it is more accurate to focus on the sky region for Day/Night detection. In [11] the entire RBG image was used and in [13] the sky regions were detected using a camera with a field of view from the dash of a vehicle using the road information.

Our method is a variation of the above in that we focus on the sky region and find the mean of Y in the sky region:

$$Y_{sky\_i} = \frac{1}{M}\sum_{j=0}^{M-1} Y_{sky\_i,j} \tag{1}$$

where Y_{sky_i} is the mean sky luminance of the i_{th} image and $Y_{sky\_i,j}$ is the luminance of the j_{th} pixel in the sky region of the

i_{th} image. M is the number of pixels in the sky region. Here we assume that the camera is static and the sky region for the camera remains the same for all the images. Our approach to sky detection is discussed in Section II-B.

We will estimate sunrise and sunset by detecting transitions from Night to Day and Day to Night. To detect Day/Night transitions from the luminance of the sky region, a threshold must be determined. If we assume the images are obtained over a 24-hour period, we know that approximately a quarter of the images are either Day images or Night images if the camera is located in the latitude range between $60\,^{\circ}S$ and $60\,^{\circ}N$. Since Y_{sky_i} has large value for Day and small value for Night, we can find a threshold for Y_{sky_i} to label the image as Day or Night. Two different thresholds for classifying Day/Night can be used:

$$th_{mean} = \frac{1}{N}\sum_{i=0}^{N-1} Y_{sky\_i}, \tag{2}$$

$$th_{mid} = \frac{max\,\{Y_{sky\_i}\} + min\,\{Y_{sky\_i}\}}{2}. \tag{3}$$

In [11] the th_{mid} was used for the threshold but when we used it to our experimental work, th_{mean} provided better results. If the mean luminance of the sky region of an image is larger than the threshold, we classify it as Day, otherwise we classify it as Night.

From the sequence of images denoted as either Day or Night, we can denote the times where the transitions between Day and Night labeled images occur. If the labels change from Night to Day, we can estimate that the sunrise occurs within the time interval between those consecutive images, if the labels change from Day to Night, we can estimate that the sunset occurs within the time interval between those consecutive images.

We then estimate the sunrise as the time of the start of Day. In this case, the accuracy of the sunrise estimation depends on the sampling interval of images. If the images are sampled every s minutes, the error of sunrise would be less than s minutes. Likewise, we can approximate the sunset as the time of the start of Night. The error of sunset would also be within s minutes. If the estimated Day/Night labels are accurate, exactly one start of Day and one start of Night should occur during the image sequence of 24-hour period. However, due to the dynamic weather conditions, some images can be falsely labeled as Night during the day. One way to eliminate these outlier images would be taking the earliest start of Day as sunrise and taking the latest start of Night as sunset.

B. Sky Region Detection

There are many methods for detecting the sky region in an image. In [13] sky detection is only considered for the special case where the images are the front view from dash cameras in vehicles. In [12] edge detection of sky region is used to predict the solar exposure. They describe a general approach to separate the sky from the rest of the image by determining the edge of the sky region. The accumulative frame difference between an image and the successive image is used to extract the sky region in [14]. The sky is assumed to be at the top of image and the clouds are dynamic. Using this method requires several sample images to detect the sky region. Also, it is valid only when the sample images are Day images since the method is based on the fact that the sky is dynamic compared to the foreground objects.

We propose a different approach to detect the sky region by using one image of a clear sky. By clear sky we mean no clouds in the sky and in our initial experiments this image was manually chosen. The sky detection approach we used is then:

1) Extract an image from the blue channel of the camera.
2) Use the Canny edge operator to find edges. This will create a binary image or edge mask where edge pixels are set to 1.
3) Use morphological filtering (dilation) to close gaps in the boundaries of the edge mask.
4) Invert the dilated binary image (edge mask) where the boundary pixels are inverted from 1 to 0 and the surface pixels are inverted from 0 to 1.
5) Find the largest connected region at the top of the binary image:
   a) Find all the connected components in the binary image.
   b) Sort the connected components with respect to the number of pixels contained in descending order.
   c) For each of the connected components check the location of each connected component to determine whether it is at the top part of the image. If the connected component is at the top part of the image, select it as the sky region and if not, go to the next largest connected component. Repeat until the sky region is found.

The results of using the the above sky detection technique are shown in Figure 1.

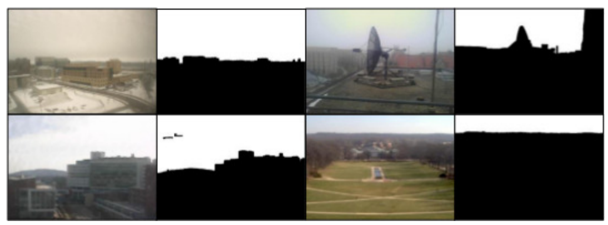


Figure 1. A collection of pairs of test images and their skymask.

C. Estimating Location from Sunrise/Sunset

Once the sunrise/sunset is estimated as described above we can use it to determine the camera location. In [10] they proposed what they called the CBM model to estimate the length of the day for a flat surface for a given latitude and day of the year. They also described a new daylength model to allow for various conditions of daylength and twilight for a full range of latitudes. Using the CBM daylength model [10] we estimate latitude by:

$$\begin{aligned}\theta = 0.2163108 + 2\tan^{-1}[0.9671396\tan[0.00860\\ \times (J-186)]],\end{aligned} \tag{4}$$

$$\phi = \sin^{-1}\left[0.39795\cos\theta\right], \tag{5}$$

$$D = 24 - \frac{24}{\pi}\cos^{-1}\left[\frac{\sin\frac{p\pi}{180} + \sin\frac{L\pi}{180}\sin\phi}{\cos\frac{L\pi}{180}\cos\phi}\right], \tag{6}$$

where θ is the revolution angle, J is the day of the year, ϕ is the sun's declination angle, D is the daylength, and L is the latitude. By numerically solving Eq. 6, we can estimate latitude (L) from daylength (D) and the day of the year (J). In this paper, the daylength coefficient (p) was set to 6.0 to correspond to the daylength definition which includes civil twilight. D is the time difference between the sunrise and sunset.

Longitude can be estimated from local noon [15]. If we know UTC (Coordinated Universal Time) when the sun is at its highest point in the sky at a location on the Earth (local noon), then we can determine the time difference between the local noon and the noon in UTC. The time difference can be converted to longitude (l) since we know that the Earth approximately rotates 15 degrees per hour.

$$l = \begin{cases} (12 - n + u) \times 15 & u \leq 12 \\ (n + u - 12) \times 15 & u > 12 \end{cases} \tag{7}$$

where n is the local noon and u is the UTC offset for the local area. All the variables l, n and u are in unit of hours. The local noon can be approximately estimated from sunrise and sunset.

$$n = \frac{t_{sunset} + t_{sunrise}}{2} \tag{8}$$

where t_{sunset} and $t_{sunrise}$ are the local time of sunset and sunrise in hours. Since the earth rotation is nearly constant, we assume that at the middle of the sunrise and sunset, the sun is at its highest point is the sky.

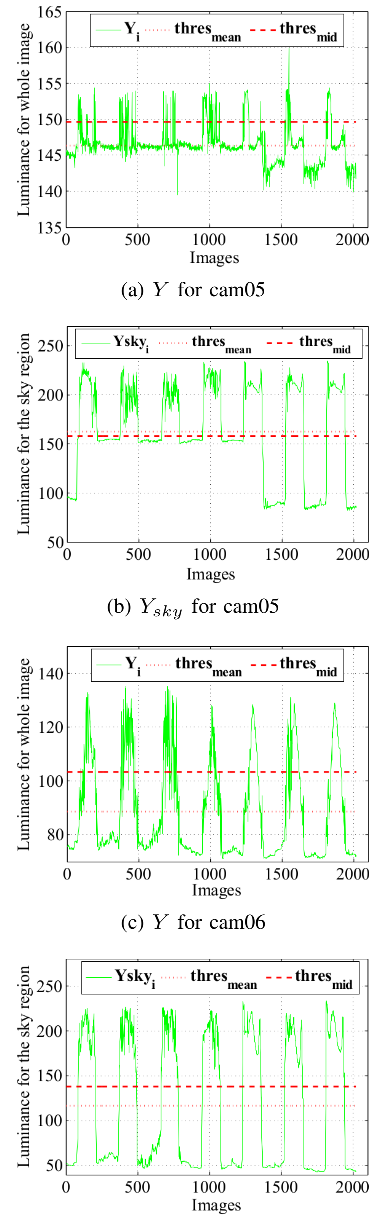
III. Experimental Results

We evaluated our methods using 10 static IP-connected web cameras. For each camera images were downloaded every 5 minutes and stored with a timestamp based on UTC-5. The images were obtained during 21-27 December 2013 (UTC-5).

The process begins by detecting the sky region for an image from each camera as described in the Section II-B. The output of this process is the sky mask of each camera. Next all images are converted from the RGB to $YCbCr$ color space and the Y component of each image is extracted (see Section II-A). The sky mask is then used for determining the mean sky luminance (Y_{sky_i}) for each image. Next images are classified as Day or Night by using the threshold. After the Day or Night images are obtained, they are used to estimate the sunrise and sunset. Finally, the latitude and longitude are obtained using the estimated sunrise and sunset (see Section II-C).

A. Sunrise and Sunset Detection

In Figure 2, th_{mean} and th_{mid} described in the previous section are denoted. Figure 2 also shows that the luminance of the sky region separates Day/Night images while the luminance of the entire image poorly separates between Day and Night images.



(a) Y for cam05

(b) Y_{sky} for cam05

(c) Y for cam06

(d) Y_{sky} for cam06

Figure 2. The mean luminance of the entire image vs. the sky region.

Table I
SUNRISE/SUNSET DETECTION FOR CAMERA01 FOR USING th_{mean}.

Date	est. rise	est. set	GT rise	GT set	rise error	set error
Dec 21	07:55	17:35	07:37	17:55	-18.4	20.3
Dec 22	07:45	17:45	07:37	17:56	-7.9	10.8
Dec 23	07:50	17:50	07:38	17:56	-12.5	6.4
Dec 24	07:40	17:50	07:38	17:57	-2.0	7.0
Dec 25	07:50	17:45	07:38	17:58	-11.6	12.6
Dec 26	07:40	17:50	07:39	17:58	-1.3	8.2
Dec 27	07:40	17:55	07:39	17:59	-0.9	3.9

The mean estimated sunrise/sunset is shown in Table I for camera01. We know the exact location of this camera and can find the ground truth sunrise and sunset from [16] using the latitude and longitude information of this camera (North 40 degree, 26 minutes, West 86 degree, 55 minutes). The “est. rise” and the “est. set” columns are the estimated sunrise and sunset in hh:mm. The “GT rise” and “GT set” columns are the ground truth sunrise and sunset in hh:mm rounded to the closest minute. For the ground truth, the sunrise and sunset civil twilight were used. The mean error for 7 days was -7.8 [minutes] with standard deviation of 6.7 [minutes] for the sunrise and 9.9 [minutes] with standard deviation of 5.4 [minutes] for the sunset.

Table II
THE RESULT FOR LATITUDE FOR USING th_{mean}.

Camera	mean[°]	std[°]	GT[°]	error[%]
1	43.6	2.0	40.4	-1.8
2	32.7	24.3	41.8	5.0
3	43.7	3.7	41.8	-1.1
4	41.3	3.5	40.4	-0.5
5	36.3	3.4	38.0	0.9
6	36.2	4.9	38.8	1.4
7	31.5	2.1	36.1	2.6
8	32.0	1.5	36.1	2.3
9	35.1	25.4	42.4	4.1
10	26.7	1.2	34.4	4.3

Table III
THE RESULT FOR LONGITUDE FOR USING th_{mean}.

Camera	mean[°]	std[°]	GT[°]	error[%]
1	-86.6	0.5	-86.9	-0.2
2	-91.9	11.9	-87.6	2.4
3	-88.2	0.8	-87.6	0.3
4	-88.0	1.2	-86.9	0.6
5	-77.6	0.8	-78.5	-0.5
6	-76.2	1.4	-76.9	-0.4
7	-75.4	1.4	-75.7	-0.2
8	-76.8	1.0	-75.7	0.6
9	-73.1	6.8	-72.5	0.3
10	-119.0	0.3	-119.8	-0.5

B. Location Estimation

In Tables II and III, the "mean" and "std" columns refers to the mean and the standard deviation of latitudes for 7 days. The "GT" column refers to the ground truth. In general we do not know the exact location of some of the cameras used in our study. The "ground truth" locations we used here were obtained from their IP addresses or using Google maps. This approach is somewhat problematic but it reflects the nature of the problem we are trying to address. In these tables, we see that the amount of error in latitude is larger compared with the error in longitude. We discovered that for each case for Cameras 2 and 9, there is erroneous estimation of the sunrise and sunset that increases the overall error. These incorrect estimations are caused by lights in the camera field of view during the night that result in a sudden rise of luminance after the sunset hence leading to the wrong estimation of sunset.

IV. Conclusion

We consider the problem of estimating the approximate location of a web cam by analyzing its images. We showed that we could effectively estimate locations with less than 2.4% error for the longitude and less than 5% error for the latitude. In future work we will investigate how we can compensate for camera AGC effects and fine grained temporal measurements. We plan on using web cams to detect weather conditions and other types of environmental monitoring. We are interested in aggregating these measurements over 10s of thousands of publicly available web cams. This is a very interesting big data problem.

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