コンピュータビジョン 76－4
(1992. 1. 23)

SHADOW PROCESSING BY APPLYING COLOR TEMPERATURE EFFECT

Nasrolah Moghadam Charkari , Hideo Mori
Dept. Of Electrical Engineering and Computer Science
Yamanashi University , Takedea-4,Kofu400, Japan

色温度を考慮する影処理

この論文は色温度によって、様々天候（晴れ、薄曇り）の道路環境で影を検出と消去する手法について提案する。
ロボットは天候の変化を色温度で検出し、日向と日影の色シフトのパラメータを設定する。さらに、色温度はアスファルト道路での日影領域の色成分を予測するために用いられる。
二次元画像でこの手法と統計を使って、道路上の車などの障害物と影を区別できることを示す。

Abstract

This paper proposes a method for shadow detection and elimination in road environment which can be applied for any weather condition, including fine and partly cloudy weather, by considering color temperature effect .

Robot uses the color temperature to detect changes in weather condition and sets up parameters related to the sunny and shadow color shift. Further color temperature is used to predict stimulus values of the shadow region on the asphalt road.

We also show that with this method it is possible to distinguish shadow from obstacle ,such as vehicle ,for the 2-D images almost perfecly.

1. Introduction

Many research groups today concentrate on outdoor robots which recognize its environment using active or passive methods. When a robot navigates in an outdoor environment its vision system should be intelligent enough to adequately analyse information related to white lane mark, shadow, obstacle, its position and so on.

In this paper we will talk about a method which can be applied for shadow detection on asphalt road with any color temperature, where the color of the sunny and shadow parts of the asphalt road is shifted due to color temperature variation of sun and sky light.

At the time of the road following process, when robot reaches to a shaded part on the asphalt road, it cannot distiguish between shadow and an obstacle region in TV. image. In other words because of the edge between sunny and shadow region, the shadow is not only recognized as a part of the road, but in many cases, as an obstacle and robot wrongly avoids shadow. Fig.1 shows this problem.

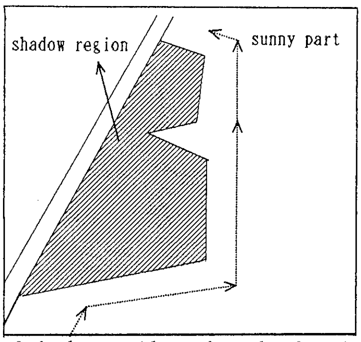


Fig.1 Plot of shadow avoidance by robot by mistake

Before dicussing our approach it will be appropriate to give a review of other works related to the shadow and obstacle discrimination. The methods applied so far can be classified into four types: Laser range sensor based method, Dynamic vision based method, Stereo vision based method, and color vision based method.

The laser range sensor based method, developed by Carnegie Mellon University, is used for obstacle avoidance. The basic operation of this method is based on measuring the time interval between transmitting the laser beam and receiving its reflection from the surface of a target[1]. The image acquisition rate of a laser range sensor can be between 64*64 or 256*256 pixels in 0.5 seconds for one frame. Although this method has a good ability to detect obstacle but it has also some deficiencies related to cross talk, ambient illumination, temperature, power consumption and its high cost, and the danger of laser beam posed to pedesterians.

The next method, the stereo vision based method gives a 3-D image of the environment to the robot. This method can distinguish the shadow from any obstacle by matching two images. However in the case of the outdoor environment there is the problem of pitching and rolling and also adjusting of two cameras accurately, the error rate for measuring the height of the shadow or the obstacle will be considerably large, and this method is not yet applied in practical sense in outdoor environment.

The dynamic vision based method for obstacle detection and avoidance was developed and implemented on VaMoRs robot by the University of Munchen[2]. According to this method the right, left, top and bottom of a moving object, for instance a car, can be detected by a local edge operator horizontally and vertically in video segmentation rate and distinguished from noise by analysing it with the previous data using Kalman filter, the velocity of the apparent object can be used to discriminate moving objects from stationary objects such as shadows. For instance the shadow moves rapidly from right to left and its area size is changed drastically, but when the robot moves, the images of the passing vehicle moves either from top to bottom or bottom to top slowly. This method is useful for high speed mobile robots, such as VaMoRs which moves with the speed of about 10 m/s.

The color vision based method was used to classify road and non road regions in Martin Marietta Denver Aerospace[3]. In addition a method called "shadow boxing" is used to classify sunny and shadow pixels in R and B scatter diagram into the two rectangulars, called sunny and shadow box. At first by applying principle component analysis the R and B axes are rotated with the angle θ, where θ is defined as a principle axis of the road cluster which discriminates the scatter diagram of the sunny and shadow pixels. This operation is performed by the following equations:

$$R' = R * \sin\theta - B * \cos\theta$$

$$B' = R * \cos\theta + B * \sin\theta$$

In the R'-B' coordination a rectangular region of shadow box is fixed by the operator manually, as a result, if any pixel placed in the shadow box it is considered as a shadow pixel.

The forth approach to shadow detection and elimination is based on color vision method was done by the Yamanashi University [4]. The method is based on the following principle: The sunny part of the asphalt road is illuminated by sunlight with color temperature of 5000° ~ 6200° and illumination of 10000 ~ 30000 lux, the shadow on the road is illuminated by the diffused light from the blue sky with a color temperature between 10000° ~ 30000° and illumination of 1000 ~ 3000 lux, this implies the hue value of the shadow region is rich in blue color. In other words, the blue component of the shadow region is richer and its intensity and red component is poorer than the sunny region of the asphalt road image. Accordingly when the sign pattern detection procedure fails then the shadow ellimination process will start. Initially the choromaticity values (r_o,b_o) of the sunny region is computed, then the choromaticity value of the shadow region is predicted from the following equations:

$$r_1 = r_o - d_{ro}$$
$$b_1 = b_o + d_{b1}$$

where d_{ro} and d_{b1} indicates the color shift of the choromaticity values red and blue.

2. Effect of the color temperature variations on r,g,b values

Color temperature which is used to describe the certain properities of light is one of the basic factors of colorimetry. In an outdoor environment it has a direct relationship with weather conditions. If the weather condition changes from partly cloudy to the fine, then the illumination of the asphalt road will change in the range of 4500° ~ 6200°. In other words this variation implies different values of r,g,b of the asphalt road.

Fig.2,3 show how the choromaticity values r and b of the sunny part of the asphalt road change due to the color temperature variations.

As a general rule when the color temperature decreases, the choromaticity value r of the asphalt road decreases and its b value increases. It should be noted that the above results were obtained with a "color measurement device, Minolta CS-100" whose accuracy is much better than video camera, therefore it does not show the video camera color response.

3. Video camera color response

In order to explain the video camera characteristics and its color response it will be better to explain briefly the video camera's parameters and the procedure of measuring colors in out door environment briefly.

The spectral distribution of sun light and diffused sky light are given by the planckian radiator as follow:

$$M(\lambda,T) = a\lambda^{-5}\,(e^{b/\lambda T}-1)^{-1}\ [W.m^{-2}.m^{-1}]$$

where λ and T denote wavelength and color temperature, and a and b are constants with values 3.7415 * 10^{-16}[W.m^{-2}] and 1.4388 * 10^{-2}[m.K] respectively. The Spectral distribution vector of the radiant flux on a road surface is expressed by $\Phi(\lambda) = M(\lambda,T)(I.n)$, where I and n denote the intensity vector of light and unit vector normal to the surface. $M(\lambda,T)(I)$ is expressed as:

$$M(\lambda,T)I = h*M(\lambda,T_{sun})*I_{sun} + k*M(\lambda,T_{sky}).I_{sky})\ [1]$$

Where Isun and Isky denote the intensity vector of the sun and sky light with the coefficients h and k between $0 \leqq h,k \leqq 1$, show the uncovering ratio of sun and sky light by such objects as cloud, building, tree, vehicles, so on. This implies that when any surface is directly illuminated by the sun light, h becomes 1.0, but if, for instance, a surface is in the shadow region, h becomes 0.0, and Eventually if surface is near to the boundaries of the shadow and sunny regions, the value of h varies between 0.0 and 1.0. (refer to Fig.4).

In other hand when the light strikes the CCD (Charged Coupled Device) it is converted to an electrical signal. Here, the lens regulates the light by auto iris mechanism. This operation is performed simply with the equation F = f/d where F and d are focal length and lens effective diameter repectively. An optical seperator behind the lens

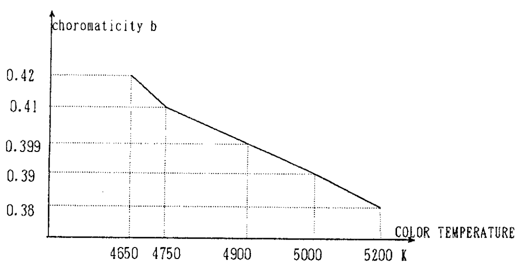


Fig.3 Relation between color temperature and r of the sunny part of the asphalt road

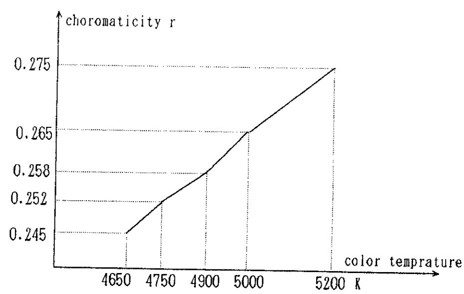


Fig. 2 relation between color temperature and r for sunny part of the asphalt road

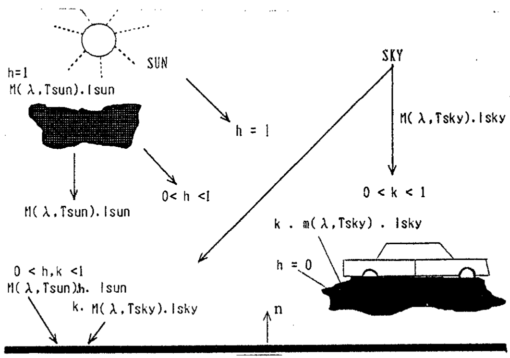


Fig.4 Simple presentation of outdoor environment

breaks the incoming light into its red, green and blue components. The result can be expressed by the following equations:

$$\phi_R = c/F \int \rho(\lambda) M(\lambda,T) I . nR'(\lambda) d\lambda \quad (2)$$
$$\phi_G = c/F \int \rho(\lambda) M(\lambda,T) I . nG'(\lambda) d\lambda$$
$$\phi_B = c/F \int \rho(\lambda) M(\lambda,T) I . nB'(\lambda) d\lambda$$

where c shows the lens and iris effects, $R'(\lambda)$, $G'(\lambda)$ and $B'(\lambda)$ are red and green and blue spectral sensitivity of the TV. camera. $\rho(\lambda)$ is defined as the spectral reflectance of the road surface.

From experience, we found that the stimulus values of R and B are enough to discriminate between sunny and shadow regions of the asphalt road. From (1) and (2) we can find R and B components of the sunny and shadow parts. As Isun is about 10 to 20 times larger than Isky we can neglect the sky effect for ϕ_{R0} and ϕ_{B0} values.

In this case we obtain the following results:

$$\phi_{R0} = c/F \int \rho(\lambda)(hM(\lambda,Tsun) Isun . nR'(\lambda) d$$
$$\phi_{B0} = c/F \int \rho(\lambda)(hM(\lambda,Tsun) Isun . nB'(\lambda) d \quad (3)$$

For the shaded part coefficient h will be almost zero. The values of R_1 and B_1 of shaded region of the asphalt road can be found by:

$$\phi_{R1} = c/F \int \rho(\lambda)(hM(\lambda,Tsky) Isky . nR'(\lambda) d$$
$$\phi_{B1} = c/F \int \rho(\lambda)(hM(\lambda,Tsky) Isky . nB'(\lambda) d \quad (4)$$

As a practical term, ϕ_{R0}, ϕ_{B0}, ϕ_{R1}, ϕ_{B1} of equations (3) and (4) apart from camera color response, and which do not show the exact values of the shaded and sunny region of the asphalt road. That is because of the problem of DC component and γ function of the video camera.

In the video signal the DC component is feed back controlled by the integrated value of Y signal of a frame. The incorrect DC level results in wrong brightness and there fore produces incorrect colors. So (2),(3) should be recorrected by adding constant values:

$$R_i = \phi_{Ri} + D_{i1} \quad (5)$$
$$B_i = \phi_{Bi} + D_{i2}$$

where i=0 indicates sunny part and i=1 indicates shaded part.

In other hand γ is a number which indicates how contrast is expanded or compressed. That is, γ shows the nonlinear relationship between the light values and video signal voltage where the Light output varies as the square of the video driving voltage. However γ function produces incorrect value of hue. Although γ corrector amplifier and auto iris control have been implemented in many video cameras, it seems that they are not enough to show the chromatic values.

4. Statistical analysis

As the color filter and color component amplifier characteristics are not opened for the users, R_i and B_i can be approximated by some statistical tools. From the experimental results we can define R, and B of the sunny and shaded part of the asphalt road by the following relations:

$$R_0 = a_{11} + a_{12}Tsun + a_{13} * A + a_{14} * A^2 \quad (6)$$
$$B_0 = a_{21} + a_{22}Tsun + a_{23} * A + a_{24} * A^2$$
$$R_1 = a_{31} + a_{32}Tsky + a_{33} * A + a_{34} * A^2$$
$$B_1 = D_{41} + a_{42}Tsky + a_{43} * A + a_{44} * A^2$$

Where A is the area of the shadow region represented by the percentage of that of the window fixed on the lower half of the TV. frame. (refer to Fig.5).

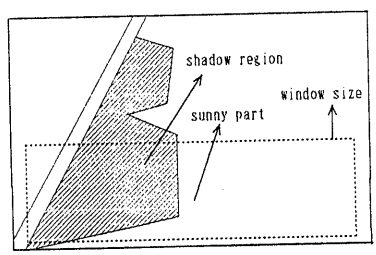


Fig. 5 The scene of road in 2_D image with defined window size in Lower half of the screen

The reason of using shadow area A is that when the area of shadow region changes, the intensity of the sunny region and shadow region change too. Strictly speaking, when the area of the shadow region increases gradually then the intensity value of either the shadow and sunny region will increase, but when the shadow region becomes greater than sunny region then the intensity of both the sunny and shadow region decrease with a small inclination. However it is a part of the video camera characteristic which we call, video camera color response.

It means that R and B of both sunny and shaded region are influenced by area of shaded region. As the correlation between A and R_o,B_o,R_1,B_1 are not so large, some non linear tendency caused by DC and γ effect are assumed to exist. That is the reason why Quadratic regression formulas for predictor variable A are applied.

4.1 Scatter diagram of sunny and shadow part

To prove the above discussion, many scenes of the road were taken under fine and partly cloudy weather condition and recorded on three video tapes #1, #2, #3. TV camera is home video camera S_VHS type (Victor BR-S20) which we used is fixed white balance (5500 °) and auto iris control. Video tapes are feeded to sunny and shaded road detection program which is able to detect sunny region automatically, and shaded region is selected manually and then calculate R,G,B,area size of shaded and sunny region automatically and save them with additinal results on a disk.

Video tape #1 was taken in fine day. TV. camera was fixed on a mobile of 140cm in height, directed to the road in 3 ~ 7 meter in distance . Here many scenes of a white car which moved from right to left was taken. In the video tape the shadow of car changes gradually from 0% to 100%.

Video tape #2, #3 were taken under fine and partly cloudy condition respectively. The TV. camera was fixed on a mobile of 140cm. The mobile moved on the sunny and shaded road of no car with 20cm/s in speed. Fig.6,7,8, and 9 show the scatter diagram of R_o-A, R_1-A, B_o-A, and B_1-A of 38 different scenes obtained from tape #1 where the abscissa indicates the shadow area A in percentages and ordinate indicate criterion variable R_1,B_1 which is betweem 0 to 255 in value.

Here the stimulus value R and B marked by a cross (+).

The following regression formula was found from tape #1:

$$R_o=130.2 + 0.808 * A \quad r=0.544 \qquad (7)$$
$$B_o=136.2 + 0.491 * A \quad r=0.373$$
$$R_1=30.74 + 0.535 * A \quad r=0.630$$
$$B_1=55.20 + 0.450 * A \quad r=0.522$$

As the color temperature is assumed to be constant for one scene, it is implied in the first

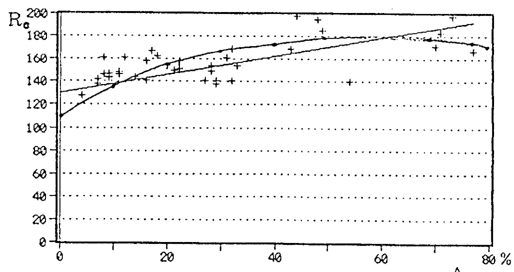


Fig.6 The scatter diagram of A and R of sunny region in fine day. The line represents: R0=130.2+0.808*A, n=38 ,r=0.544 the curve represents 0=113.4+2.24*A-0.02*A^2

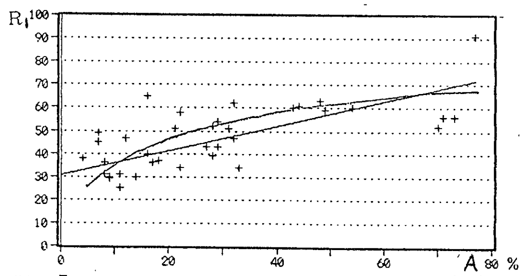


Fig. 7 The scatter diagram of A and R of shadow region in fine day. The line represents: R1=30.74+0.535*A, n=38 ,r=0.63

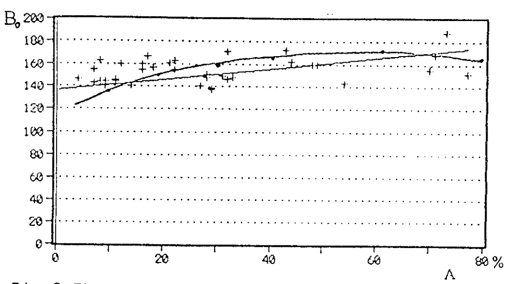


Fig.8 The scatter diagram of A and B of sunny region in fine day. The line represents: B0=136.2+0.491*A, n=38 ,r=0.373 the curve representsB0=121.4+1.75*A-0.017*A^2

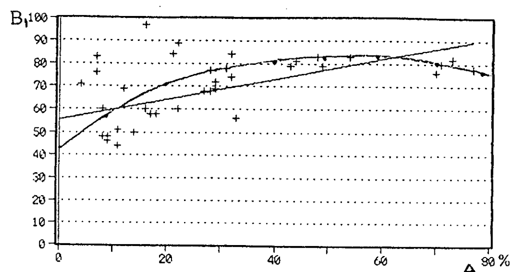


Fig.9 The scatter diagram of A and B of shadow region in fine day. The line represents: B1=55.2+0.45*A, n=38 ,r=0.522

factor of the (7). The forth factor is also neglected to have a linear approximation. From (7) it is found that the R,B of shaded and sunny regions are influenced by the area of the shadow region. We found that the correlation r of (7)is not so large. It means there are some non linear ship tendency caused by DC and γ in measurement. In order to find a better prediction, the quadratic regression formula applied again for the tape #1.

$R_0 = 113.4 + 2.24 * A - 0.020 * A^2$ r=0.64

$B_0 = 121.4 - 1.75 * A - 0.017 * A^2$ r=0.48

It is found that the correlation r improved by adding quadratic factor of A.

To investigate the color shift of sunny and shaded region from fine to the partly cloudy weather video tape #2 ,#3 was used. Fig.10, Fig.11 show the scatter diagram of R_1-B_1 of 110 and 138 different scenes of fine and partly cloudy respectively. From Fig.10 and Fig.11 we find that The dispersion of the R_1-B_1 of the fine weather is much smaller than partly cloudy condition. As a second result we find the big correlation between R_1-B_1 for the both of the fine and partly cloudy condition.

5.Basic Parameters for Shadow detection

In the case of shadow detection the following should be considered :

1) The following relations can be obtained from Fig.11, and Fig.12 in different color temperature or in other word different weather conditions:

$R_0 > R_1$

$B_0 > B_1$ where $b_1 > b_0$

2) The intensity values of shadow and sunny regions are functions of the shadow area size in the defined window size as shown in Fig.6 to Fig.9.

3) When the weather changes from sunny to the partly cloudy then the cluster of the shadow and sunny parts of the asphalt road shifts smoothly. In this case the hue of the shadow region will increases in B component and decreases in red color, as shown in Fig.10 and Fig.11.

4) In order to distinguish shadow region from obstacle, for instance car and its shadow, multi regressional analysis which relates the R_1, and B_1 of shadow region to sunny region should be used.

According to the Fig.10 and Fig.11, because of the strong correlation between R_0,R_1 and B_0 and B_1, it is possible to predict the stimulus values of the shaded region with the stimulus values of the sunny part of the asphalt road with a good precision by using the following equations:

$R_1 = \alpha_1 * R_0 + \beta_1$

$B_1 = \alpha_2 * B_0 + \beta_2$

Where α_i indicates correlation between R_0, R_1 and B_0, B_1, and β_i indicates level shift influenced by A and color temperature.

6.Result of shadow detection and elimination

With the parameteres defined in above the shaded area on the asphalt road can be detected and elliminated in outdoor environment with a good accuracy. According to the method robot first detects weather condition by investigating the color temperature and brightness value and then sets up those values related to the color shift. After filtering and edge base segmentation of the original image if sign pattern detection fails in road following mode then shadow detection procedure starts. Initially the intensity and R,B values of each region are checked. If the values are in the defined ranges then regressional analysis is applied. If the result of the analysis is with in the acceptable range then that region is considered as shadow region and its R,G,B values are changed by sunny's one and finally the edge between the shadow and the sunny part of the asphalt road is eliminated. Fig.12 shows the shadow detection procedure for the shadow of the building on the asphalt road. Fig.13 shows the shadow

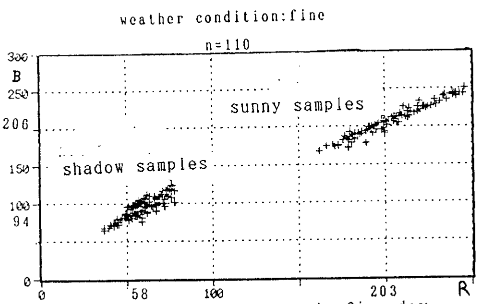


Fig.10 R-B scatter diagram in fine day.
sunny samples: R_0=203, STD=20.8, B_0=206, STD=21
n=110, r=0.967
shadow samples: R_1=58, STD=10.1, B_1=94, STD=14
n=110 , r=0.862

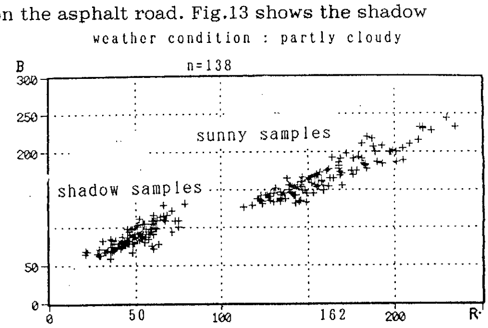


Fig.11 R-B scatter diagram in partly cloudyday.
sunny samples: R_0=162, STD=11.5, B_0=171, STD=16
n=138, r=0.873
shadow samples: R_1=50, STD=29, B_1=99, STD=29
n=138 , r=0.847

detection and ellimination of a car which has almost the same color as the shadow. As it is seen, although the small part of the car is colored by the color of the sunny region but the edge between the body of the car and and its wheel with the sunny part is still remained, when the shadow is detected and eliminated successfully.

7. CONCLUSION

In this paper we talked about a new method for shadow detection in outdoor environment.

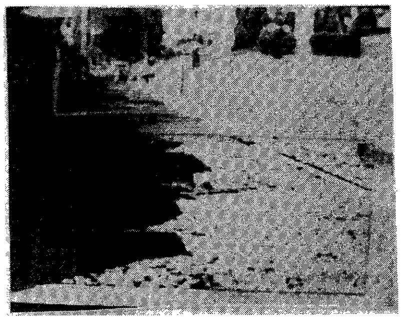
Choromaticity of sunny and shaded part of asphalt road are changed by weather condition. To express weather condition we introduce the concept of color temperature. Spectral distribution of the sun light and diffused sky light is represented by color temperature T.

We can calculate photometrically R,G,B values by integrating R,G,B spectral sensitivities for reflected light from road surface which is illuminated the sun and sky light, but the real R,G,B component of TV. camera do not match this theory. The reason is that, in converting physical light to video signal DC level adjustment and γ correction are applied by mechanism of auto iris and electrical circuit of video amplifier.

We found that robot can detect weather condition by one of the folowing methods, using the the color shift of the G component of the standard white color chart measured by video camera or using the color of the sky measuring by the colorimetric device.

We apply multi regressional analysis to the sunny and shaded region of the asphalt road, and assume that R and B of sunny and shaded region of TV. image area as criterion variables, and color temperature and the area of the shadow region as predict variables. As a result we can represent formulas which can predict the stimulus values R,B of the shadow region by that of sunny region. By applying these formulas we can detect shadows of the car and eliminate them by software in considerably short time.

We will appretiate any suggestion and advice related to our approach for shadow detection and elimination.



Edge base segmentation

After shadow detection
and ellimination

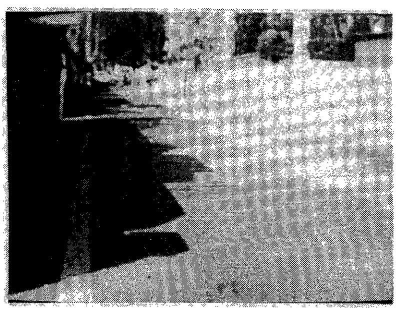
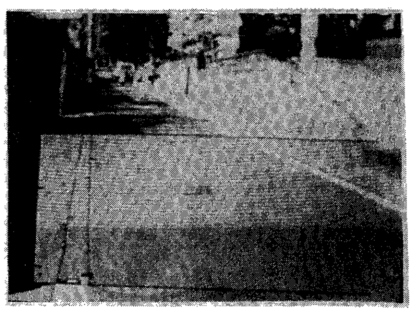


Fig.12 Original image



After edge ellimination

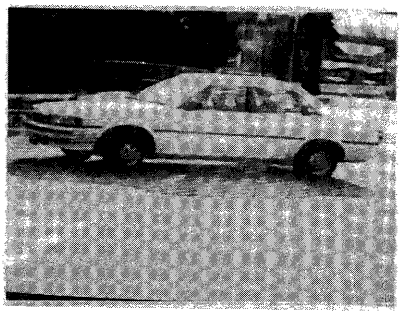
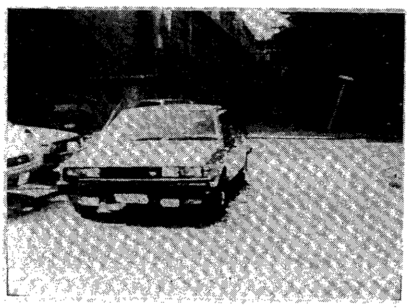


Fig.13.a Original image

After shadow detection and ellimination

Fig.13.b Original image



After shadow detection and ellimination

References

[1]M.Herbert,E.Krotkov,"3-D Measurement From Imaging laser Radar: How good are they ? ", International intelligent Robots and system,IROS91,p.359-364

[2]V.Graefe,U.Jacobs,"Detection Of passing vehicles by a Robot car Driver",International Intelligent Robots and System, IROS,1991,p.391-396

[3]A.Turk,"Color road Segmentation and Video Obstacle detection",SPIE, vol.727 Mobile Robot ,1986

[4]H.Chen,H.Mori,"Sign Pattern Detection on Shaded road",IEEE/RJS International Workshop on intelligent robot and systems,1989,p.350-357

[5]B.Judd,L.Macadam,G.Wyzecki,"Spectral Distribution of a daylight as a function of Correlated color temperature",Journal of the optical society of America,1964,p.1031-1040

[6]R.gershon,"From R,G,B to surface Reflectance: Computing Color Constant Descriptors in Images",p.755-758

[7]A.Turk,"VITS-A vision system for autonomous land vehicle navigation",IEEE transaction on pattern analysis and machine intelligence,1988, p.342-361

[8]F.Blommaert,An object oriented model for brightness perception,spatial vision ,1990,p.15-40