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FROM THE PHOTOGRAPHIC CAMERA TO AN ELECTRO-OPTICAL IMAGING SYSTEM

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Abstract

The photography camera and a video camera system have used in many purposes from a hand camera to space imaging system. This paper is concerned to upgrade the photography camera that used for survey or surveillance applications. A direct method is to replace the film magazine and the shutter by a Charge Couple Device (CCD). Since the most of these photographic camera systems have a big size, in which the adapted CCD detectors are hard to be available or assembled. An alternative new technique will be described through this paper to upgrade the photography camera to an electro-optical imaging system. An example was applied to illustrate the upgrading procedures, and many experiments were done using survey photographic camera and the results were successfully.

Key words: Electro-Optical Detectors, Photographic Camera, Digital Image Processing.

I Introduction

The photography camera system provides ground imagery on standard thin film. Like these systems are designed for acquisition of high quality photography on square image for surveying or reconnaissance purpose. Most of these imaging systems are used with different platforms like airplanes or spacecrafts. In reconnaissance applications, a good imagery can be obtained with a photographic camera (panchromatic) under almost any conditions clear enough for flying different altitudes photographic missions. However, significantly better photographs can be obtained when, under the proper atmospheric conditions and near midday.

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It is important to mention here, that the film should have high-resolution capability than the other imaging sensors. In comparison between the film that used in surveillance applications and x-ray film, the former is much finer resolution than the latter, but it is also much slower. It means the photographic film that used in reconnaissance imaging system needs twice the exposure of x-ray film. This makes the photography camera system much more dependent on the platform stability and high illumination levels [1].

In 1980's, the optical lens systems have been developed to resize the camera system to be compact to fit its platform like spacecraft and airplanes. The photographic camera systems were upgraded to electro-optical systems, and the research on this field was mainly concentrating on replace the camera body (the film magazine and shutter) by electro-optical sensor like CCD device. The first reason for that was to transfer images electrically through the communication networks. The space technology has a greet demand to send images from space to ground through data links rather than throwing films down to the earth as Russian did through 1960's. The second reason was to save the time of the film processing until get the image view. Currently, the development of electro-optical camera system was concentrated in pixel resolution to increase the capacity of CCD elements to be more than 25 mega pixels and the wave band of the optical part to be dual band (visible/infrared) to obtain high resolution imaging system.

II Photographic camera and CCD detector

In this work, the photographic camera system was upgraded using two methods. The first method is to replace the film magazine and the shutter with a solid-state device to sense the image information, which is coming through the lens set of the photographic camera. Unfortunately, the size of that CCD detector should be identical to the dimension of the film magazine/shutter of the photographic camera. In case of the big dimension of the film magazine, the matched CCD sensors will not be available at the market. An alternative method is to do assembly off small sensors to obtain the adapted CCD detector. However, a novel method is to reduce the image size of the photographic camera to match the available CCD detector. The specifications of the CCD sensor, which can be used instead of the film magazine and the shutter of the photographic camera, can be described through the following steps,

(1) The pixel size of the CCD, d_{CCD} will be calculated as,

$$d_{CCD} = f\,(r_G / h_G)\ , \qquad (1)$$

Where r_G and f is the ground resolution, and the focal length of the photographic camera at altitude h_G.

(2) The dimension of the CCD detector wxw will be the same as the film frame size $w_f x w_f$.

(3) The number of pixels N_p in each side of the CCD sensor is computed as,

$$N_p = w_f / d_{CCD} \tag{2}$$

Regarding to that work, a surveying photographic camera type UMK 10/1318 was used as an example to illustrate the methods that described in this paper. The specifications of surveying camera UMK 10/1318 is shown in Table 1.

Camera parameter	Data
Objective: Type Focal length Maximum distortion	 Carlzeiss 200 mm ± 5μm
Shutter: Exposure time Diaphragm setting	 T, B, 1, …, 1/400 sec f/8, …, f/32
Aperture:	40 mm
Focusing:	From ∞ to 5.8 m
Picture size:	120x166 mm
Field of View: Long, short, and diagonal picture size	 45°, 33°, and 51°

Table 1. The specifications of surveying camera UMK 10/1318.

Instead of the shutter and the film magazine of the camera UMK, CCD detector of dimension 6.6x8.8mm, 0.2 megapixels resolution, and all one chip of type TC241 produced by Texas Instruments for B/W NTSC TV applications was used. The CCD detector was apart of a TV video camera type CUHO, 4810 series, and it was exploited in this applications. Different objects were fixed upon 4.5 meters from the camera UMK inside the geomatics lab, and many snapshots were recorded when the CCD device moves from position to other in the image plane. Fig. 1 shows a sample of snapshots that captured by the camera UMK and recorded by the CCD detector (TC241). Since the CCD dimension of the CCD is $6.6 \times 8.8mm$ with 0.2 megapixels resolution, then there are about 324 CCD detectors. It is obvious that the dimension of the film magazine of the camera UMK is too large compared to the standard CCD detectors of size 4096x4096 pixels and with pixel pitch ranging from about 3 to 30 microns [2].

Fig. A sample of images that captured by the camera UMK and the CCD is at its image plane.

It is obvious from above discussion that this solution is not applicable from the dimension and capacity points of view. It is important to mention here, that the resolution of the photographic camera is measured in terms of a pair of lines per millimeter. Therefore, the sensitivity of the film represents a critical parameter of the camera resolution. In the CCD camera, the image resolution depends upon the pixel size and the number of the pixels in each side. In other words, the more pixels in, the more resolution will be obtained. The reasons for upgrading the photographic imaging system is a greet demand because of: (1) the cost-effective; (2) the film time processing; (3) the applications of the data link.

III Upgrading photographic camera

In previous section, a CCD sensor or group of CCD detectors is replaced the film magazine and shutter of the photographic camera. Unfortunately, that solution is not applicable. However, in this section we will present a new method to upgrade the photographic camera to an electrical one. The photographic system-universal surveying camera type UMK 10/1318 will be used as an example to demonstrate the upgrading technique. The present technique has been based on reducing the image plane of the camera UMK to match the CCD detector (TC241) by adding compound lenses in between the original lens and the CCD detector.

Based on the ray tracing method [3], an optical program Oslo version LT5.4 was used to design the required lenses that should be added between the lens f_0 and the CCD detector. The ray tracing design model can be summarized as fellow,

(1) The ray incident (with angle θ_1) to the lens f_0 of the photographic camera passing to the first added lens to the image plane as shown in Fig. 2, where θ_1 is calculated as,

$$\theta_1 = \tan^{-1}(0.5 \times r_2 / f_0) \quad (3)$$

Where r_2 is the height of the image plane of the camera UMK and the angle θ_1 was found to be 16.69º.

Fig. 2. The original lens and the two added lenses.

(2) Using Oslo program and based on that ray and the field of view of the camera UMK defined in Table 1, the material of the lenses was selected from the library of the program and it was BK7, grade A, fine annealed optical glass with refractive index of n=1.515 at $\lambda = 6328A^0$ near the middle of the visible range.

(3) As shown in Fig. 2, the angles θ_1, type of glass BK7 and the output ray angle θ_4 (zero degree or collimated beam) have to input to the Oslo program. The designer should input the program with the type of the added lenses convex or concave (each separate), the radius of the lens curvature, and the aperture of each lens, keeping the specification of the lens f_0 and CCD detector fixed.

(4) Starting by two lenses, the program could be applied to see how the output beam will be. If the output beam is not collimated, the designer shall modify the position of the added lenses or change the specification of the added lenses to meet the required conditions. The number of the iterative will depend on the experience of the designer.

(5) Not having collimated beam at the output requires adding another lens to our optical design.

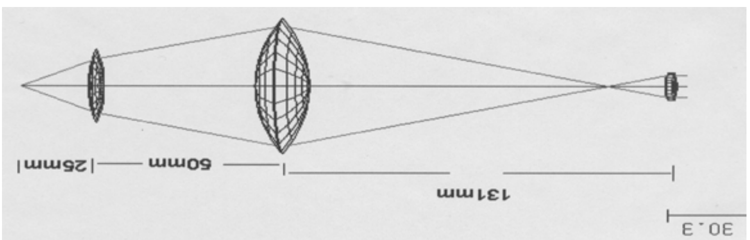
(6) Once the output-collimated beam is obtained, the focal length of the added lenses is calculated as,

$$1/f = (n-1)(1/R_1 - 1/R_2), \qquad (4)$$

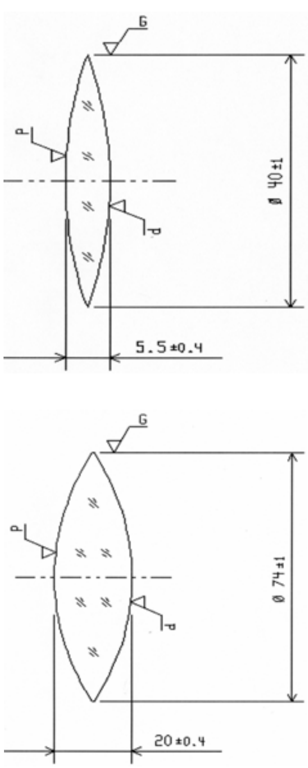
Where R_1 and R_2 are the radius of curvature of the thin lens from the incident and refraction directions respectively and R_2 should be in negative.

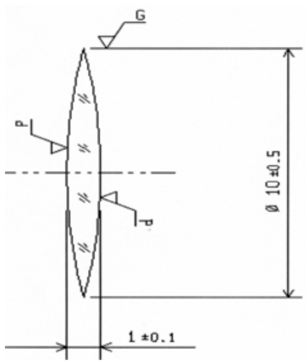
The above steps are applied using the Oslo program to obtain the specifications of the added lenses and the distances in between. Fig. 3 shows the path of the rays and specification of the added lenses.

Table 2 illustrates the specification of the added lenses f_1, f_2, and f_3, where D_f is the distance between each lens and the lens f_0. The field of view of the whole system was calculated using the output drawing of rays shown in Fig. 3 (a) and the focal length of the lens f_0, and it was found to be 46º. The minification of the added lenses was calculated and it was found to be 0.050. It obvious that the designed field of view and the demagnification values are close to required values, which are 45º (horizontal) and 0.053 in correspondence.



(a)





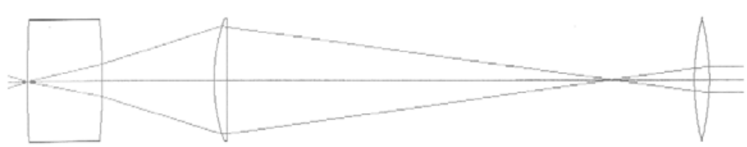
(b)

Fig. 3. (a) The design of the added lenses f_1, f_2, and f_3, where all numbers are in mm, (b) the specifications of the added lenses.

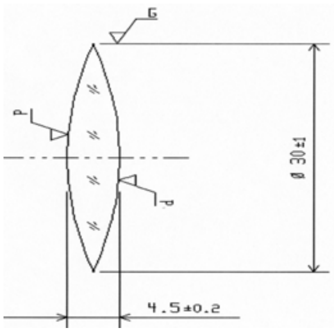
Parameter	Lens f_1	Lens f_2	Lens f_3
Radius of curvature	75.0 mm	75.0mm	25.0mm
Thickness	5.5 mm	20.0 mm	1.0 mm
Aperture	40.0 mm	74.0 mm	10.0 mm
Focal length	72.8 mm	72.8 mm	24.3 mm
D_f	30 mm	80 mm	213 mm

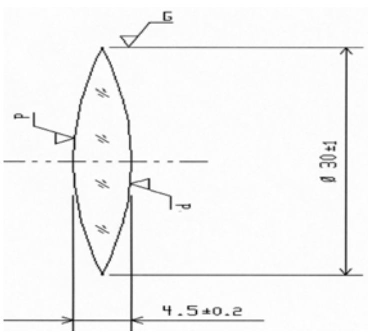
Table 2. The specification of the added lenses f_1, f_2, and f_3.

Unfortunately, the aperture of the lenses at hand was 25.4mm, so we have been redesigned another optical model using ray tracing method, Oslo program and the design steps just mentioned. The new optical model consists from the original lens f_0 and two added lenses f_1 and f_2, and CCD detector as shown in Fig. 4. Table 3 shows the specification of the lenses f_1 and f_2, and the distances in between. The field of view was calculated to be 16.7°, and the minification ratio between the original image plane and the CCD plane is about 0.12, however these values are far compared to the required values, but they are match to the lenses at hand.



(a)





(b)

Fig. 4. (a) The design of the added lenses f_1 and f_2, where all numbers are in mm, (b) the specifications of the added lenses.

Parameter	Lens f_1	Lens f_2
Radius of curvature	50.8 mm	50.8mm
Thickness	4.5 mm	5.0 mm
Aperture	30.0 mm	30.0 mm
Focal length	49.3 mm	49.3 mm
D_f	32.0 mm	236 mm

Table 3. The specification of the added lenses f_1 and f_2.

IV Coverage and resolution

The coverage depends mainly on the field of view and target distance. The field of view of the new camera was measured practically in horizontal and vertical directions in the physic lab and was found 12.1º and 17.8º respectively. The field of view of the camera decreases by about 37 percent than the original field of view, and the same for the coverage area. Fig. 5 shows an example illustrating how the field of view was measured in the horizontal direction.

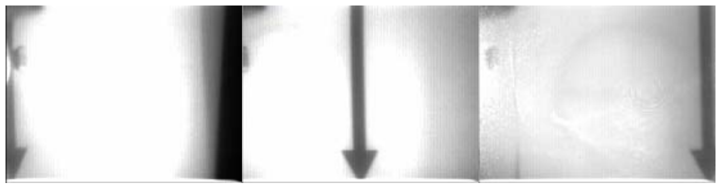


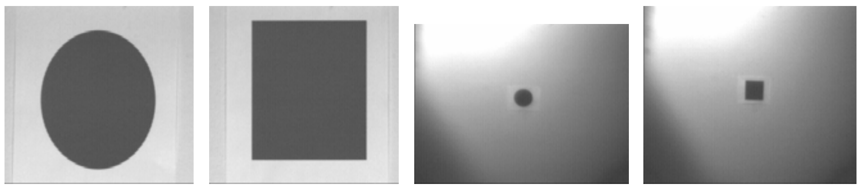
Fig. 5. Three snapshots of arrow moves in horizontal plane (all numbers are in cm).

Digital image resolution divided into two basic categories. Much of the confusion over digital image resolution can be settled by understanding the difference between pixel count resolution and spatial resolution. Spatial resolution is a variable property of an image, and does not apply to an image file, only to a physical image, and it is commonly referred to in terms of dpi or ppi (dot per inch or pixel per inch). Pixel count resolution is expressed in either megapixels or pixel dimensions, and it is a fixed property of an image. Unless the image is resample or cropped the image remains the same number of pixels. It means that pixel count resolution and spatial resolution are two independent factors of one another. However, there is another term of image resolution is called target resolution, which means how much length; the pixel covers from the target. The target resolution was measured carefully in the lab in two cases: (1) the CCD detector fixed in the image plane of the camera UMK (camera-I); (2) after adding the two lenses f_1 and f_2 (camera-II). Two images were taken for two objects one is a circle of diameter 15.2 cm and the other one was square of side length as the diameter of the circle, where the distance between the object and the camera was 6.2m as shown in Fig. 6.

The images are digitized and corrected geometrically according to the value of the aspect of ratio of the CCD detector (0.75). The width of the square or the circle images

r_T covered by only one pixel of the CCD detector is calculated using the digital image processing, and it was found 0.78mm and o.33mm in vertical and horizontal respectively in case of camera-I, and 5.4mm and 2.3mm in correspondence in case of camera-II, where the target was at distance h_T=6.2m. The angular resolution θ_{ang} of the camera-I and the camera-II are calculated as,

$$\theta_{ang} = 2\ \tan^{-1}(r_T / 2h_T) \tag{5}$$



(a) (b)

Fig. 6. (a) A circle and square images captured by the camera UMK without lenses, and (b) the same images captured by the camera UMK with the added lenses.

Since the angular resolution θ_{ang} is a fixed value to the camera, and the target resolution are considered as the average between the vertical and the horizontal target resolution, it was found in the case of camera-I, the target resolution can be calculated as,

$$r_T \approx 0.86 \times 10^{-4}\, h_T \tag{6}$$

However, in case of camera-II, equation (6) will be modified to the following relation,

$$r_T \approx 6.2 \times 10^{-4}\, h_T \tag{7}$$

The target resolution of the camera-II and I are calculated at different target distances, and Fig. 7 shows the target resolution in the two cases. It is obvious that the target resolutions for both cameras are nearly close at low altitudes; however, the target resolution of the camera-I is superior to the camera-II by a factor 7.0 at medium and high altitudes. If the number of pixels of both sides of the CCD detector increases to 1708x5460 pixels, and the pixel pitch changes to 3.8x1.6µm, then the target resolution of the camera-II and I could be similar.

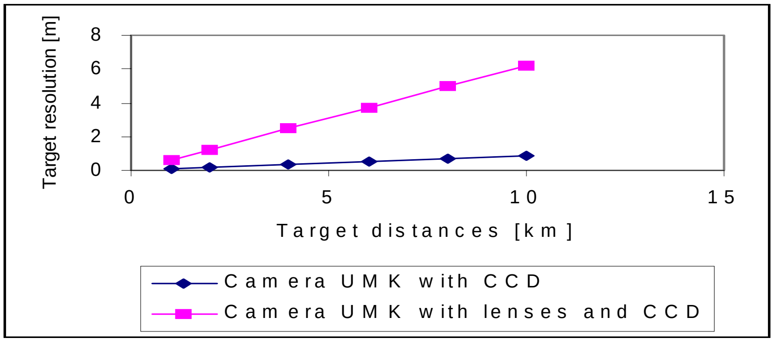


Fig. 7. The target resolution of the camera-camera-II and I.

V Experiments and results

Since real object distance for actual imaging is from 5.8m to ∞, accomplishing an optical design was hardly possible in the physics lab. Thus, the following optical setup has been considered to reduce the image plane from size to size. The image size of the camera UMK should be reduced by a factor of 0.054 to match the CCD detector (TC241). This optical match has been done successfully using two lenses that are fixed between the lens of the camera UMK and the CCD detector, and the setup for optical measurements (as shown in Fig. 8) will be summarized as,

(1) A laser source of type Helium-Neon generating laser beam of wave length $\lambda = 6328A^{\circ}$.

(2) A pinhole ($100\mu m$) and an aperture to generate circular diffraction pattern and filter higher diffraction orders respectively.

(3) Two Bi-convex lenses type (KPX091 and KPX085) with focal lengths 88.3mm and 62.9mm respectively were used to obtain a relatively high quality collimated laser beam.

(4) A beam splitter and a mirror were used to split the laser beam into two beams with an angle equal 17.5º corresponds to ½ the vertical field of view of the camera UMK.

(5) Two optical lenses of type Bi-convex with the same wavelength 50.2 mm with apart of about 23.5 cm were fixed on the back of the photographic camera. The first lens was fixed inside the camera UMK behind its lens with apart of 2.7 cm. The specifications of the lenses f_1 and f_2 is close to the design lenses shown in Fig. 4 and Table 3.

(6) The CCD detector (TC241) was fixed along the optical axis within a distance about 6.5

cm from the lens f_2, keeping all the optical equipments were aligned to the same optical axis.

(7) To measure total minification M_t of two added lenses, two snapshots were captured the two spots of the laser beams before and after adding the two lenses at distances 34.4mm and 2.6mm respectively and M_t was found to be 0.075 as shown in Fig. 9.

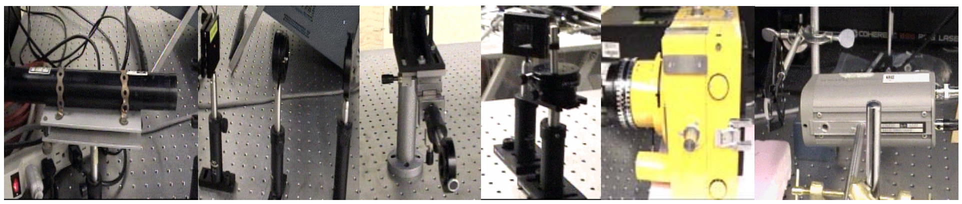
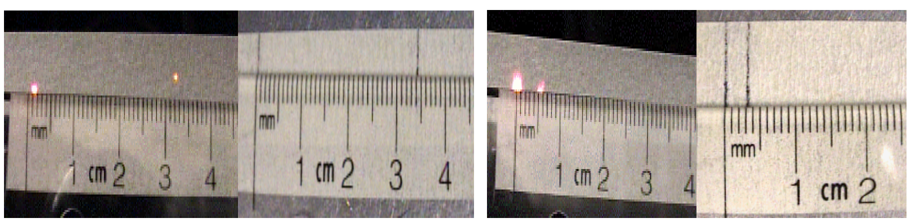


Fig. 8. An image for the optical line that used to measure the optical match between the lens f_0, the two added lenses and the CCD detector.



(a) (b)

Fig. 9. (a) and (b) The image of the two spots of the laser beams before and after adding two lenses to the camera UMK.

The images shown in Fig. 10 were for the same object (a circle of a diameter 8.5cm.) that fixed at a distance 1 m from the camera UMK. The resolutions of these images seem different and the coverage of the left image is larger than the others since the field of view of the camera UMK is larger than the others. Fig. 11 shows the outdoor images through the daytime using the three cameras (camera-II, CUHO-4810 series, and Sony-TRV20).

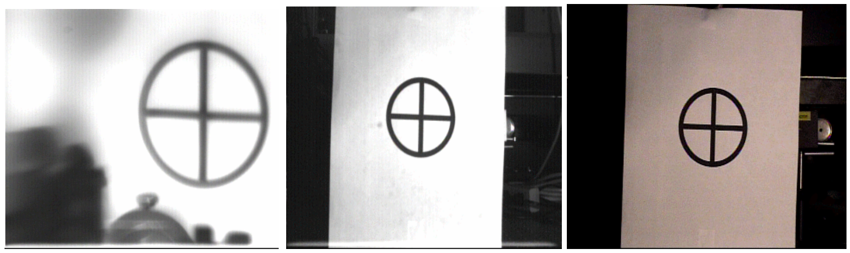


Fig. 10. From left to right three images are captured using the camera-II, camera CUHO and camera Sony model (DCR-TRV20) respectively.

The images of the camera-II seem to be better than the camera CUHO because the camera-II has a high quality lens (Carlzeiss 200/8), and the lens of the camera CUHO is TV lens of 12.5mm focal length. The distance between objects and any one of these cameras was about 108m.

Fig. 11. From lift to right shows two samples of outdoor images were captured by the camera-II, and the other two images (of the same object) were captured by camera CUHO and camera Sony respectively.

VI Conclusions and discussions

Many researchers have been concerned about upgrading the photographic camera system to an electro-optical imaging system by replacing the film magazine and the shutter to an equivalent electro-optical sensor of one-dimensional or two dimensional array CCD devices. In most cases, the field of view that covers the film magazine and the shutter of the photographic camera is greater than that one covers the standard CCD detectors. In this work, the ray tracing technique was exploited to resize the image plane of the photographic camera to the standard CCD sensors.

Two optical models are described through this paper to demonstrate the upgrading of a surveying camera model UMK10/1318 to an electrical-optical one. It was great; when the output of the design optical models was close to the experimental results. It was important to mention here that the field of view and the target resolution could be similar as the concerned values, if the required lenses and CCD detector with high pixel resolution and low pixel pitch are at hand.

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