# Hidden grids, moiré patterns and optoelectronically measurement of distances

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## ABSTRACT

Hidden grids from the photocopy process are used to produce moiré patterns. The method of production of moiré patterns is extended to hidden grids generated in the optoelectronical CCD observations. An application of this moiré is proposed to measure distances.

**Keywords:** photocopier hidden grids, CCD hidden grids, moiré effect, distance measurement.

## 1. HIDDEN GRIDS AND MOIRE PATTERNS

Various methods exist to make photocopies of an original image. Photocopies are produced on opaque paper or transparent plastic sheets. The original image can also be a slide that is projected onto the photocopier window or scanned. Each method has its proper form to generate the copied image. In general, matrix of equally or stochastically spaced points or equally spaced lines are employed to reproduce half tones and colours. Figure 1 shows these two types of hidden grids observed under microscope. Also, Figure 1 shows the Fraunhofer diffraction patterns of both grids. The light sources used were a 15 cm long filament lamp and a fluorescent tube.

The matrix of points of the array of lines can be considered as hidden grids that are incorporated to the image through the photocopy process. Hidden grids can be used to encode information into the reproduced image in order to characterize some properties of the original object.

This paper deals with an application of the hidden grids to measure distances in the original object space using the moiré effect to decode the necessary information.

## 2. PROPOSED METHOD TO MEASURE DISTANCES

Figure 2 shows the geometrical optics principle to form an image through a lens. Let be the object a plane -like a wall- that is perpendicular to the optical axis of the photographic objective O. The optical axis corresponds to the Z-axis of the Cartesian reference system (X, Y, Z). Onto the photographic film, the coordinate system (x, y, z) is the Cartesian reference in the image space. The optical axis corresponds to the z-axis. Points $P_1$ and $P_2$ on the wall are reference marks to define the metric in the object space. They are separated a distance D. Points $p_1$ and $p_2$ are the images of $P_1$ and $P_2$ , which are reproduced without aberrations. If the distance L from the camera objective to the wall is large enough, the distance d from point $p_1$ to point $p_2$ on the film can be expressed as $d = f\,D/L$, where f is the focal lenght of the objective. If the photographic camera is rotated an angle $\alpha$ around the z-Z axis, the distance d maintains its value on the film because it is an invariant under rotations.

The proposed method to measure distances requires of two slide pictures of the wall to be photographed. The first one corresponds to the position of the camera on which x-axis and y-axis on the film are parallel to the X-axis and Y-axis on the wall respectively. The second slide picture corresponds to the position of the camera rotated an angle $\alpha$ around the z-Z axis. Transparencies from both slides are prepared in the normal fashion. Each transparency reproduces an enlarged slide image. Points $p_1$ and $p_2$ on the slides are reproduced as points $p'_1$ and $p'_2$ on the transparencies. If the magnification of the photocopier optical system is M, the distance $d'$ between points $p'_1$ and $p'_2$ can be expressed as $d' = Md$. Besides, the superposition of both transparencies generates a moiré pattern. In order to measure distances the superposition must be done in such a way that images of $p'_1$ and $p'_{1\alpha}$ and $p'_2$ and $p'_{2\alpha}$ be in coincidence. Then, it is possible to observe moiré fringes generated by transparency-hidden grids rotated through an angle $\alpha$. So, it means that the moiré pattern decodes the rotation operation that was encoded in transparencies. Figure 3 describes the geometrical situation. If the period of the hidden grid is $T_G$, the period of the observed moiré fringes results:

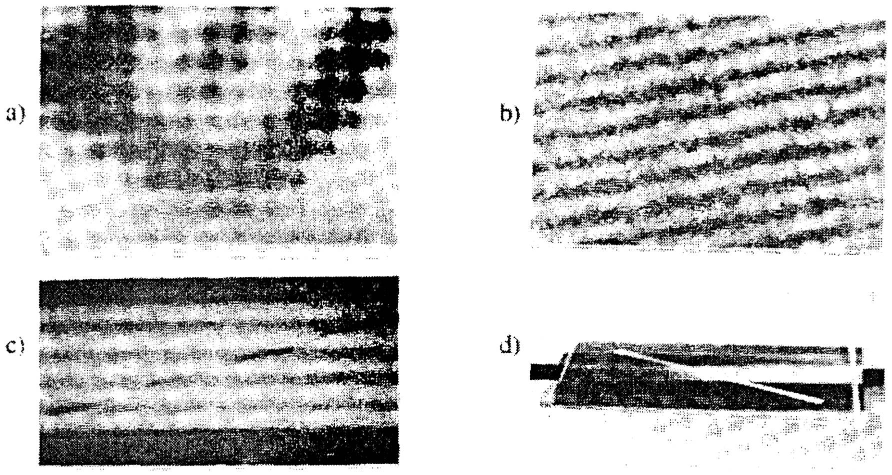


Figure 1. a) Hidden matrix 100 µm x 100 µm point array (Kodak color thermal copier); b) Hidden grid 128 µm spaced lines (Cannon color laser copier); c) Fraunhofer diffraction pattern of the hidden array at a) using a 15 cm long filament lamp as light source (positive), and d) Fraunhofer diffraction pattern of the hidden grid at b) using a fluorescent tube as light source (negative).

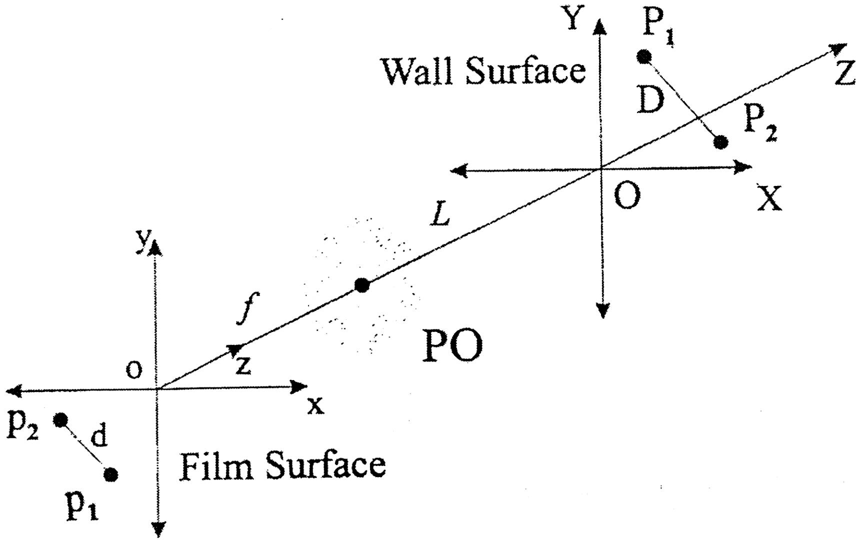


Figure 2. The photographic objective PO forms images $p_1$ and $p_2$ onto the film surface from points $P_1$ and $P_2$ placed onto the wall surface.

$$T = T_0 / 2 \sin(\alpha/2)$$

Then, the distance d' can be expressed as a function of T. The bisector BB' of hidden grids is perpendicular to moiré fringes. As the segment d' forms an angle $\beta$ with BB'', it is possible to express d' as a function of T. Taking into account that the positions of points $p'_1 \equiv p'_{1\alpha}$ and $p'_2 \equiv p'_{2\alpha}$ can be placed between moiré fringes, it is necessary to introduce the fractional orders $\varepsilon_1$ and $\varepsilon_2$ of a period in the moiré pattern, as it is shown in Figure 3. Finally, the distance L from the photographic objective to the wall, can be expressed as:

$$L = D f M (\cos\beta) / (n + 1 + \varepsilon_1 - \varepsilon_2)\ T$$

Where n is the number of complete moiré periods contained in d′ cos β.
An easy observation of the moiré pattern can be achieved through the Fraunhoffer diffraction pattern of hidden grids. Figure 4 shows the moiré pattern superimposed on the diffraction pattern.

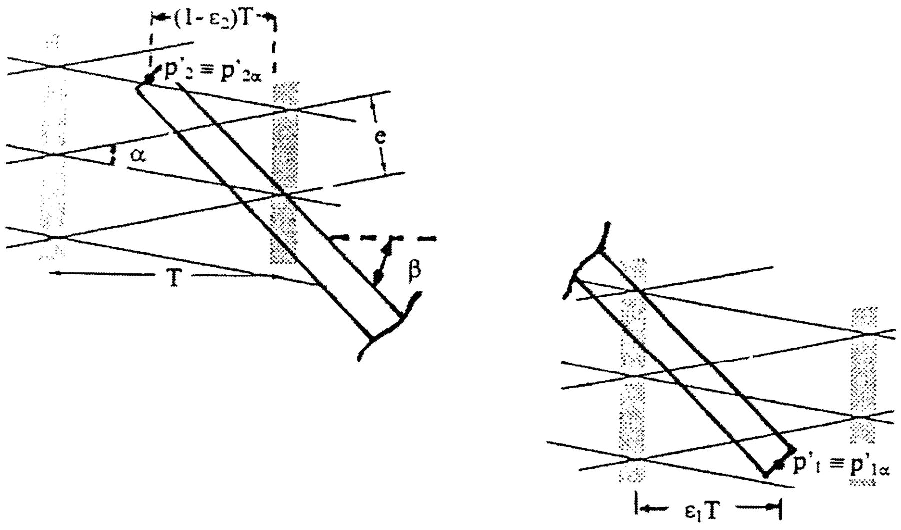


Figure 3. The moiré field positions of the ends of the segment d′ corresponding to points $p'_1 \equiv p'_{1\alpha}$ and $p'_2 \equiv p'_{2\alpha}$ are defined by the fractional orders $\varepsilon_1$ and $\varepsilon_2$ with respect to their neighbour left moiré fringes.

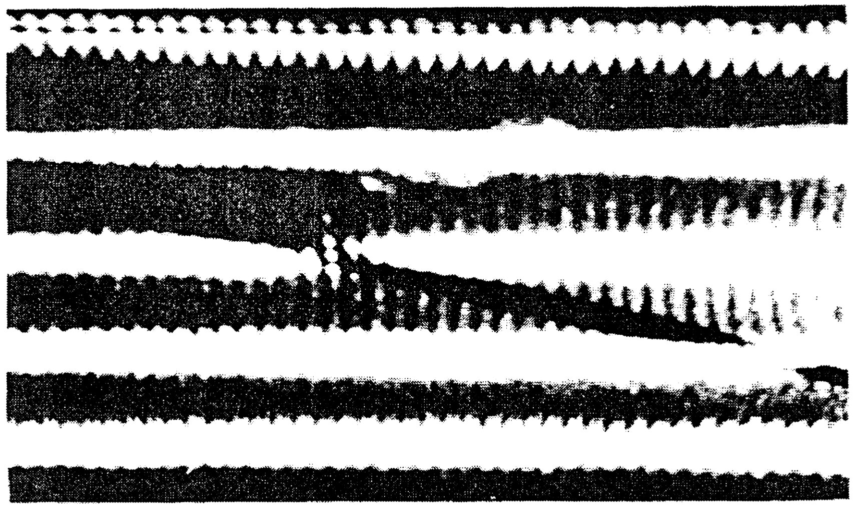
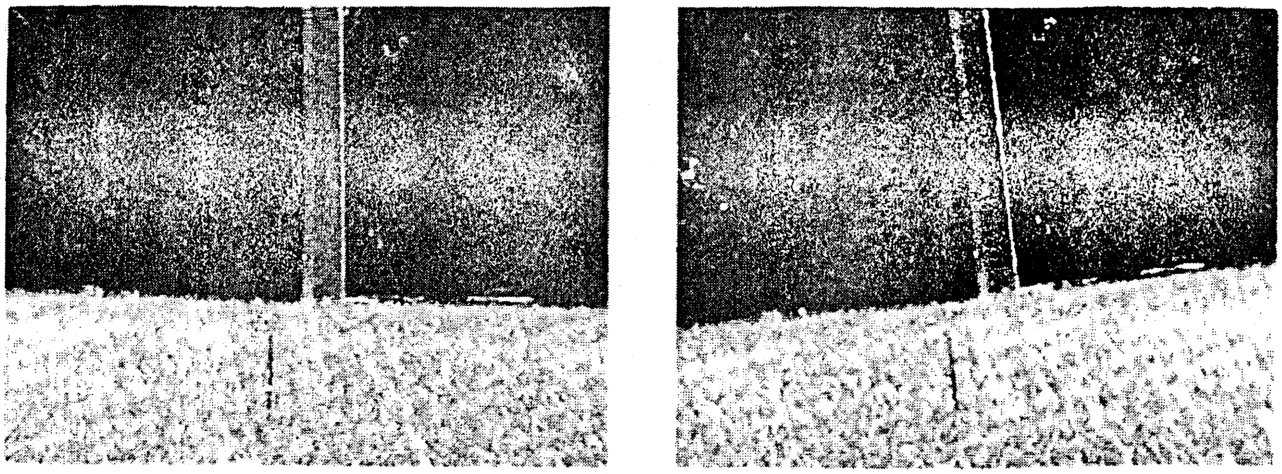


Figure 4. The moiré pattern superimposed on the diffraction patern



a) b)

Figure 5. Water tank of the Campus of Technology at Gonnet photographed from 200 m. a) horizontal view and b) inclined view. Note the three white reference marks on tank columns.

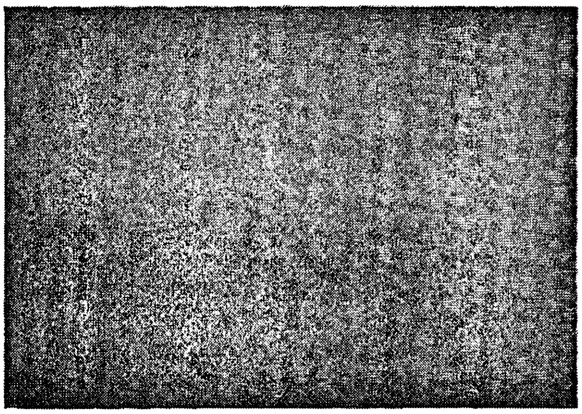
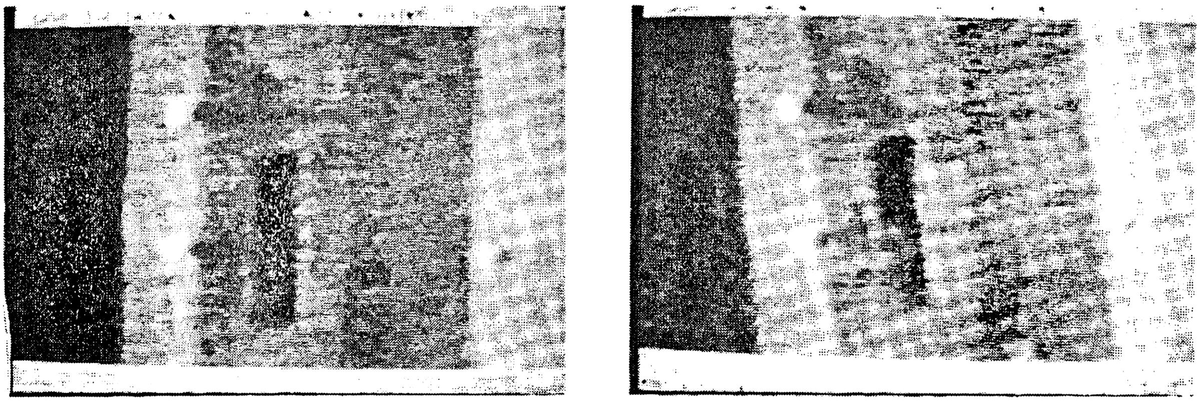


Figure 6. CCD detector microphotograph. Pixels are 8.8 μm x 8.8 μm area.



a) b)

Figure 7. Water tank at Figure 5) captured from 50 m. by the CCD camera and enlarged 8:1 on the screen monitor. a) horizontal view and b) inclined view. Note the pixeled pattern of the image and the three white reference marks.

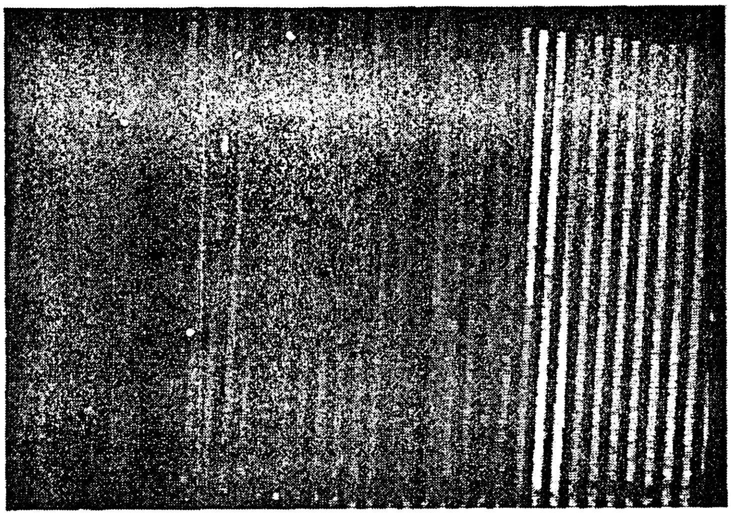


Figure 8.Moiré pattern generated by the electronical superposition of Figures 5 a) and b).

## 3. CONCLUSION REMARKS AND PROPOSALS

A method to measure distances can be accomplished by using the moiré pattern generated by transparency-hidden grids. However, these types of grids are physically unstable because they suffer the thermal copying processes. More stable and closed grids are observed in CCD optoelectronically captured images. Then, the pure optical method to measure distances can be extended and converted in a pure electronical one. Figure 5 shows a typical view of the CIC - Campus of Technology at Gonnet. Both pictures -Figure 5 a) and b)- were photographed from a distance of 200 m; they were pictured by rotating the camera through the optical z-Z axis an angle of 7.5°. The same pictures al Figure 5 were captured using a CCD camera, whose detector was microscopically observed. Figure 6 shows an enlarged view of a part of the CCD detector. The area of each pixel is 8.8 µm x 8.8 µm. The pixel area of the CCD camera generates an optoelectronical hidden grid. Finally, Figure 7 a) and b) show screen monitor pictures of the campus water tank basis; 8:1 zoom was applied and the pixeled structure of the CCD camera is easily observed.

Figure 8 shows the electronically generated moiré pattern between the information contained in figures 7 a) and 7 b).

A scale scene was defined by three reference marks using three white targets pasted on the concrete columns of the water tank. Following the described moiré procedure between both optoelectronical grids, distances of the order of hundred meters were measured with an uncertainty of 2%.

## 4. ACKNOWLEDGEMENTS

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## 5. REFERENCE

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