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# Development of a Novel Camera for Conical Panoramic Photography

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## 1. INTRODUCTION

The principles governing the operation of panoramic cameras which are capable of making extremely wide angle photographs by rotating roughly about a nodal point of their lenses while moving film behind an open slit located just in front of the film surface are well known. Basic relationships are presented below in general terms to establish a common level of understanding so that the rest of the material can be presented in the context of where it fits in with established camera systems.

Among the earliest panoramic cameras of the type described above is the Cirkut camera, introduced by Eastman Kodak in the late 1800's and which was available in a wide variety of film sizes. Modern cameras of similar design include the Hulcherama, the Alpa Rotocamera, the Panalux or Roundshot and the Globuscope.

Panoramic records made with "cirkut" type cameras are made by rotating the camera about a vertical axis thus scanning the scene in front of the camera in sequential fashion. The film accumulates the changing image information presented to it by the scanning camera and eventually builds up a record on a length of film containing a view of any desired angle even up to (or beyond) 360 degrees. For the record to look sharp the film must move at the same velocity as the image. This is accomplished by moving a length of film equal to  $2\pi$  times the lens focal length past the open slit during the time for one revolution of the camera. In actuality it is the rear nodal point to film distance that matters but since in most applications the object distance is large, the lens focal length is usually a close enough approximation to this measure.

It is fundamental to fully understand the method by which these cameras operate to realize that they record subject DISTANCE, or image position, along the slit and TIME at right angles to the slit.

Related to the panoramic camera, the peripheral camera is not as well recognized in either the literature or in terms of working models. The cause for this lack of recognition for peripheral photography is probably due to the fact that this application is somewhat more specialized. It is interesting to note, however, that the making of peripheral photographs, sometimes called cyclographs, of Greek and Mayan pottery, has been practiced since the late 1800's in a number of major museums and also in industrial situations.

Peripheral records of the surface of cylindrical subjects can be easily made by rotating the subject in front of the camera. The film in the camera is made to move at right angles to

the axis of rotation of the subject and in the same direction as its image. The slit restricts the angle of view along the axis parallel to film motion to a very narrow angle, thus it encompasses only a small portion of the cylindrical subject's surface. At the slit, then, the image of the subject's surface appears to pass by in linear fashion, as in racetrack photography. Again, the film velocity is set to match the value given by the subject's surface velocity multiplied times magnification.

Note then, that peripheral records of subjects which vary in circumference can only be reproduced properly at those points where their image velocity happens to match the film velocity.

Since the film can only match one particular image velocity, it follows that image velocities which are slower than the film velocity will produce records which are stretched out and those which move faster will produce compressed reproductions. That is, since the lengths of the images recorded behind any given point along the slit are all the same, this results in invariable distortion of all areas which did not move at the same velocity as the film.

Finally, the other two variations on the above themes, that of racetrack photofinish and synchroballistic cameras and that of aerial strip cameras, apparently complete the applications circle of those cameras which make more or less realistic records by moving a length of film past a slit and capturing the image of the subject by making its image travel across this slit at the same speed as the film. In effect, in these cameras the moving image scans itself onto the passing film by virtue of its motion.

In these "linear" type cameras, the film is simply made to move at the expected velocity of the image. In racetracks the camera is fixed and the image of the racers passes over the slit in the camera. The film velocity is adjusted to approximately match the expected velocity of the images of the subjects. In aerial cameras, the plane moving with respect to the ground below causes a moving image to pass by the slit of the camera. The film velocity is again adjusted to match that of the passing image. Film velocity can be adjusted as the plane changes velocity by making a visual comparison between the motion of the ground's image with the motion of a chain which is matched mechanically to the velocity of the film. Alternately, it is possible to make the comparison electronically. When neither is practical, then camera operators must take into account the operating magnification of the camera and adjust the film velocity to the apparent subject velocity multiplied by the camera magnification.

Generically all of these cameras or systems can be labeled as variants of "strip" recording cameras and can be called simply "strip cameras". Examples of images made by each of these approaches are shown in Figure 1. At this point it is assumed that the operating principle of these cameras has been discussed in sufficient detail and the development of the present camera will be presented next.

Figure 1. a) 360 degree panoramic photograph with characteristic distortion; b) partial peripheral photograph of automobile tire surface; c) typical photofinish photograph where

print is line as a function of time; d) moving strip camera sees subjects head-on and thus building sides are not visible.

## **2. CONICAL PANORAMIC PHOTOGRAPHY**

### 2.1 Development of conical panoramic camera.

By way of introduction to this camera it may be appropriate to state that it is a well established operational fact among panoramic photographers that panoramic cameras must rotate about a vertical axis unless one is willing to accept horizon lines that wander up and down along the panoramic image. A variation on this theme is one in which photographers have tilted their cameras down while still keeping the axis of rotation vertical so that the horizon line effectively remains level. Attachments, notably the Goldbeck "wedge", are available, particularly for the Cirkut-type cameras, which allow the cameras to point up, or down, while still keeping the axis of rotation of the camera vertical. The idea is that if one can raise or lower the angle of view and still keeping the axis of rotation vertical, one can lower or raise the horizon line while still keeping it parallel to the film edges along the panorama.

The difficulty which photographers who have investigated the use of these camera tilting attachments have found is that their photographs are no longer sharp from top to bottom, although indeed the horizon line is parallel to the edges of the film from end to end. The reason for this lack of sharpness is that in this mode the slit and film plane in their basic strip panoramic camera no longer describe a cylindrical path but rather a conical one. The result is that while the camera views equiangular rates of change along the slit these do not encompass equidistant displacements in the subject. In fact, if the camera could be tilted so far down or up that the point about which the camera rotates were included on the film, this point would be standing still. The consequence of this is that the tilted slit of the camera uneven image velocity along the slit.

Yet, since the film in the Cirkut or other strip panoramic camera, moves in linear fashion behind the slit, the film velocity is constant along the slit of the camera. Because there is a mismatch in image to film velocities this introduces the blurring along the vertical dimension of the film when one tilts a Cirkut camera with the Goldbeck wedge.

To solve this particular problem and to produce conical panoramic images, I realized one would have to design a camera where the film moved at different velocities along the slit of the camera.

### 2.1 Development of the camera

The development of the present camera is a direct result of a conversation at the Las Vegas meeting of the IAPP in the 1980's where this problem with the Goldbeck wedge was mentioned. Typically photographers had tried to use the tilts of a moveable front and rear standard to attempt to introduce differential magnification to compensate for the change in subject elevation. This does not work.

At the heart of the solution to the problem was a modification of the standard panoramic camera itself. This panoramic camera design modification neatly solved the problem of differential image velocity along the slit by moving the film in a circular, rather than linear, fashion, as is the practice in all other "strip" panoramic cameras.

The basis for the design was the realization that on a turntable the surface velocity is a function of the distance from the center of rotation. When a slit is extended from the center of a turntable, a piece of film attached to the turntable moves past this slit at increasing velocities with increasing distance from the turntable's center. At a later date I made another connection with an existing imaging system when I noticed that the manner in which a conventional strip peripheral camera delivers undistorted records of cylindrical objects is similar to the operation of a printing press. Here, a cylinder with information on its surface, transfers onto the support a series of perfect rectangles. That is, the length of the transferred images per revolution of the impression cylinder is the same at one end as at the other since the circumference of the original cylinder is also uniform from one end to the other.

When one tries the same procedure with a conical subject by rolling it along a surface, it becomes obvious that the surface which is generated is a circular one. If the cone has an apex, then the apex will be located at the center of the circle. The number of degrees out of a complete circle which the cone describes during one revolution is a function of the steepness of the angle of its side. The steeper the angle, or more pointy the cone, the smaller part of a complete circle which will be produced by making the cone complete one revolution. If it is so steep that it is, in fact, a cylinder, then the length of the image along the circle will be reduced to the width of a single line. In the case that the cone is so flat that it is actually a flat circle, then the transferred record will also be a full 360 degree circle. These conditions are obviously extremes but it helps to think of these extremes to relate them to standard strip cameras and to appreciate how these systems work.

Anyway, once I realized the operating principle of a camera which could transport the film past a slit at various velocities, it took me very little time to build a prototype model. It is shown in Figure 2. The camera was designed to accept 4" diameter discs of film cut from regular sheet film. These discs were held on the surface of the rotating circular film holder by means of two-sided adhesive tape. The rotation rate of the film holder could be varied by changing the voltage to the DC gearhead motor to which it was directly attached.

There was provision built into the camera lens mount to allow it to move along the length of the slit so that an image could be formed at any given distance less than 50mm away from the center of the film disc.

The present camera can achieve film rotation rates of about 10 degrees per second, and the slit is about 1 degree in size so that minimum exposure times are in the order of 1/10 th of a second. The film can be slowed down to about 1 degree per second by simply decreasing the voltage to the DC gearhead motor.

Note: just to set the record straight the camera was actually first used to make peripheral photographs of tapered ceramic-ware and only after the IAPP convention was it applied to panoramic photography.

### 3.2 Setting up for conical panoramic photography

The operating procedures for using this camera in the panoramic mode depend on the lens which will be used and the dimensions and characteristics of the cone which one wishes to make. Once the lens focal length which will be used is chosen and the desired side angle of the cone is fixed, these two parameters determine where the lens must be placed with respect to the center of the film disc and the relationship between the time for one revolution of the film disc in relationship to the time for one revolution of the camera.

The inside side angle which is chosen must be the angle that the film disc surface must maintain with respect to the horizontal as the camera rotates about a vertical axis. The camera may be pointed upward or downward. In the former case the slit must be located above the axis of rotation of the film disc, while in the second case the slit must be located below the axis. Alternately, the camera needs to be merely inverted when it is pointed downwards. The reason for the location of the slit above or below the disc rotation axis is that the center of the disc must record those areas of the subject which are nearest the apex of the cone which the rotating camera is describing. In both instances the film disc must be turned in such a direction that it matches the direction in which the image moves with respect to the slit in the camera.

The location of the lens from the center of rotation of the film disc,  $D(L)$ , is a function of the lens focal length,  $F(L)$ , and the side angle. More precisely, the rear nodal point of the lens must always be located directly above or below the center of rotation of the film disc. This displacement of the lens axis from the center of the disc is a function of the tangent of the inside angle and the lens focal length:

$$D(L) = F(L) \times \text{tangent inside angle}$$

This relationship fixes that the lens position, when the side angle is 0 degrees, equaling the inside angle of a flat "cone", must be such that the lens axis is directly above the center of rotation of the disc. In this case the camera is pointed straight up and only half of the image circle produced by the lens falls on the slit. Conversely, when the inside angle approaches 90 degrees, the lens must be located at a great distance from the center of the film disc in order for it to be above the center of the disc. At a side angle of 90 degrees the lens will be infinitely far away. At such a distance, as far as the lens is concerned, the film will move in linear fashion rather than circular fashion. At this extreme the length of film required to cover a 360 degree panorama will be equal to  $2\pi$  times the lens focal length. In fact, this extreme is a special case of the "conical" camera, and is exemplified by the traditional cirkut type panoramic camera!

The above factors determine whether the film disc available in a given camera is large enough to accommodate the chosen lens at a desired side angle. For any given diameter film disc, use of long focal length lenses will restrict the camera to the production of shallow cones, while short focal length lenses will allow cones of steep inside angle although at reduced image sizes. The four inch diameter disc which this camera uses can make cones of up to about 65-70 degrees side angle (average for lamp shade use) with lens focal lengths of about 20mm.

Unlike cylindrical panoramic cameras, where the lens can be raised or lowered to alter the position of the horizon line, in conical cameras, the placement of the lens at other than the one position determined from the factors named above will produce blurring along the height of the panorama or radius of the circle. As with any other strip camera design, this blurring can be minimized by choice of a small slit size thus reducing exposure time but increasing the risk of banding.

The relationship between the time for the film disc making one revolution,  $R(f)$ , and the time taken by the camera to scan 360 degrees,  $R(c)$ , are given by:

$$R(c) = R(f) \times \cos \text{ side angle}$$

This means that under normal conditions, more than one 360 degree panorama can be included on one disc of film. In fact, when the inside angle of the cone is 60 degrees, exactly two 360 panoramas can be recorded because the cosine of this angle is .5.

The angular rotation rate of the film determines the exposure time for a given angular slit width. Exposure time is determined through exactly the same procedures described above when they were applied to the making of peripheral photographs. Figures - and - illustrate the general set-up of the camera for making a conical panoramic record and the resulting negative.

### 3.3 Applications for conical panoramic images

The images produced this way could find direct application in transfer to such items as lampshades, novelty hats, and decorative purposes for any number of items which have a more or less conical shape. Presently, adaptation of standard images to the surface of objects of conical section requires digital analysis and manipulation which is not an impossible task but not readily available to photographers used to more standard recording techniques.

A further application of the present camera is that with a slight loss in sharpness it could be used to distort conventional cylindrical panoramic or other images so that they could be bent into, or adapted to fit, conical shapes. This loss in sharpness is associated with the mismatch in image vs. film velocities resulting from the alteration of the aspect ratio of the original as the conical image is made. The blurring effects of this differential movement of the image with respect to the film can be minimized by making the

exposing slit very narrow, thus limiting the exposure time during which blurring can affect the recorded image.

Of course, as other strip cameras, this camera can also be used for peripheral photography. You can read about the application of this camera for such purposes in an article published in an SPIE publication, Proceedings of a 1989 meeting on Current Developments in Optical Engineering and Commercial Optics held in San Diego and published by SPIE, the International Society for Optical Engineering, Bellingham, WA.

#### **4. CONCLUSION**

In summary, the development and operating characteristics of a camera suitable for making essentially blur-free conical panoramic photographs and their subsequent display as conical objects has been reported. When the operating limits of the circularly moving film camera design, as exemplified by the present camera, were investigated it was established that strip cameras in which the film moves in linear fashion are special cases of the design and operating principles of the circularly moving film approach described above. When applied to panoramic work, this camera is able to produce photographs which are suitable for a variety of utilitarian purposes without additional manipulation.

**END**