Rolling Shutter Image Compensation

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Abstract. This paper describes corrections to image distortion found on the Sony AIBO ERS-7 robots. When obtaining an image the camera captures each pixel in series, that is there is effectively a 'rolling shutter'. This results in a delay between the capture of the first and last pixel. When combined with movement of the camera the image produced will be distorted. The sensor values from the robot, coupled with knowledge of the camera's timing, are used to calculate the effect of the robots movement on the image. This information can then be used to remove much of the distortion from the image. The correction improves the effectiveness of shape recognition and bearing-to-object accuracy.

1 Introduction

Rolling shutters are commonly found in low-cost, low-power CMOS cameras. These cameras are being commonly used in many non-stationary and robotic applications. Cameras that contain rolling shutters do not expose the entire image at one instance, as is done with a global shutter. Instead rolling shutters have pixels that have been exposed at different times and merged together to form a single image. This causes problems when the scene changes in a time which is less than that taken to expose the entire image. This causes some pixels to have newer information than others. The combination between new and old information causes distortions in the image when viewing an object with movement relative to the camera.

These distortions are evident on the CMOS cameras found in the Sony AIBO ERS-7 robots used in the RoboCup Four-Legged League. However these errors will also be found whenever similar camera technology is used in non-stationary cameras. A major contribution to this distortion is the desire to constantly move the camera to gather as much information about the surrounding environment as possible.

These distortions can cause differences in the co-ordinates, as well as the shape of the objects that the robot has seen. Since the distortion stretches or compresses the image of objects, the co-ordinates derived from that image are also altered. The changed co-ordinates, in particular the bearing to an object, have the potential to cause problems when attempting to determine the location of the object. While the distortion causes problems when the shape of the object is used for its identification or measurement. An example of which is the circle fitting on a ball image in the Four-Legged robotic League. If the ball is no longer circular in shape, circle fitting loses some of its effectiveness.

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There are two main sources for this relative velocity that causes distortions in the image. The movement may be that of the object, or the movement of the camera itself. In many cases there is a mixture of both. The velocity from the camera can in most cases be measured, or at least estimated, however the velocity of the object is far less easily determined from a single frame.

This paper covers the technique used to correct the distortion caused by the rolling shutter. The correction was designed for the Sony AIBO ERS-7 robot, the hardware used for the RoboCup Four-Legged League. In this case the image is corrected for the movement of the robot's camera caused by the panning motor on the robot. This has been observed to be a major cause of this type of distortion, particularly when calculating the bearing to objects or attempting to identify shapes. A correction method used to improve similar problems with bearings was briefly mentioned in [1] and [3].

Fig. 1. Effect of image distortion can be seen on both the round ball, and the rectangular goals

2 De-Skewing Approach

The following section describes the principles and equations used to calculate the required constants for image de-skewing. Followed by the equations required to implement the correction using these values.

2.1 Delay for an Entire Image

Before the image can be de-skewed, the timing of the camera must be known. The magnitude of the delay determines the magnitude of the distortion on the image. To find this value an image was taken of a fluorescent light that flickers at a know frequency (100Hz). When viewed, the fluorescent light displayed three light and dark bands upon the image. This shows that the light went through three dark/light cycles in the time one image was taken. Given the period of the cycles (0.01s), the time taken to capture the frame was calculated to be approximately 0.03s (1). This value is very close to the frame rate of the camera, which operates at 30 frames per second. Therefore it was assumed that the

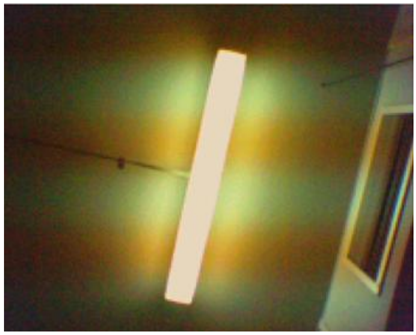

Fig. 2. Image of the fluorescent light shows three distinct light/dark cycles

entire period between frames is used to capture the next frame. This gives an approximate period of 33.3ms.

$$T_{camera} \approx 3 \times T_{FL} = 30ms \approx 33.3ms = T_{Image} \quad (1)$$

2.2 Conversion Between Pan Angle and Pixel Position

All pixels in an image have a equivalent angle offset from the center of the image. The center pixels always have an offset of zero, however the pixels near the edge of the image have an offset determined by the camera's field of view. This offset is required when converting from a pixel to a relative pan location. The relationship between image pixel and offset angle was calculated using the following trigonometry;

First an effective camera distance is found using the field of view of the robot and the resolution of the image in pixels. (figure 3). The effective camera distance is used to convert the pixel position to an offset angle and back again (figure 3).

$$CameraDist = \frac{1/2 \times ImageWidth}{\tan(1/2 \times FOV)} = \frac{104}{\tan(28.45)} = 191.9\, pixels \quad (2)$$

$$x = CameraDist \times \tan(\theta) \quad (3)$$

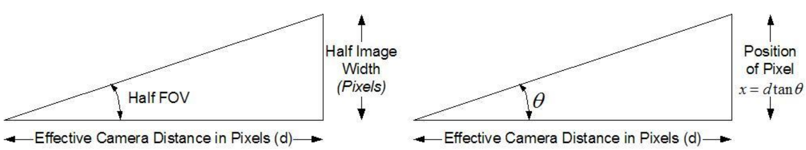

Fig. 3. Calculation of effective camera distance.($left$), Pixel position calculation using angle (θ).($right$)

2.3 Finding the Angle of Distortion

The position of each pixel at the time of capture is required to correct the image. The total pan angle change during the image is proportionally applied over the pixels within the image. Since the first pixel was captured at the camera's original position it has the maximum distortion. The distortion subsequently drops for each pixel captured until the last is assumed to be captured at the camera's current position. This maximum distortion is calculated using the difference between the camera's previous position and the current position. This calculation is simplified since the camera was found to take the entire time between frames to capture a new image.

$$\theta_{MaxDistortion} = \theta_{prev} - \theta_{curr} \tag{4}$$

2.4 Applying Correction

To apply the correction the panning movement of the robot is assumed to be constant between frames. While the velocity of the camera may change within a frame, the inclusion of these changes makes de-skewing much more processor intensive. Also such changes tend to be relatively small and insignificant. For these reasons the total velocity of the camera is used to calculate a linear approximation of the camera's position at the time of pixel capture.

On the AIBO robots the pan sensor reports angles to the right to be negative, while angles to the left are positive. The pixels within the picture are described in (x, y) coordinates with the upper left hand corner $(0, 0)$. For this reason the equations assume these systems, converting between the two coordinate systems as necessary.

First, the angle of the current pixel is found using equation (5). This equation also shifts the coordinates so that the center of the image is at 0 radians. Angles and pixels to the right of this are negative, while angles and pixels to the left are positive.

$$\theta_{original} = \arctan\left(\frac{\frac{ImageWidth}{2} - x}{CameraDist}\right) \tag{5}$$

A linear approximation is then made for the pan angle for this particular pixel. Finding the amount of distortion the pixel has in relation to the bottom right pixel.

$$\theta_{distorted} = \theta_{MaxDistortion} \times \left(\frac{y \times ImageWidth + x}{TotalPixels} - 1.0\right) \tag{6}$$

This calculated distortion is then subtracted from the current pixel's angle, giving the corrected angle for that particular pixel.

$$\theta_{corrected} = \theta_{original} - \theta_{distorted} \tag{7}$$

Using this new corrected angle, the x location of this pixel can be found using equation (3). This is then shifted back to the image's (x, y) coordinate system (8).

$$\left(\frac{ImageWidth}{2} - CamDist \times \tan(\theta_{Corrected}), y\right) \tag{8}$$

Using an equation to correct individual pixels allows the correction to be performed only on the interesting pixels in the image. This means that only the required information, such as an object's X and Y values, have to be corrected, rather then the entire image. This reduction in processing allows de-skewing to be applied to more items with a less noticeable impact on CPU time.

3 Applications of Correction

The following section describes some of the uses for the correction.

3.1 Applying Correction to Shape Fitting

The rolling shutter can cause errors in both the perceived location and shapes of an object. This may cause problems when attempting to identify an object by shape and subsequently determine its position. To over come this, object candidates are first located in the distorted image. These candidates have their edge pixels corrected for skew. From these corrected points the object can then be identified by shape. If further details are needed on the object for position or distance data, the properties of the shape can be used without needing to re-correct the pixels. The use of de-skewing in this manner to verify probable objects reduces the processor load when compared to correcting the entire image.

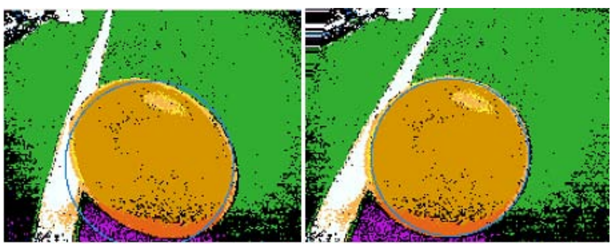

Fig. 4. Visual correction of classified image of ball. Circle fitting shown in blue. *Left* : Original Image, *Right* : Corrected image.

3.2 Line Detection

The use of field lines for localisation provides great benefits, particularly with recent reductions in the number of beacons on the roboCup field. Lines offer a good source of extra information for localisation, since the they are visible from almost anywhere on the field. Although field lines generally provide only ambiguous information for localisation, they may still allow a robot to remain localised without seeing a distinct marker. In particular, the orientation of a field line in the image may be important information.

Field lines are more susceptible to distortion due to camera skew. To use a line from an image in localisation two bearings to that line are needed. This allows

Fig. 5. Visual correction of classified image of line. *Left* : Original Image, *Right* : Corrected image.

the robot to calculate the line's angle and position relative to the camera. Since lines often stretch the length of the image, distortions have a more pronounced effect. Such distortions are then accentuated when the line is translated into real world co-ordinates.

4 Experimental Results

To determine the potential advantages from image correction, a simple experiment was performed. The experiment involved a robot viewing a ball in a known stationary position while quickly panning its head. The data that is most distorted by this kind of action is the bearing to an object. To measure the expected improvement produced by a corrected image the bearing was calculated from both the original and corrected points. Comparing both the values allows the performance of the correction to be evaluated.

The bearing to the ball was first measured by having the robot view a stationary ball with no relative movement. The bearing was calculated to be approximately -1 degree. This value contained very little noise, and was therefore assumed to be the correct bearing.

The robot was then set to pan back and forth. These images were captured and both the corrected and uncorrected bearings recorded. The sensor data from the robot was also recorded for later analysis and verification.

The results show that the correction improved the accuracy of the calculated bearing. While both the corrected and uncorrected values gave an average bearing close to the non panning value, the spread of the corrected data was lower in comparison. However there is still significant noise present in the corrected bearing values. This may be a result of acceleration during the exposure of the frame, which is not taken into account by the linear approximation.

Table 1. Overall results of panning test

	Uncorrected	*Corrected*
Average	-1.434	-1.272
Std.Deviation	6.186	2.961

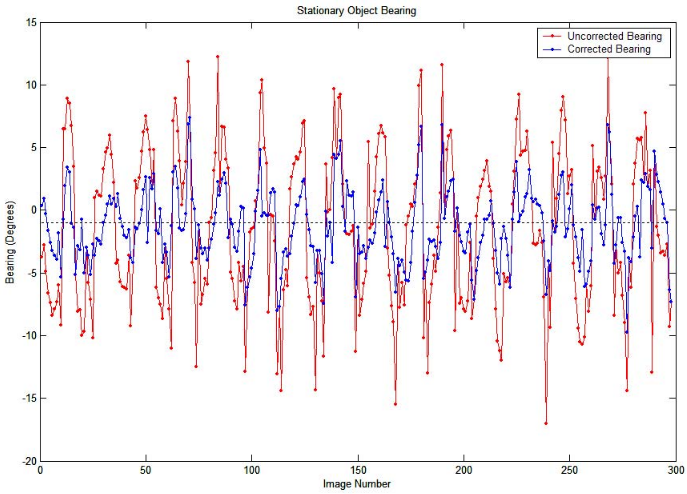

Fig. 6. Resulting bearings to stationary object test

Visual testing was also done to verify that the corrections performed were suitable. In this case the full image was visually corrected (figure 4).

5 Discussion

The correction accounts for the movement of the robot's camera. This however leaves the possibility that once the robot's distortion is corrected, then the perpendicular velocity of the object may be found from the remaining distortion. The distortion left being that created by the movement of the object. If the distance to the object is known and the relative angle that it has moved can be inferred from the distortion, then the perpendicular velocity can be calculated. This would allow a robot to calculate the object's velocity from a single image frame, instead of the normal two or three.

The correction works only on the panning of the head. Vertical movements are not accounted for as they are reliant on many more parameters on the ERS-7 robot. These including two vertical head joints and the body position, and therefore all 12 of the ERS-7s leg joints. Because of a reliance on so many different joints the calculated movement is very noisy. This noise makes it difficult to accurately determine the movements of the robots body.

6 Conclusion

The usage of a rolling shutter causes a distortion in the image when the camera is moving. These distortions skew the objects being viewed resulting in bad shapes and inaccurate bearings. By using the described de-skewing technique these distortions can be reduced or removed. Once the distortion has been removed from the image the data obtained on an object is improved, with improvements in the bearing to an object of better than 50%.

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