Projection System Adapted to Arbitrary Surfaces

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Abstract :

This project aims towards calibrating the images projected on arbitrary surfaces. We use projector and camera system to calibrate the projected image. Calibration is done by first recognizing the geometric shape of the projected surface. This is done by projecting binary coded images on the surface and then calculating transformation in various parts of the images. Now we pre-distort the new image before projecting on the surface in order to compensate for the distortion don by the surface. The pre-distortion is done by applying reverse transformation on the new image. The initial calibration process completes in about 2 minutes. Once we have calibrated for a surfaces, we project calibrated image very fast. This method can be used on any kind of static arbitrary surface.

Introduction :

Today the available projectors are very high resolution. But these projectors can only project well on surfaces normal to the direction of projection. Usually we project images on planar screen so we get a very clean projection of image. But it is not always easy to find planar surface. When the projection is done on non planar surface the image we perceive is distorted because of irregularity of surface. Figure shows a projection on a corner of room. Here we can see the final projection is distorted. We have student made planetarium in our institute. The physical structure of planetarium includes an inner spherical surface where the projection is being made. Here also the projection surface is non planar.The final projection comes out to be distorted. Our goal is to correct the to be projected image in such a way that the final projection looks undistorted i.e. similar to the original image. The procedure for correction is explained in section: Calibration Process.

Figure 1: A corner of the room and image projected in the corner

Related Work :

Surati uses a precise mesh-grid in front of the screen to locate a camera in screen space. This method obtains the correct mapping from projectors to the screen by building a form which leads fast mapping transformation. PixelFlex assumes both of the camera shooting and projector projection are similar to pinhole projection. Therefore,PixelFlex creates a homography matrix between the camera and projector. SimWall removes the non-linear factors on line by projecting twice. This geometric calibration method simplifies all the procedures, and also promotes the calibration precision as well. Those methods above are mostly based on a refined projection environment with some artificial features around the screen. For irregular surface, the most difference from plane is the more complicated mod-

elling on projected surface. Once the modelling finishes, the rest of steps are almost the same as plane projection. Those complicated surface which can not be mathematical formulated, it will be difficult to implement. Raskar takes advantage of the binocular vision method to model the whole scenery. However, this method is not adapted to the environment. It needs to fix the position of cameras (at least two) and projector to solve this problem

System Architecture :

This projected image calibration system consists of hardware as well as software part. The hardware part consists of additional camera and the software part includes the algorithm to pre-distort the image. Before trying on actual camera and projector system, we simulated the system on 3D designing software 3Ds-Max. In the following parts we will describe the systems in detail.

3Ds-Max Simulation:

3Ds-Max is an animation software developed by Autodesk used mainly for creating games, animation, visual effects etc. Since both camera and projector options are available on 3Ds-Max we used it initially to test our algorithm. In lightening on 3Ds max we used target light with square projection. Here we can map it to any image which can be projected so henceforth projector is ready. As our idea is mainly motivated by Planetarium projection system we are making inner surface of spherical dome as test surface for projection. Using the camera option camera is placed to capture projected image. In setup of rendering the camera is selected as viewpoint for rendering output. Figure 2 shows two different configurations in which testing is being done.
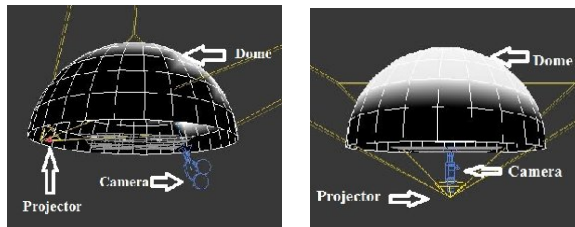

Figure 2: Geometric Configurations in 3Ds Max

Real Camera projector system :

After testing our algorithm using simulation. Later we performed experiments on real camera projector systems. We did the experiments at two kinds of surfaces:

- Edge of two walls

- Spherical surface: Inner surface of planetarium dome

For testing on surface made by edge of two walls we used Hitachi Projector and Logitech HD webcam. The projector is placed in front of the edge almost on angle bisector of two walls and the camera is placed nearer to projector facing the wall.

Now for testing of projection on Inner spherical surface of planetarium, we used same Hitachi projector but camera we used is Canon DSLR with fish eye lens (focal length 10mm to 18mm). Figure 3 shows the arrangement of camera-projector system. The spherical mirror shown in the figure is used to increase the field of projection in Planetarium projection system. We used maximum field of view setting of lens while collecting the feedback images.
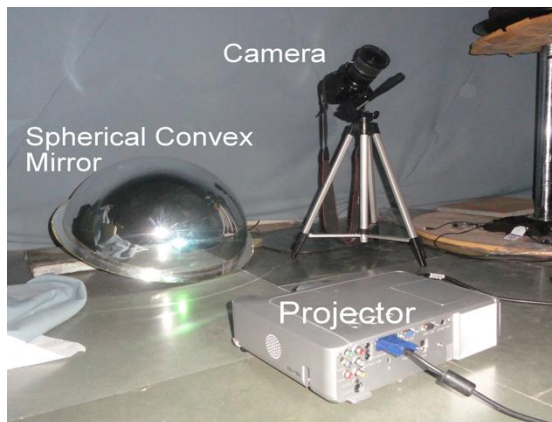

Figure 3: Arrangement of testing system inside Planetarium

Calibration Process :

Feature Image Collection :

Importance of Feature Images :3D measurement methods use binary-coded feature images as active structured light. The examples are 3D surface construction and 3D contour detection. In our project indirectly we need to estimate the depth in the image. The binary codes images are used to determine the relationship between the projector and the projected surface.

The feature image consists of certain number of points N distributed uniformly on the image. The feature image points are projected on the surface as structured light. The intersection these points on surface can't be geometrically decided, so each is numbered from 1 to N to ensure the identity.The value of N is decided on the basis of quality requirement and the nature of surface. If the projected surface is very irregular, then we need more number of points. In our project we have used 480x640 size images and on this images we have taken 12x16 points.

Points Creation : To visualize the feature points on the images by camera , wee need the size of the points on the image larger. In out system circular disks of 10 pixel radius were enough to be captured by the camera and later on detected easily. The distance between the disks was 10px. Therefore total number of disks possible in a 480x640 images was $12 * 16 = 192$. Each of the point is numbered from 1 to $N = 192$ starting from left-top to right-bottom corner.

Binary-coded Images For a complex projection surface, the structured light will be distorted. To identify each point on the projected surface, we user binary coded image. In the binary coded image, each number is represented in binary. In our feature image maximum index of any point was 192. This number can be represented by 8 bits. Therefore we need to create 8 images. In these 8 images each image i contains the points for which i^{th} bit from left to right is 1 in its binary representation. In this way all the images are created. These 8 images mark each point with a unique binary code. For example to the binary

representation of 40 is 00101000 therefore 40th point of feature image will be projected as same color(red) in 3rd and 5th binary-coded image. Based on this fact we enumerate the points on the projected image. The 8 images are projected successively and then captured by camera.
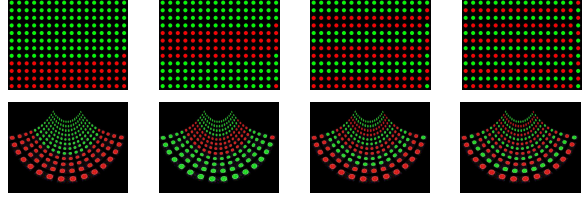

Figure 4: The first 4 input binary-coded images with 4 leftmost bits of the numbers and their corresponding output ob projected surface
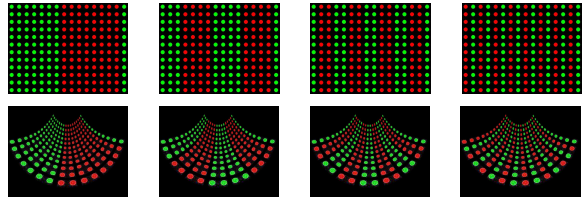

Figure 5: The last 4 input images binary-coded with 4 rightmost bits of the numbers and their corresponding output ob projected surface

Image Processing on the Collected Images : On the captured images, we do image processing, to extract the disks cleanly and separately. We use erosion and dilation technique and then binary conversion to enhance the points in the captured images. For this part, we take the colors to represent 1 and 0 which have high contrast and are very different from the background. Now we calculate the centroid of each of the disk. Once we have extracted the points in the binary-coded images, we enumerate the points based on their appearances in all the 8 images and their centroid.

Transformation Calculation :

Discrete Mapping Algorithm
From here on we call the final image obtained from camera as Feedback Image and the image input to the projector as Input Image. In this section, we take the Feedback image and the Input image and calculate the mapping between

these images. This mapping is one to one mapping of enumeration of points in the Feedback image and Input image. Let's assume the coordinate of a point in the Feedback image is (U_i, V_i) that of same point in Input image is (X_i, Y_i). Then:-

$$(U_i, V_i) = G(X_i, Y_i)$$

G is the mapping.

Now we tessellate the Feedback image to get triangular mesh $T(V, S)$, where V : set of vertices in mesh which is set of indexes of the points projected on the surface S : the set of edges in the mesh. We use delaunoy triangulation for tessellating the Feedback image. This creates optimal triangulation on the points obtained. In this way we divide the Feedback image into triangular therefore planar surfaces.

Now for each triangle A in T there exists a corresponding triangle A' in the Input Image. Now we calculate the transformation from A' to A. This is the transformation that is effectively applied by the projector and irregular system to produce the distorted image. Mathematically, if A is represented by vertices (u_i, v_i) and A' is represented by (x_i, y_i), where $i = \{1, 2, 3\}$, the transformation H between them is as follows

$$\begin{bmatrix} u_1 & u_2 & u_3 \\ v_1 & v_2 & v_3 \\ 1 & 1 & 1 \end{bmatrix} = \begin{bmatrix} h_1 & h_2 & h_3 \\ h_4 & h_5 & h_6 \\ h_7 & h_8 & h_9 \end{bmatrix}_H * \begin{bmatrix} x_1 & x_2 & x_3 \\ y_1 & y_2 & y_3 \\ 1 & 1 & 1 \end{bmatrix}$$

or

$$A = H * A'$$

Let the triangles in T are numbered as $A_1, A_2, \cdots A_n$. Now For each of these triangles, we have a transformation matrix calculated by the above method. Let the set of such transformations is $H_{img} = \{H_1, H_2, \cdots H_n\}$

Transformation in the New Image :

In the next step we take the to be projected image I and distort it before feeding to projector such that we get planar output on the projected surface. This distortion is obtained in this way:-

We apply the triangulation T in I and obtain triangulation. The image I is divided into triangles $A_1, A_2, \cdots A_n$. Now on each A_i we apply inverse transformation H_i^{-1} to get A_i^f.

$$A_i^f = H_i^{-1} * A_i$$

$$i = 1, 2, \cdots n$$

The out image that is given to the projector is defined as follows :-

$$I_{out} = A^f = (A_1^f) o (A_2^f) o \cdots (A_n^f)$$

where o means image is composed of all local areas

Projection Area

The output image in the last section appears planar on the projected surface, but the outer parts of the image may be missing. This happens due to sparse mapping of coordinates in the reverse transformation. To remove this kind of problem we estimate effective projection area in the out image, this is done by calculate maximal rectangle in the Feedback Image obtained. Based on this maximal rectangle, we scale down the to be projected image to be fit into this area. Now no part of image is missing.

Intensity of Image :

Since the mapping at the reverse transformation is sparse, there are unfilled spaces between mapped pixels of the output image. These unfilled spaces appears to reduce the intensity of the image. So we are using dilation method to make the image continuous. We used matlab function 'imdilate' to do this. Since imdilate works o ance the intensity of image.
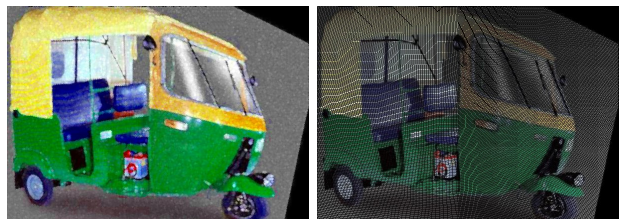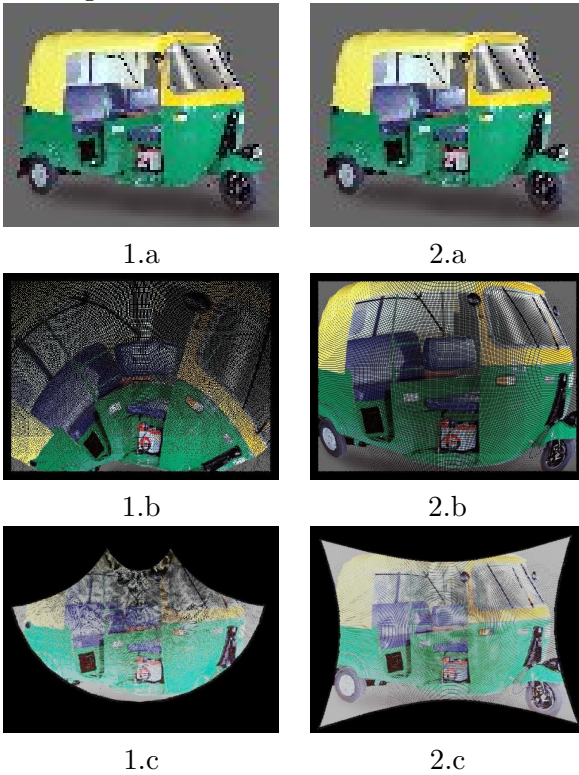
Results :

3Ds-Max:For the two configurations mentioned earlier the simulation is done. Table 6 shows the results of simulation for the mentioned configurations respectively. In table 6 a is original image, b is to be projected image and c is final image collected from camera

Figure 6: 3Ds-Max simulation results

1.a	2.a

1.b	2.b

1.c	2.c

So from above results we can see that the final output image seems almost similar to the original image despite some part of the original image is cropped out. Significant amount of original image part has been lost in 1.c because of the fact that geometrical configuration in this case is highly complex. Hence we can say the more complex the geometry of system is, less will be the effective projection area. In 2.c the final image is more or less same as original image if we neglect the small gaps in the image which are because of sparse mapping in the reverse transformation.

For edge of two walls the results are shown in table , where (a) is original image, (b) is collected image without correction, (c) is corrected to be projected image, (d) is final collected image. In (a) we have scaled down original image so that the main object can come inside the projected area completely.
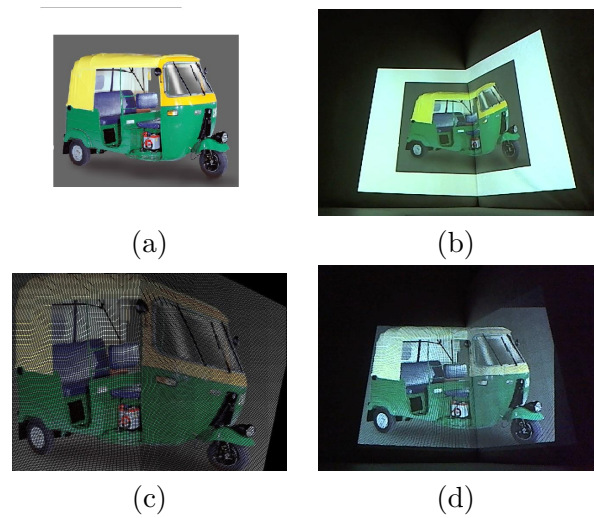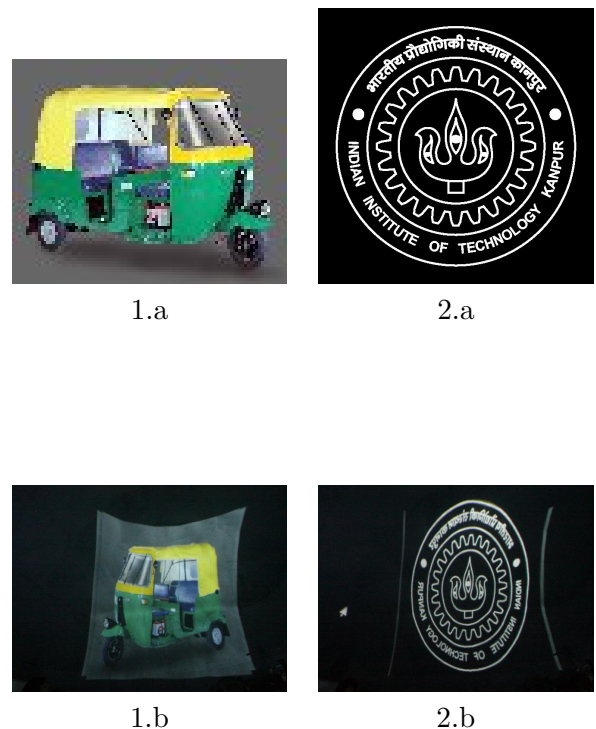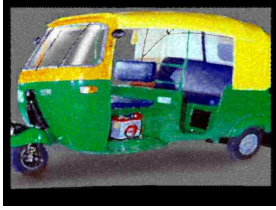

(a)	(b)
(c)	(d)

Figure 7: Test results of Edge of Walls

So from table we can see that auto-rikshaw in (a) and (d) are almost same.
Results of experiment inside planetarium is shown in table , with two images one is of Auto-rikshaw and second one is logo of IIT Kanpur.

1.a	2.a

1.b	2.b

1.c   2.c

1.d   2.d

Figure 8: Test results of Projection on Inner surface of Planetarium Dome

Here also we can see that the final output is similar to original image. Here we also used dilation to remove the sparsity and then increased the saturation to enhance the color of to be projected image.

Limitations of Our Work :

Though we are able to project any image on any kind of surface, here are some aspects of the adaptive projection that need improvements :

1– Since most of the time, the shape and the size of projected image differs from that on planar one, while applying reverse transformation, the mapping is sparse. Due to this reason we get unfilled spaces in the output image. This reduces the quality of projection.
2– Some due to many to one mapping in the reverse transformation, we get data loss in the final projected image.
3– The projector system needs a little(approximate 2 minutes) time in the beginning to calibrate according to surface.
4– The number of disks in the binary coded images is required according to the extent of irregularity in the surface and quality on image we want in output. So number of disks should be changed for various type of surfaces.
5– This system works only on static projection

surfaces.

References

[1] Bo Zhu, Li-jun Xie, Qi-hui Wang, Ting-jun Yang, and Yao Zheng. An intelligent projection system adapted to arbitrary surfaces. In *Proceedings of the 2011 First International Conference on Instrumentation, Measurement, Computer, Communication and Control*, IMCCC '11, pages 293–298, Washington, DC, USA, 2011. IEEE Computer Society.