Adding Shot Chart Data to NBA Scenes

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Abstract

Shot charts have become a popular way to visualize the shooting efficiency of NBA players and teams from different parts of the court. Despite their utility, it is difficult to present shot charts as an effective visual aid in a TV broadcast. Here, a technique is demonstrated to superimpose shot charts onto NBA broadcast images, enhancing the TV viewing experience for NBA games.

Previous work has discussed the processing of basketball broadcast images to identify the court outline and perform camera calibration [1]. In this work, court identification and camera calibration methods are implemented and shown to be robust in the presence of most typical court occlusions. Following camera calibration, the desired shot chart coloring is projected onto the broadcast image of the playing court. The proposed method works well across a wide range of courts and performs accurate calibration and projection. The shot chart coloring is superimposed onto the court only, improving aesthetic presentation and visual depth perception by excluding players, referees, and fans blocking the court in the image.

1. Introduction

The tracking and analysis of data in the National Basketball Association (NBA) has seen a marked increase in recent years. Data and analytics has altered teams' understanding of the sport, resulting in changes to coaching and decision making in the NBA. As data changes the way the game is played, it becomes more important to be able to accurately and intuitively present informative data to fans.

One of the more commonly cited statistics in basketball is a player's or team's shooting percentage. This gives some idea of offensive efficiency and is often used to compare players. However, a much more insightful view can be gained when looking at shooting percentages from different parts of the court, rather than looking at a single number to represent the whole.

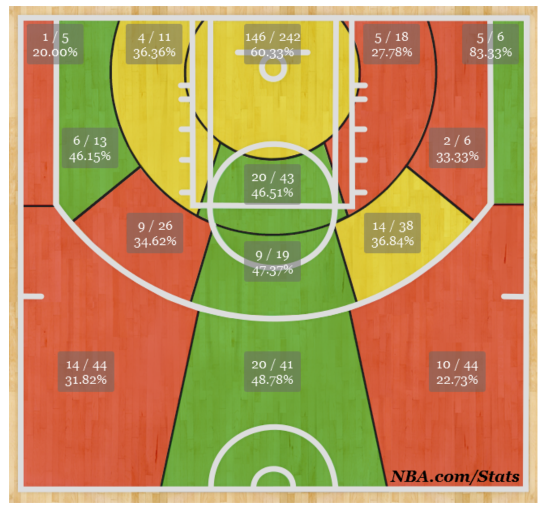
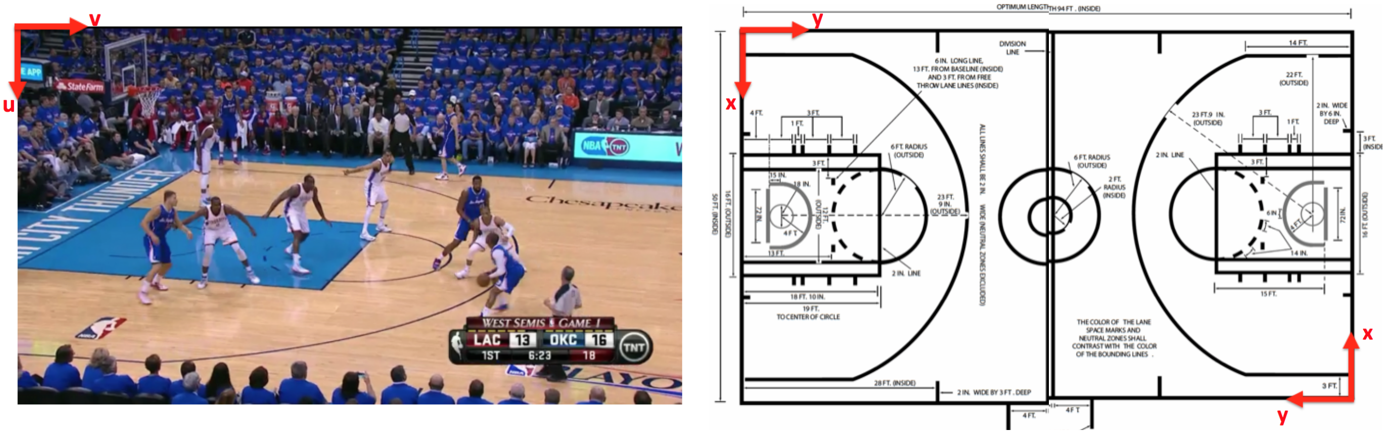


Figure 1: A shot chart obtained from NBA.com/stats

A shot chart (Figure 1) provides an effectively way to do this visually. On the chart, the court is divided into 14 regions. Each of these regions is assigned a color – either red, yellow, or green – according to the shooting percentage compared to the NBA average in that region. This provides an effective visualization of specific locations on the court from which certain players excel or struggle shooting the ball. Shot charts have become widespread enough that they are made easily available to fans on `NBA.com/stats`.

While shot charts are useful visual tools, it is difficult to use them to convey meaningful information during a TV broadcast of an NBA game. Viewers see the court from a broadcast camera angle, but a shot chart is only displayed as a separate image shown from an overhead view of the court, such as in Figure 1. Projecting a shot chart onto the court in a broadcast image could add the context needed to help a shot chart easily convey the desired information to the viewer. While adding color to the court may be exces-



(a) Broadcast image of left side of court (b) Left side court geometry (c) Right side court geometry

Figure 2: Broadcast image (a) with image coordinates (u, v). Court geometry shown in (b), (c) along with court coordinates (x, y) used in each case

sive during live gameplay, a projected shot chart could help commentators provide salient insight about a player's or team's shot selection quality during a replay.

This work presents an algorithm to project shot chart coloring onto a broadcast image. Given a broadcast image, the pixels corresponding to the different region in the shot chart must be identified, and pixels corresponding to players, referees, or fans obstructing the court should be excluded from this classification. Then, the court can be colored like the appropriate region of the shot chart. The key (colored rectangle near the hoop) is excluded from the shot chart projection in this work. A broadcast image and shot chart are assumed to be given; there is no attempt to identify which player is shooting the ball. The broadcast images used are typical views used of half-court sets on the left or right side of the court.

2. Problem Statement

In order to project the desired shot chart onto the broadcast image, camera calibration must be performed to obtain a mapping between the image coordinates and the position on the court. As shown in Figure 2a, each pixel in the image is assigned a (u, v) coordinate pair. Each position on the court has a (x, y) coordinate pair, with the origin located according to Figure 2b for the left side of the court or Figure 2c for the right side of the court.

As illustrated by Hu et al. [1], the camera matrix to map from homogeneous court coordinates p to the homogeneous image coordinates p' can be expressed as a 3x3 homography matrix H.

$$p' = \begin{bmatrix} u \\ v \\ 1 \end{bmatrix} \quad p = \begin{bmatrix} x \\ y \\ 1 \end{bmatrix} \tag{1}$$

$$p' = Hp \tag{2}$$

Camera calibration using at least 4 known points on the court can be used to find the matrix H. Once H is known, the (x, y) coordinate on the court for each pixel in the court mask can be obtained using $p = H^{-1}p'$. Each (x, y) position maps to one of the regions in the shot chart, allowing the appropriate color to be assigned to each court mask pixel. Finally, an image of the colored court mask is combined with the original image to yield the image of the projected shot chart.

3. Technical Content

The basic algorithm and corresponding sample images are shown in Figure 3. The steps shown in Figure 3 are detailed in the following sections.

3.1. Court Mask Identification

Previous work has shown that detecting the dominant colors in an image of a basketball court can segment out the court from the rest of the image[1]. Since the entire court, excluding the key, is of a relatively homogeneous color, identifying which pixels contribute to the most common colors in the image identifies the pixels on the court fairly selectively. In this work, a Hough voting scheme was used to identify these pixels. The Hough space was 3-dimensional, correspond-

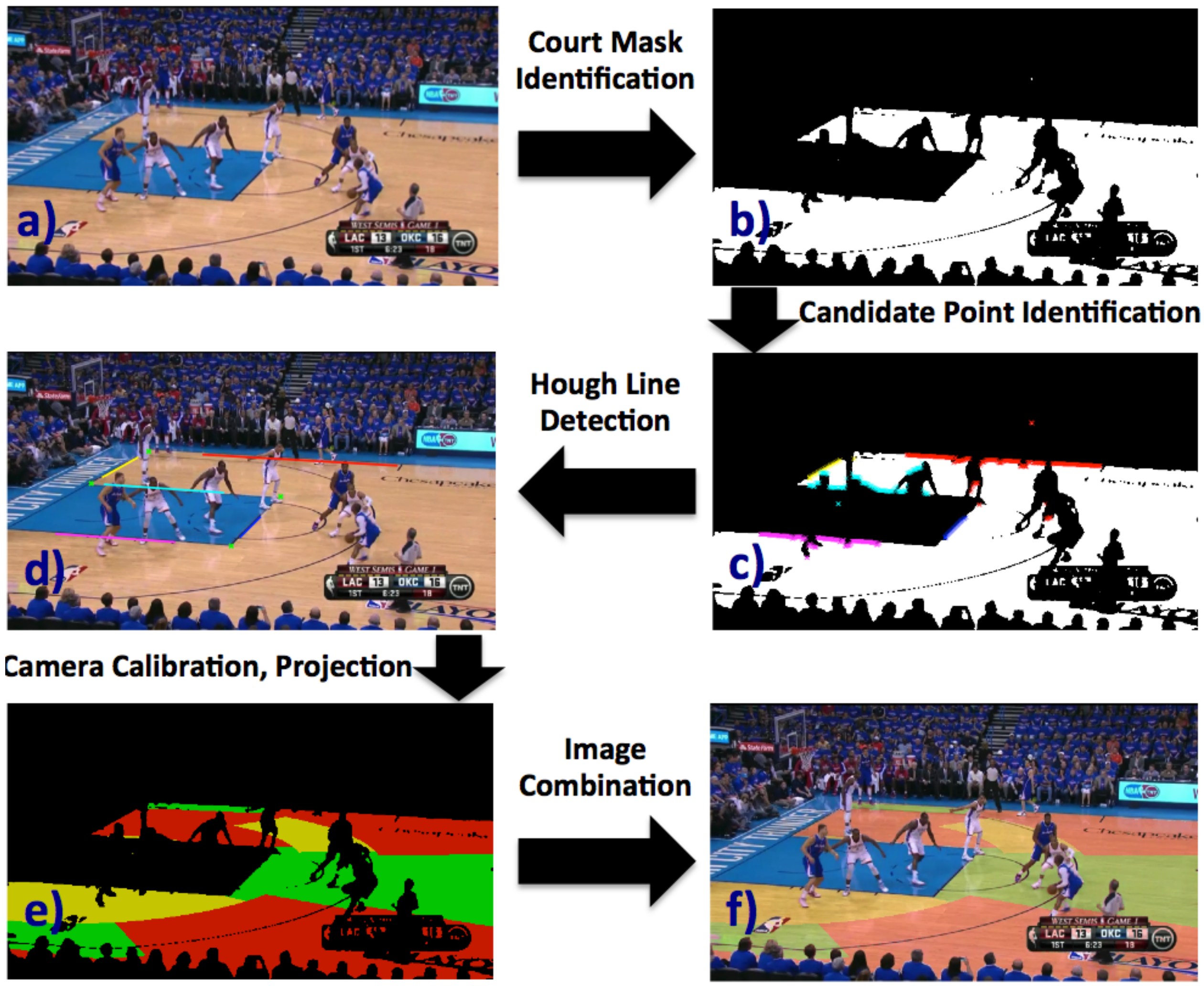


Figure 3: Flow chart of algorithm including images generated at each stage

ing to the HSV colorspace of the pixels. Each dimension was divided into a n bins ($n = 3$ or $n = 4$) for a total of n^3 bins in the Hough space. Each pixel in the bottom 75% of the image voted for the bin corresponding to its HSV numbers. The top 25% of the image was discarded because the court typically does not extend to that part of the image. Bins corresponding to low value pixels were discarded since the court is not dark and black is a common background color that can result in coherent votes for non-court colors. The highest remaining m bins ($m = 1$ or $m = 2$) were retained, and pixels contributing to these bins were identified as the court mask. The values of n and m were varied depending on which court was shown in the image. Because of some differences in the court designs of the 30 NBA teams, different values of n and m gave the best results for the different courts.

Using this Hough voting scheme, some isolated pixels would end up as false positives or false negatives. Since the court is mostly continuous in the image, a median filter was applied to the court mask output from the Hough voting scheme in order to eliminate isolated pixels. The size of the median filter was varied for images of different courts to give the best results. After thresholding the output of the median filter, the final court mask, shown in Figure 3b, was obtained. This court mask does not include players or referees, and it successfully separates the court from most of the occlusions on the court.

3.2. Key Point Identification

Following identification of the court mask, this mask was used to identify key points on the court to be used for camera calibration. Without prior knowl-

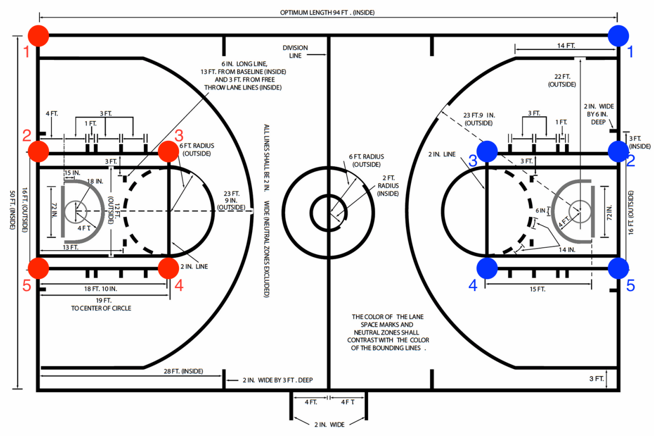


Figure 4: Key points used for camera calibration for images of the left (red) and right (blue) sides of the court

edge of the scene, it cannot be known whether any particular point on the court is occluded. To make the identification of key points for camera calibration more robust to variations between broadcast images, key points are selected at the intersection of lines on the court, as shown in Figure 4. To find these points, the lines are identified in the image, and the point where they intersect is taken as the key point. As long as enough of the relevant court lines are unobstructed in the image, key points can be accurately located. The 3x3 camera calibration matrix H has 8 independent unknowns, so at least 4 points are required for camera calibration. In this work 5 points shown in Figure 4 were used for camera calibration.

The court lines that intersect at the key point locations in Figure 4 are all along the perimeter of the court mask shown in Figure 3b. Therefore, potential points that lie on these lines can be identified by finding the edges of the court mask. First, the side of the court shown in the image is determined by counting whether there are more court mask pixels near the left or right edge of the image. Then, the extent of the court in the image is determined by finding the minimum and maximum rows and columns in the image that contained a significant number of court mask pixels. Using this information, the appropriate places in the image to search for the 5 lines of interest are estimated.

Figure 3c shows the points identified as possibly belonging to the lines of interest on the court. Some of these points clearly do not lie on the desired court lines because the edge of the court mask is misshapen due to the presence of players on the court. However, the proper lines on the court can still be determined by fitting the selected points using the Hough transform, so long as enough of the points fall along the desired line of interest. These detected lines are superimposed on the image in Figure 3d. Once the court lines in the image have been found, their intersection can be used to locate the key points in the image. These key points are shown in green in Figure 3d.

3.3. Camera Calibration

Once the key points have been identified, the 3x3 camera matrix H can be identified using camera calibration. If we express H as

$$H = \begin{bmatrix} h_1 \\ h_2 \\ h_3 \end{bmatrix} \tag{3}$$

then the image coordinates (u_i, v_i) for key point i can be expressed in terms of the homogeneous court coordinates p_i defined in (1) as follows:

$$u_i = \frac{h_1 p_i}{h_3 p_i}, \quad v_i = \frac{h_2 p_i}{h_3 p_i} \tag{4}$$

From (4), the following steps can be performed to obtain a homogeneous system to be solved for the camera matrix H using the 5 correspondence points.

$$h_1 p_i - u_i h_3 p_i = 0, \quad h_2 p_i - v_i h_3 p_i = 0 \tag{5}$$

$$h \triangleq \begin{bmatrix} h_1^T \\ h_2^T \\ h_3^T \end{bmatrix} \tag{6}$$

$$P \triangleq \begin{bmatrix} p_1^T & \mathbf{0^T} & -u_1 p_1^T \\ \mathbf{0^T} & p_1^T & -v_1 p_1^T \\ \vdots & \vdots & \vdots \\ p_5^T & \mathbf{0^T} & -u_5 p_5^T \\ \mathbf{0^T} & p_5^T & -v_5 p_5^T \end{bmatrix} \tag{7}$$

$$Ph = 0 \tag{8}$$

The matrix P defined in (7) is known from the court coordinates p_i of the key points in Figure 4, as well as the corresponding image coordinates (u_i, v_i) found using the key point identification algorithm. The set of court coordinates p_i are referenced using the coordinate system in Figure 2b or 2c for images of the left or right side of the court, respectively. These coordinate systems allow the different shot chart regions to be treated identically for images of the left and right of the court following camera calibration. The vector h defined in (6) is unknown and can be solved for from the homogeneous system in (8) using SVD. Once h is known, it can be rearranged into the camera matrix H.

3.4. Shot Chart Projection

Following camera calibration, the court coordinates (x, y) of each pixel in the court mask can be found by first solving for the homogeneous court coordinates p and then extracting the x and y coordinates.

$$p = H^{-1} \begin{bmatrix} u \\ v \\ 1 \end{bmatrix} \quad (9)$$

$$x = \frac{p_1}{p_3}, \quad y = \frac{p_2}{p_3} \quad (10)$$

Using the (x, y) coordinates of each court mask pixel, the corresponding shot chart region is be identified by converting the (x, y) court coordinates to polar coordinates centered under the hoop. Figure 3e shows the coloring of court mask pixels according to the shot chart in Figure 1.

The final image combination is performed by combining the pixels that are not in the court mask with a weighted average of the original image pixels in the court mask and the colored court mask. One of these final combined images is shown in Figure 3f. The shot chart is projected onto the court (excluding the key), while players, referees, fans, and other areas that are not part of the court maintain their original coloring.

4. Experimental Setup and Results

The entire shot chart projection algorithm was tested using several combinations of NBA broadcast images and shot charts. Some of the resulting shot chart projections are shown in Figure 6. The algorithm appears to perform fairly accurately, although slight differences between the desired and projected shot chart boundaries can be observed in some instances. In each case, the court is successfully identified and largely separated from occlusions. However, in some images there are variations in the lighting on the court that result in small patches of the court not being recognized by the dominant color detection and therefore being excluded from the court mask.

The error in key point location in the image was used as a quantitative metric to evaluate the algorithm. Inaccuracies in the inferred key point location in the image result in inaccuracies in the camera matrix H obtained from the camera calibration. This leads to error in the shot chart regions on the court when the shot chart is projected onto the image. Accurate pixel coordinates for each key point were selected manually and tested to ensure that they gave good shot chart projections when used for camera calibration. The key point image coordinates obtained

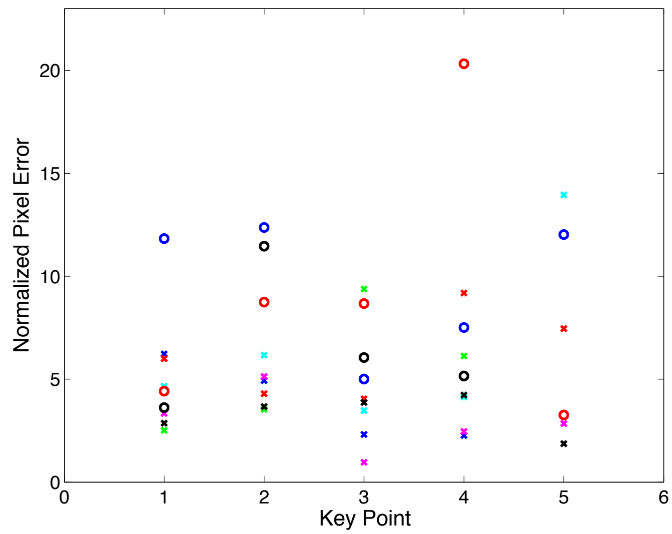


Figure 5: Normalized distance between inferred and actual key point locations for 9 images, with each image represented by a different color and shape. The key points are numbered according to the labels in Figure 4. Key point 5 was not visible in all images.

using the algorithm are compared to the manually selected key point coordinates, and the distance in pixels between the accurate and inferred key points is normalized to a 640x360 image size and used as an error metric. Nine separate broadcast images of either the left or right side of the court were tested, and the error values are shown in Figure 5.

The greatest inaccuracies appear to occur in cases in which there are significant player occlusions along the court lines whose intersections are used to locate the key points for camera calibration. In these cases, many of the points used for Hough line detection are located along the player outlines rather than the court lines, resulting in some error in the court line returned by the Hough transform method. If the returned line is inaccurate, the key points taken at the intersection of the line with other court lines will also have errors. The results shown in Figure 6 demonstrate that the method is mostly robust to player occlusions of court lines, but the algorithm does not perform well in extreme cases when one of the court lines used in the calibration is almost completely blocked.

5. Conclusions

A method of projecting shot charts onto NBA broadcast images has been demonstrated. The major steps of the algorithm – illustrated in Figure 3 – include dominant color detection to identify which pixels belong to the court, identification of lines on the

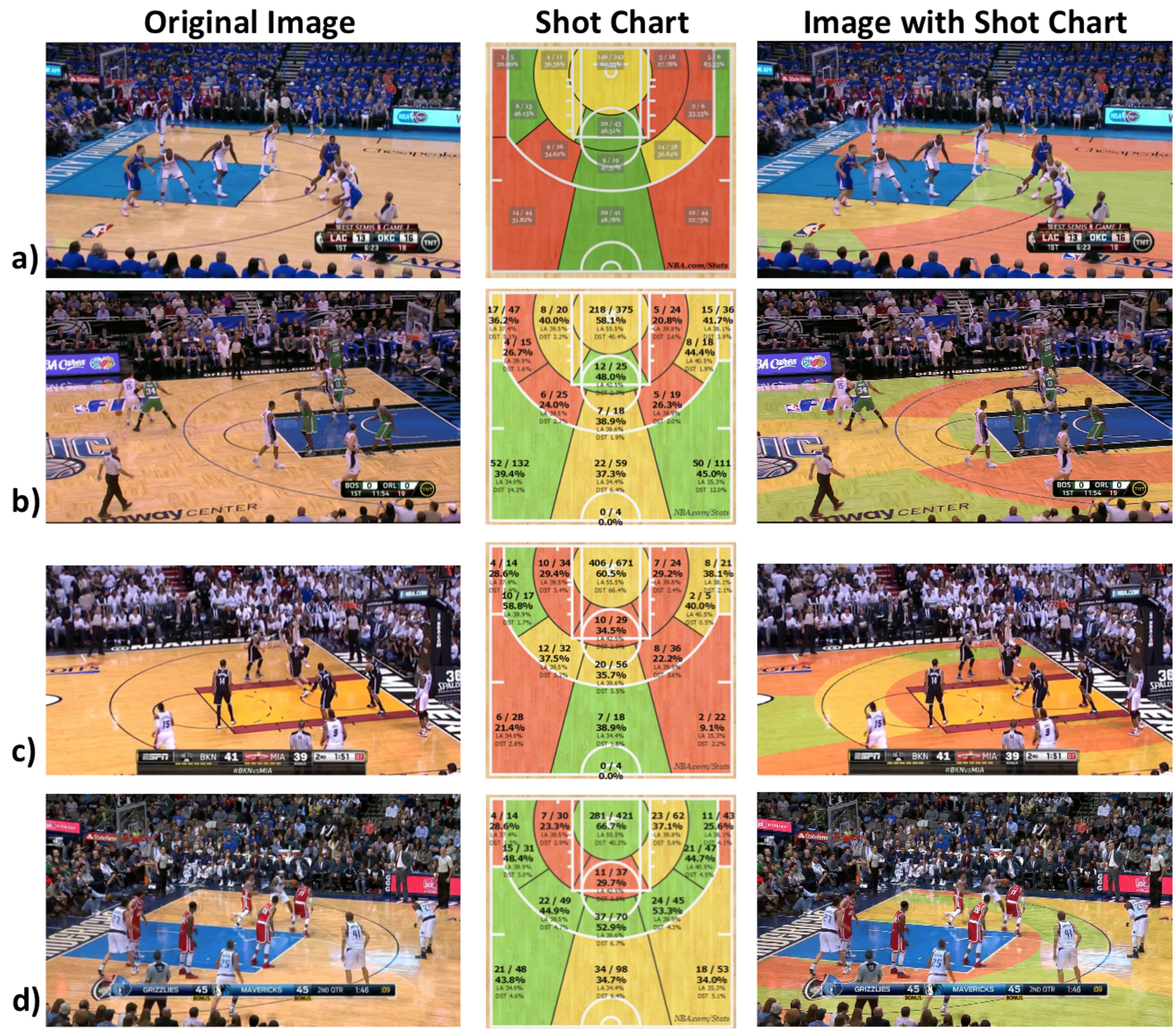


Figure 6: Four results of the algorithm projecting shot charts onto broadcast NBA images. Image (a) corresponds to blue X in Figure 5; (b) to green X; (c) to red X, (d) to blue O

court to find key points in the image, camera calibration and assignment of pixels on the court to shot chart regions, and combination of the original image with the image of the projected shot chart. The method shows reasonable accuracy in separating the court from other features in the image as well as having boundaries between shot chart regions at the appropriate locations in the image.

The method was applied to a variety of different NBA courts, and the dominant color detection method that was implemented through a Hough transform appeared to work very well despite some differing color schemes for these different courts. Some difficulties were encountered in images of certain playoff games, in which fans were provided with shirts of the same color. Rather than the region of fans near the top and bottom of the image having an arbitrary assortment of colors, in these cases there were many pixels in the image that would vote for the same incorrect bin in the HSV Hough space that was used. This issue was overcome by ignoring the top 25% of the image, which is nearly always occupied by the crowd, and by enforcing that the Hough bins corresponding to dark pixels with low values were ignored when identifying the dominant colors.

Only images using a broadcast angle and focusing primarily on the left or right side of the court were considered. However, the camera angle in the broadcast is not stable in these situations, so there was some variability in the images used to test the algorithm. This variability resulted in some difficulty in the step for detection of potential points on the court lines of interest, shown as the transition from Figure 3b to 3c. Knowledge of the court based on the shape and extent of the court mask had to be incorporated in order to accurately identify these candidate points across a range of camera angles.

Considering images of both the left and right sides of the court also resulted in a need to differentiate between these images when identifying points along the lines of interest. Using different sets of court coordinates, shown in Figures 2b and 2c, for camera calibration of images showing the left and right sides of the court allowed these different cases to be treated identically for the later steps in the algorithm following camera calibration.

This method excludes the key, the colored rectangle near the hoop, when projecting the shot chart onto the court. In order for a good projection to be made onto the key, its color would have to be changed so that the projected shot chart would be visible in the final image. This was not done for this work due to difficulties in changing the color of the entire key while ignoring occluding players and maintaining the court markings that exist in the key. However, implementing this into the algorithm would be a good next step to extend this work further.

This algorithm could definitely improve the viewer experience of an NBA broadcast if implemented appropriately. The addition of shot chart data in proper context to the broadcast would help commentators make salient points with the help of a great visual aid. Future work to further increase the accuracy of the projection and identification of court pixels, along with the inclusion of the key in the shot chart projection, would result in a useful tool to enhance NBA broadcasts.

The Matlab code and images used for this work can be accessed at the following link: `https://stanford.box.com/s/akh4sdyput0ez37yy0he3la43y2ono3s`
The shot chart projection is done by running *program_main.m*.

6. References

[1] Hu, Min-Chun, Ming-Hsiu Chang, Ja-Ling Wu, and Lin Chi (2011), "Robust camera calibration and player tracking in broadcast basketball video." IEEE Transactions on Multimedia, 13(2): 266- 279.