# HOMOGRAPHY MATRIX COMPUTATION IN THE SOCCER IMAGES


## ABSTRACT

In this work, homography matrix computation is proposed based on the soccer broadcast images. In order to achieve this, at least 4 key points are detected by using various image processing algorithms. Homography matrix, between the 2D soccer field and the broadcast image, is calculated based on the detected key points. Various statistics about soccer games can be obtained by using the computed homography matrix, since it gives the 2D reflection of the soccer field.


## INTRODUCTION

Nowadays, data analysis is becoming more and more popular in the soccer industry. Teams are getting more aware of the power of the data to analyze the games. There are various applications of soccer video analysis. The common applications are player localization and tracking, ball tracking, event detection and summarization, virtual advertisement, computer assisted refereeing etc [2]. One of the most important steps to develop these applications is computing the homography matrix between the soccer field and the 2D model.

There is a lot of research and various approaches to tackle this problem. In the work [3], intersection points of lines or ellipses are detected, and homography matrices are computed by point correspondences in the penalty and center fields. Kalman filtering is applied to track the intermediate fields on the soccer pitch. For the work [4], a similar approach [3] is applied to compute the homography, additionally they detect the players by template matching. In the work [2], line masks are extracted and initial homography is obtained. After, the initial homography is optimized iteratively.

In this work, a very basic approach for computing the homography matrix for single frame soccer field images, is presented. It can be improved for real time soccer video applications. Mostly, the works [3, 4] are followed with small modifications on the framework.

In order to experiment with the suggested work, IAUFD [1] dataset is used. This dataset contains 100k soccer images, and it is collected from 33 different soccer games with various weather conditions. Also, the dataset is annotated for 10 different categories for event detection. In this work, the dataset is only used for the detecting key points of the soccer field and computation of the homography matrix.

## METHOD

In order to detect the key points in the image, the soccer field should be extracted from the image. Soccer field is extracted by using histograms on the HSV space. The most dominant pixel value on the H(Hue) channel is considered as a soccer field. H channel is used, because it describes the pure color, and green playfields can be extracted. Since one pixel value is not enough to detect the whole field, a predefined pixel value range is used as a soccer field mask. Finally, a series of morphological operations are performed to reduce the noise in the field mask. Figure 1 demonstrates the field extraction process.

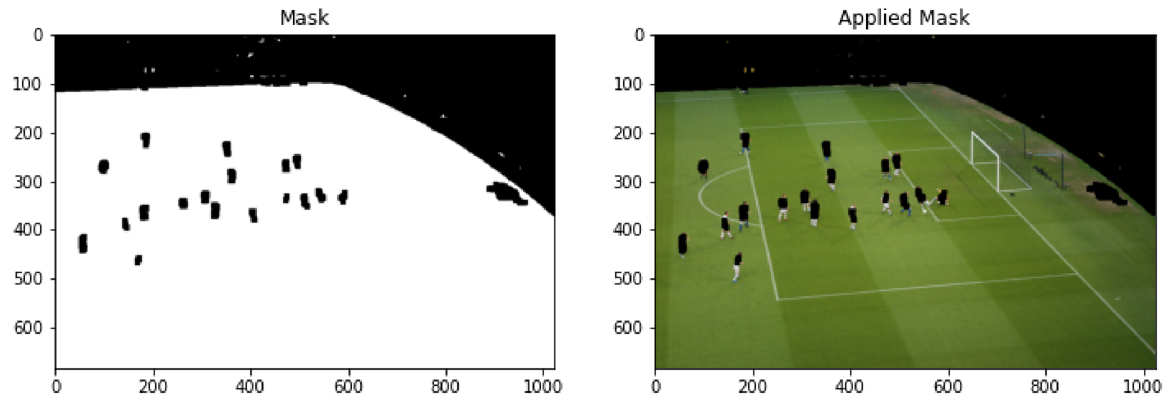


**Figure 1**

After obtaining the field mask, the soccer image is converted into grayscale. Before applying the mask to the image, tophat operation is performed to enhance the bright pixels so that the chance of missing important lines is reduced. Finally the tophat image is binarized, and the field mask is applied to the binary image to get white soccer field lines. Figure 2 shows the obtained images for the applied steps.

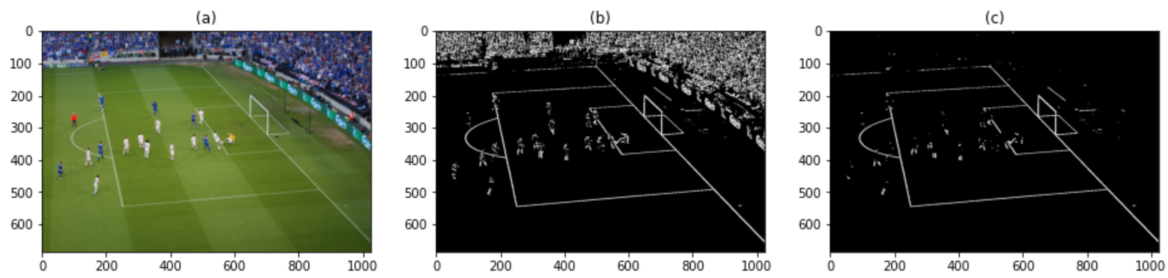


**Figure 2:** a) Source image; b) Binarized image after the tophat operation; c) Filtered image with the play field mask

In order to detect the lines on the soccer field, the Hough Transform algorithm is used on Figure 2(c). The idea behind the Hough Transform is that it represents the points in the image space as lines in the parameter space. Parameter space keeps all possible parameters(slope and b) of lines that pass through a point. Intersection points of the multiple lines in the parameter space represents a line in the image space. Therefore a point in the image space represents a line in the parameter space, and a point in the parameter space represents a line in the image space.

Detected lines that are below some threshold in terms of length, are filtered out to remove the noise. Also, for 1 line there could be many similar detected lines, those lines are merged by their slope values and intersections. Lastly, all lines are extended through the soccer field.

After line detection, a decision algorithm should classify the image as center field or penalty area, since the algorithm can not work on the intermediate frames. It is impossible to find at least 4 key points in the intermediate steps, so the homography matrix can not be calculated. If there is any detected line that has an angle with the x axis as between 85–95 degrees, it is considered as a center field image. If there is no center line and there are at least 2 parallel lines, it is considered as a penalty area image. Figure 3 depicts the 2 different image types and detected lines.

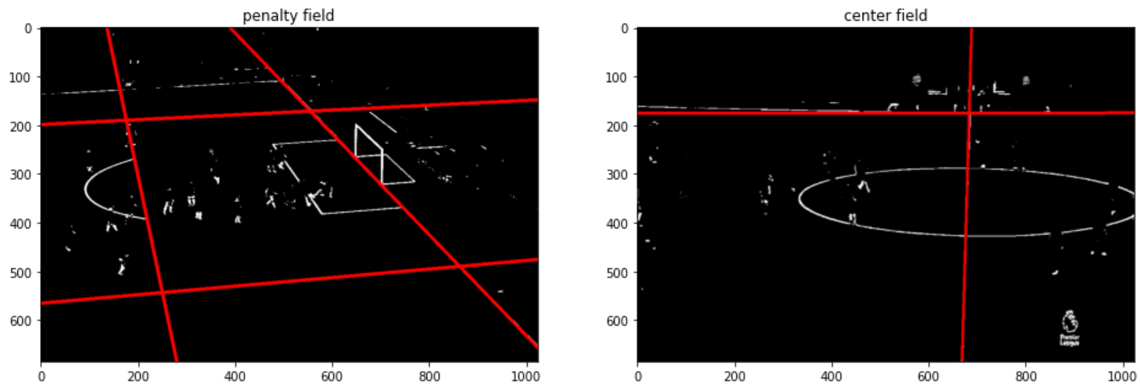


**Figure 3**

In order to compute homography, 2 cases on Figure 3 are considered separately. For the penalty field case, every possible 4 combinations of intersection points are obtained. For every combination of points, a proper rectangle is created, and the homography matrix between the soccer 2D model and the binary source image is computed by matching points. The 2D model is projected onto the binary source image by using the obtained homography matrix.

In order to calculate the homography matrix, a minimum of 4 pairs of points(source and destination) are needed and (1) should be solved based on these points.

$$\begin{bmatrix} x_d^i \\ y_d^i \\ 1 \end{bmatrix} = \begin{bmatrix} h_{11} & h_{12} & h_{13} \\ h_{21} & h_{22} & h_{23} \\ h_{31} & h_{32} & h_{33} \end{bmatrix} \begin{bmatrix} x_s^i \\ y_s^i \\ 1 \end{bmatrix} \tag{1}$$

In formula (1), i denotes each pair of points, d denotes destination points, and s denotes source points. After applying some algebraic operations to (1), the following formula (2) can be obtained.

$$\begin{bmatrix} x_s^1 & y_s^1 & 1 & 0 & 0 & 0 & -x_d^1 x_s^1 & -x_d^1 y_s^1 & -x_d^1 \\ 0 & 0 & 0 & x_s^1 & y_s^1 & 1 & -y_d^1 x_s^1 & -y_d^1 y_s^1 & -y_d^1 \\ & & & & & . & & & \\ & & & & & . & & & \\ & & & & & . & & & \\ x_s^n & y_s^n & 1 & 0 & 0 & 0 & -x_d^n x_s^n & -x_d^n y_s^n & -x_d^n \\ 0 & 0 & 0 & x_s^n & y_s^n & 1 & -y_d^n x_s^n & -y_d^n y_s^n & -y_d^n \end{bmatrix} \begin{bmatrix} h_{11} \\ h_{12} \\ h_{13} \\ h_{21} \\ h_{22} \\ h_{23} \\ h_{31} \\ h_{32} \\ h_{33} \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ . \\ . \\ 0 \\ 0 \\ . \\ . \\ 0 \\ 0 \end{bmatrix} \tag{2}$$

If we introduce the total number of pairs of points as n, first matrix as A in which all the values are known, and second matrix as h, unknown matrix h can be found by solving the following formula (3) with constraint. The given constraint prevents the obtaining of a trivial solution h as zero matrix.

$$Ah = 0 \text{ subject to } ||h||^2 = 1 \tag{3}$$

Finally (3) can be solved by the following constrained least squares formula (4) where Ah is minimized.

$$\min_h ||Ah||^2 \text{ subject to } ||h||^2 = 1 \tag{4}$$

After getting the homography matrix, cosine similarity between the projected image and binary source image is calculated. Cosine similarity measures how similar 2 vectors are by measuring the cosine of the angle between them. The best homography matrix is selected with the highest cosine similarity value. In order to calculate the cosine similarity, images are flattened and formula (5) is applied.

$$\cos(\theta) = \frac{\sum_{n=1}^{H*W} X_n Y_n}{\sqrt{\sum_{n=1}^{H*W} X_n^2} \sqrt{\sum_{n=1}^{H*W} Y_n^2}} \tag{5}$$

Here X and Y are the flattened images(vectors), and H*W denotes the multiplication of height and width of the image. Therefore, H*W gives the size of the flattened image vector. Figure 4 shows the entire process step by step.

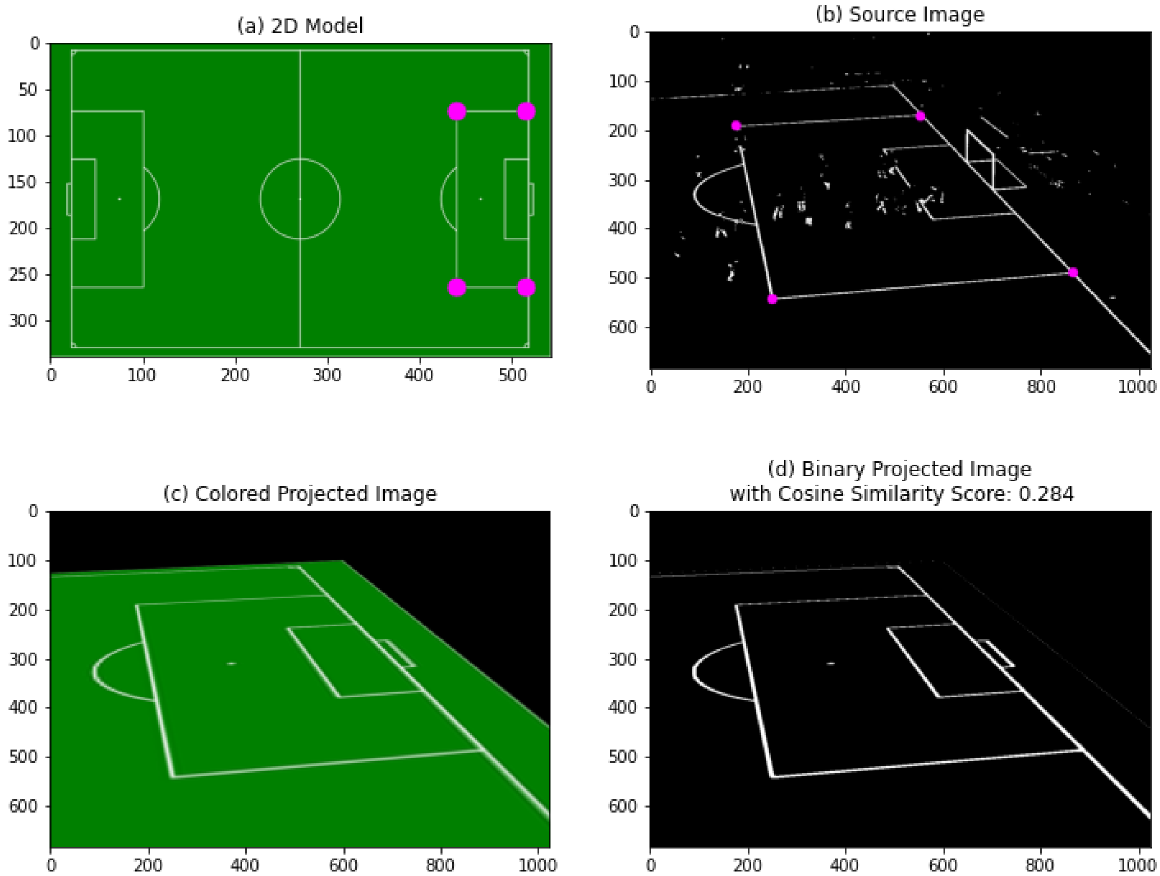


**Figure 4:** a) 2D soccer field model with matching points; b) Binary source image with detected intersection points; c) 2D model is projected onto the source image; d) Binarized projected image, cosine similarity score is calculated with the source image (b)

For the center field case, it is impossible to find 4 non-linear key points, but the circular area on the center field can be detected. In order to detect the circular area, a set of lines that have a certain angle range with the center line, are detected from the masked image. Start and end points of these lines are used to fit an ellipse.

The formula (6) represents an ellipse where i denotes the number of points on the ellipse.

$$\begin{bmatrix} x_1^2 & x_1y_1 & y_1^2 & x_1 & y_1 & 1 \\ x_2^2 & x_2y_2 & y_2^2 & x_2 & y_2 & 1 \\ & & . & & & \\ & & . & & & \\ & & . & & & \\ x_n^2 & x_ny_n & y_n^2 & x_n & y_n & 1 \end{bmatrix} \begin{bmatrix} A \\ B \\ C \\ D \\ E \\ F \end{bmatrix} = 0 \qquad (6)$$

Although the formula (6) can be solved by eigenvalue decomposition [5], there are some problems regarding ellipse fitting. Figure 5 (a) shows that all of the points do not represent an ellipse, there are a lot of outliers. Therefore, the RANSAC(RANdom SAmple Consensus) algorithm can be integrated into the ellipse fitting method, so that the best ellipse can be found among the huge number of outliers. The idea behind the RANSAC is to generate a set of models from randomly selected pairs of observations [6]. In order to apply RANSAC algorithm following steps [7] can be followed for this case:

- Randomly choose s samples from the point clouds of n.
- Fit the model for the samples s.
- Get the number M as counts of data points (inliers) that fit the model within an error.
- Repeat the steps above for the given number of iterations.
- Finally choose the model with the maximum M.

Figure 5 shows the result of the ellipse fitting algorithm.

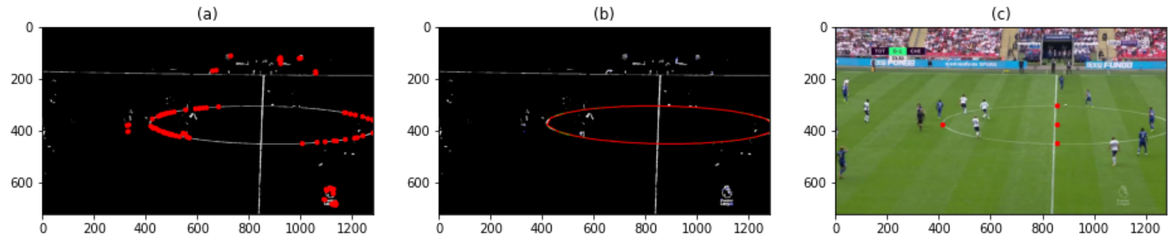


**Figure 5:** a) Detected candidate points to fit an ellipse curve; b) Fitted ellipse curve; c) Points that are used for calculating homography matrix (The last point is out of bounds of the image, but it is not important in terms of homography matrix calculation.)

The key points, for the 2 different cases as penalty and center fields, are detected. The last operation is to calculate the final homography matrix between the soccer image and the 2D soccer field model. Finally, the soccer image can be reflected to the 2D model by using the calculated homography matrix. It is important to mention that in Figure 4, the 2D model is reflected into the binarized soccer image, but now the soccer image is reflected into the 2D model. Figure 6 shows the desired output for 2 different cases.

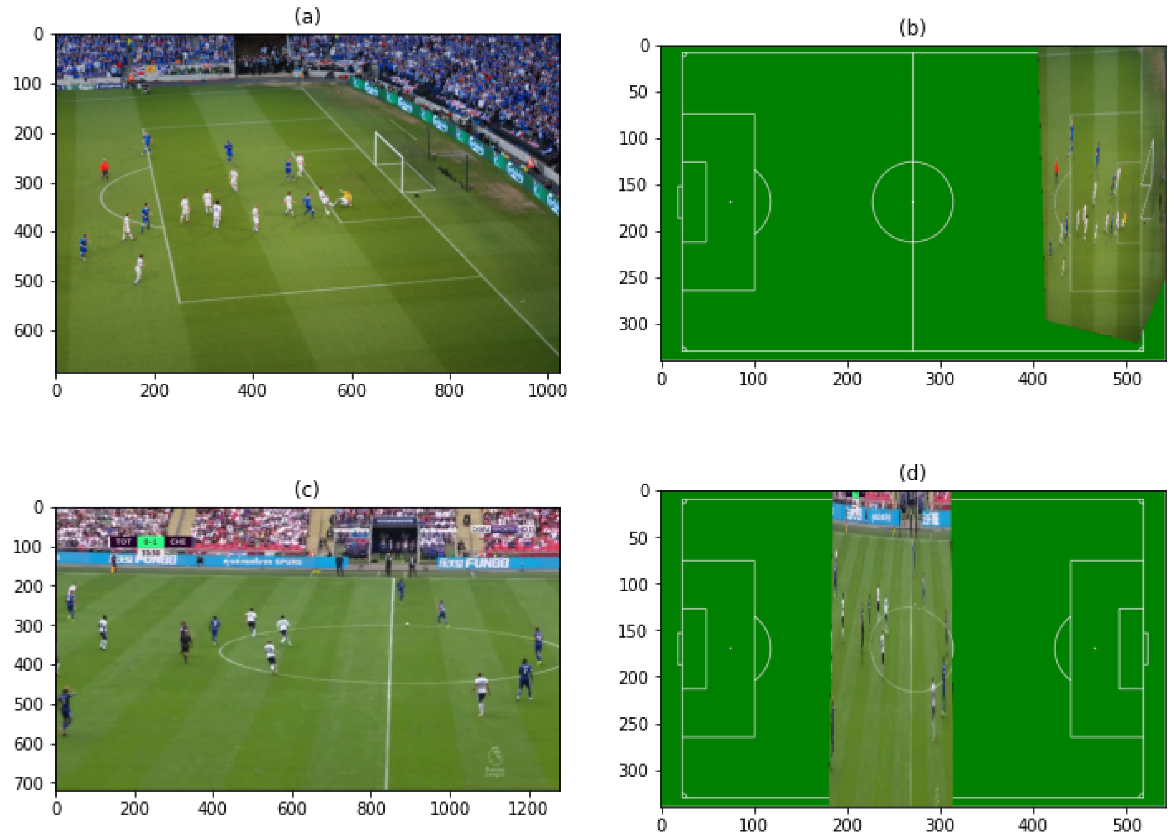


**Figure 6:** a) Penalty field source image; b) Penalty field source image is projected into the 2D model; c) Center field source image; d) Center field source image is projected into the 2D model

# CONCLUSION & FUTURE WORK

In this paper, a basic approach is presented to compute the homography matrix for soccer images that contains the center or penalty area. In order to compute the homography in the intermediate areas where it is impossible to detect key correspondences, different algorithms can be integrated to the system. Also, various algorithms like player detection, event detection etc., can be integrated to the system, so that useful information can be extracted from the soccer videos in real time.

# REFERENCES

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