Augmented Reality

Question 1  Error Propagation on a soccer field

In this exercise, we would like to create a software that helps to detect offside situations in soccer games. For the scope of this exercise, it is sufficient to know that an offside situation occurs when the attacking player is closer to the baseline than the last player of the other team at the moment the ball is kicked by a third person (Figure on the right).

The software receives a picture (taken with an arbitrarily positioned camera) at the moment the ball is kicked, and a user has to click on the two players involved. From the positions on the screen, the distance between the two players along the x-axis of the field is computed (see Figures). As a given offside would seriously interrupt the game, one wants to be really sure that it is an offside, and for that the error distribution of the measurements (clicks) is taken into account.

(1) Before the actual match, we need to determine how precisely the user is able to click on a point on the screen. For that, he is asked to repeatedly click on the same point. This results in the following 2D coordinates:

\[(4, 1)^\top, (0, 7)^\top, (6, 3)^\top, (7, 6)^\top, (2, 8)^\top, (4, 4)^\top, (3, 2)^\top, (8, 9)^\top, (10, 4)^\top, (6, 6)^\top\]

Compute the mean \(\bar{p}\) and the covariance \(C\) of the point distribution.

(2) Assume that, during a real game, the user marks the position of two players by clicking on the two 2D points \(p_1 = (4, 5, 1)^\top\) and \(p_2 = (2, 2, 1)^\top\). You are also given a homography

\[H = \begin{pmatrix} 2 & -2 & 0 \\ 2 & -5 & 1 \\ 3 & -2 & -4 \end{pmatrix}\]

that converts screen to field coordinates. Derive a function \(f\) for error propagation that maps any point \(p\) to the transformed (by \(H\)) inhomogeneous point \(p'\).
(3) Compute the difference in the x-coordinate between the two players in the soccer field.

(4) Forward propagate the covariance of the two clicked image points to the corresponding points in the football field. Assume that both image points have equal covariance $C$, obtained in a). Hint: Derive the Jacobian of $f$ with respect to $x, y$ and think of which parts of the Jacobian are of interest in this problem.

(5) You now have the individual variances of the x-coordinates of the two players in the football field. How do you obtain the desired variance of the difference in the x-coordinate?

**Question 2 Putting it all together**

We now have finished our marker tracking and rendering programs, it’s time to put them together. Your task is to make the snowman move and rotate according to the marker movement. The easiest way to achieve this is to call a marker-tracker method in the rendering loop of GLFW.

*Note:* If you want to display OpenCV windows, you still have to call `cv::waitKey` at the end of the idle function, otherwise, you won’t see them. *Note:* You can use `glLoadTransposeMatrixf()` to convert between column-major and row-major matrices or implement your own solution.

In an Augmented Reality (AR) application, real and virtual information are merged. We should therefore also render the video data, in addition to the virtual snowman. For this, images have to be passed from the tracker part to the renderer part of the program. The basic steps to integrate the video as background into your rendering window are:

- Set the pixel zoom and storage parameters (`glPixelStorei()`, `glPixelZoom()`).
- Store default projection matrix and disable the depth test (`glDisable()`).
- Set an orthogonal projection matrix covering the entire screen (`gluOrtho2D()`).
- Set the raster position (`glRasterPos2i()`).
- Call `glDrawPixels`, passing the pixel buffer from the `cv::Mat`.
- Restore the original projection matrix and re-enable the depth test.
- Load the modelview matrix of your marker and draw the snowman.

**Question 3 Paper Review (for graduate students)**

If you are enrolled in the 684 section of the course, you are required to give a 15-20 minute presentation covering the details of the paper that you are assigned. Even if you are not presenting, you are required to attend these presentations and highly encouraged to engage in the discussion. You will be presenting during our regular lecture period either on April 26th or April 28th, NOT when the assignment is due. The paper assignment and presentation order is posted on Piazza. Please email me your presentations by April 25th at the latest.