Projective Geometry in Computer Vision

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10. Pose estimation
11. Aruco
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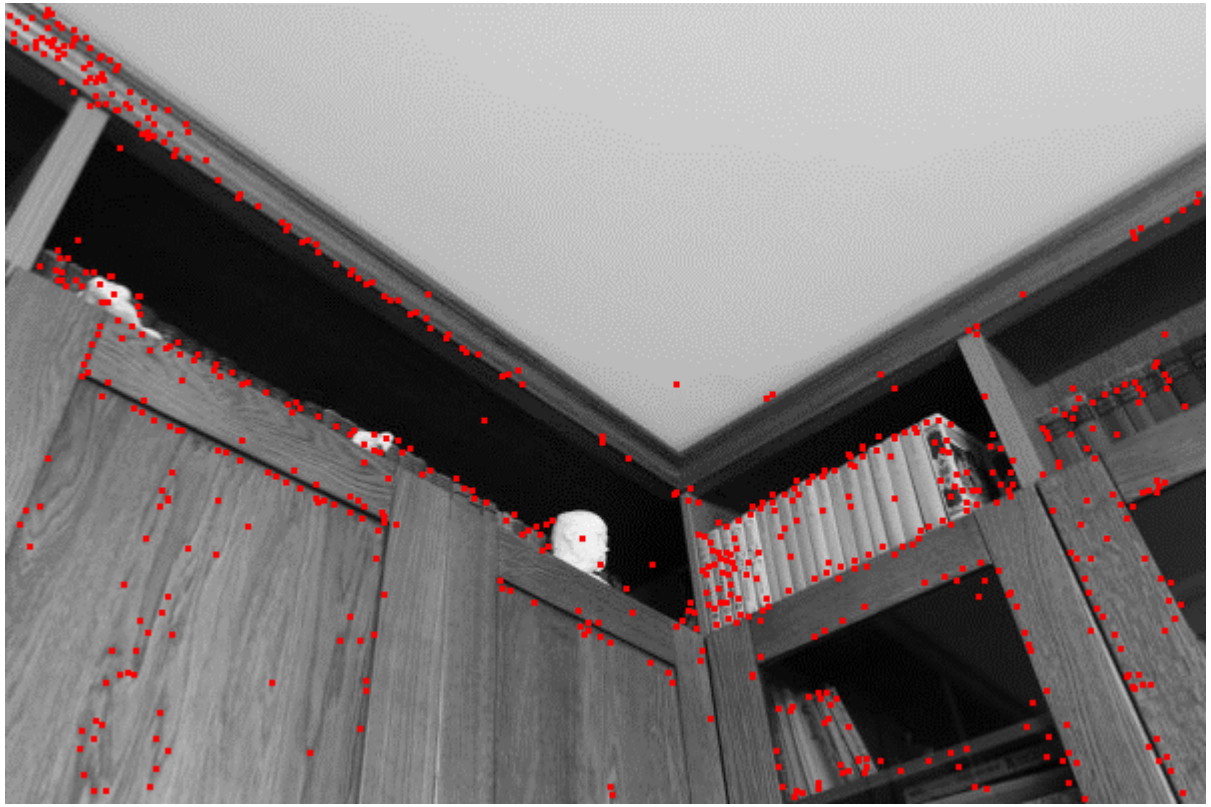
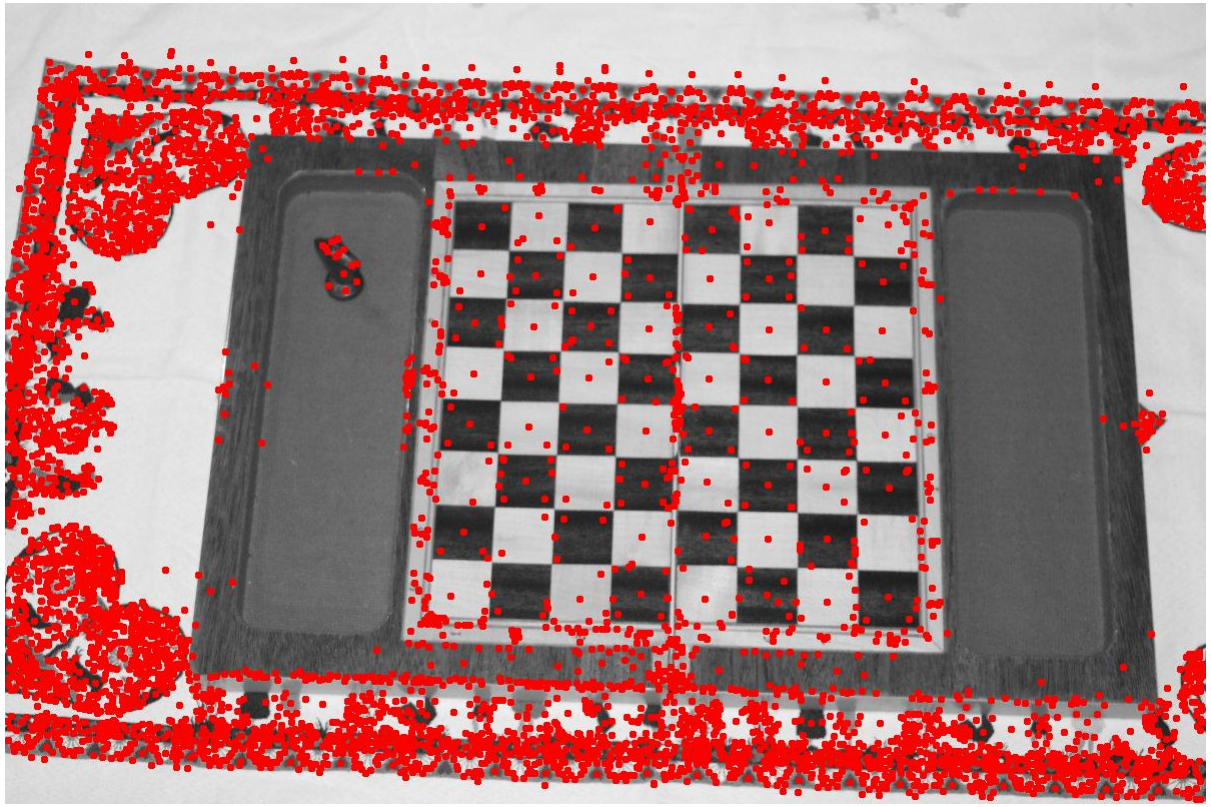
1. KeyPoints detection

KeyPoints detection

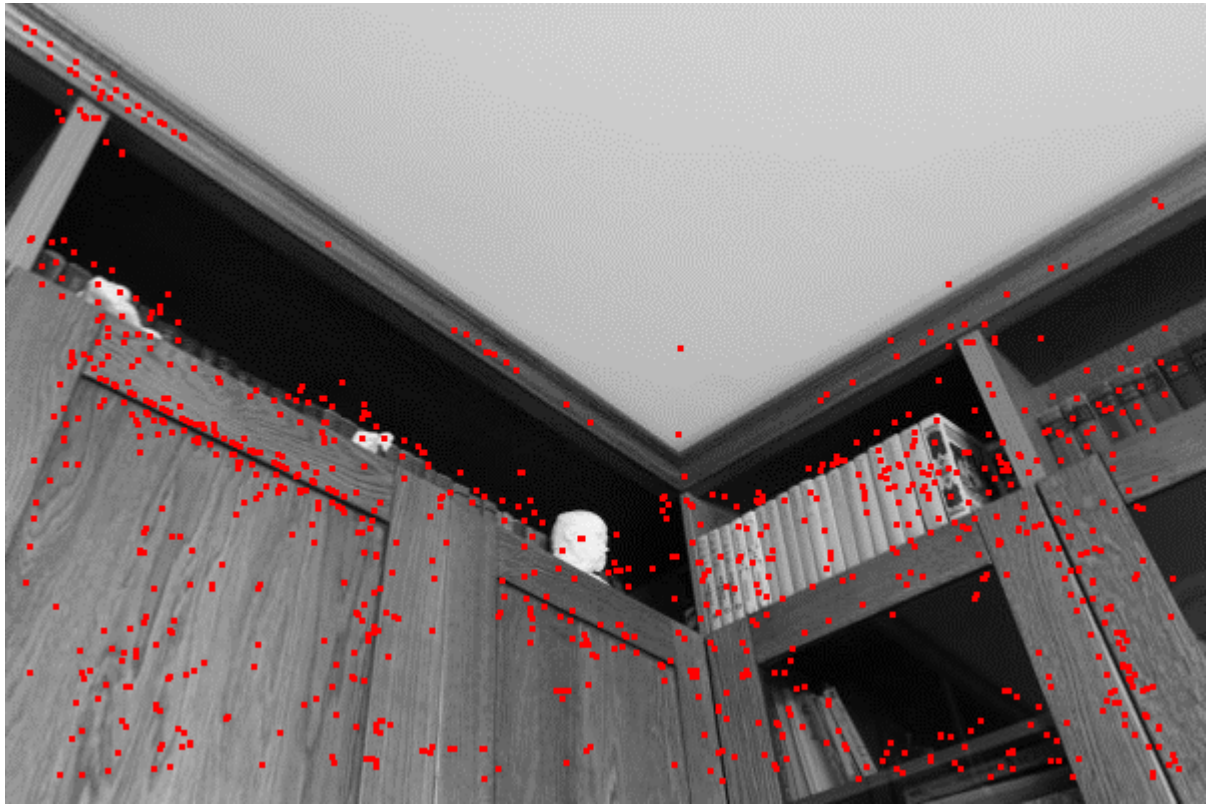
SIFT: Scale-Invariant Feature Transform

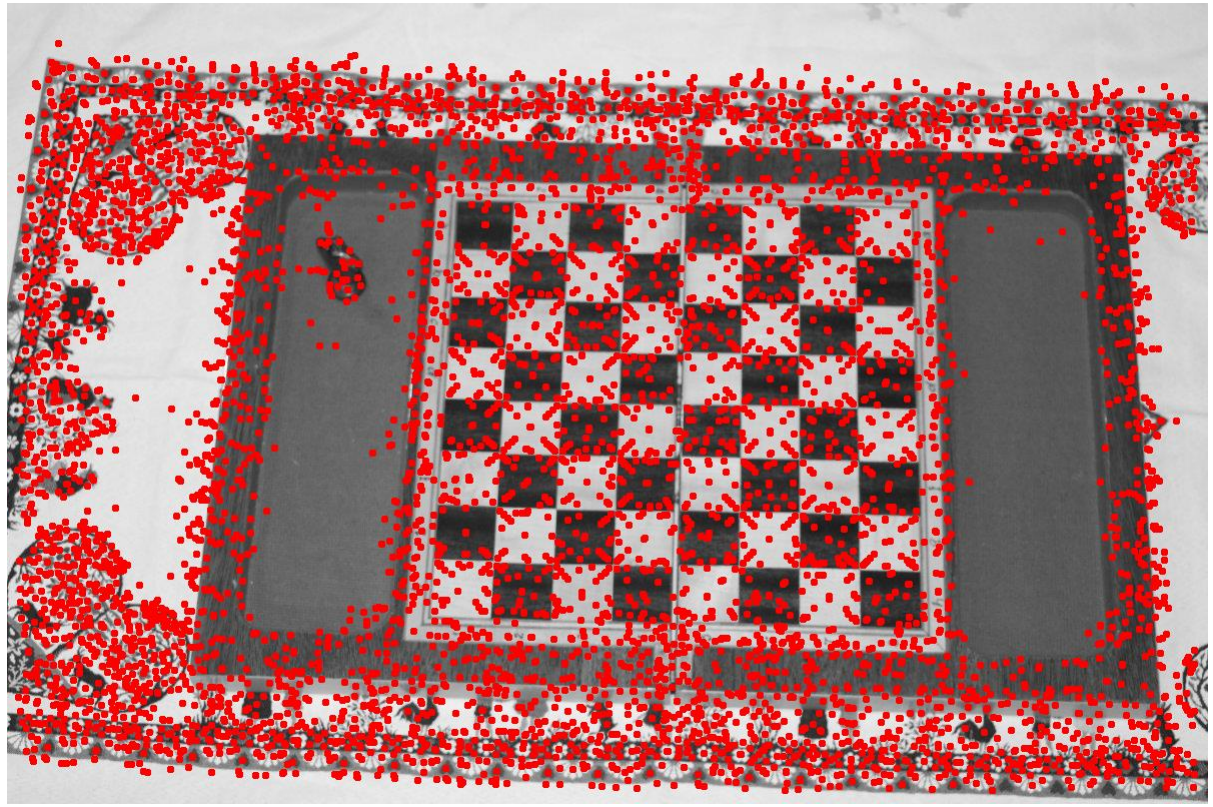




KeyPoints detection

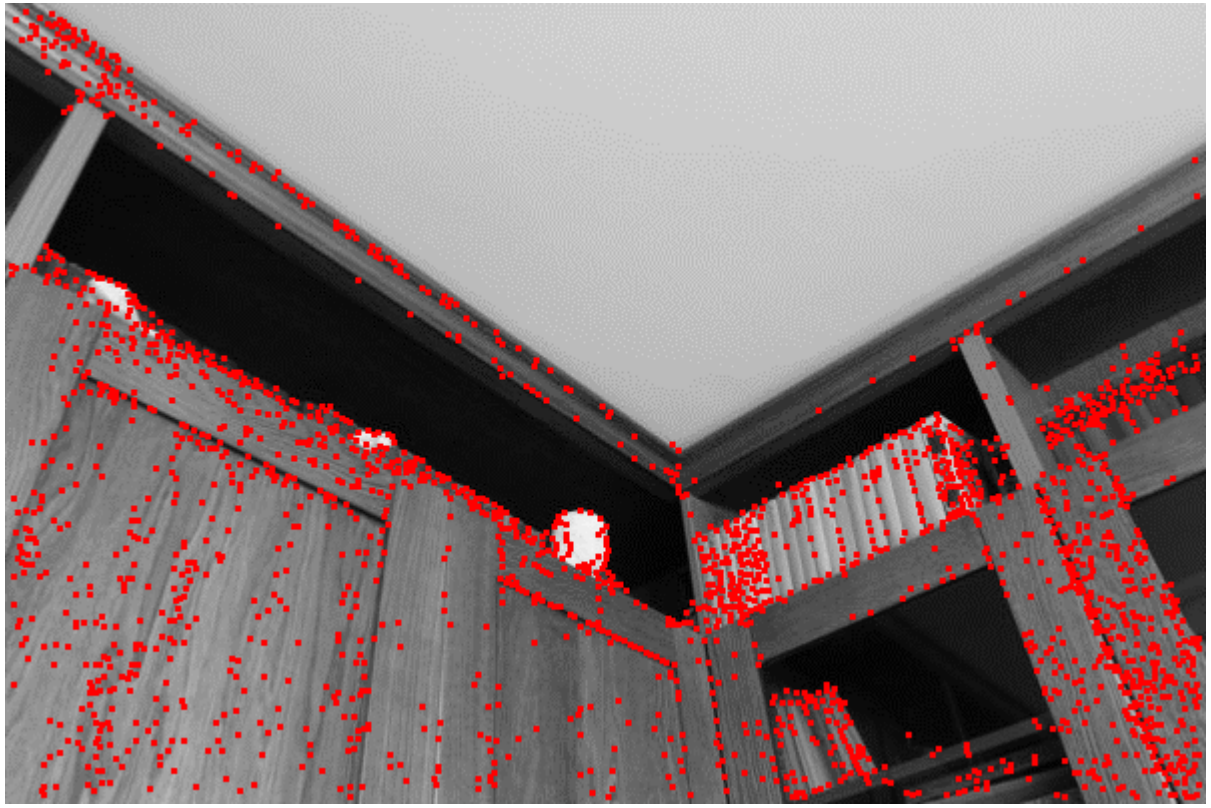
SURF: Speeded-Up Robust Features

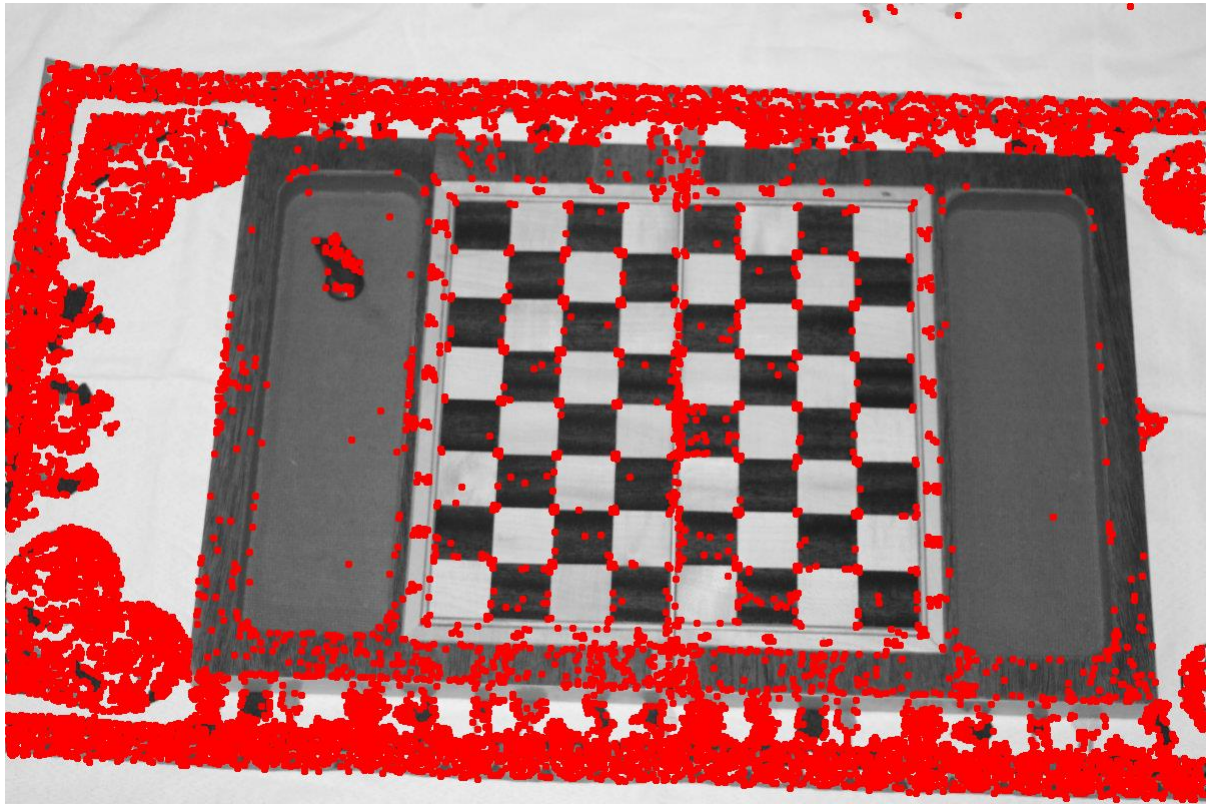




KeyPoints detection

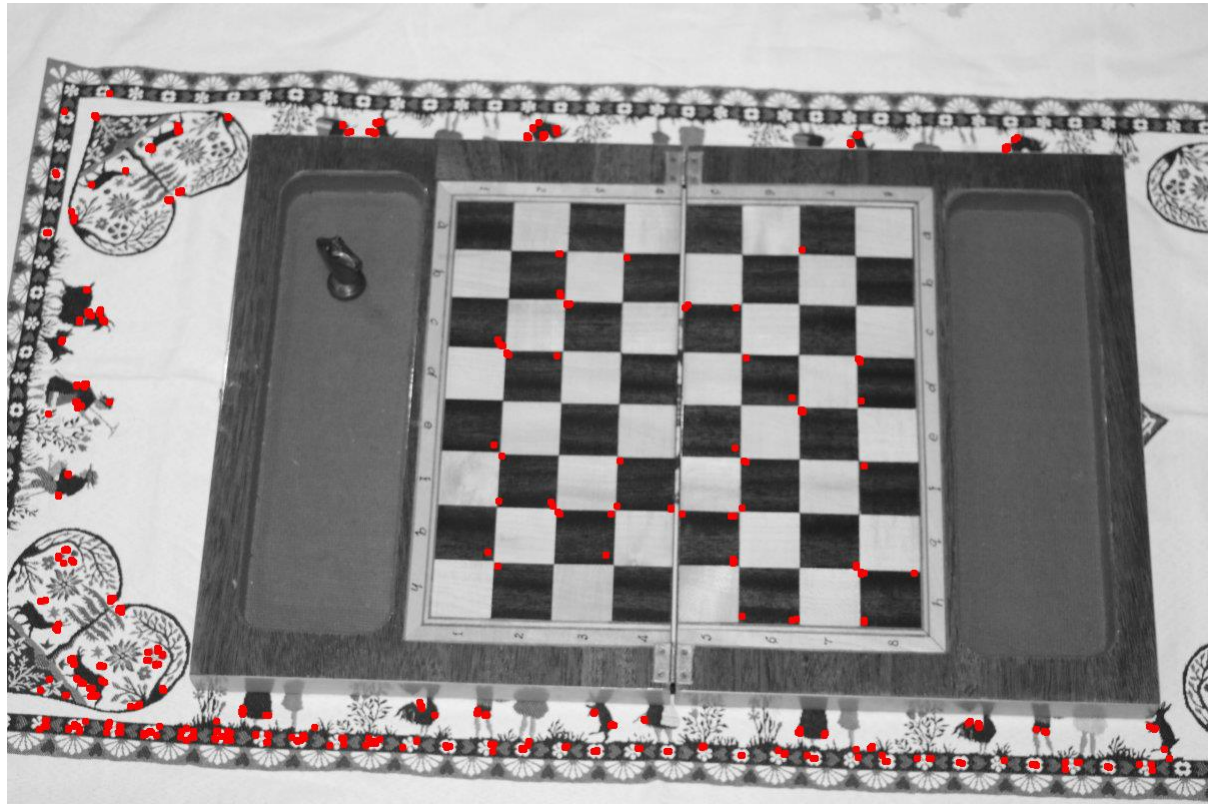
FAST: Features from Accelerated Segment Test





KeyPoints detection

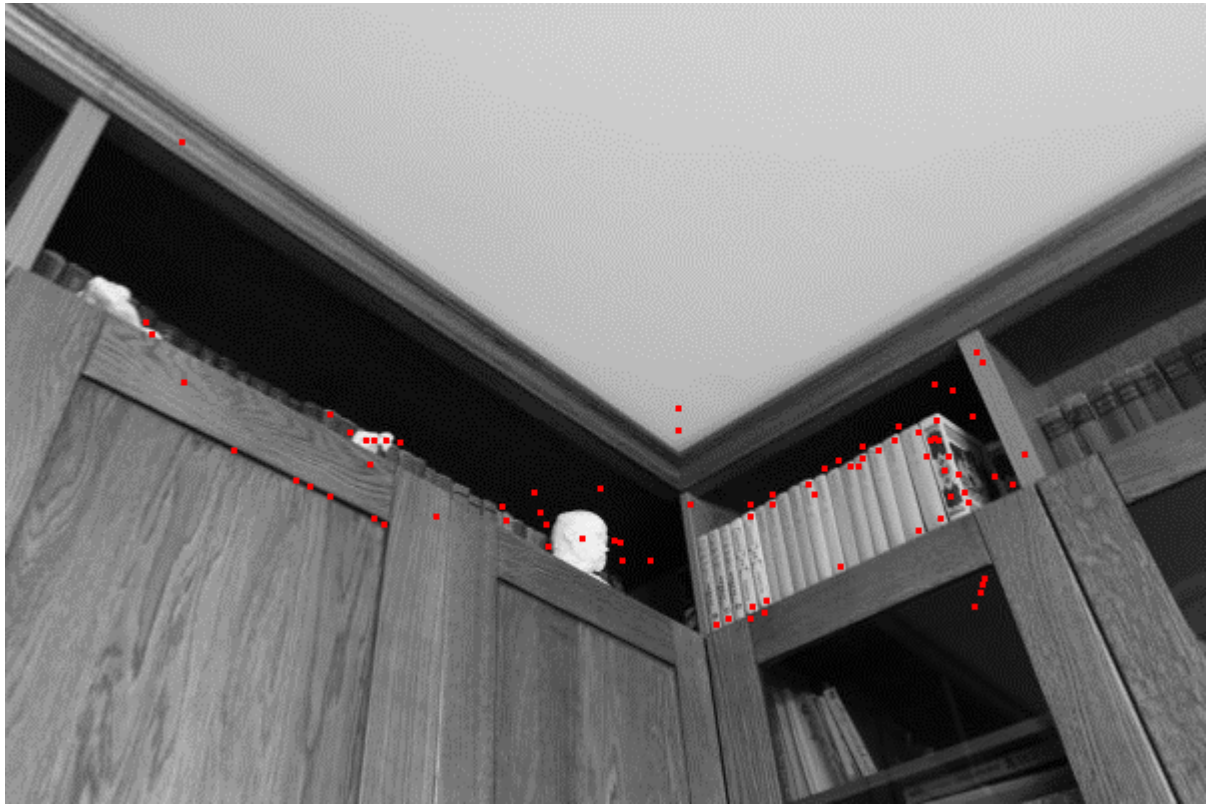
ORB: Oriented FAST and Rotated BRIEF

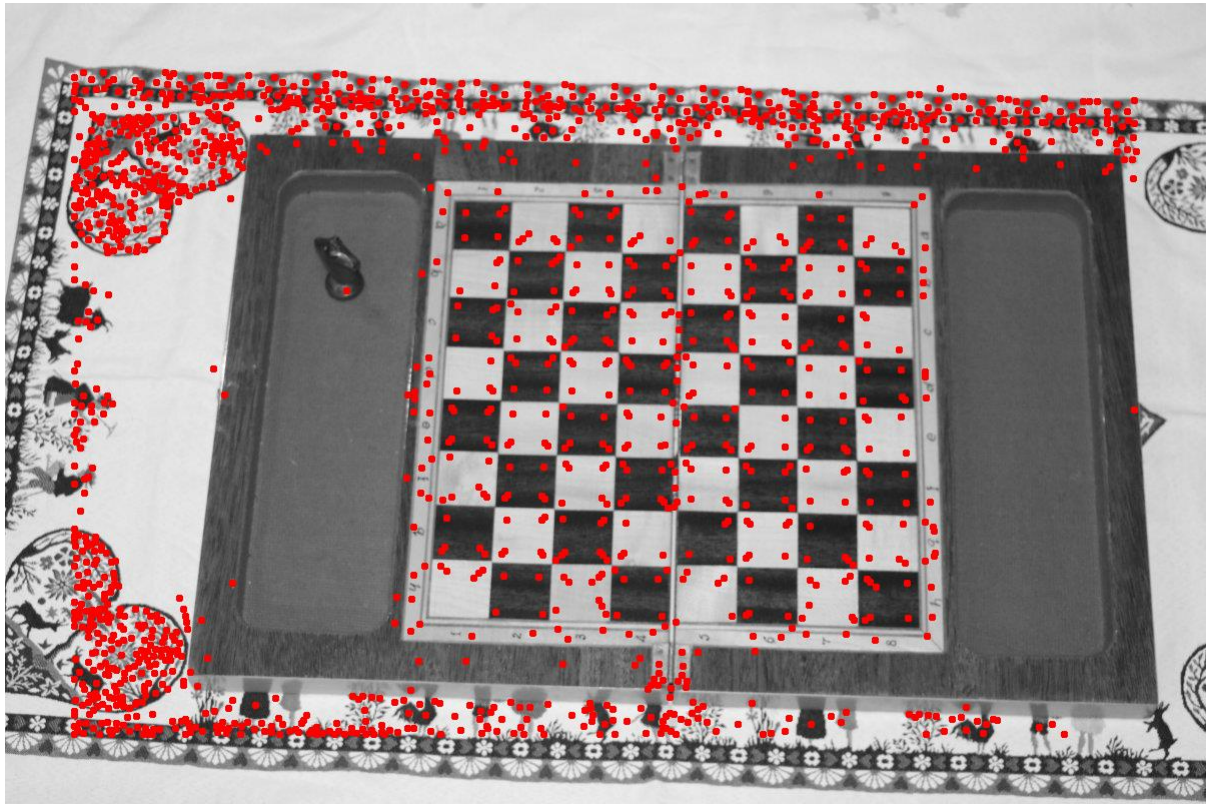


KeyPoints detection

STAR: scale-invariant **cen**ter-**surr**ound detector(CENSURE)

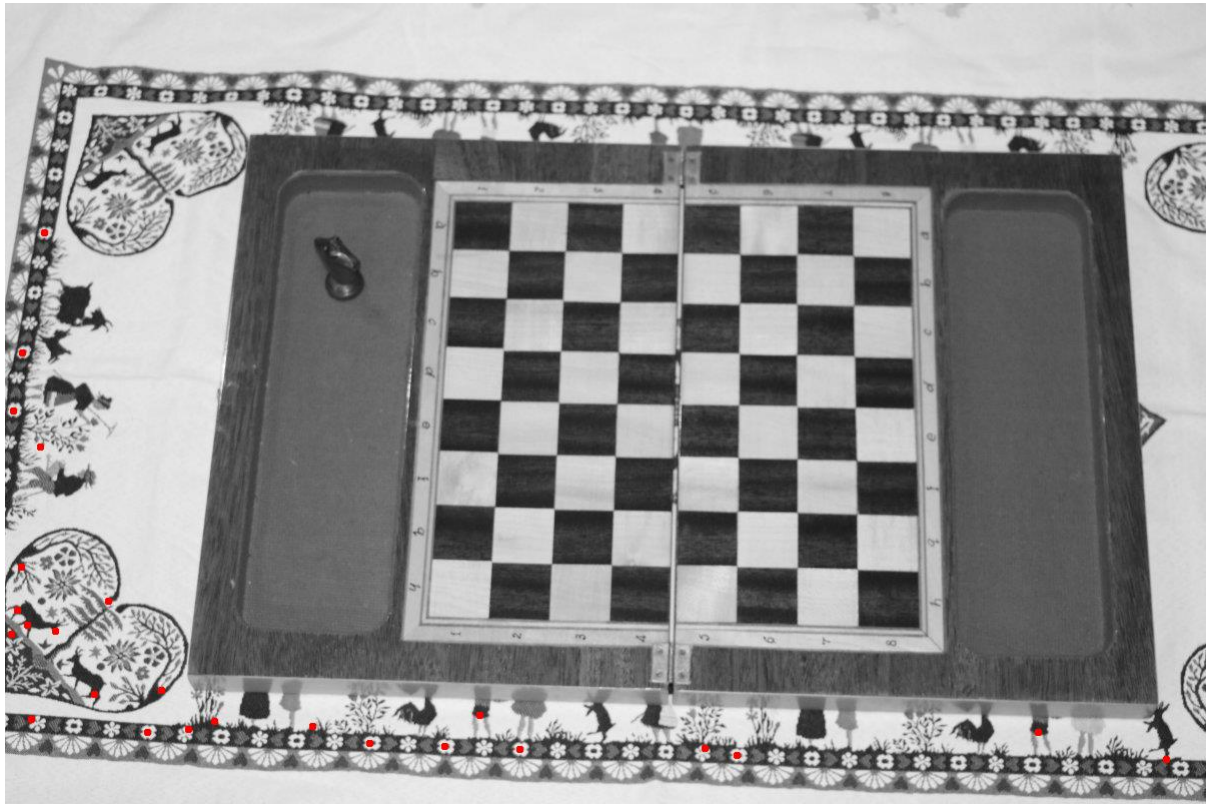
called STAR detector in OpenCV





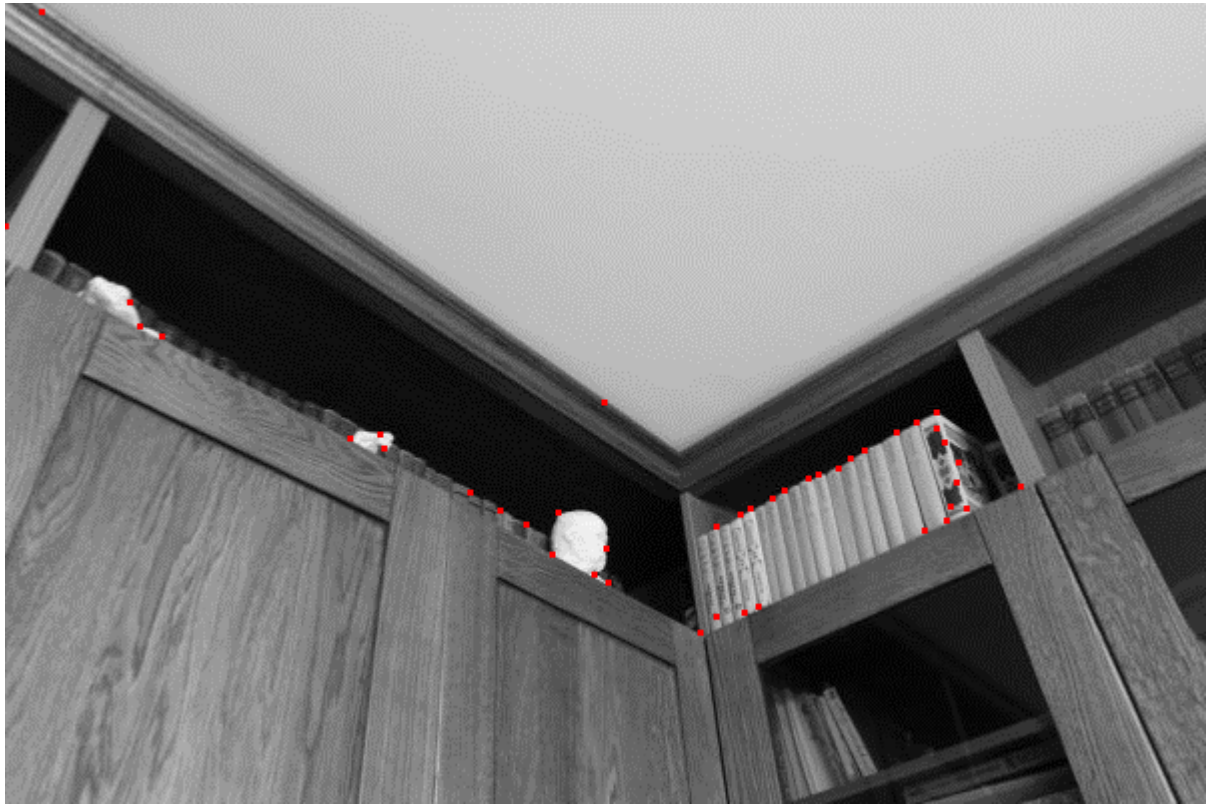
KeyPoints detection

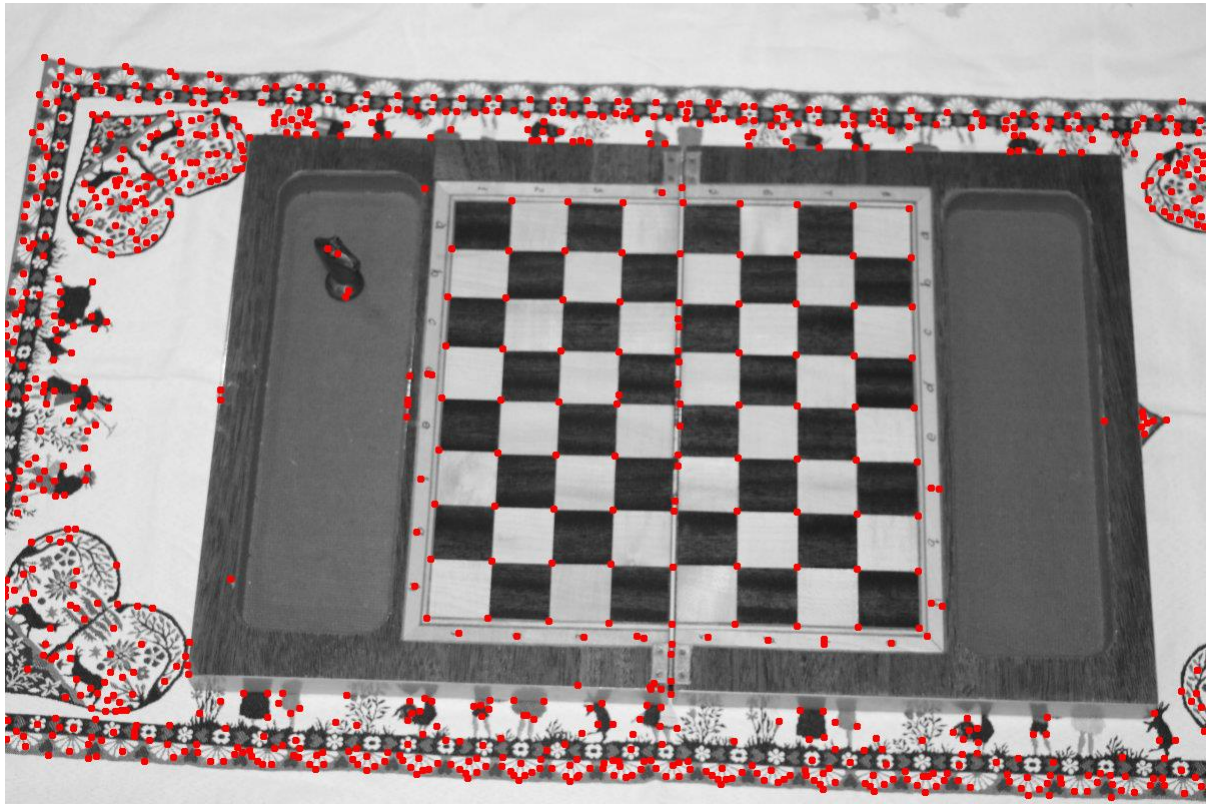
Shi-Tomasi



KeyPoints detection

Harris

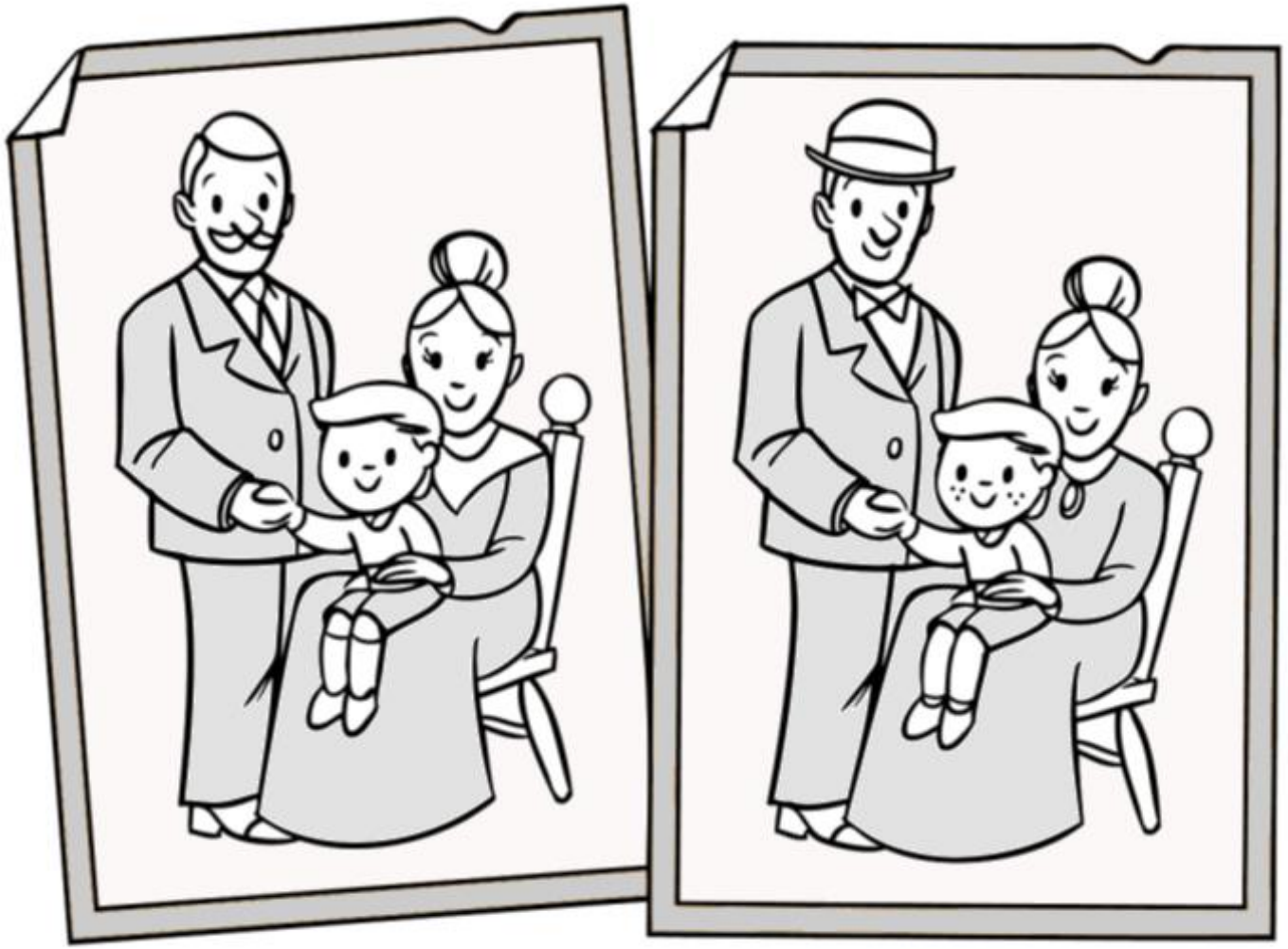




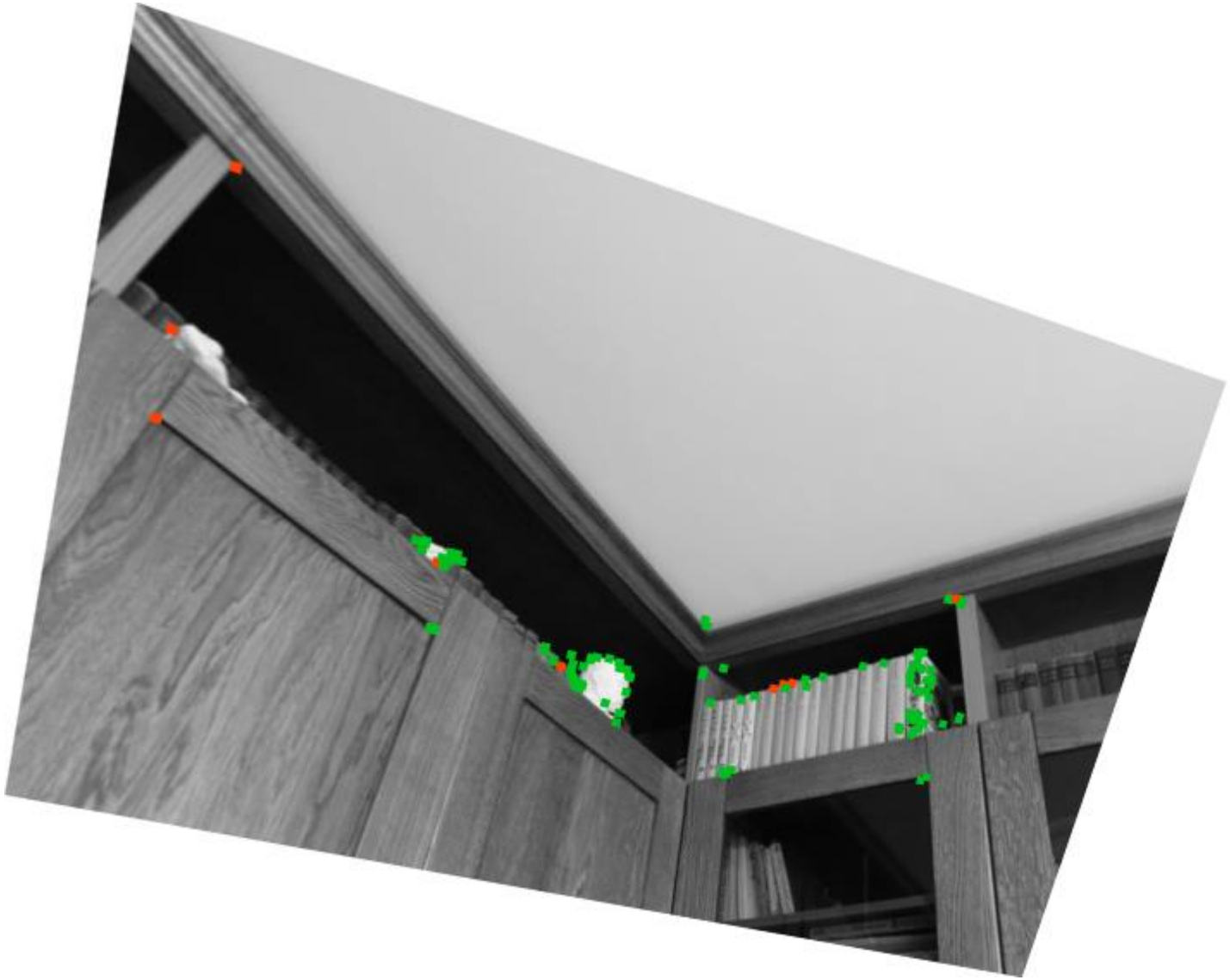
KeyPoints detection

```
def get_keypoints_desc(image1, detector='SIFT'):
    if len(image1.shape) == 2:
        im1_gray = image1.copy()
    else:
        im1_gray = cv2.cvtColor(image1, cv2.COLOR_BGR2GRAY)

    if detector == 'SIFT':
        detector = cv2.xfeatures2d.SIFT_create()
    elif detector == 'SURF':
        detector = cv2.xfeatures2d.SURF_create()
    else:  # detector == 'ORB'
        detector = cv2.ORB_create()

    kp, desc = detector.detectAndCompute(im1_gray, None)

    points = []
    if (len(kp) > 0):
        points = numpy.array([kp[int(idx)].pt for idx in range(0, len(kp))]).astype(int)

    return points, desc
```

2. Matching the KeyPoints



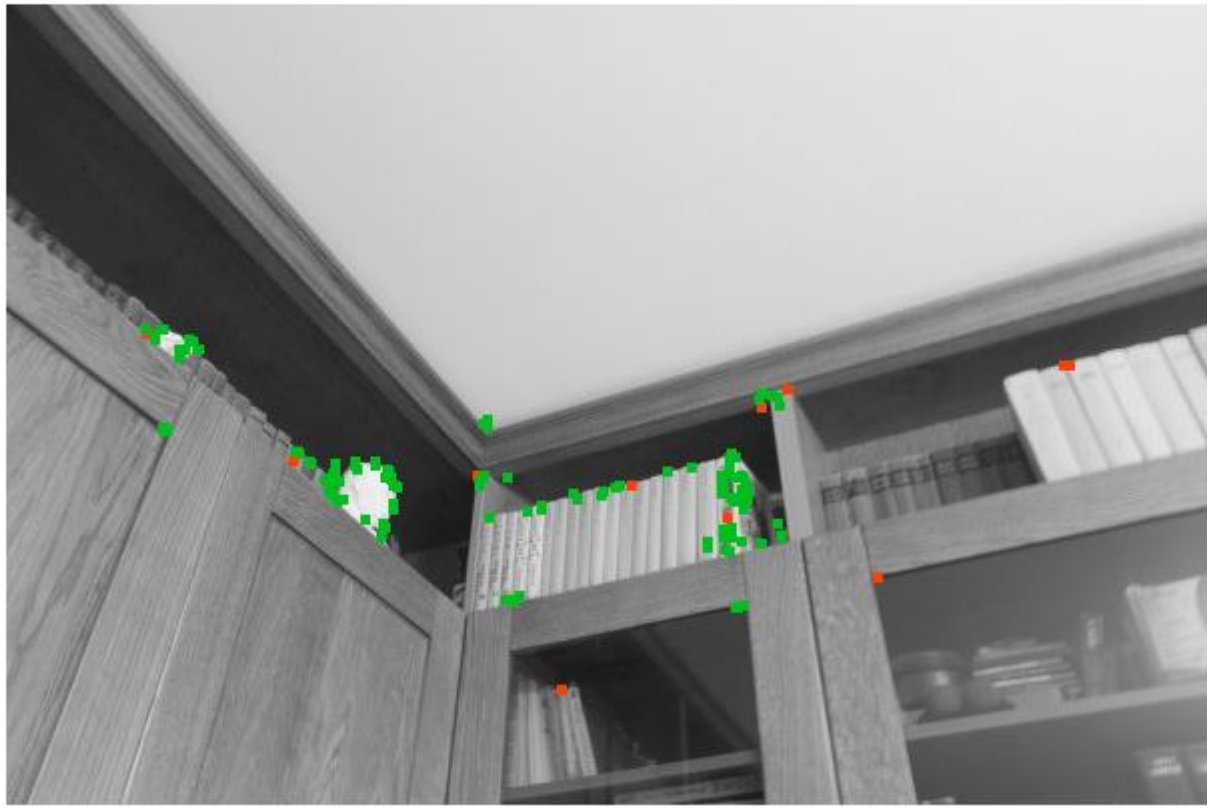
Matching the KeyPoints



Detector: ORB
Matcher: FLANN

True Positive
False Positive

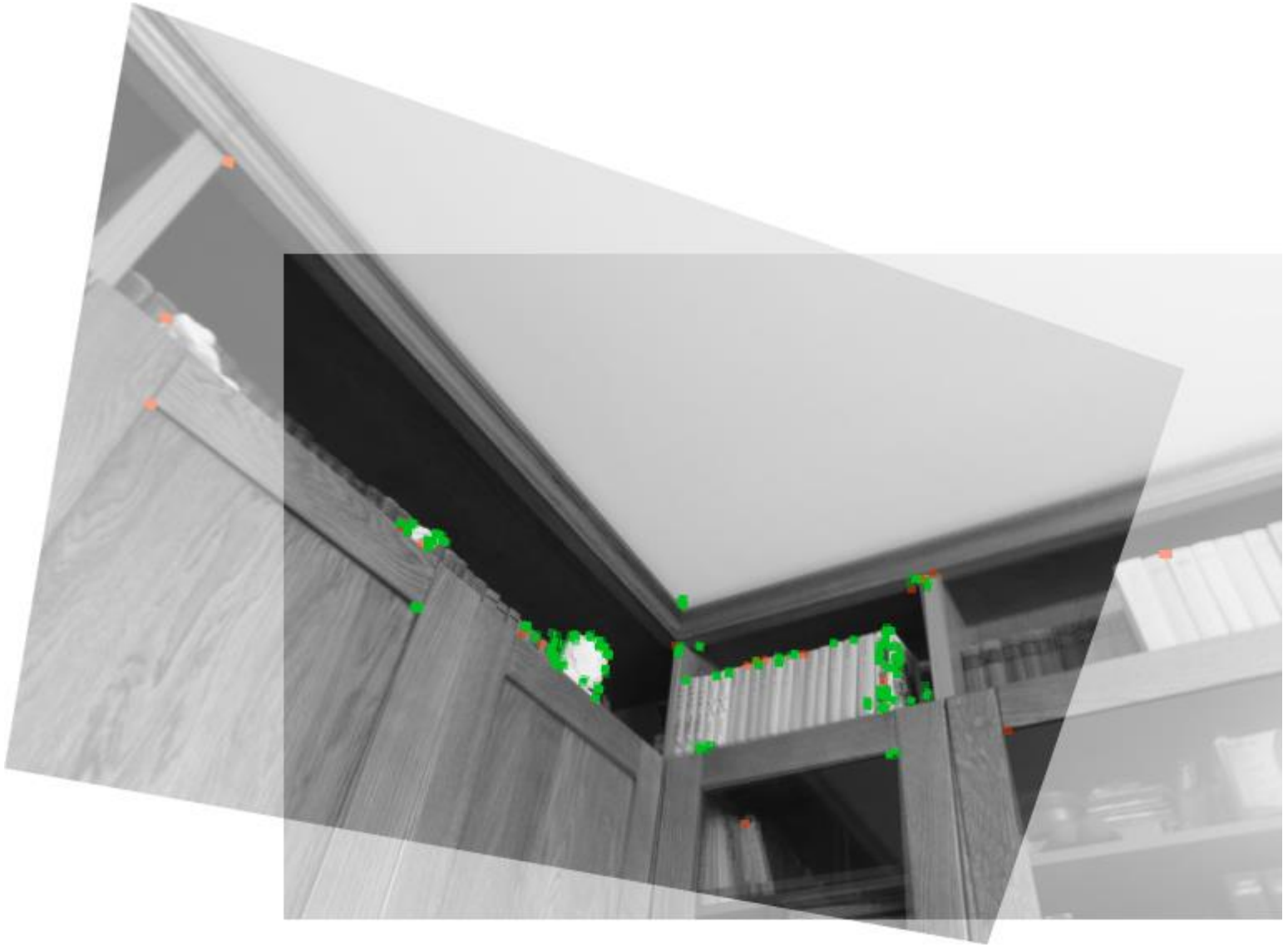
Matching the KeyPoints



Detector: ORB
Matcher: FLANN

True Positive
False Positive

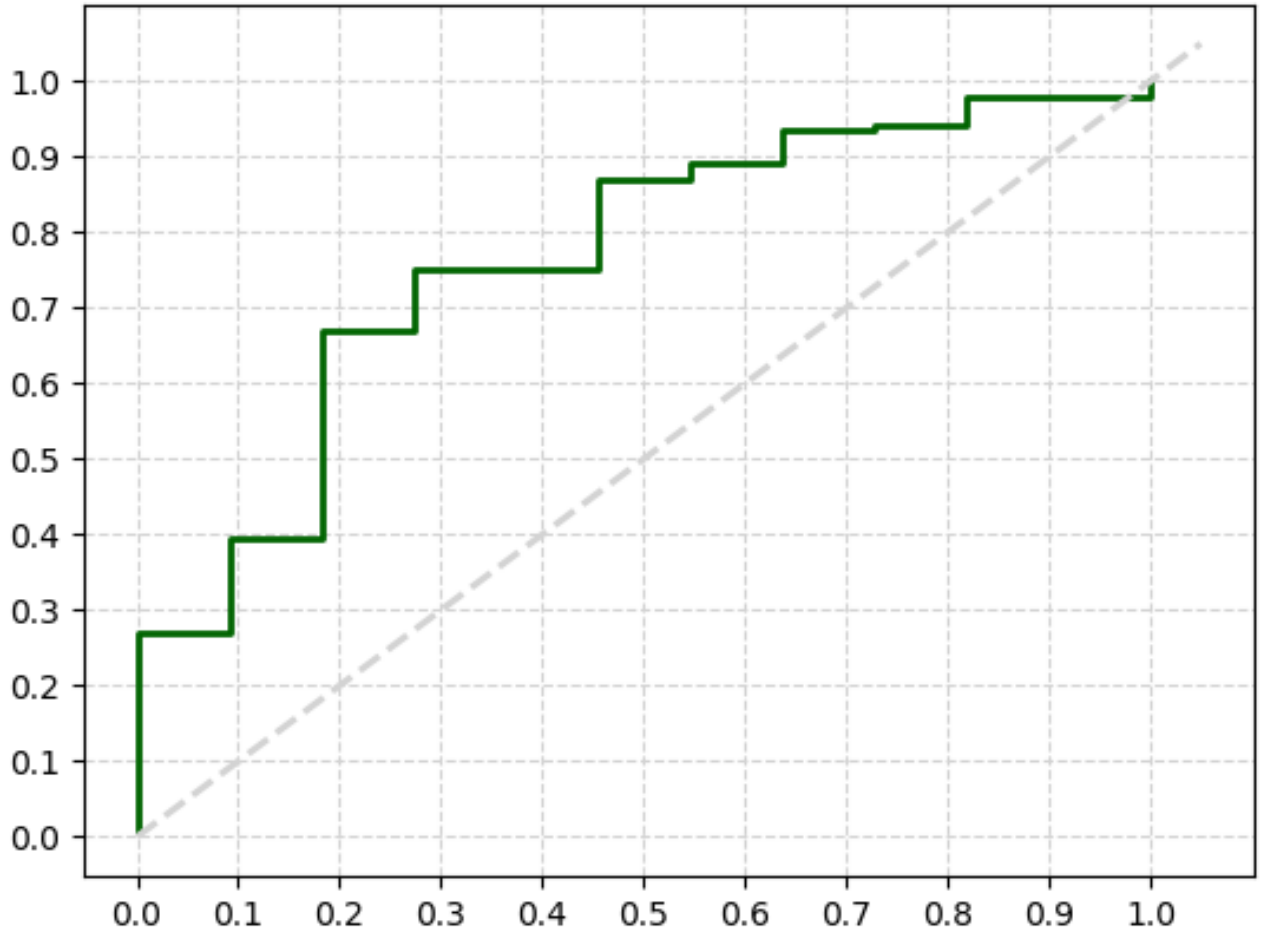
Matching the KeyPoints



Detector: ORB
Matcher: FLANN

True Positive
False Positive

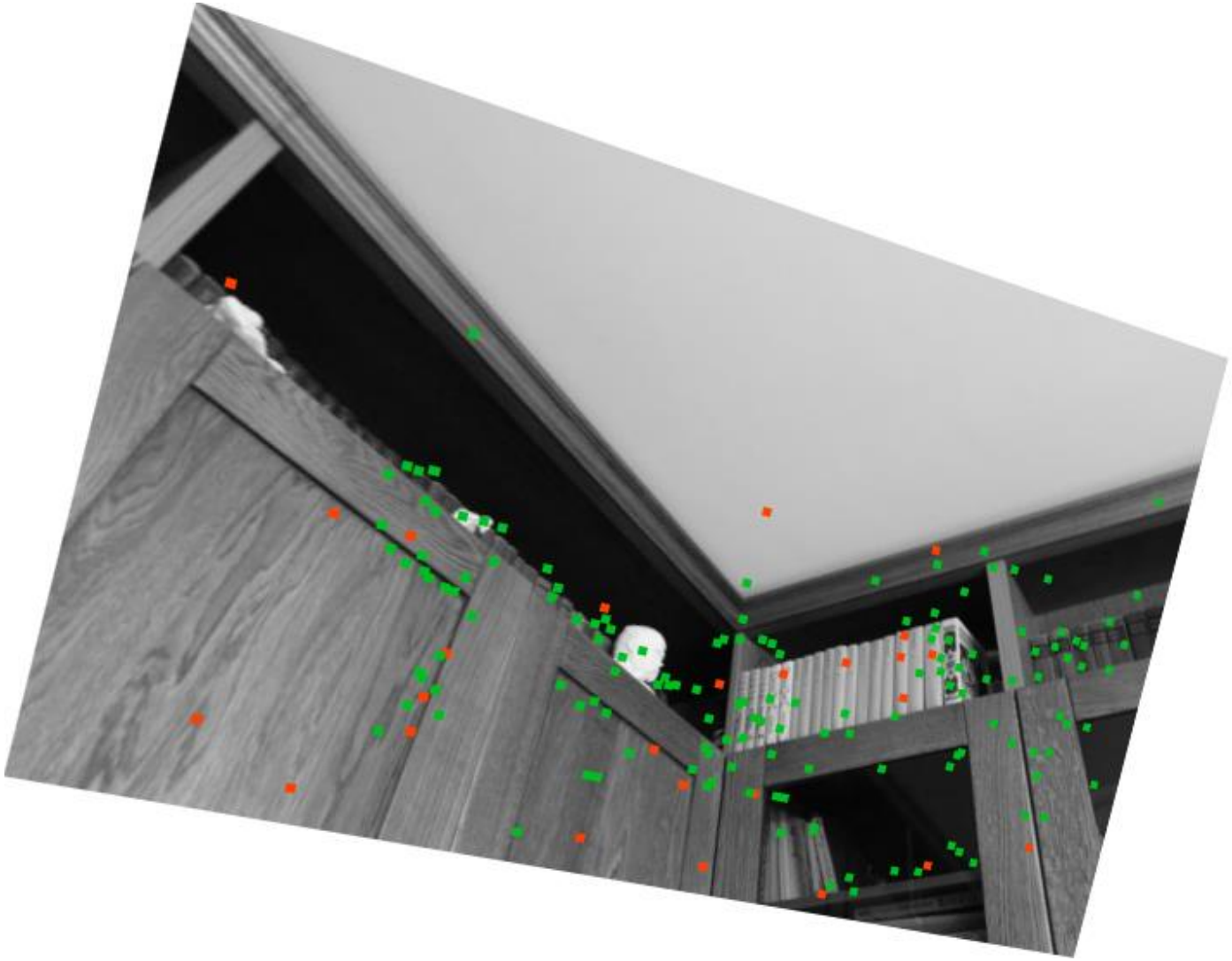
Matching the KeyPoints



Detector: ORB
Matcher: FLANN

AUC = 76%

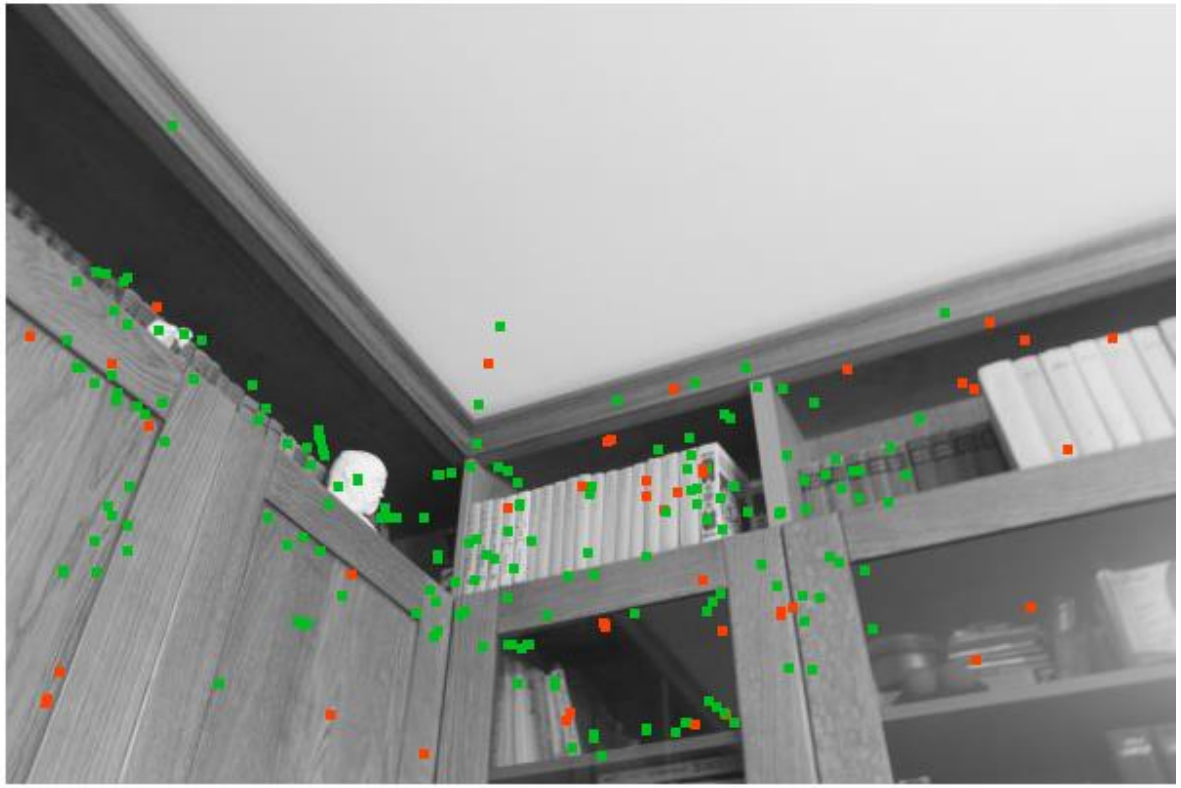
Matching the KeyPoints



Detector: SURF
Matcher: KNN

True Positive
False Positive

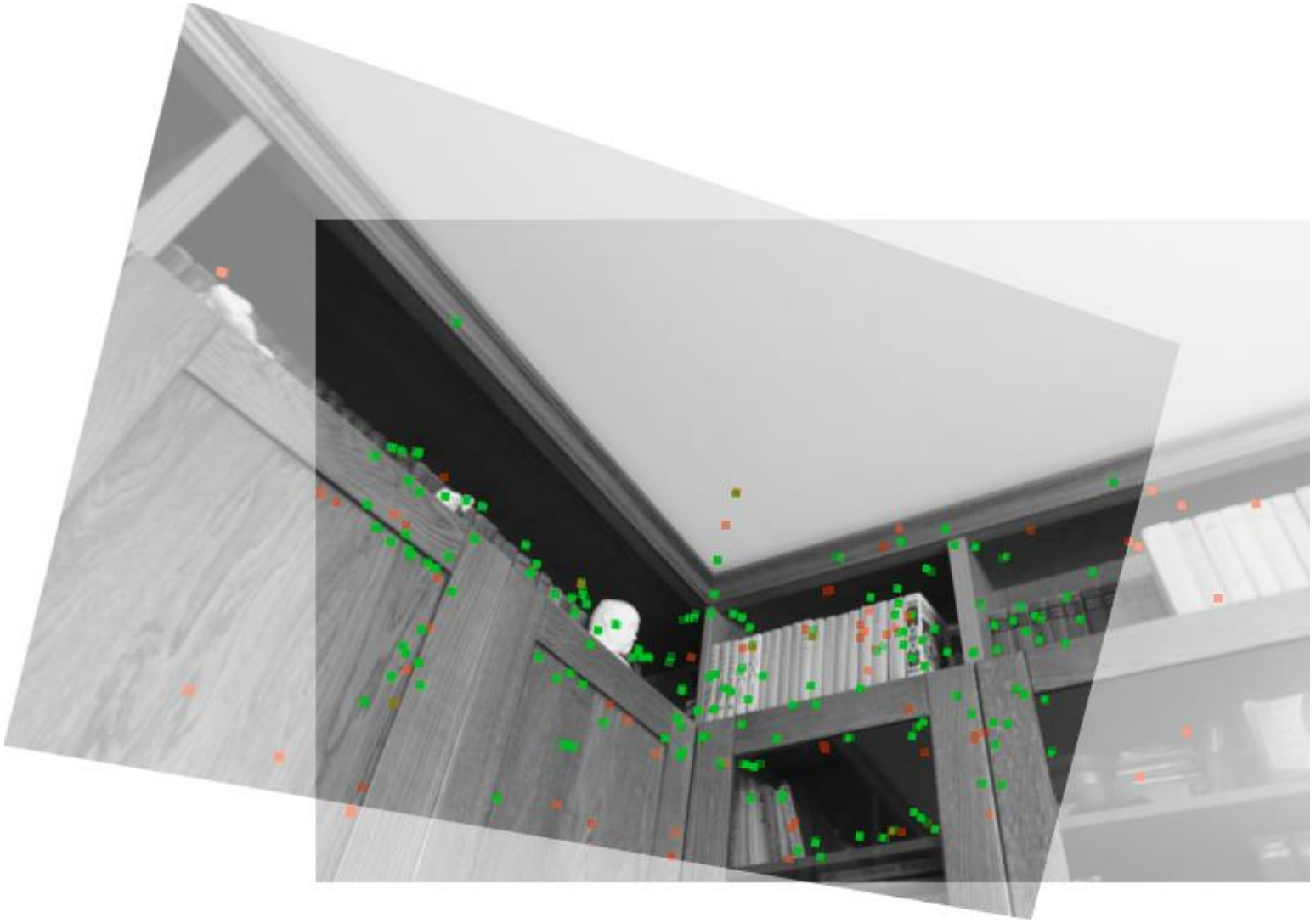
Matching the KeyPoints



Detector: SURF
Matcher: KNN

True Positive
False Positive

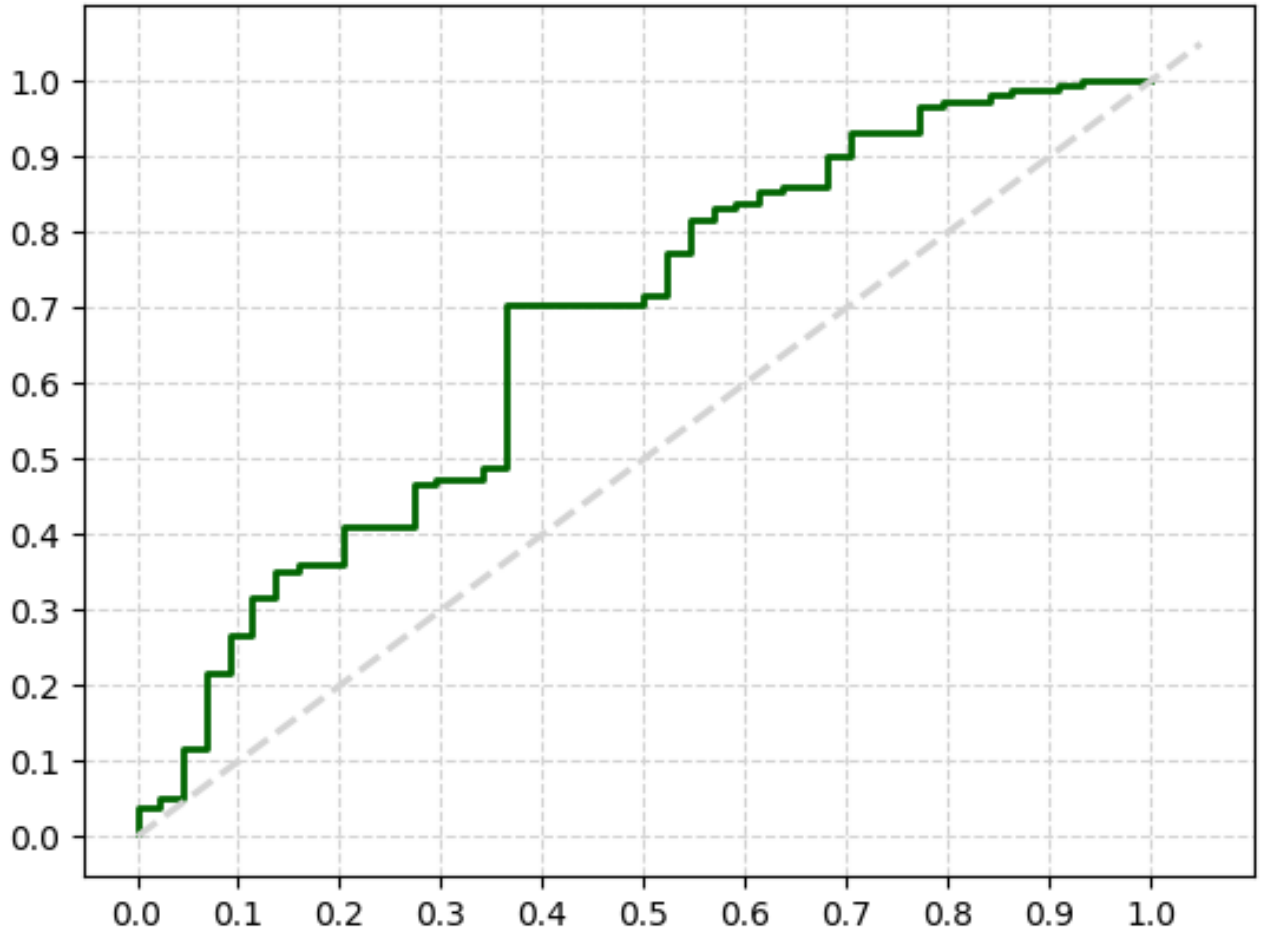
Matching the KeyPoints



Detector: SURF
Matcher: KNN

True Positive
False Positive

Matching the KeyPoints



Detector: SURF
Matcher: KNN

AUC = 67%

Matching the KeyPoints

	BFMatcher.**match**	BFMatcher.**knnMatch**	**Flann**BasedMatcher.knnMatch
ORB	91%	75%	76%
SIFT	63%	69%	70%
SURF	-	67%	69%

Matching the KeyPoints

```
def get_matches_on_desc_flann(des_source, des_destin):

    FLANN_INDEX_KDTREE = 1
    index_params = dict(algorithm=FLANN_INDEX_KDTREE, trees=5)
    search_params = dict(checks=50)  # or pass empty dictionary
    flann = cv2.FlannBasedMatcher(index_params, search_params)
    matches = flann.knnMatch(des_destin.astype(numpy.float32),
des_source.astype(numpy.float32), k=2)

    verify_ratio = 0.8
    verified_matches = []
    for m1, m2 in matches:
        if m1.distance < 0.8 * m2.distance:
            verified_matches.append(m1)

    return verified_matches
```

Matching the KeyPoints

```
def get_matches_on_desc_knn(des_source, des_destin):

    bf = cv2.BFMatcher()
    matches = bf.knnMatch(des_destin, des_source, k=2)

    verify_ratio = 0.8
    verified_matches = []
    for m1, m2 in matches:
        if m1.distance < 0.8 * m2.distance:
            verified_matches.append(m1)

    return verified_matches
```

Matching the KeyPoints

```
def get_matches_on_desc(des_source, des_destin):

    bf = cv2.BFMatcher(cv2.NORM_HAMMING, crossCheck=True)
    matches = bf.match(des_destin, des_source)
    matches = sorted(matches, key=lambda x: x.distance)

    return matches
```

3. Homography

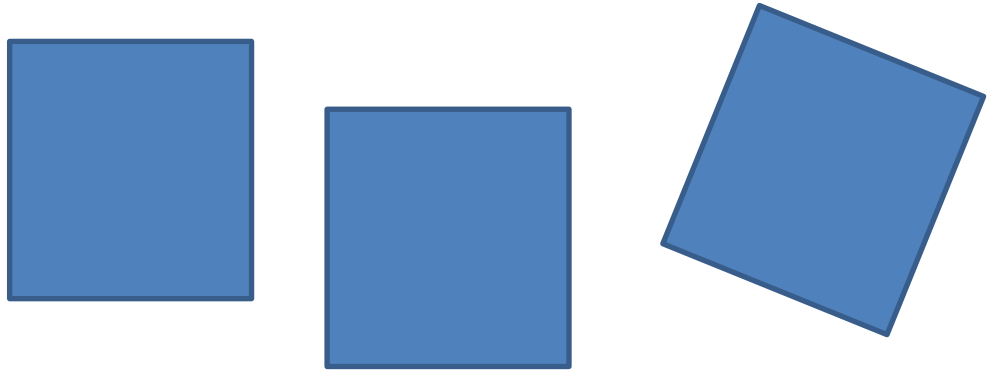
Homography: transformations

- *findTransformECC*
- *findHomography*

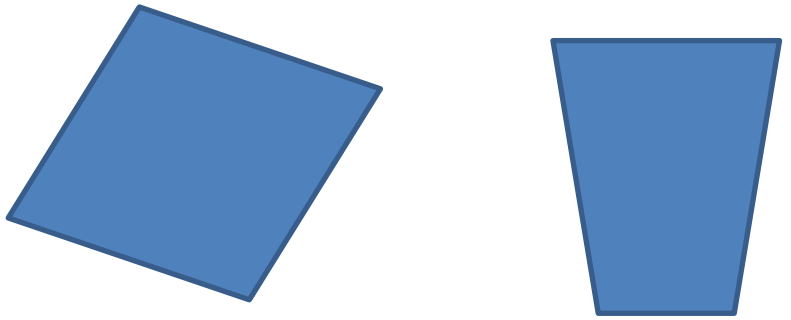
- *estimateAffine2D*,
- *estimateAffinePartial2D*

- *transform*
- *perspectiveTransform*
- *getPerspectiveTransform*

- *warpAffine*
- *warpPerspective*



Original **Translation** **Euclidian**



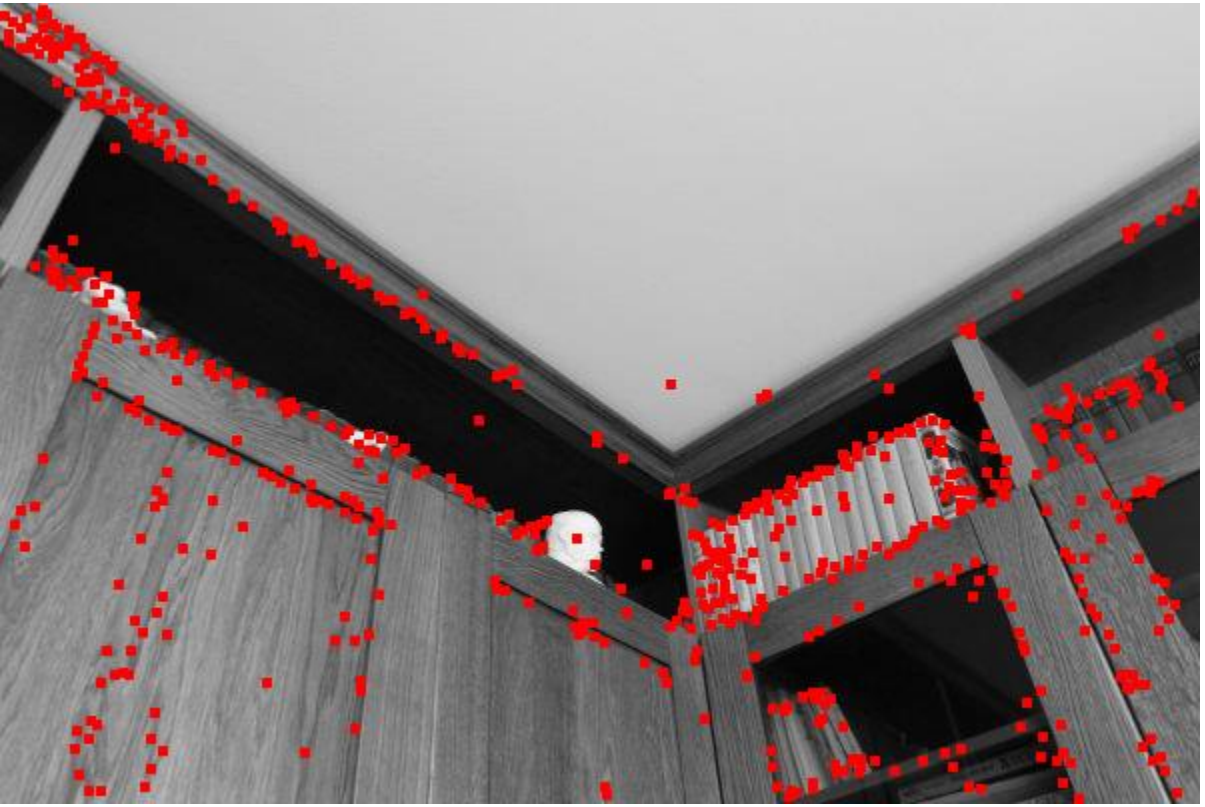
Affine **Homography**

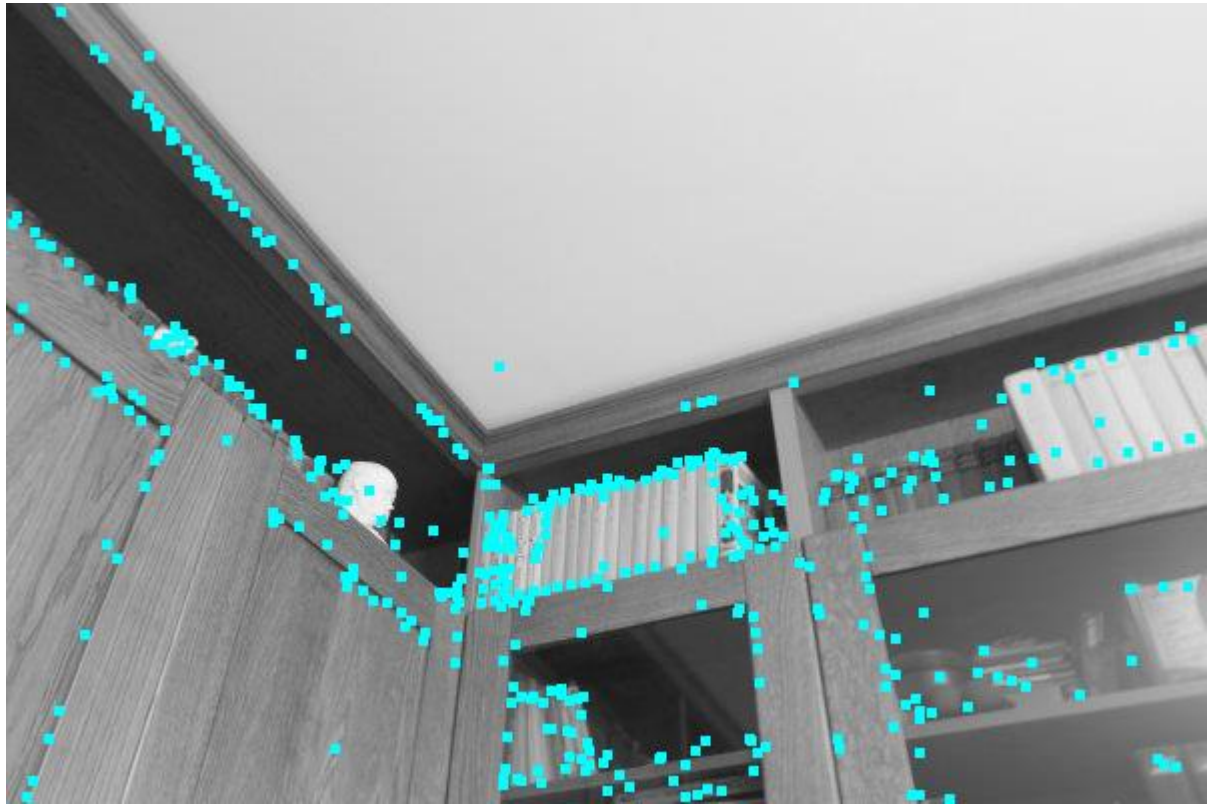
Homography: manual match

Homography: manual match

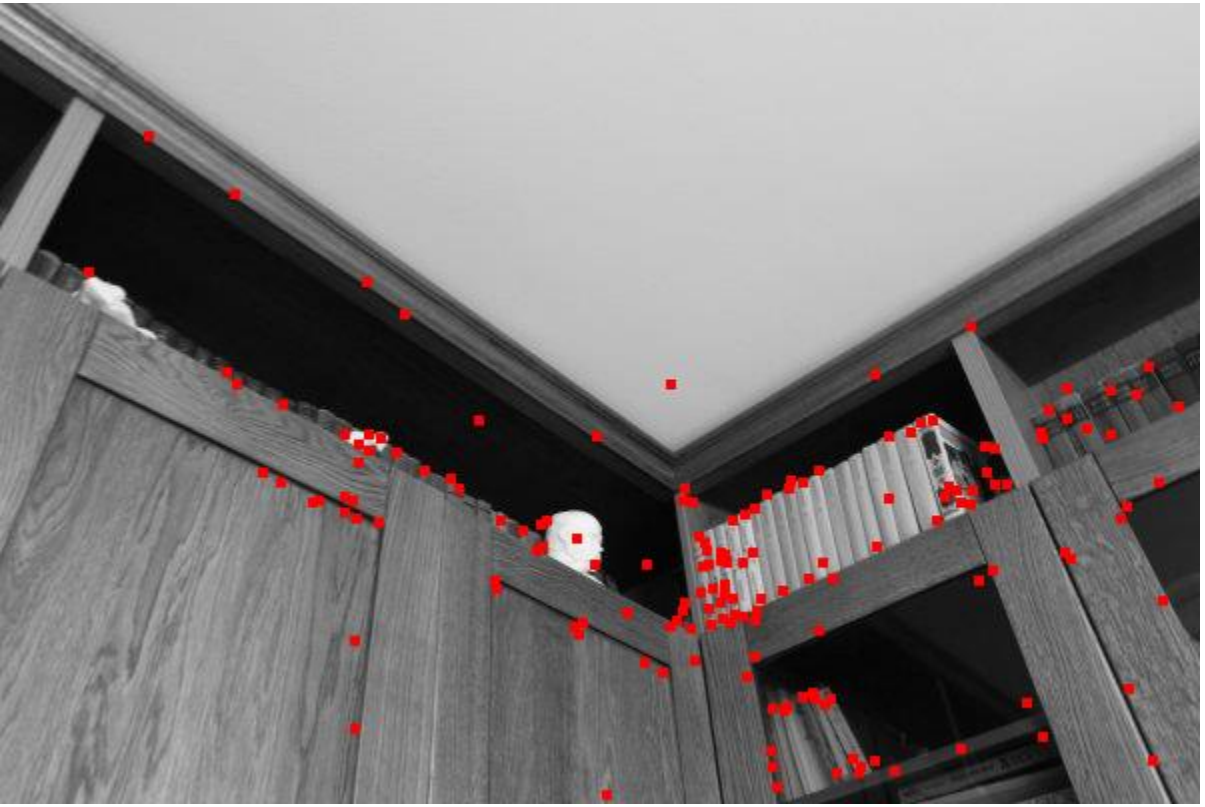
```
def example_03_find_homography_manual():

    folder_input            = '_images/ex03_manual/'
    im_scene                = cv2.imread(folder_input + 'background.jpg')
    im_rect                 = cv2.imread(folder_input + 'rect.jpg')
    folder_output           = '_images/output/'

    filename_output_rect    = folder_output + 'rect_out.jpg'
    filename_output_blend   = folder_output + 'bachground_out.jpg'

    if not os.path.exists(folder_output):
        os.makedirs(folder_output)
    else:
        tools_IO.remove_files(folder_output)

    pts_scene = numpy.array([[296, 95], [571, 178], [404, 614], [130, 531]])
    pts_rect  = numpy.array([[0  , 0]  , [300, 0]  , [300, 400], [0 , 400]])

    homography, status = cv2.findHomography(pts_rect,pts_scene)
    im_rect_out = cv2.warpPerspective(im_rect, homography, (im_scene.shape[1], im_scene.shape[0]))
    im_scene = tools_image.put_layer_on_image(im_scene, im_rect_out)

    cv2.imwrite(filename_output_rect, im_rect_out)
    cv2.imwrite(filename_output_blend, im_scene)

    return
```

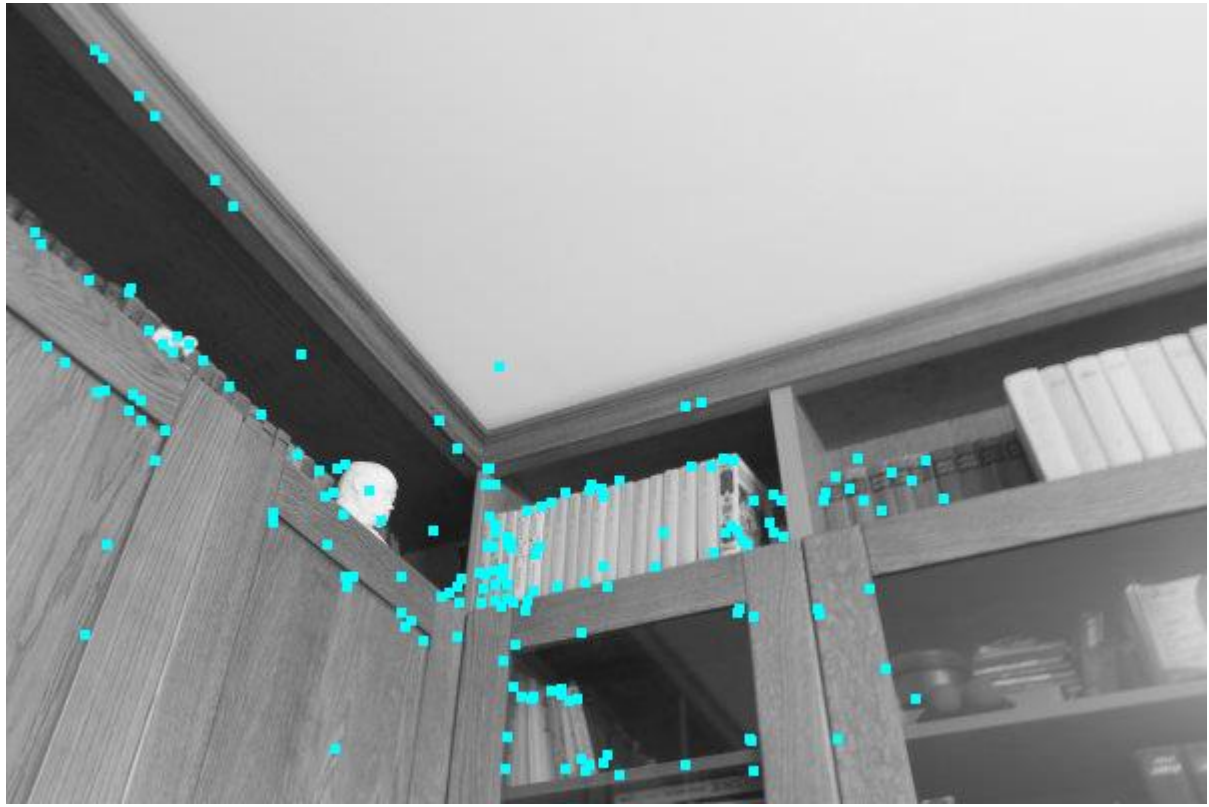
Homography: auto-match



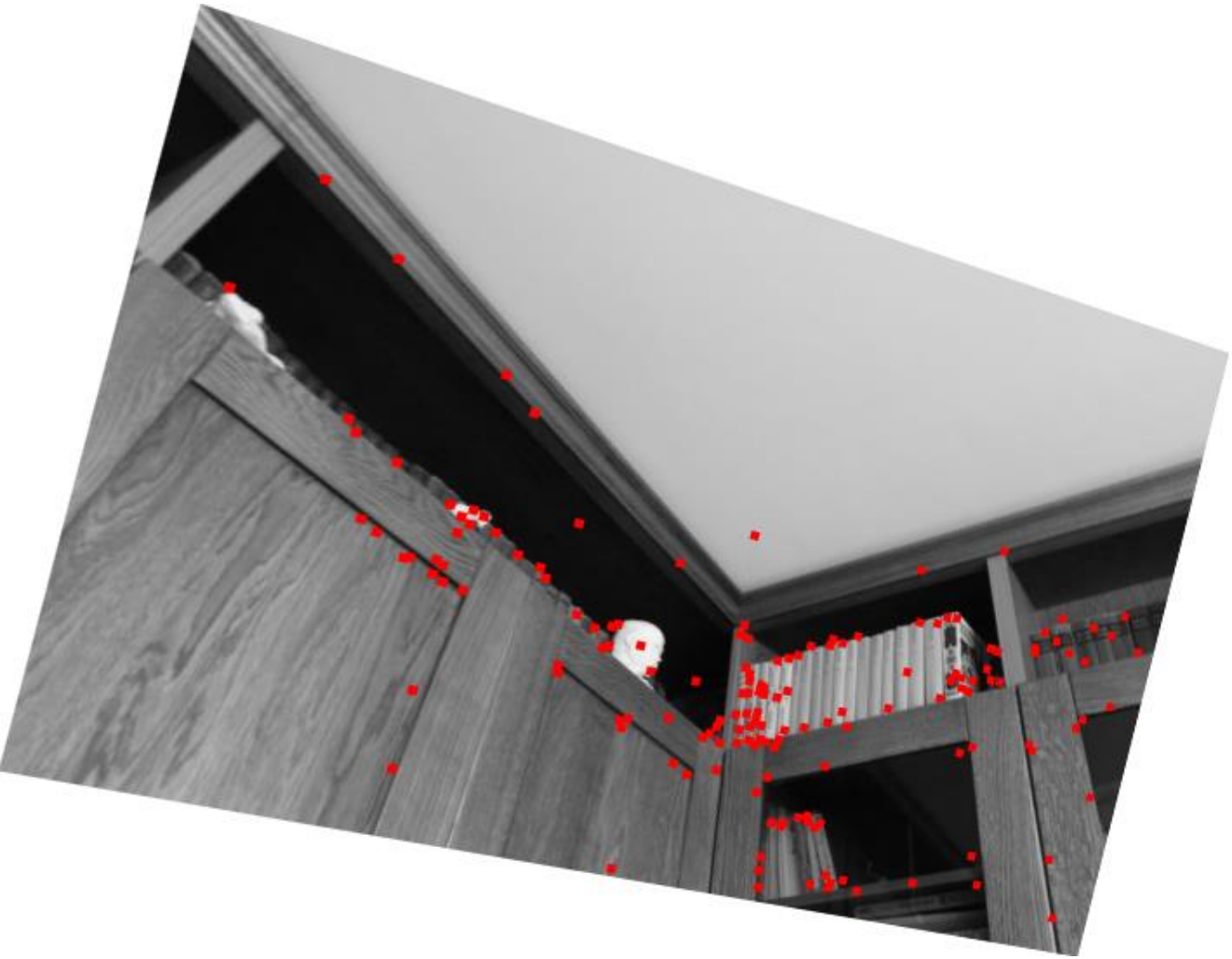


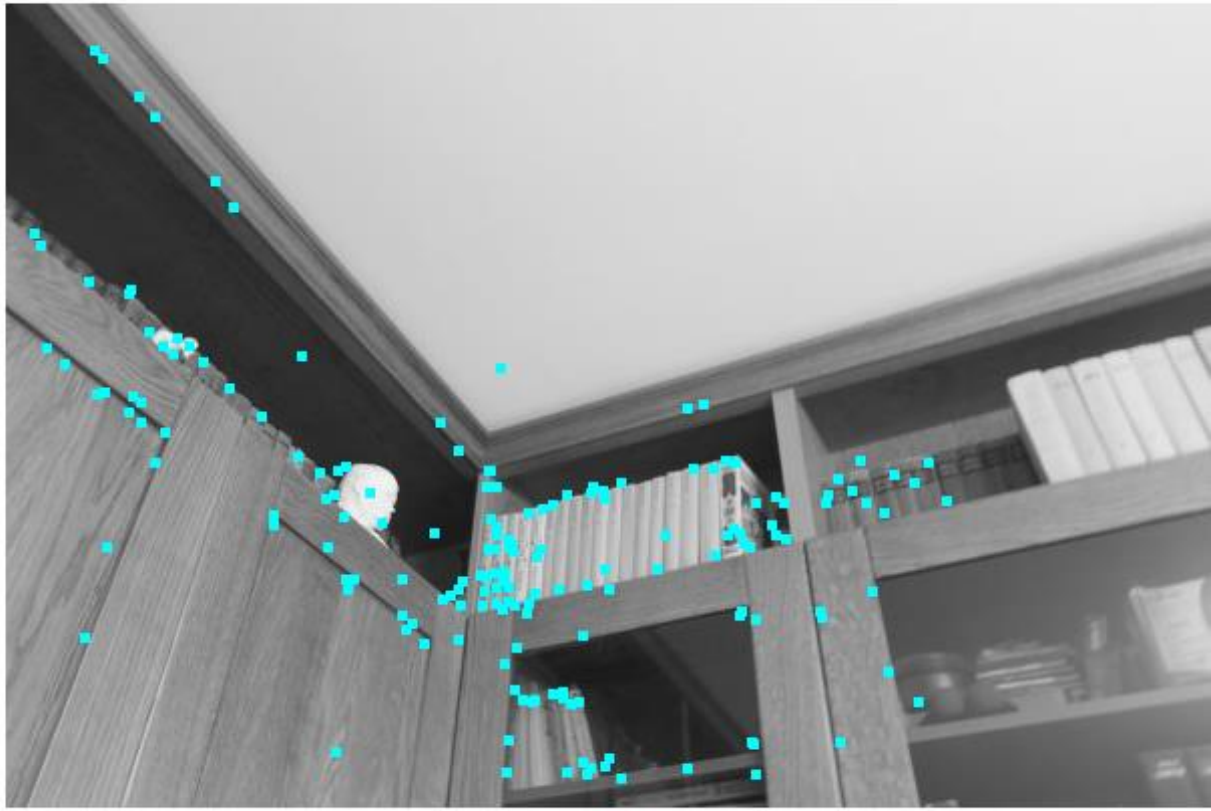
Homography: auto-match



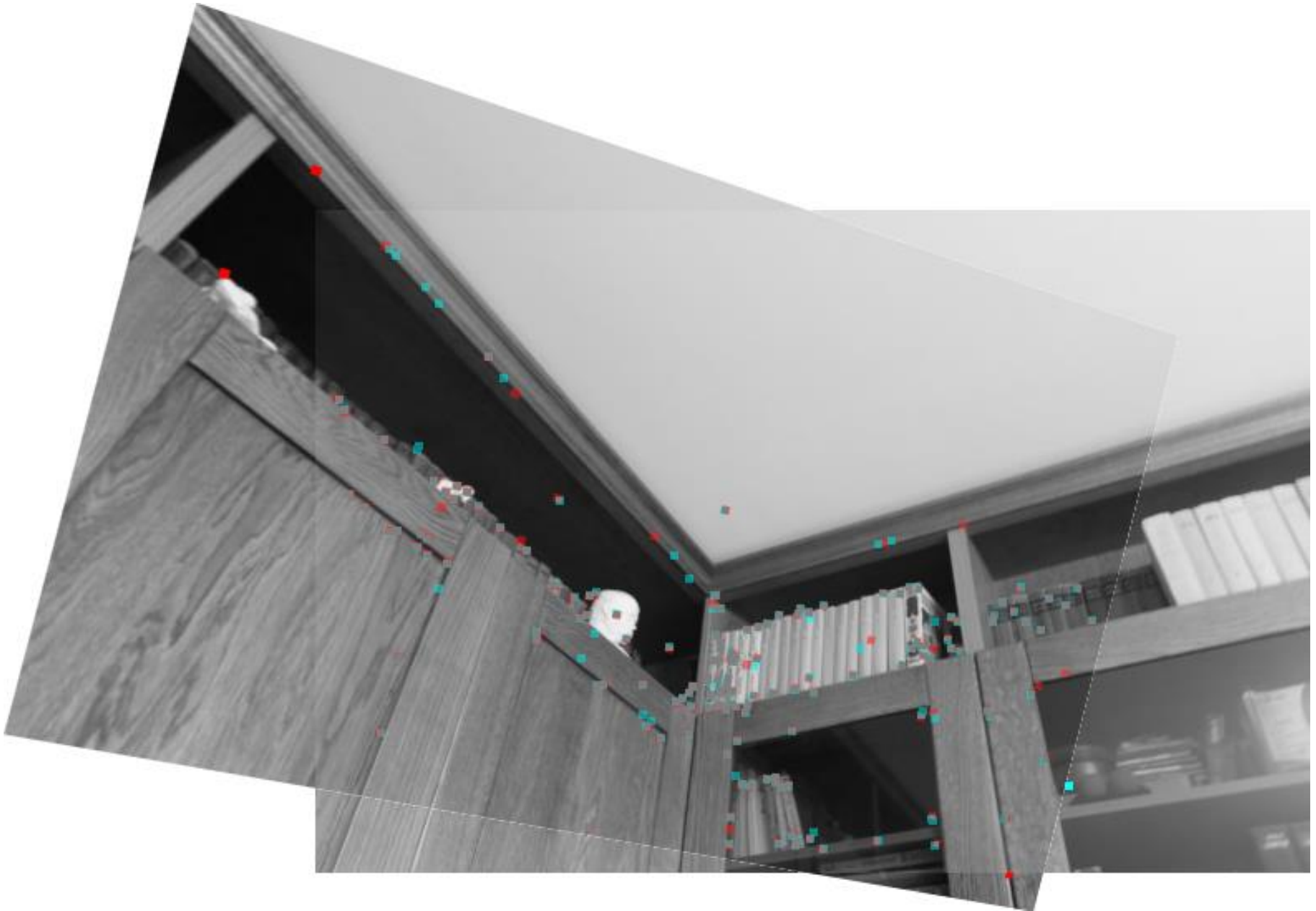


Homography: auto-match

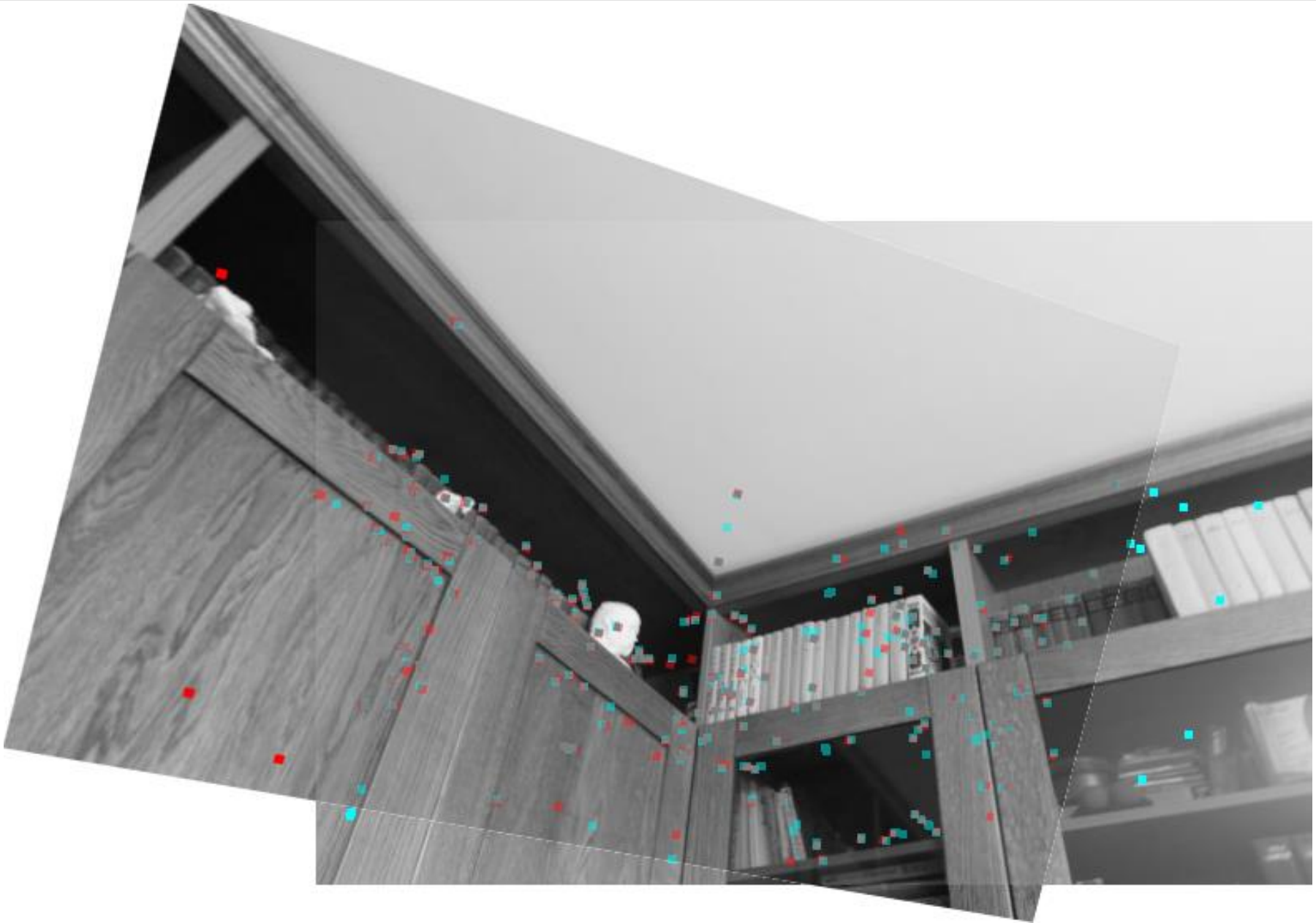




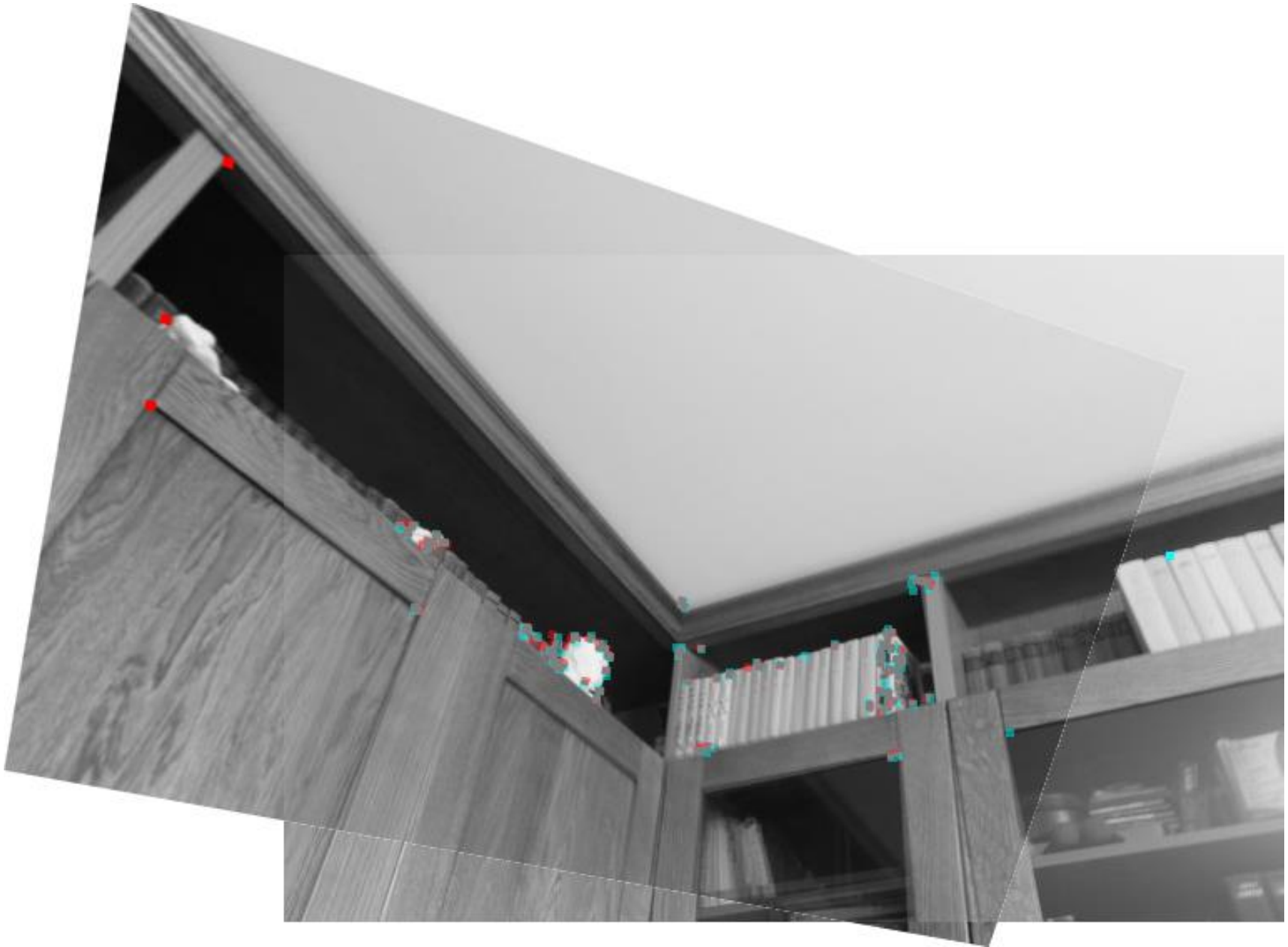
Homography: auto-match SIFT



Homography: auto-match SURF



Homography: auto-match ORB



Homography: auto-match

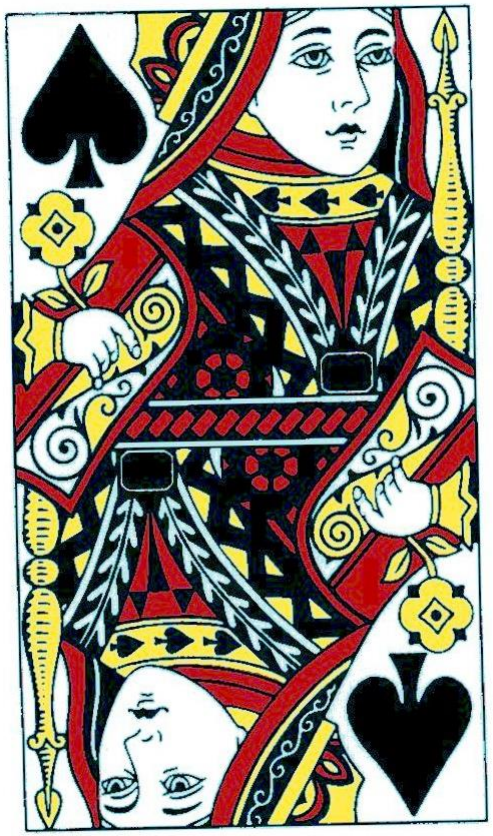
```
def get_matches_on_desc(des_source, des_destin):

    bf = cv2.BFMatcher(cv2.NORM_HAMMING, crossCheck=True)
    matches = bf.match(des_destin, des_source)
    matches = sorted(matches, key=lambda x: x.distance)

    return matches
```

Homography: auto-match

```
def get_keypoints_desc_SIFT(image1):
    if len(image1.shape) == 2:
        im1_gray = im1.copy()
    else:
        im1_gray = cv2.cvtColor(image1, cv2.COLOR_BGR2GRAY)

    detector = cv2.xfeatures2d.SIFT_create()
    kp, desc= detector.detectAndCompute(image1, None)

    points=[]
    if (len(kp) > 0):
        points = numpy.array([kp[int(idx)].pt for idx in range(0,
len(kp))]).astype(int)

    return points, desc


def get_homography_by_keypoints_desc(points_source,des_source, points_destin,des_destin,matchtype='knn'):

    if matchtype=='knn':
        matches = get_matches_on_desc_knn(des_source, des_destin)
    else:
        matches = get_matches_on_desc(des_source, des_destin)

    src = numpy.float32([points_source[m.trainIdx] for m in matches]).reshape(-1, 1, 2)
    dst = numpy.float32([points_destin[m.queryIdx] for m in matches]).reshape(-1, 1, 2)

    M = get_homography_by_keypoints(src, dst)
    return M
```

Homography: bitmap transformation

first



second

Homography: bitmap transformation

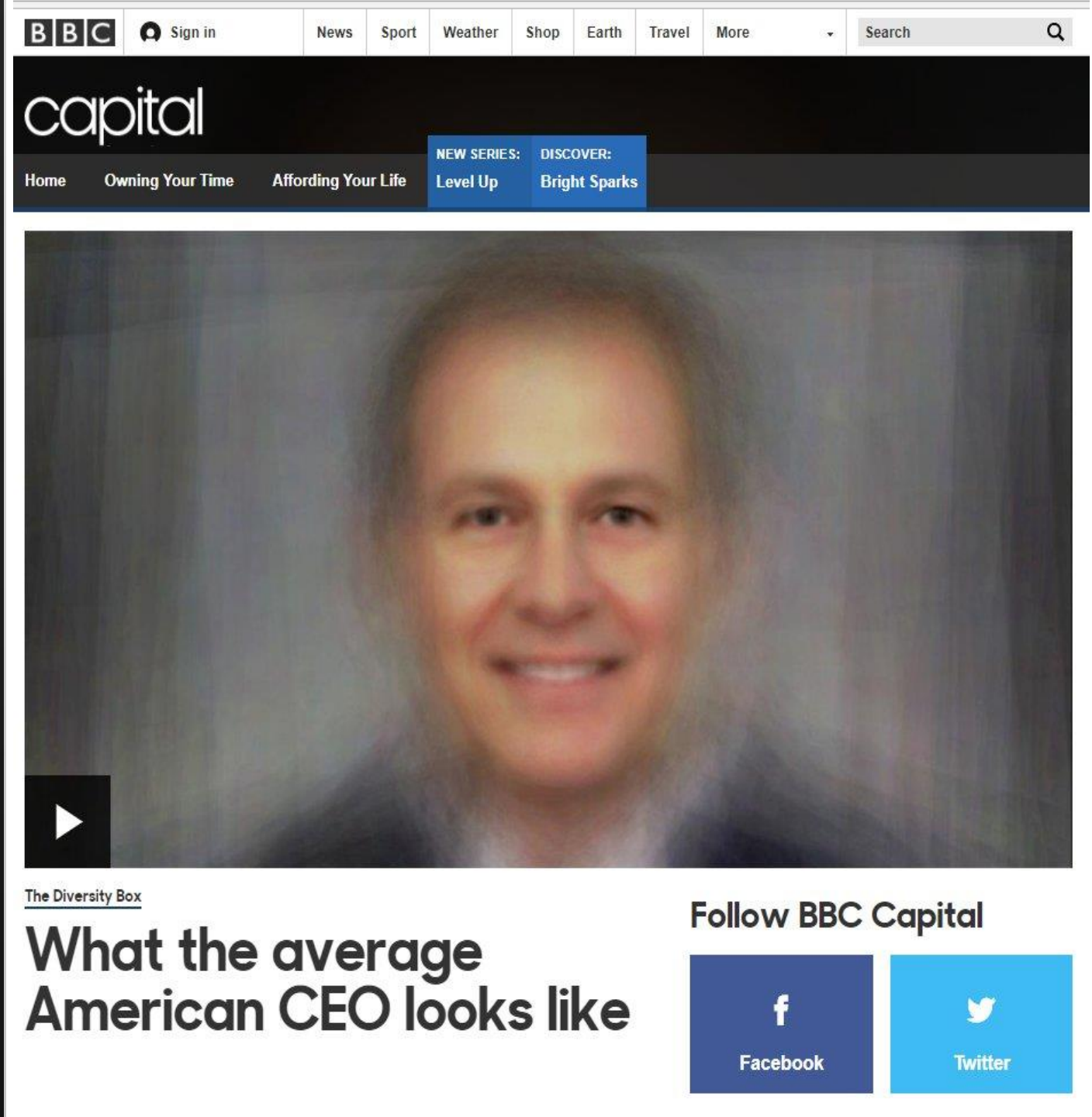
*transformed **second***

*transformed **first***

Homography: bitmap transformation

```
criteria = (cv2.TERM_CRITERIA_EPS | cv2.TERM_CRITERIA_COUNT, 5000, 1e-10)

if warp_mode!= cv2.MOTION_HOMOGRAPHY:
    (cc, transform1) = cv2.findTransformECC(im1_gray, im2_gray, numpy.eye(2, 3, dtype=numpy.float32), warp_mode,criteria)
    (cc, transform2) = cv2.findTransformECC(im2_gray, im1_gray, numpy.eye(2, 3, dtype=numpy.float32), warp_mode,criteria)
    result_image11, result_image12 = tools_calibrate.get_stitched_images_using_translation(im2, im1, transform1)
    result_image22, result_image21 = tools_calibrate.get_stitched_images_using_translation(im1, im2, transform2)
else:
    (cc, transform1) = cv2.findTransformECC(im1_gray, im2_gray, numpy.eye(3, 3, dtype=numpy.float32), warp_mode,criteria)
    (cc, transform2) = cv2.findTransformECC(im2_gray, im1_gray, numpy.eye(3, 3, dtype=numpy.float32), warp_mode,criteria)
    result_image11, result_image12 = tools_calibrate.get_stitched_images_using_homography(im2, im1, transform1)
    result_image22, result_image21 = tools_calibrate.get_stitched_images_using_homography(im1, im2, transform2)
```

4. Blending


BBC
Sign in
News
Sport
Weather
Shop
Earth
Travel
More
Search
capital
Home
Owning Your Time
Affording Your Life
NEW SERIES:
Level Up
DISCOVER:
Bright Sparks
The Diversity Box
What the average American CEO looks like
Follow BBC Capital
Facebook
Twitter

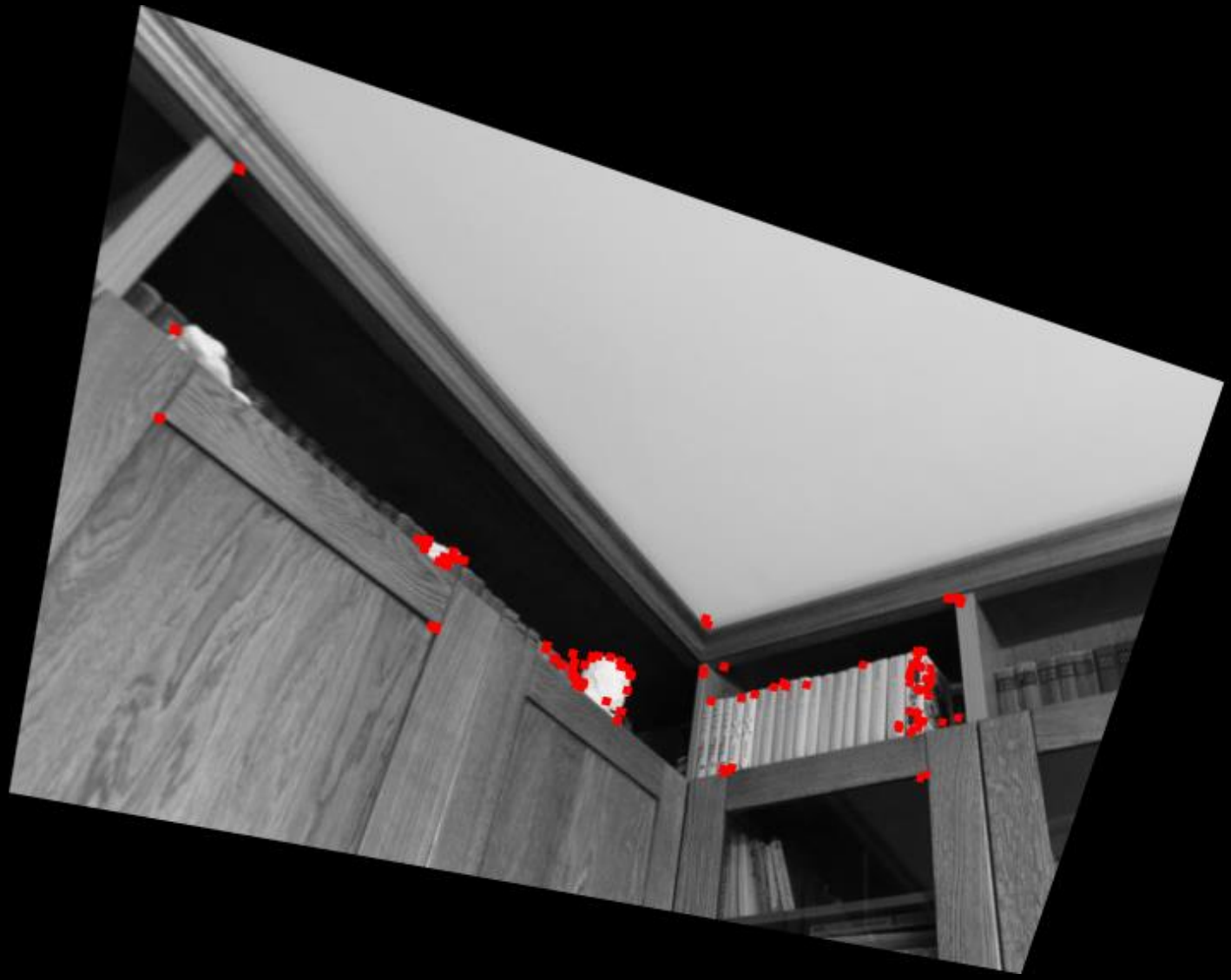
Blending: average

Blending: average

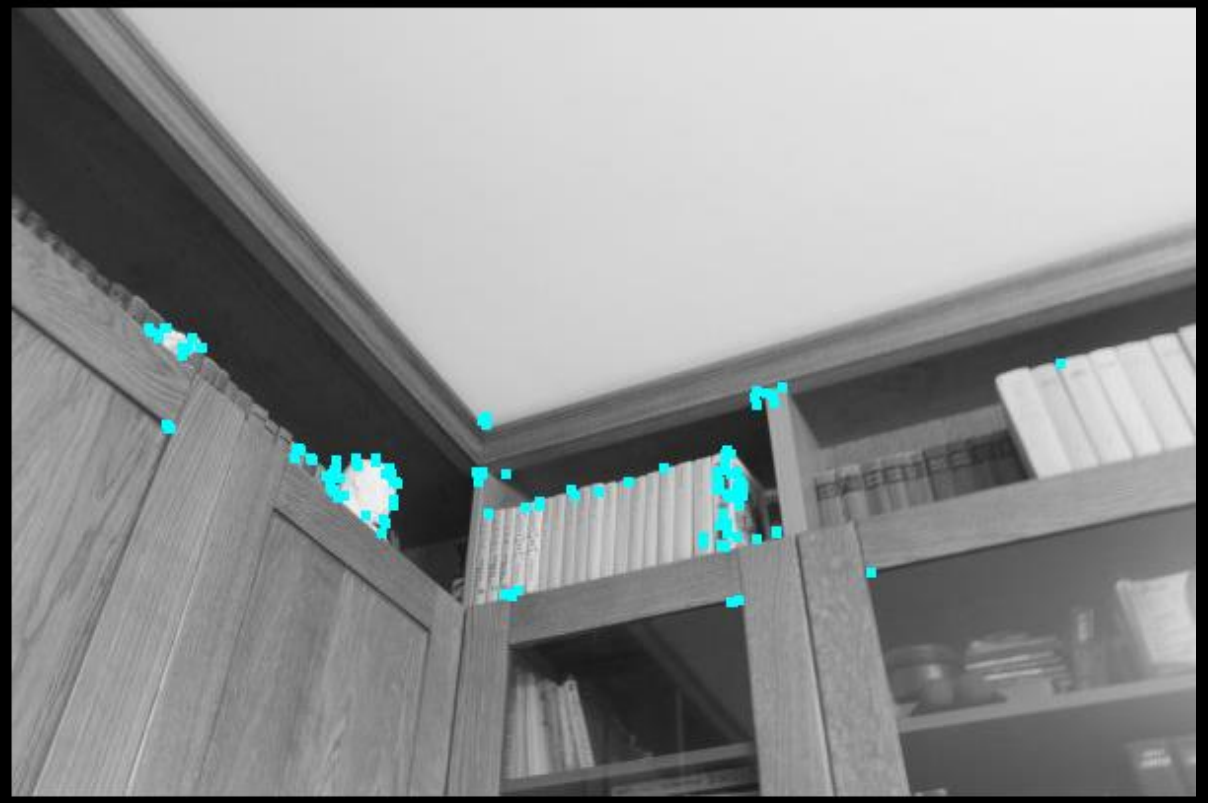
Blending: average

Blending: average

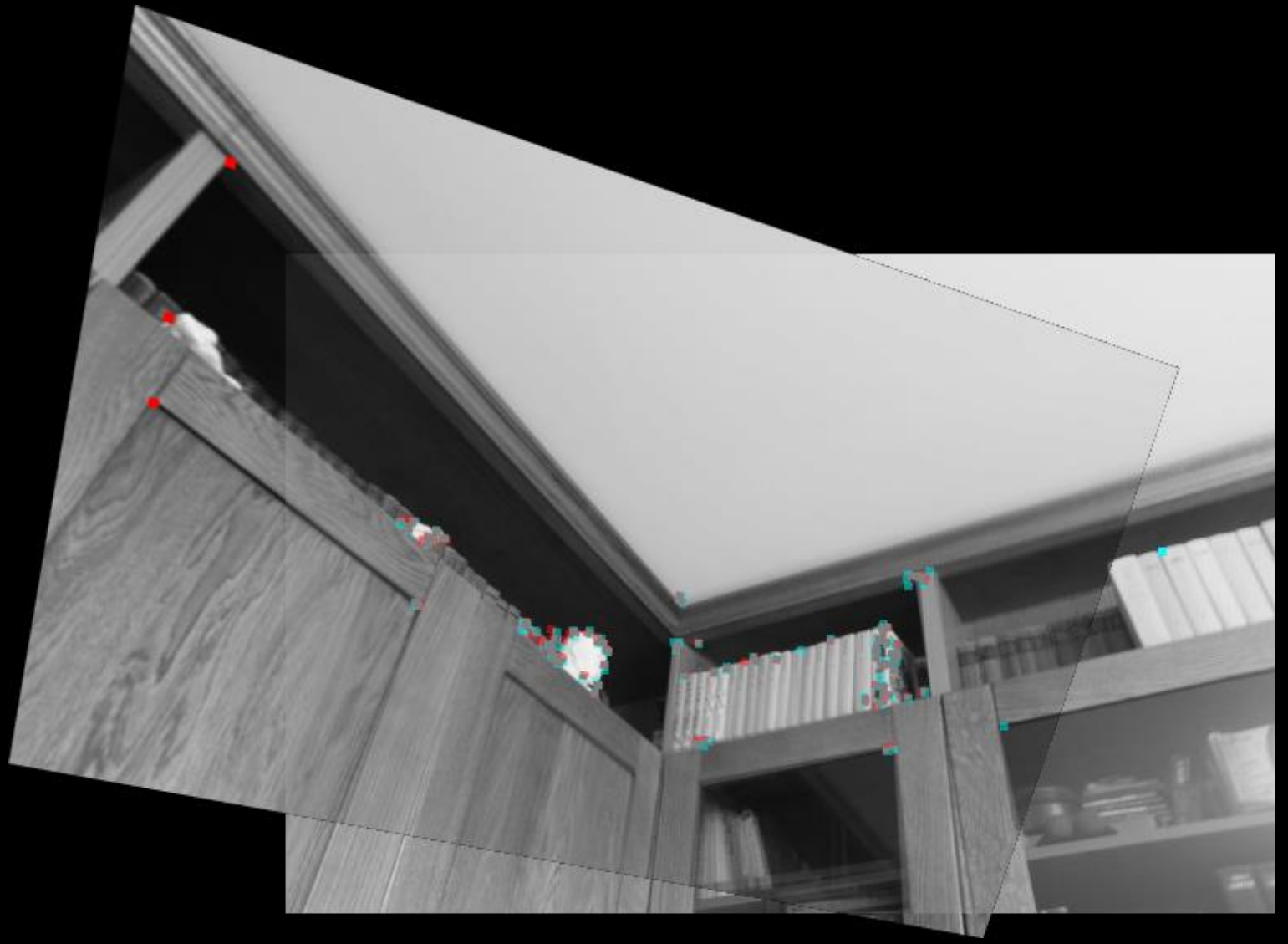
Blending: average



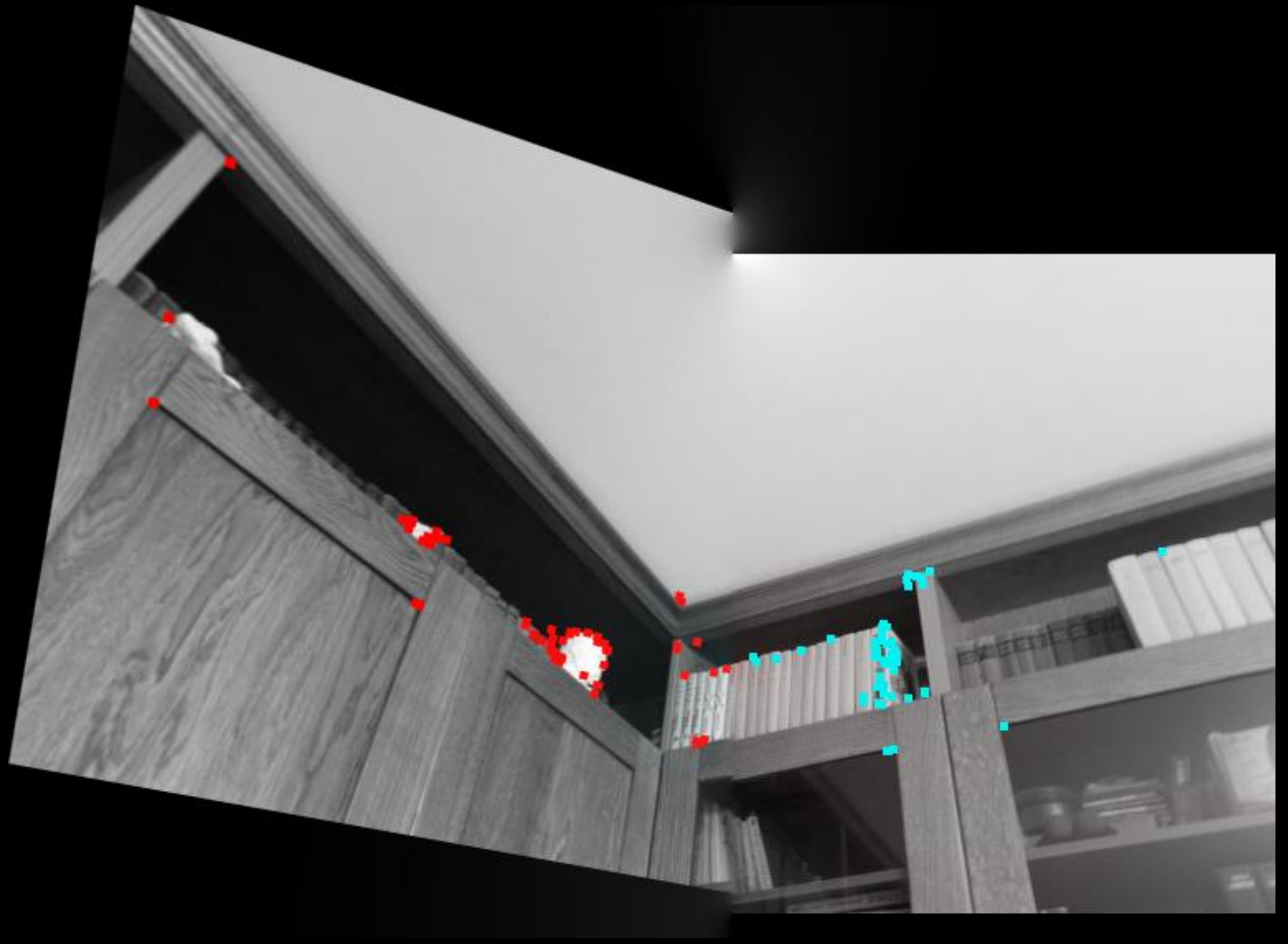
Blending: average



Blending: average



Blending: average



Blending: average

```
def blend_multi_band(left, rght, background_color=(255, 255, 255)):

    left_l, left_r, left_t, left_b = get_borders(left, background_color)
    rght_l, rght_r, rght_t, rght_b = get_borders(rght, background_color)
    border = int((left_r+rght_l)/2)

    mask = numpy.zeros(left.shape)
    mask[:, :border] = 1

    leveln = int(numpy.floor(numpy.log2(min(left.shape[0], left.shape[1]))))

    MP = GaussianPyramid(mask, leveln)
    LPA = LaplacianPyramid(numpy.array(left).astype('float'), leveln)
    LPB = LaplacianPyramid(numpy.array(rght).astype('float'), leveln)
    blended = blend_pyramid(LPA, LPB, MP)

    result = reconstruct_from_pyramid(blended)
    result[result > 255] = 255
    result[result < 0] = 0
    return result
```

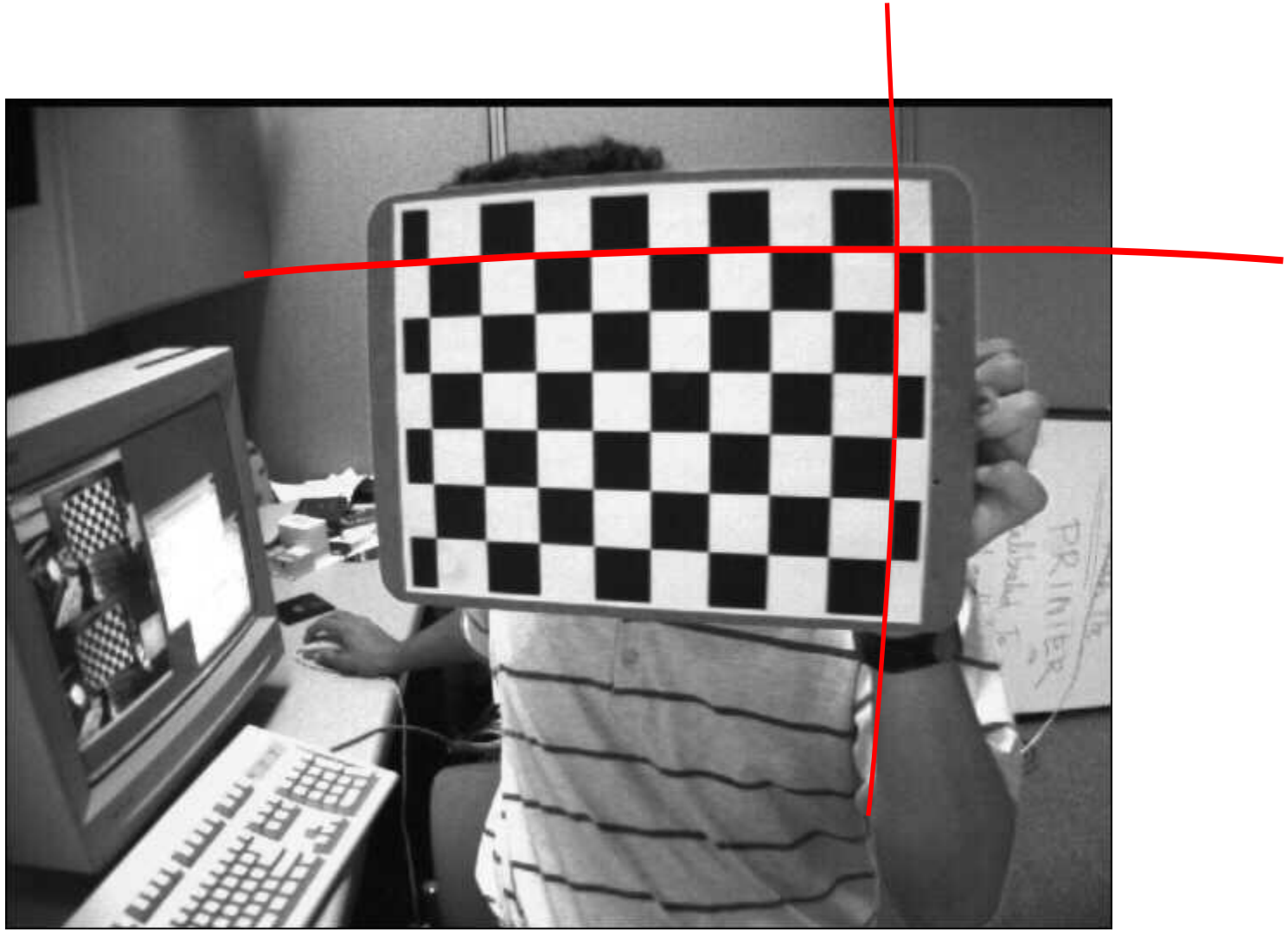
5. Panorama

5. Panorama

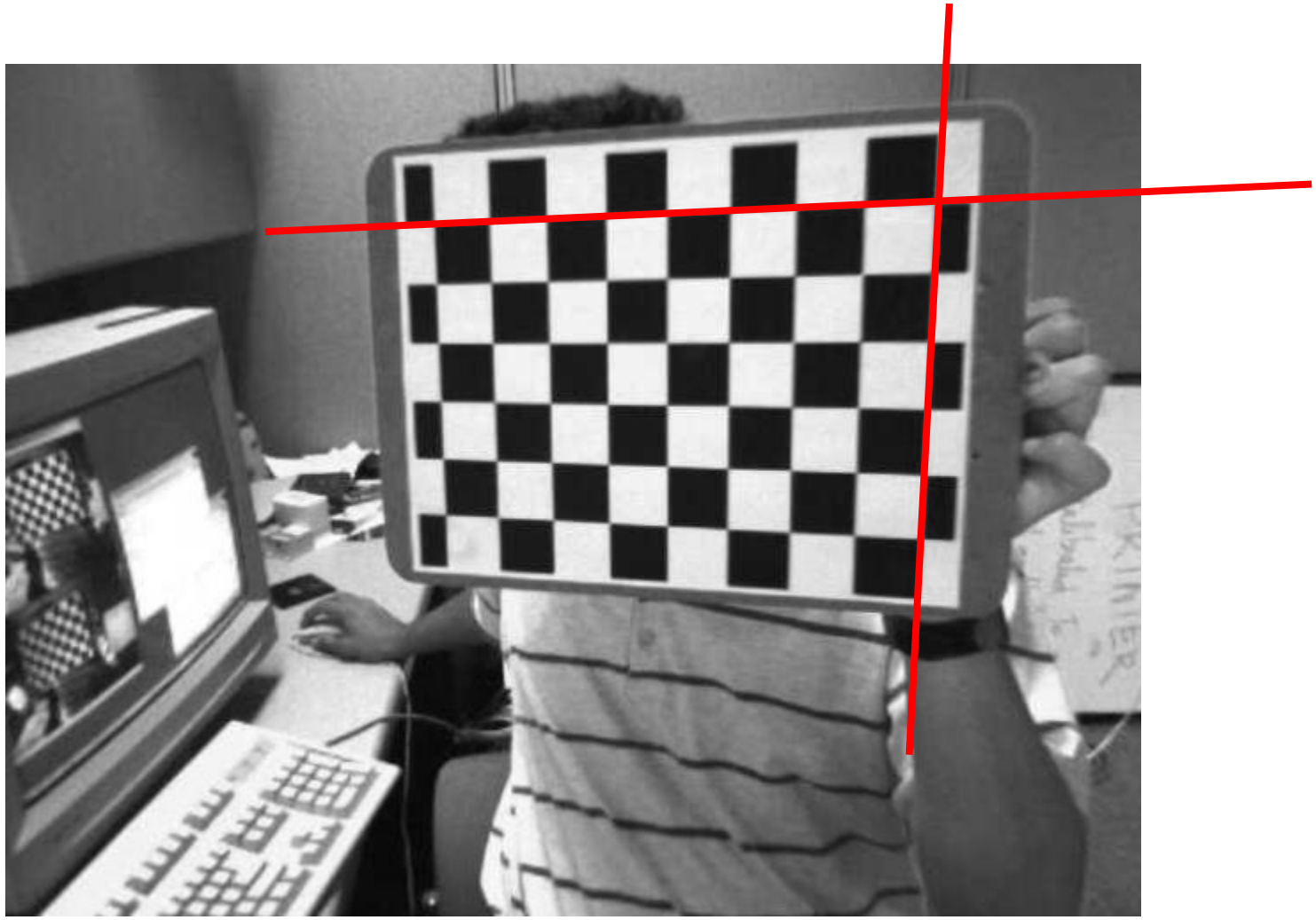
https://github.com/dibya-pati/ComputerVision/tree/master/HW2-Panoramas

6. Camera calibration

Camera calibration



Camera calibration

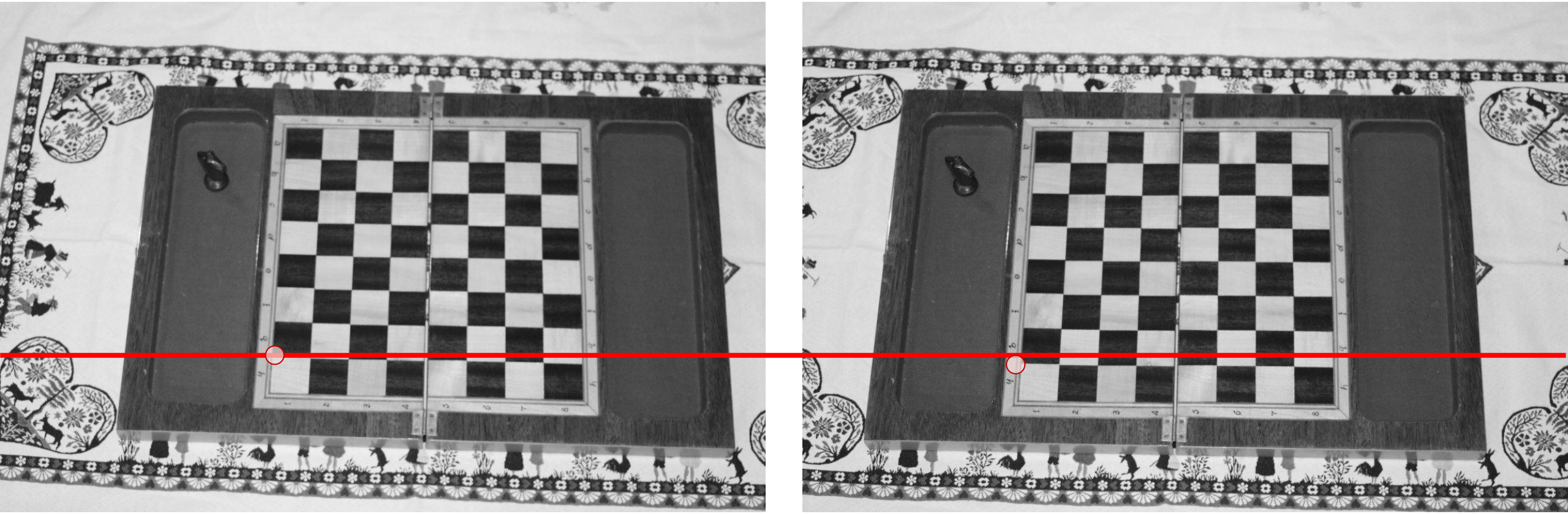


Camera calibration

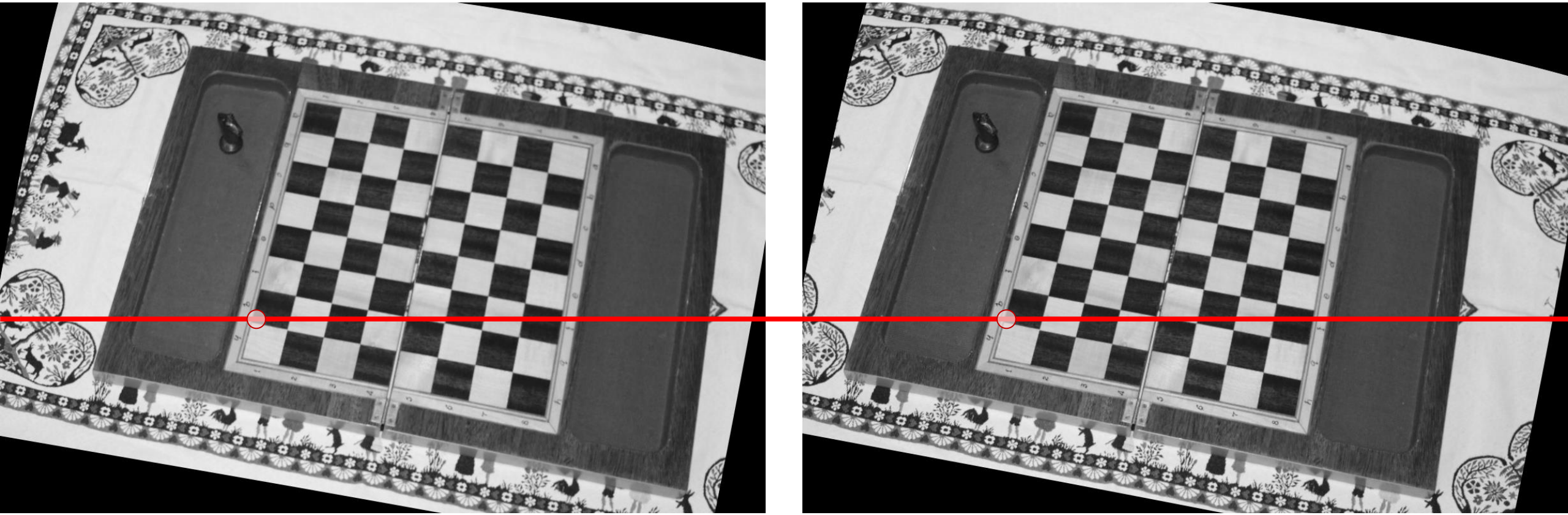
```
def example_01_calibrate_camera():

    filename_input_grid     = '_images/ex01/grid.jpg'
    folder_input_chess      = '_images/ex01/left/'
    filename_input_chess    = folder_input_chess + 'left01.jpg'

    folder_output           = '_images/ex01_out/'
    filename_output_chess   = folder_output + 'undistorted_chess.jpg'
    filename_output_grid    = folder_output + 'undistorted_grid.jpg'
    chess_rows=6
    chess_cols=7

    if not os.path.exists(folder_output):
        os.makedirs(folder_output)
    else:
        tools_IO.remove_files(folder_output)

    cameraMatrix, dist =
Calibrate.get_proj_dist_mat_for_images(folder_input_chess,chess_rows,chess_cols)
    undistorted_chess  = Calibrate.undistort_image(cameraMatrix, dist, filename_input_chess)
    undistorted_grid   = Calibrate.undistort_image(cameraMatrix, dist, filename_input_grid)
    cv2.imwrite(filename_output_chess, undistorted_chess)
    cv2.imwrite(filename_output_grid , undistorted_grid)

    return
```

7. Stereopair rectification

Stereopair rectification



Stereopair rectification

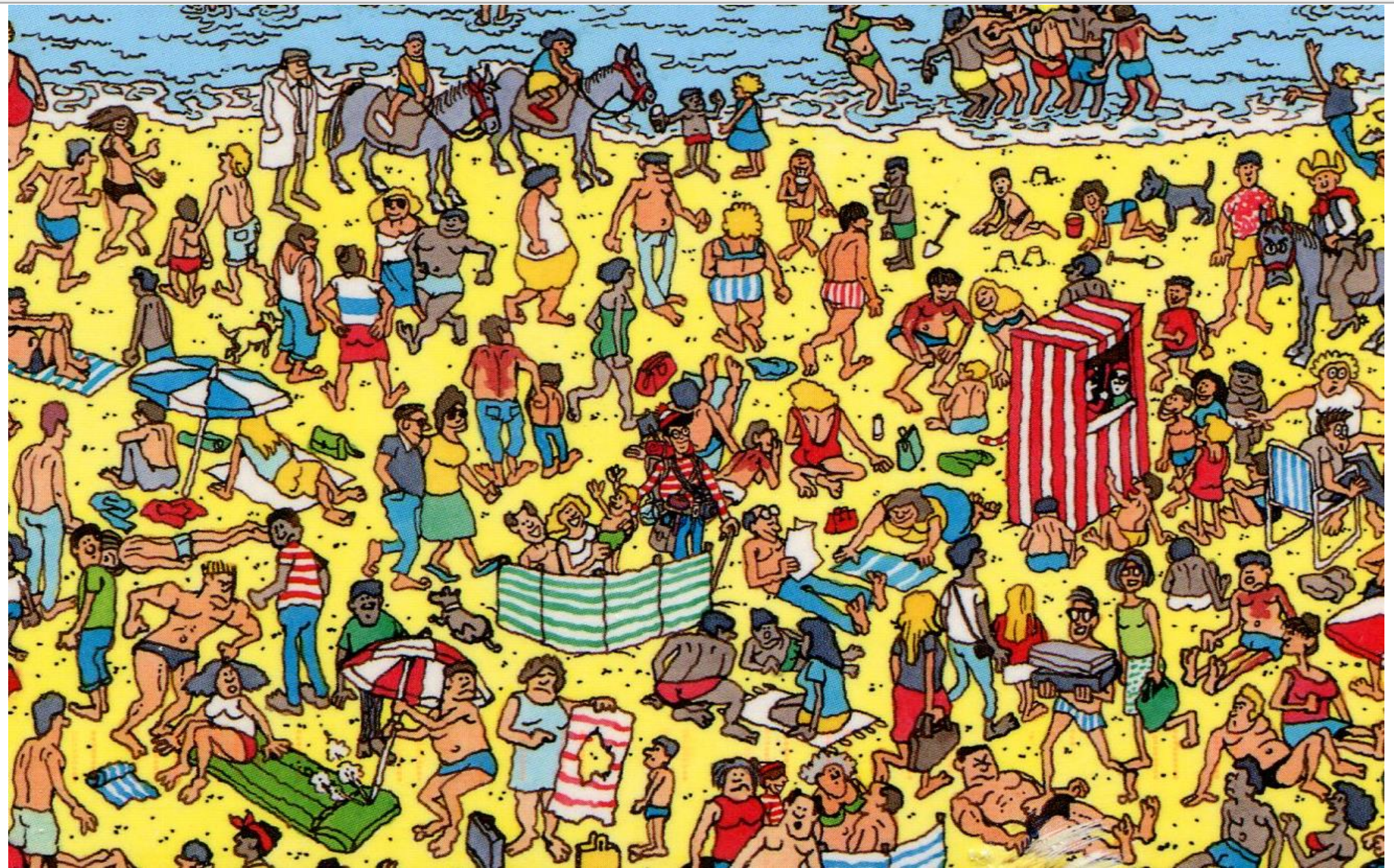


Stereopair rectification

```
def example_02_rectify_pair():

    folder_input_chess = '_images/ex01/left/'
    folder_input       = '_images/ex01/'
    filename_input_1   = folder_input + 'left/left01.jpg'
    filename_input_2   = folder_input + 'right/right01.jpg'
    folder_output      = '_images/ex01_out/'
    filename_output_1  = folder_output + 'left01_rect.jpg'
    filename_output_2  = folder_output + 'right01_rect.jpg'

    chess_rows=6
    chess_cols=7

    if not os.path.exists(folder_output):
        os.makedirs(folder_output)
    else:
        tools_IO.remove_files(folder_output)

        cameraMatrix, dist = tools_calibrate.get_proj_dist_mat_for_images(folder_input_chess, chess_rows, chess_cols)

    im1_remapped, im2_remapped = tools_calibrate.rectify_pair(cameraMatrix, dist, filename_input_1, filename_input_2, chess_rows,
chess_cols)
    cv2.imwrite(filename_output_1, im1_remapped)
    cv2.imwrite(filename_output_2, im2_remapped)

    return
```

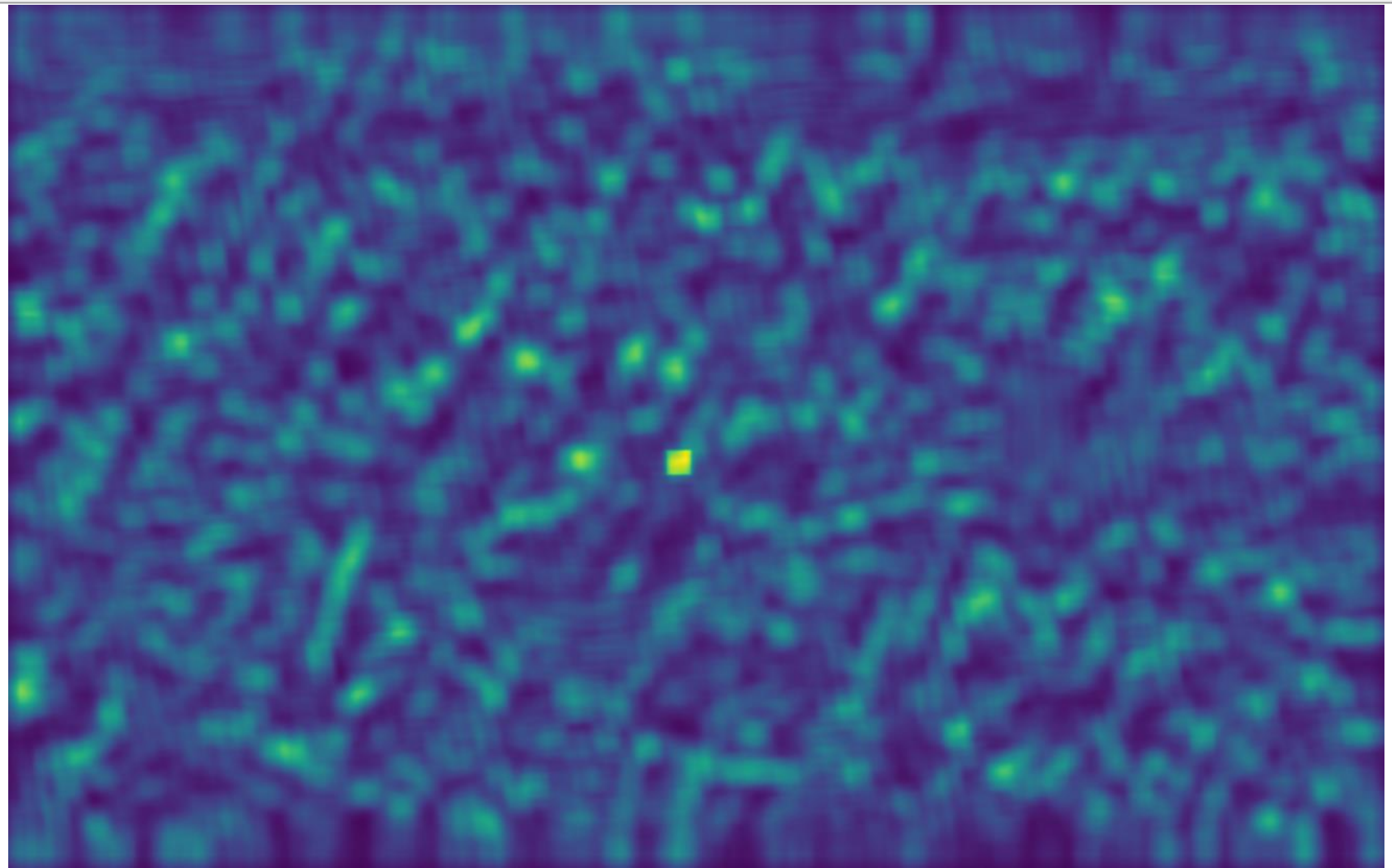
8. Template matching

Template Matching

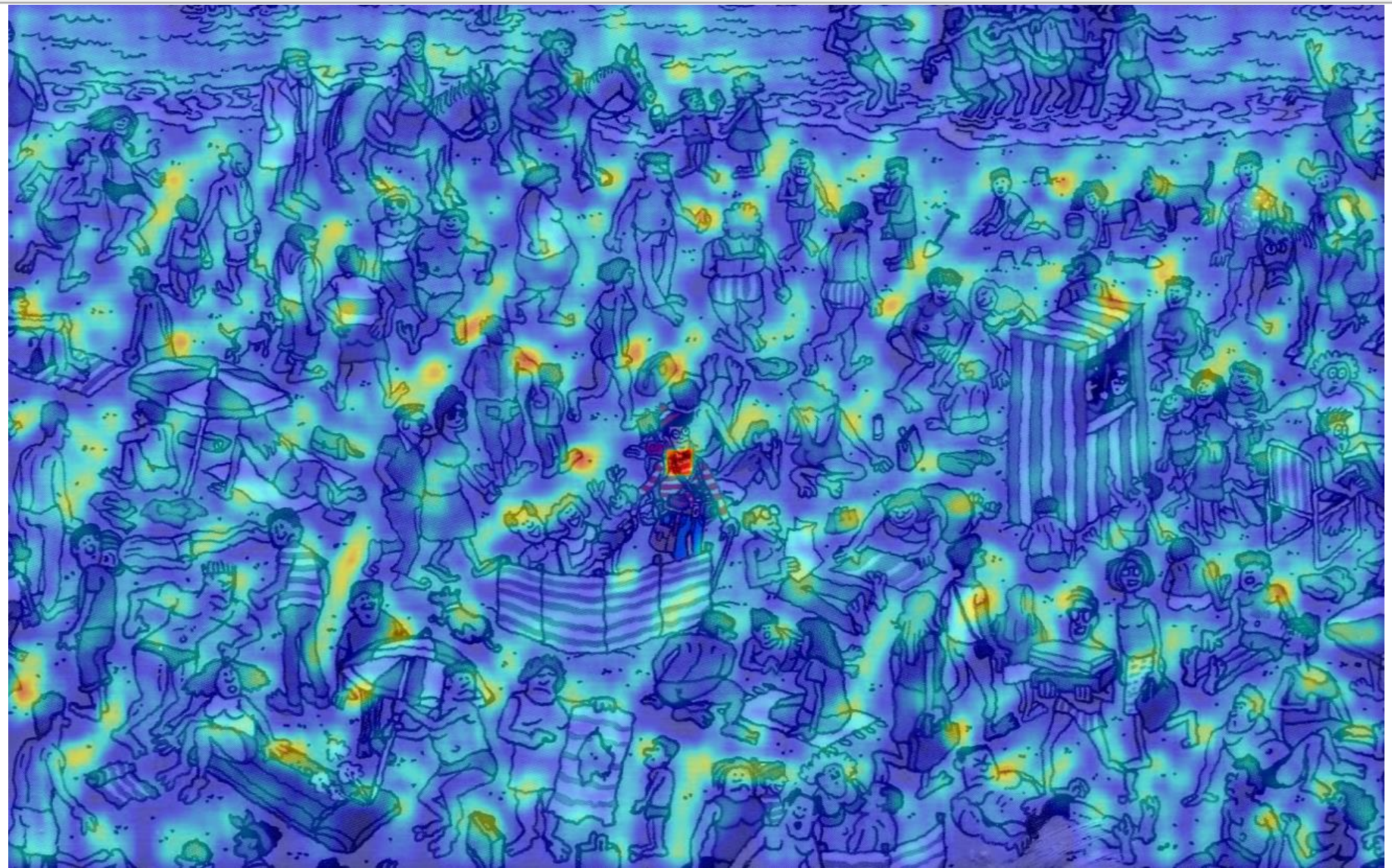


Template Matching

Template Matching



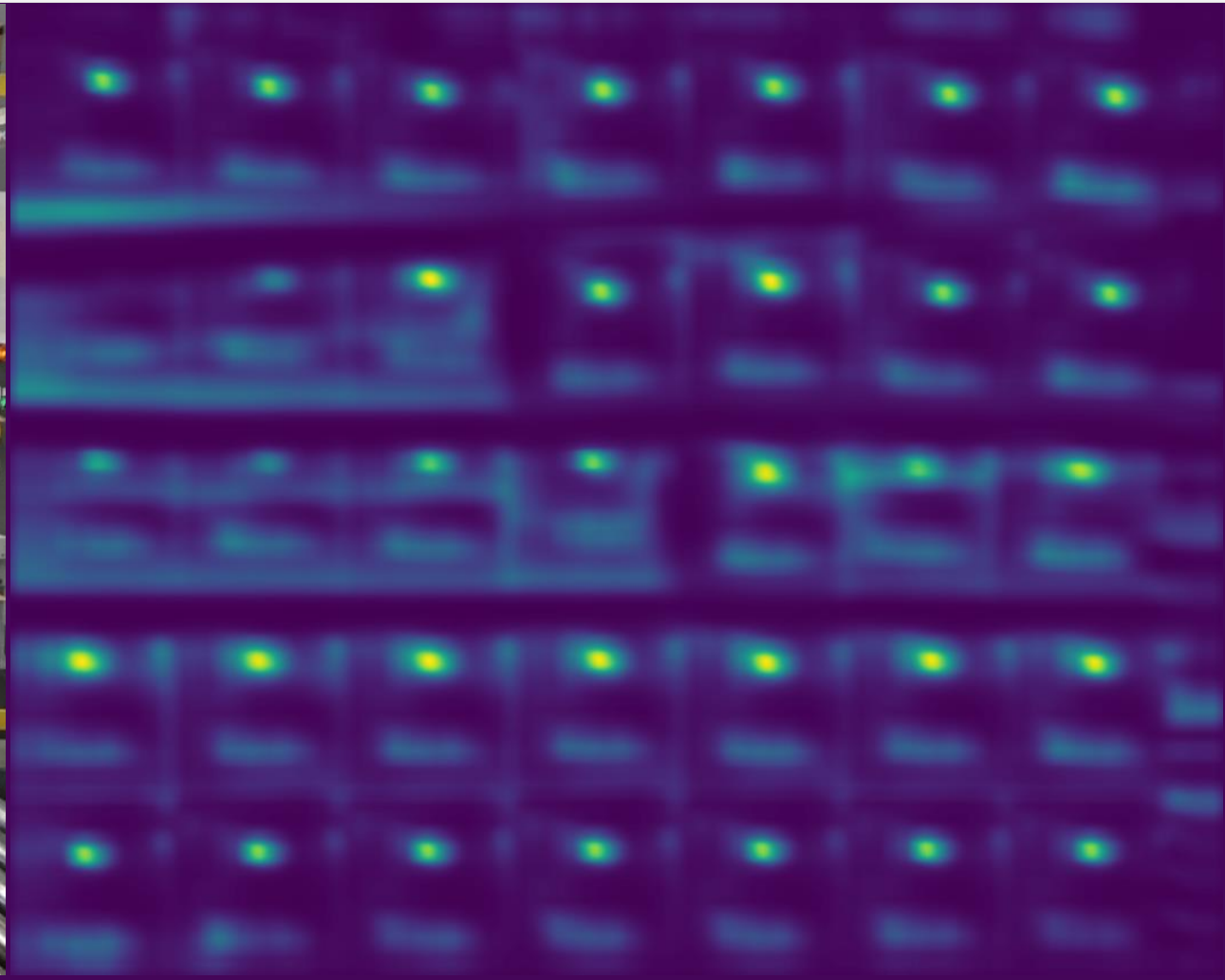
Template Matching



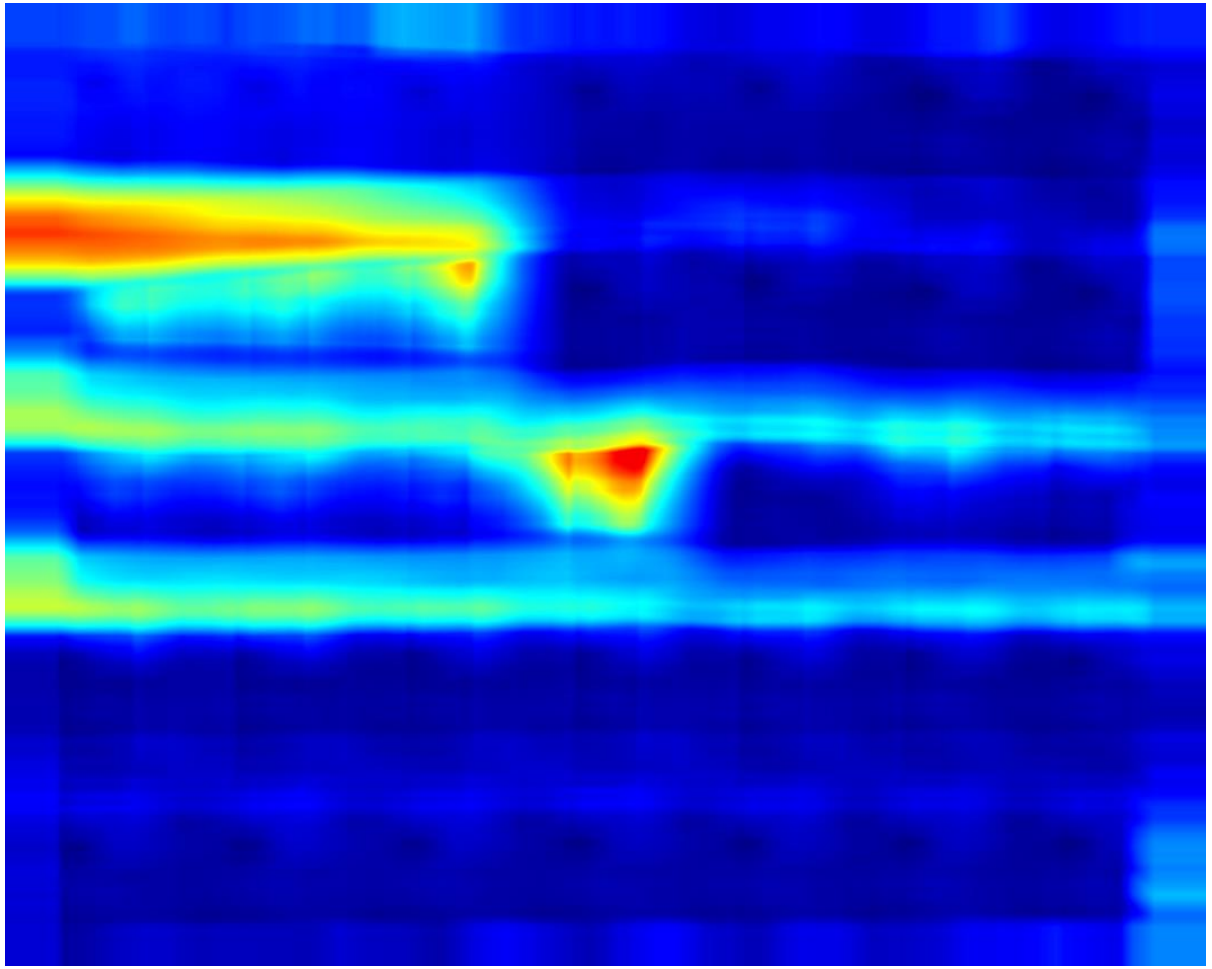
Template Matching

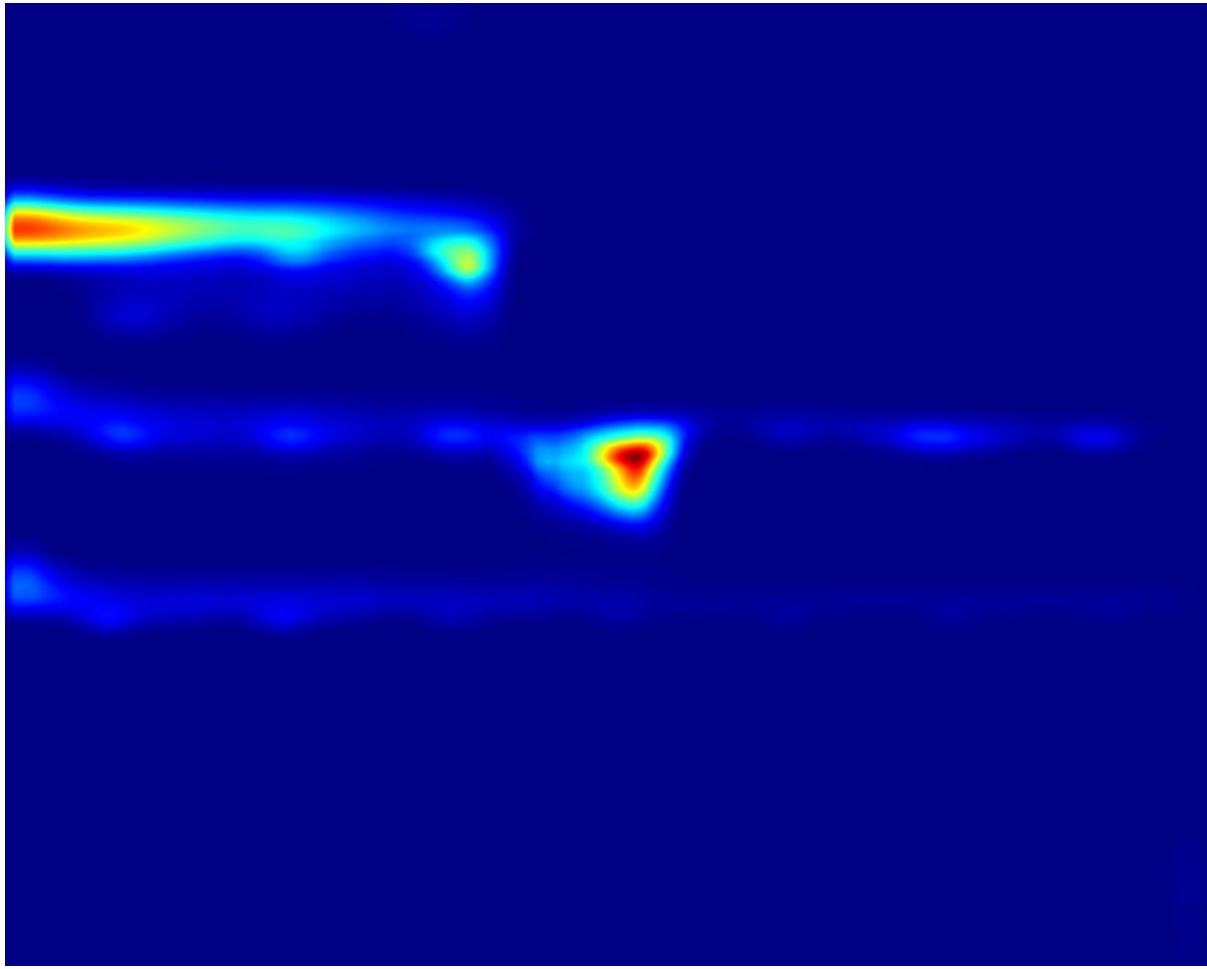
Template Matching

Template Matching

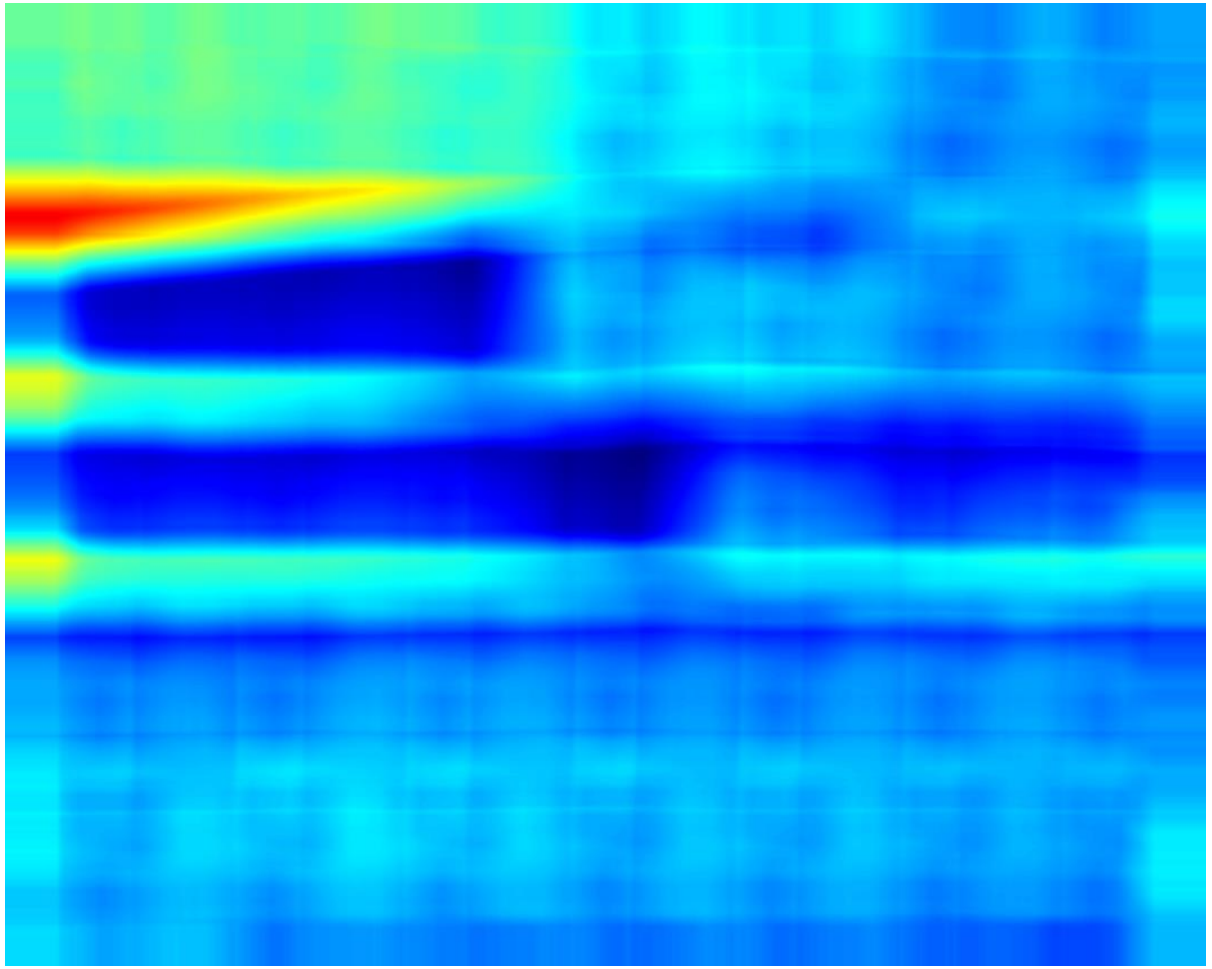


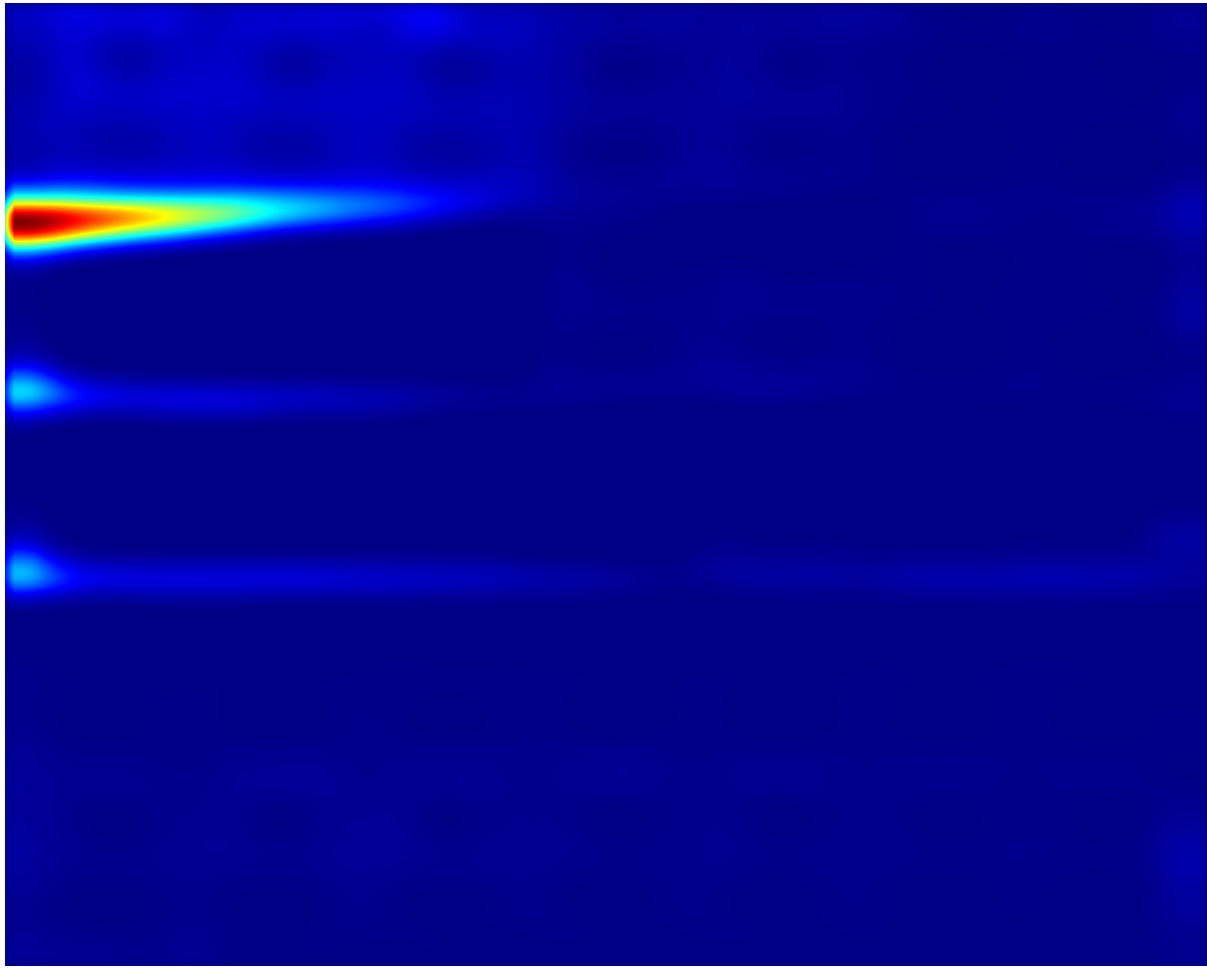
Template Matching: TM_SQDIFF_NORMED



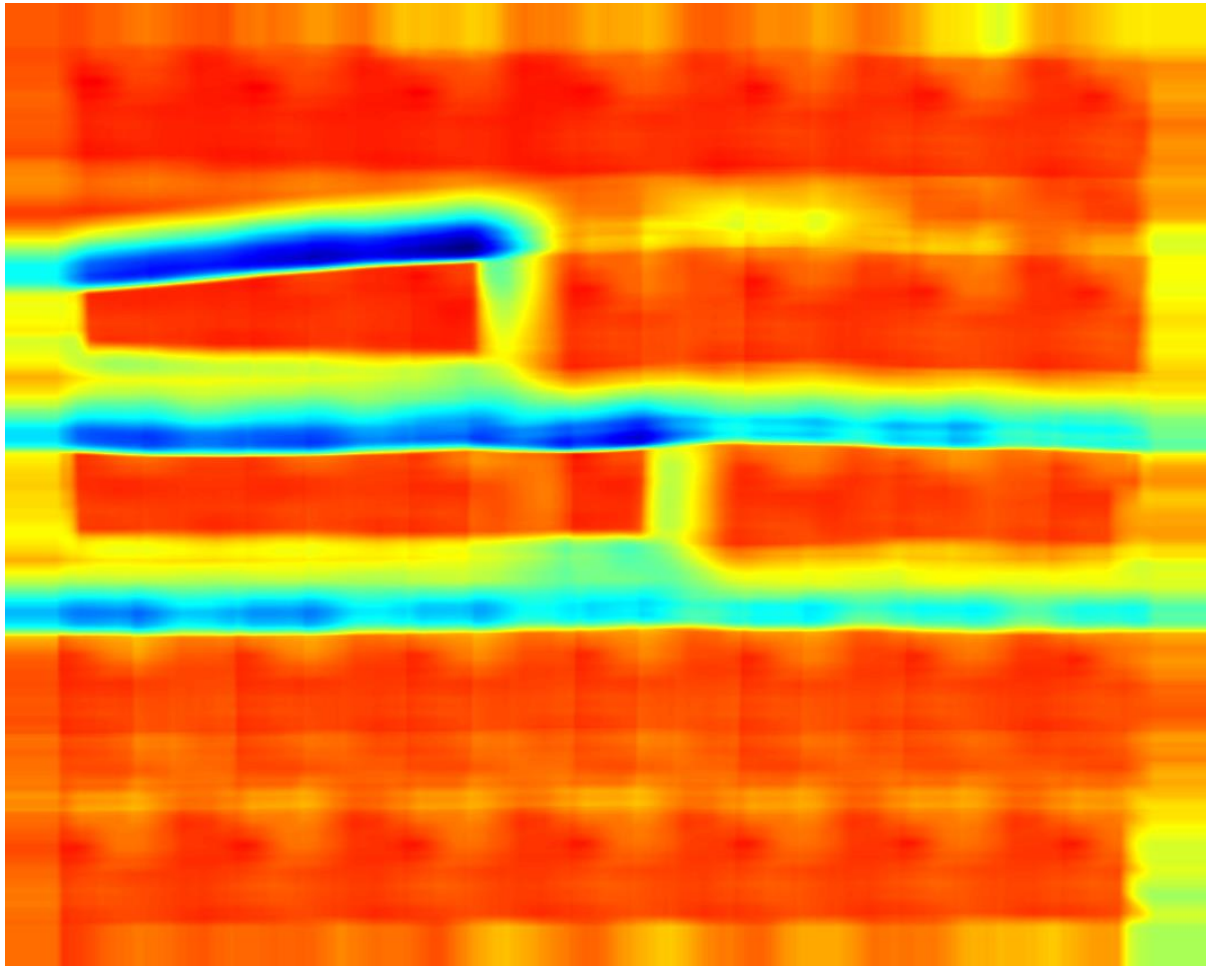


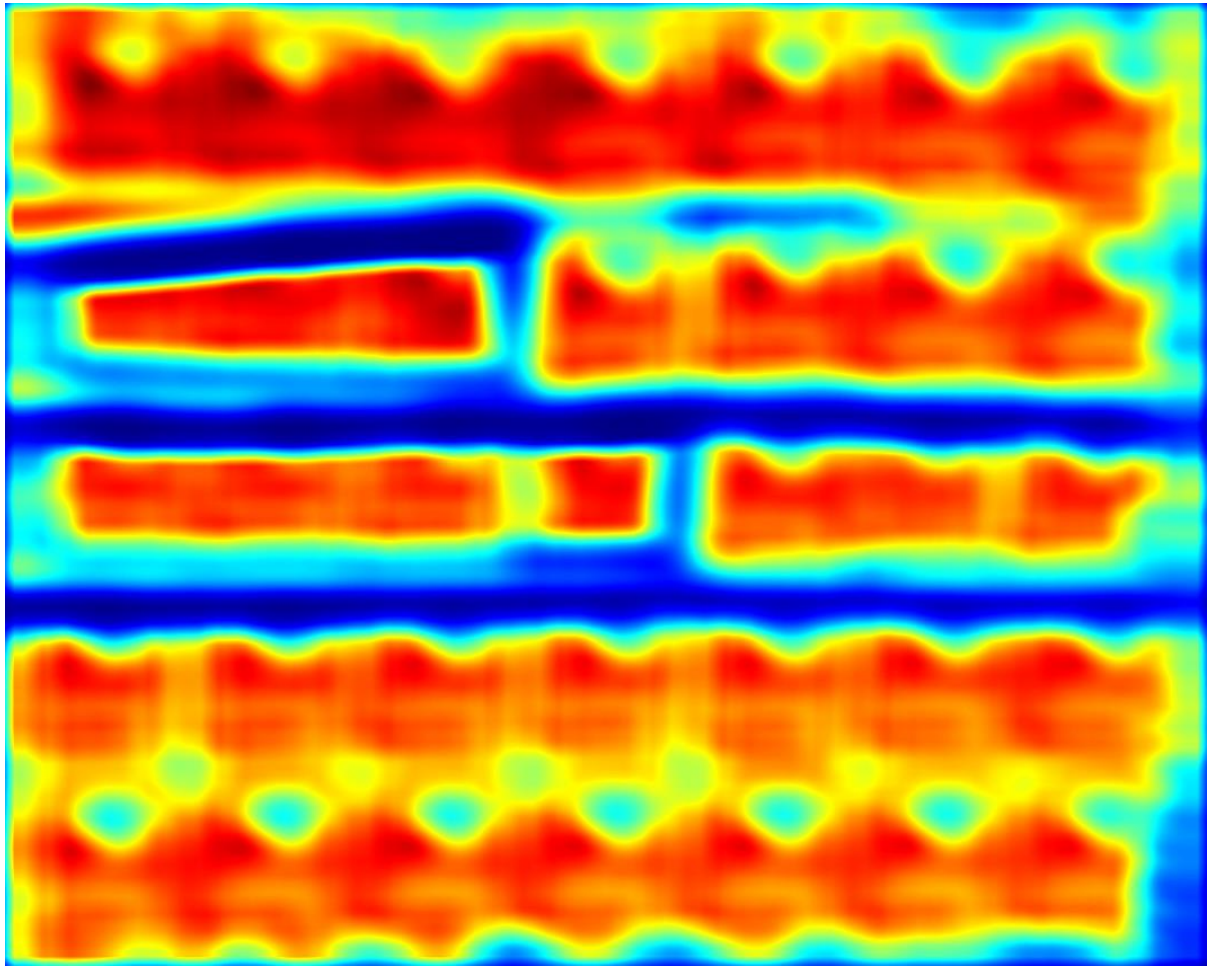
Template Matching: TM_CCORR



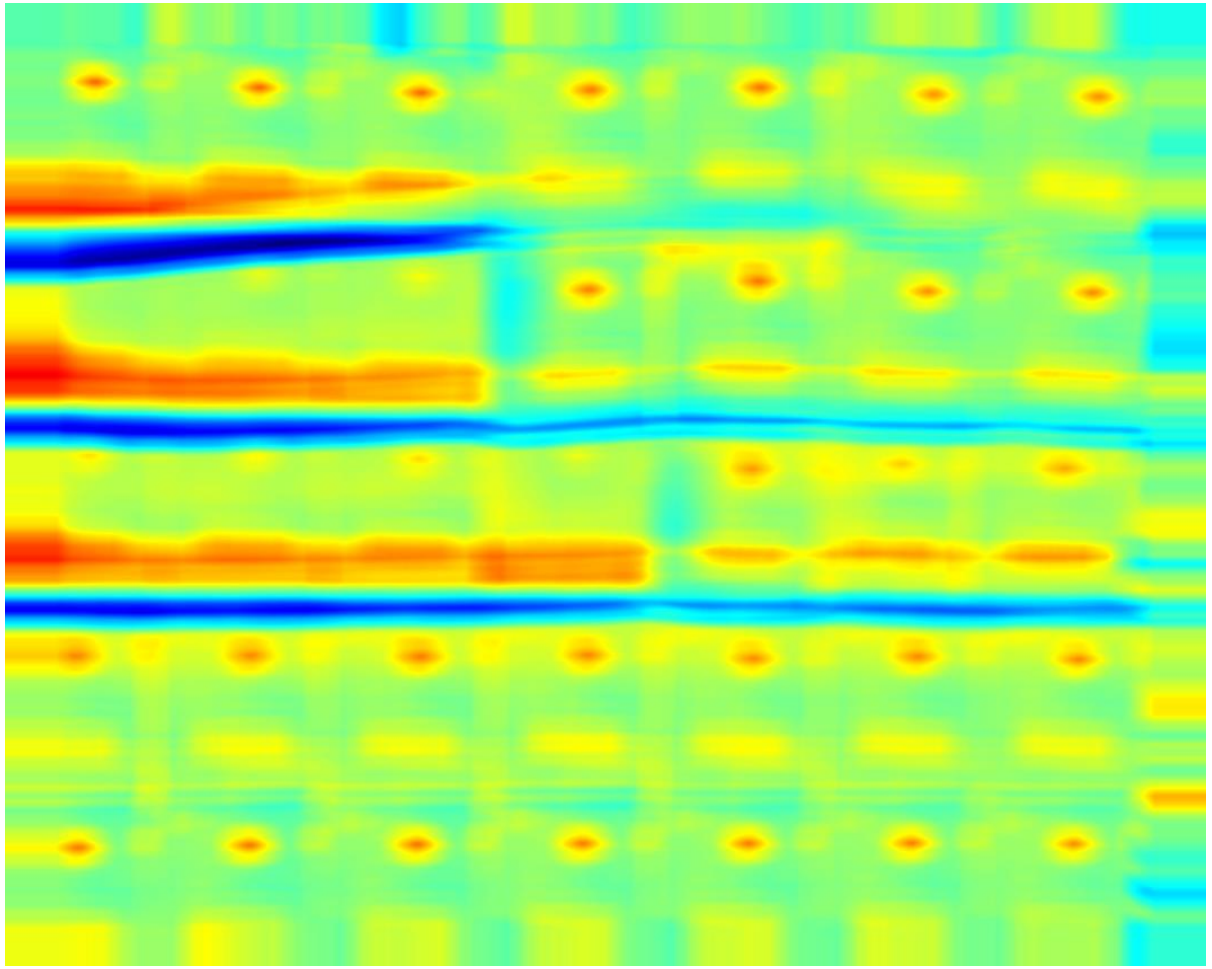


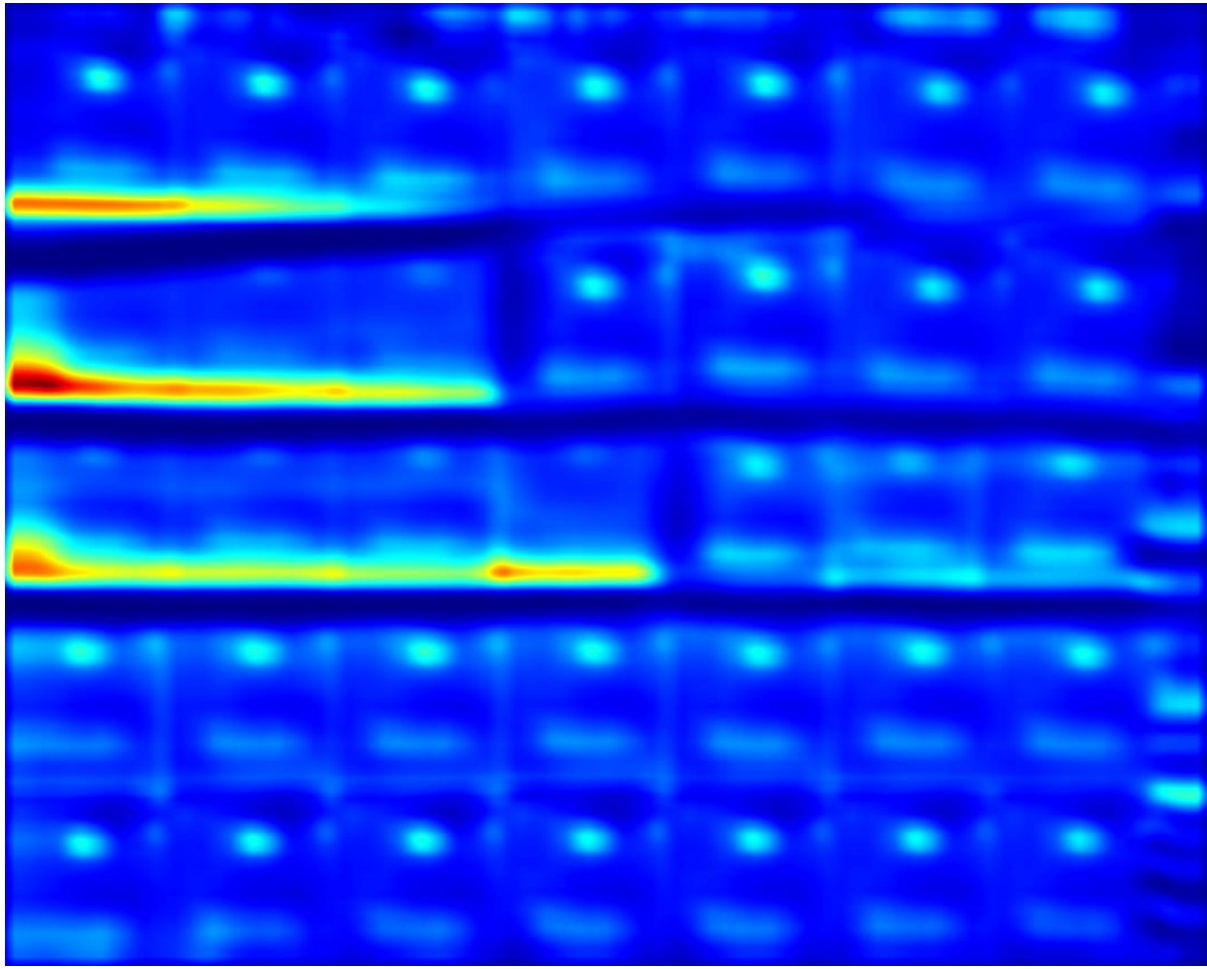
Template Matching: TM_CCORR_NORMED



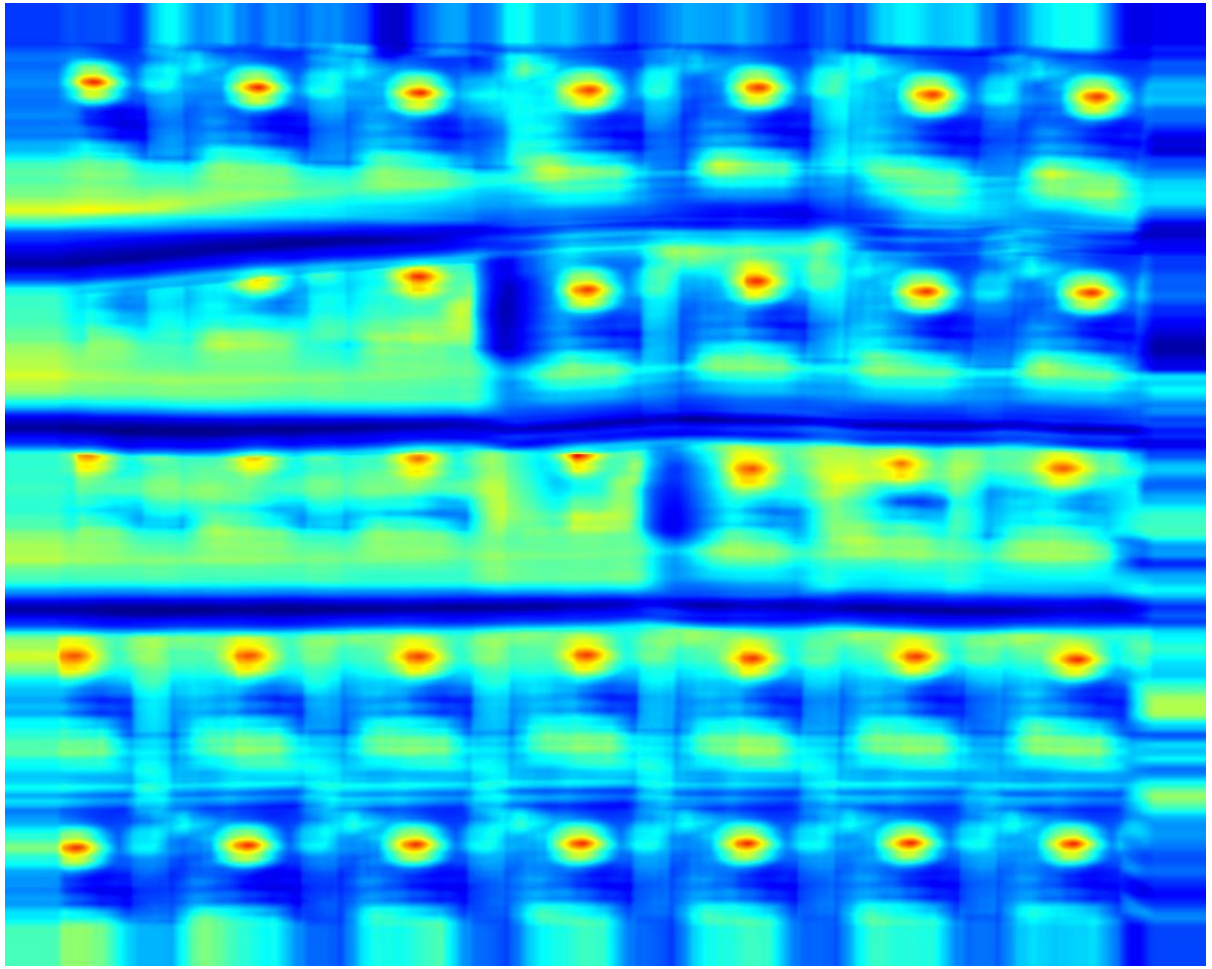


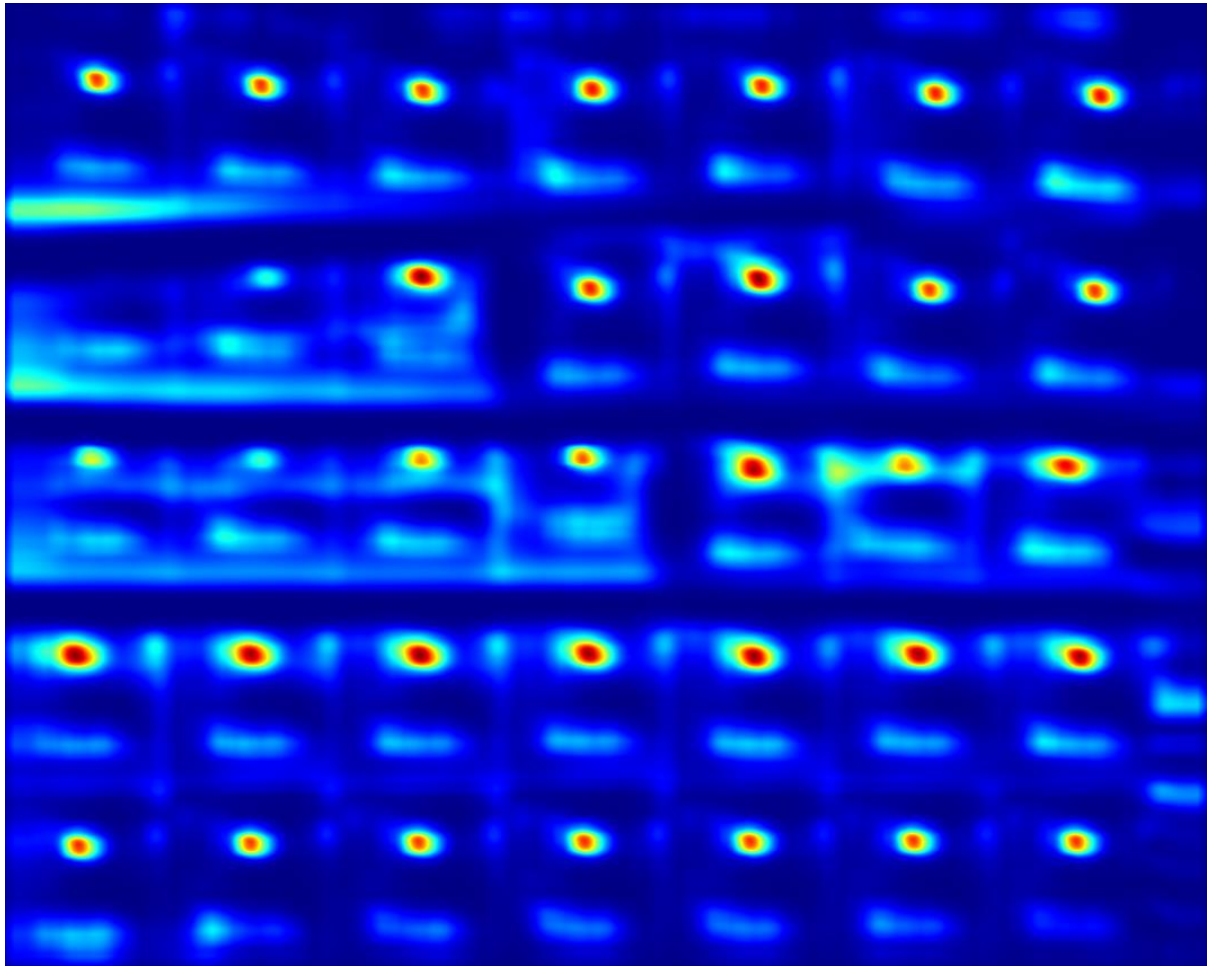
Template Matching: TM_CCOEFF





Template Matching: TM_CCOEFF_NORMED





Template Matching

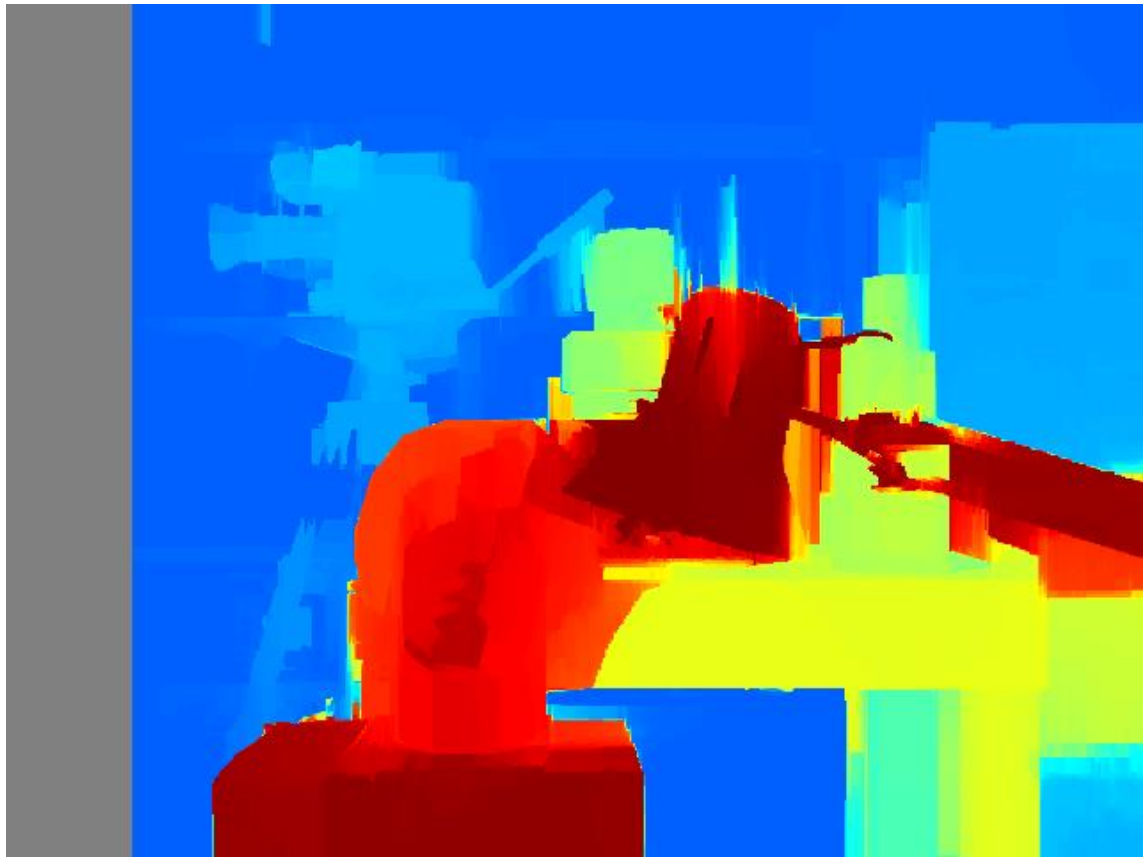
```
def calc_hit_field_basic(image_base, image_pattern,mask=None):

    hitmap_gray = cv2.matchTemplate(image_base, image_pattern, method=cv2.TM_CCOEFF_NORMED)

    min = hitmap_gray.min()
    max = hitmap_gray.max()
    hitmap_gray = (225 * (hitmap_gray - min) / (max - min)).astype(numpy.uint8)
    hitmap_gray = numpy.reshape(hitmap_gray,(hitmap_gray.shape[0],hitmap_gray.shape[1],1))

    hitmap_gray2 = numpy.zeros((image_base.shape[0],image_base.shape[1],1)).astype(numpy.uint8)
    shift_x = int((image_base.shape[0] - hitmap_gray.shape[0])/2)
    shift_y = int((image_base.shape[1] - hitmap_gray.shape[1])/2)
    hitmap_gray2[shift_x:shift_x+hitmap_gray.shape[0], shift_y:shift_y + hitmap_gray.shape[1], 0] =
hitmap_gray[: , :, 0]


    hitmap_gray2[:shift_x                              , shift_y:shift_y + hitmap_gray.shape[1], 0] =
hitmap_gray[0 , :, 0]
    hitmap_gray2[shift_x + hitmap_gray.shape[0]:       , shift_y:shift_y + hitmap_gray.shape[1], 0] =
hitmap_gray[-1, :, 0]

    for row in range(0,hitmap_gray2.shape[0]):
        hitmap_gray2[row,:shift_y                            , 0] = hitmap_gray2[row, shift_y
, 0]
        hitmap_gray2[row, shift_y + hitmap_gray.shape[1]:, 0] = hitmap_gray2[row, shift_y +
hitmap_gray.shape[1]-1 , 0]


    hitmap_2d = numpy.reshape(hitmap_gray2, (hitmap_gray2.shape[0], hitmap_gray2.shape[1]))
```

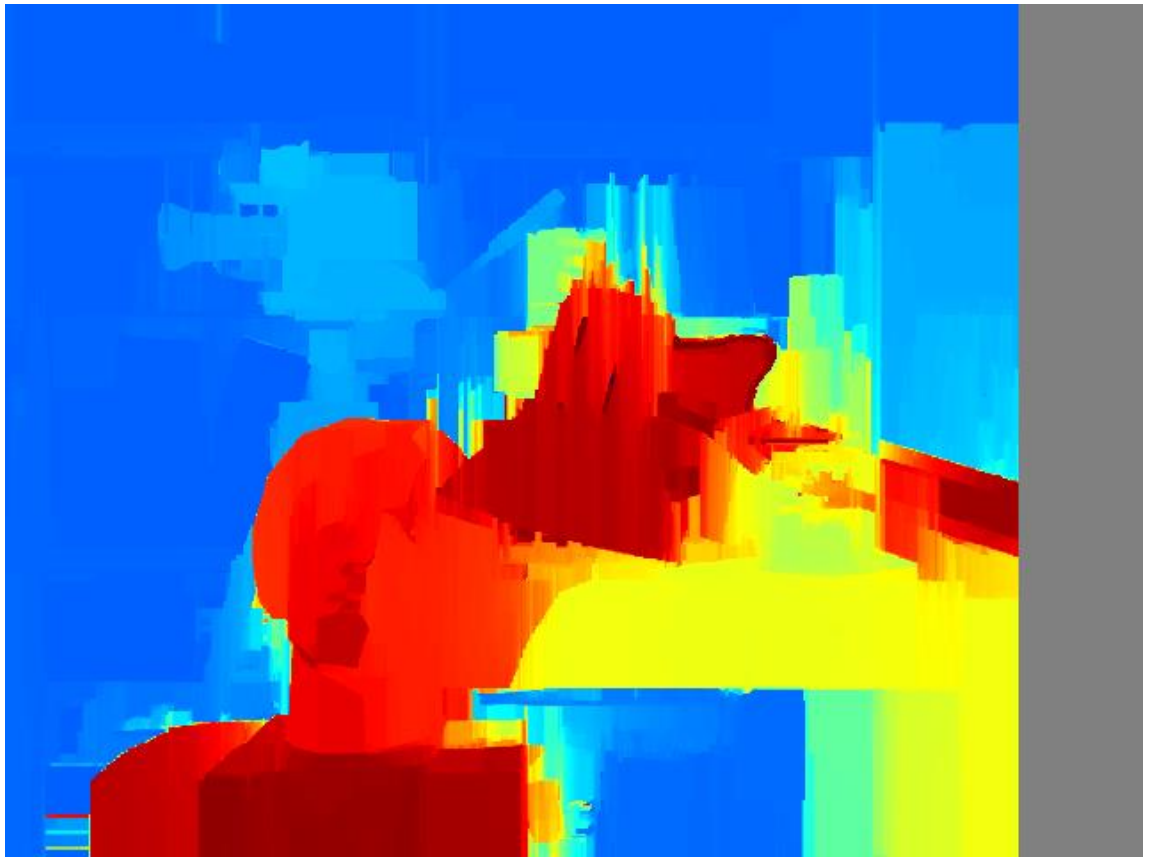
9. Stereo Vision

Stereo vision

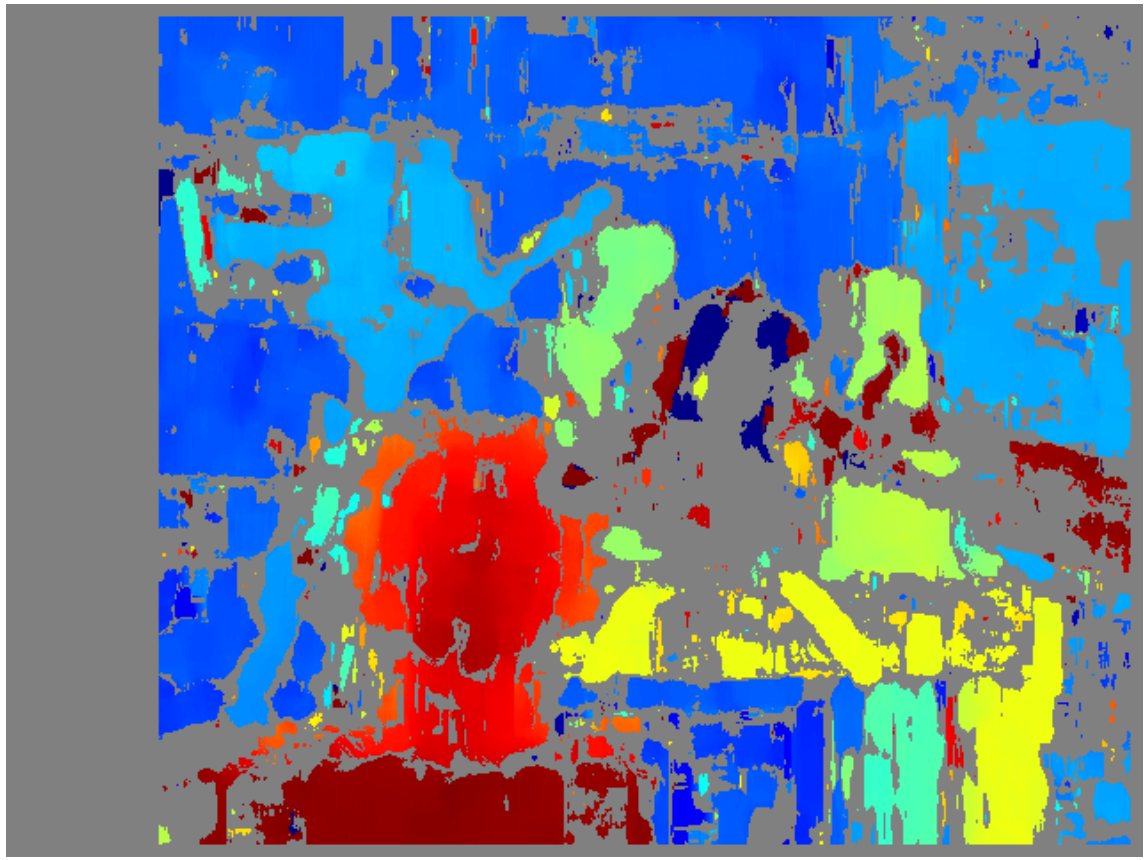
Stereo vision

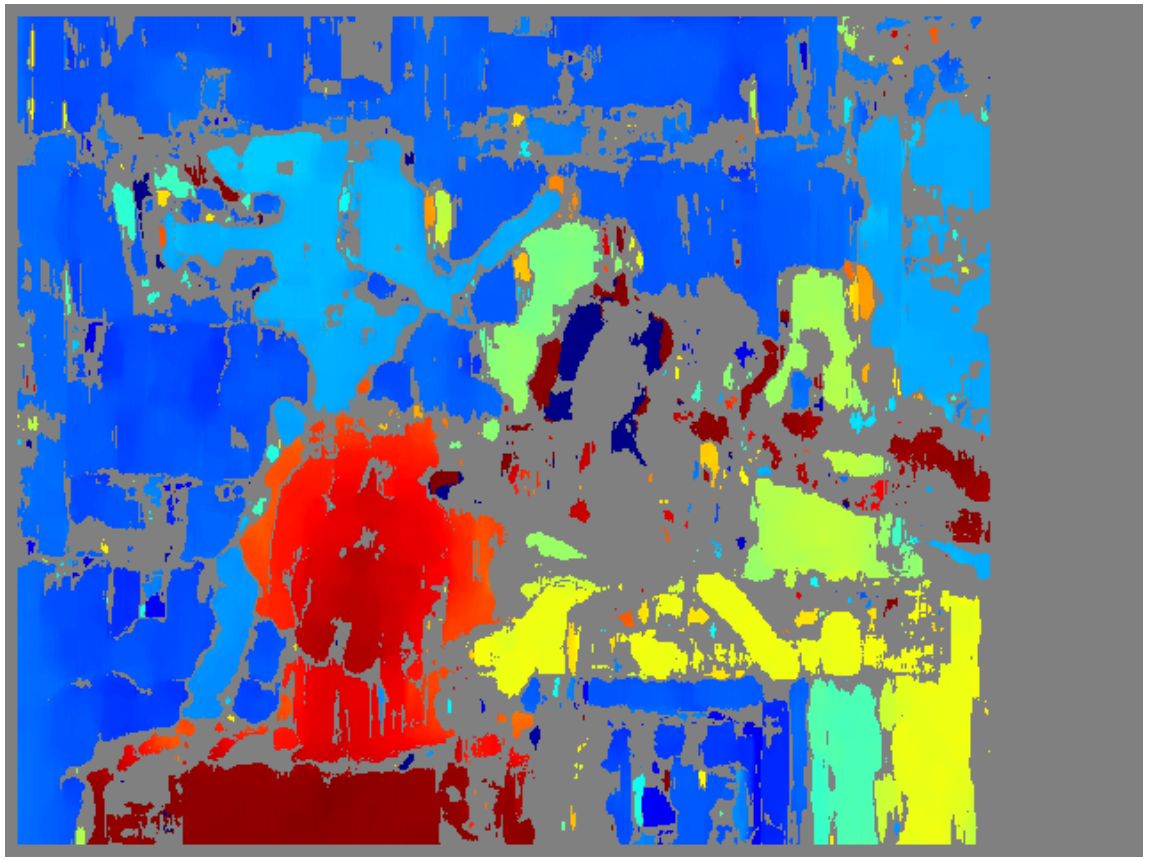
Stereo vision





Stereo vision





Stereo vision

```
def get_disparity_v_01(imgL, imgR, disp_v1, disp_v2, disp_h1, disp_h2):
    window_size = 7
    left_matcher = cv2.StereoSGBM_create(
        minDisparity=disp_h1,
        numDisparities=int(0 + (disp_h2 - disp_h1) / 16) * 16,
        blockSize=5,
        P1=8 * 3 * window_size ** 2,
        P2=32 * 3 * window_size ** 2,
        disp12MaxDiff=disp_h2,
        uniquenessRatio=15,
        speckleWindowSize=0,
        speckleRange=2,
        preFilterCap=63,
        mode=cv2.STEREO_SGBM_MODE_SGBM_3WAY
    )

    right_matcher = cv2.ximgproc.createRightMatcher(left_matcher)
    dispr = right_matcher.compute(imgR, imgL)
    displ = left_matcher.compute(imgL, imgR)

    wls_filter = cv2.ximgproc.createDisparityWLSFilter(matcher_left=left_matcher)
    wls_filter.setLambda(80000)
    wls_filter.setSigmaColor(1.2)

    filteredImg_L = wls_filter.filter(displ, imgL, None, dispr)
    wls_filter = cv2.ximgproc.createDisparityWLSFilter(matcher_left=right_matcher)
    filteredImg_R = wls_filter.filter(dispr, imgR, None, displ)
```

Stereo vision

```
def get_disparity_v_02(imgL, imgR, disp_v1, disp_v2, disp_h1, disp_h2):
    max = numpy.maximum(math.fabs(disp_h1), math.fabs(disp_h2))
    levels = int(1 + (max) / 16) * 16
    stereo = cv2.StereoBM_create(numDisparities=levels, blockSize=15)
    displ = stereo.compute(imgL, imgR)

    dispr = numpy.flip(stereo.compute(numpy.flip(imgR, axis=1), numpy.flip(imgL, axis=1)), axis=1)
    return -displ / 16, -dispr / 16
```

10. Pose estimation

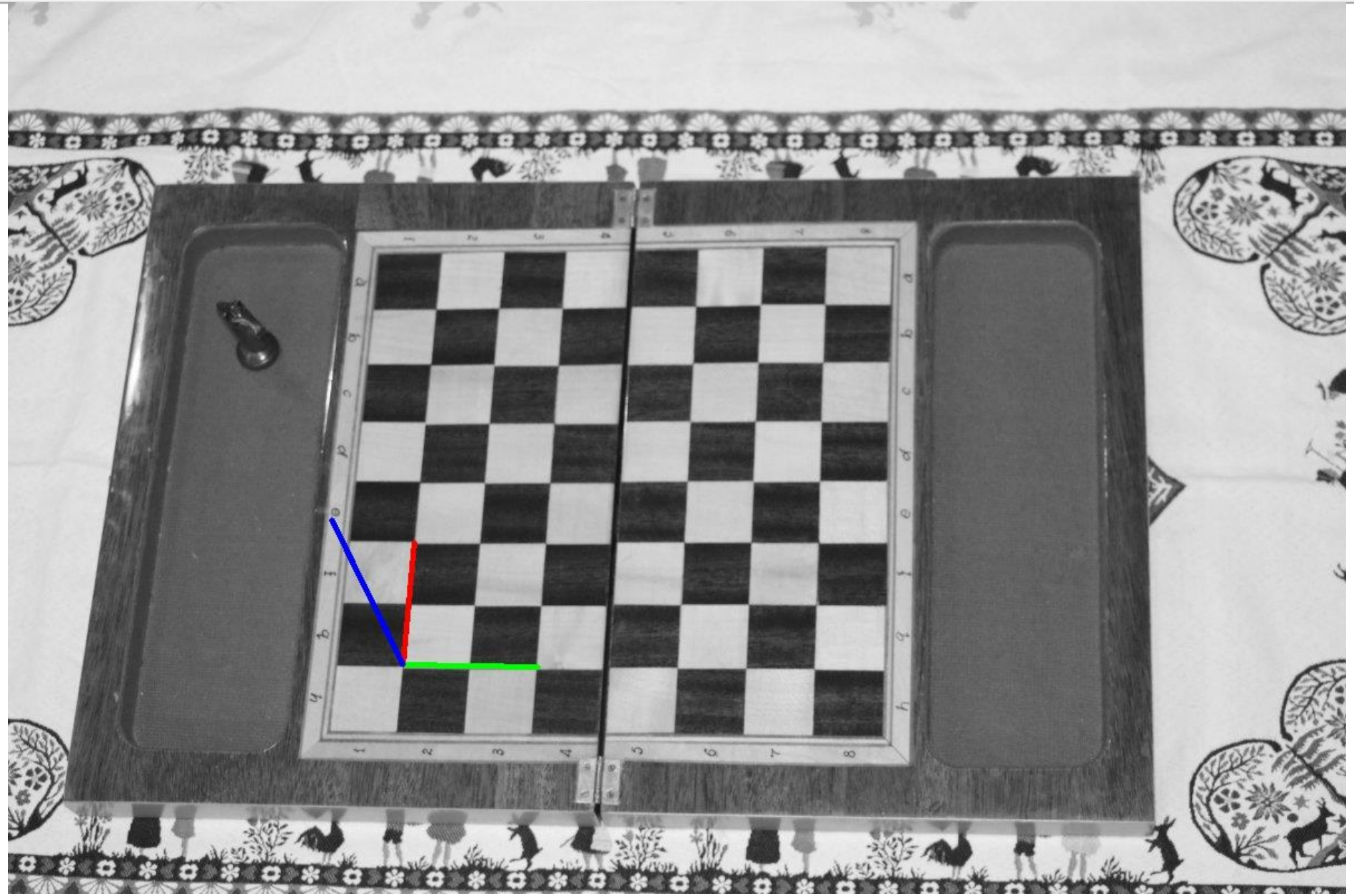
Pose estimation

```
def get_rvecs_tvecs(img,chess_rows, chess_cols,cameraMatrix, dist):
    corners_3d = numpy.zeros((chess_rows * chess_cols, 3), numpy.float32)
    corners_3d[:, :2] = numpy.mgrid[0:chess_cols, 0:chess_rows].T.reshape(-1, 2)
    gray = cv2.cvtColor(img, cv2.COLOR_BGR2GRAY)
    ret, corners_2d = cv2.findChessboardCorners(gray, (chess_cols, chess_rows), None)

    rvecs, tvecs=numpy.array([]),numpy.array([])

    if ret == True:
        corners_2d = cv2.cornerSubPix(gray, corners_2d, (11, 11), (-1, -1),(cv2.TERM_CRITERIA_EPS, 30,
0.001))
        _, rvecs, tvecs, inliers = cv2.solvePnPRansac(corners_3d, corners_2d, cameraMatrix, dist)

    return rvecs, tvecs
```

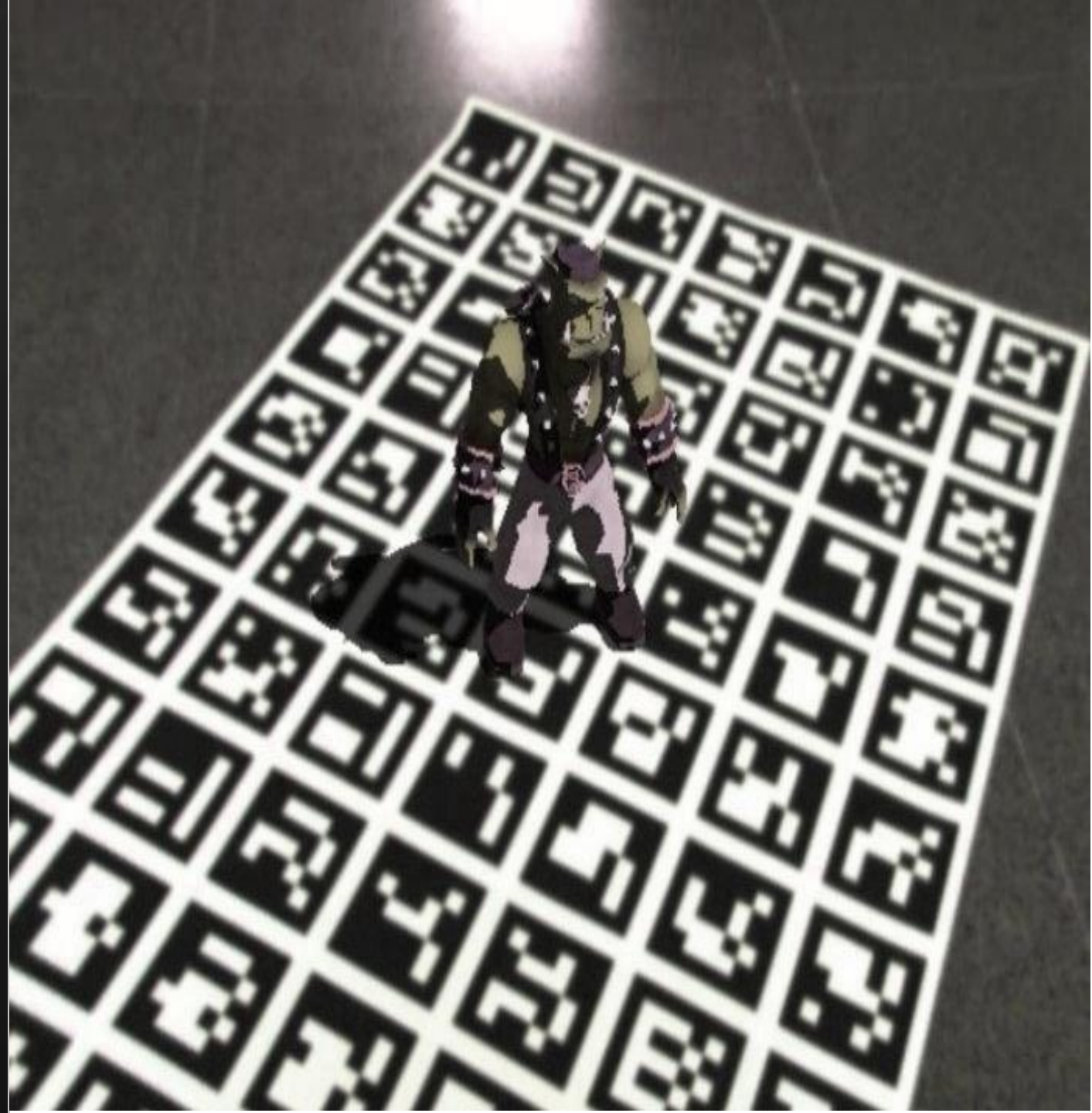
Pose estimation

```
img = cv2.imread(folder_input + image_name)
rvecs, tvecs = tools_calibrate.get_rvecs_tvecs(img,chess_rows, chess_cols,cameraMatrix, dist)

if rvecs.size!=0:

    axis_2d_end, jac   = cv2.projectPoints(axis_3d_end  , rvecs, tvecs, cameraMatrix, dist)
    axis_2d_start, jac = cv2.projectPoints(axis_3d_start, rvecs, tvecs, cameraMatrix, dist)
    img = tools_draw_numpy.draw_line(img, axis_2d_start[0,0,1], axis_2d_start[0,0,0], axis_2d_end[0,0,1],axis_2d_end[0,0,0],
(0,0,255))
    img = tools_draw_numpy.draw_line(img, axis_2d_start[0,0,1], axis_2d_start[0,0,0], axis_2d_end[1,0,1],axis_2d_end[1,0,0],
(0,0,255))
    img = tools_draw_numpy.draw_line(img, axis_2d_start[0,0,1], axis_2d_start[0,0,0], axis_2d_end[2,0,1],axis_2d_end[2,0,0],
(0,0,255))
```

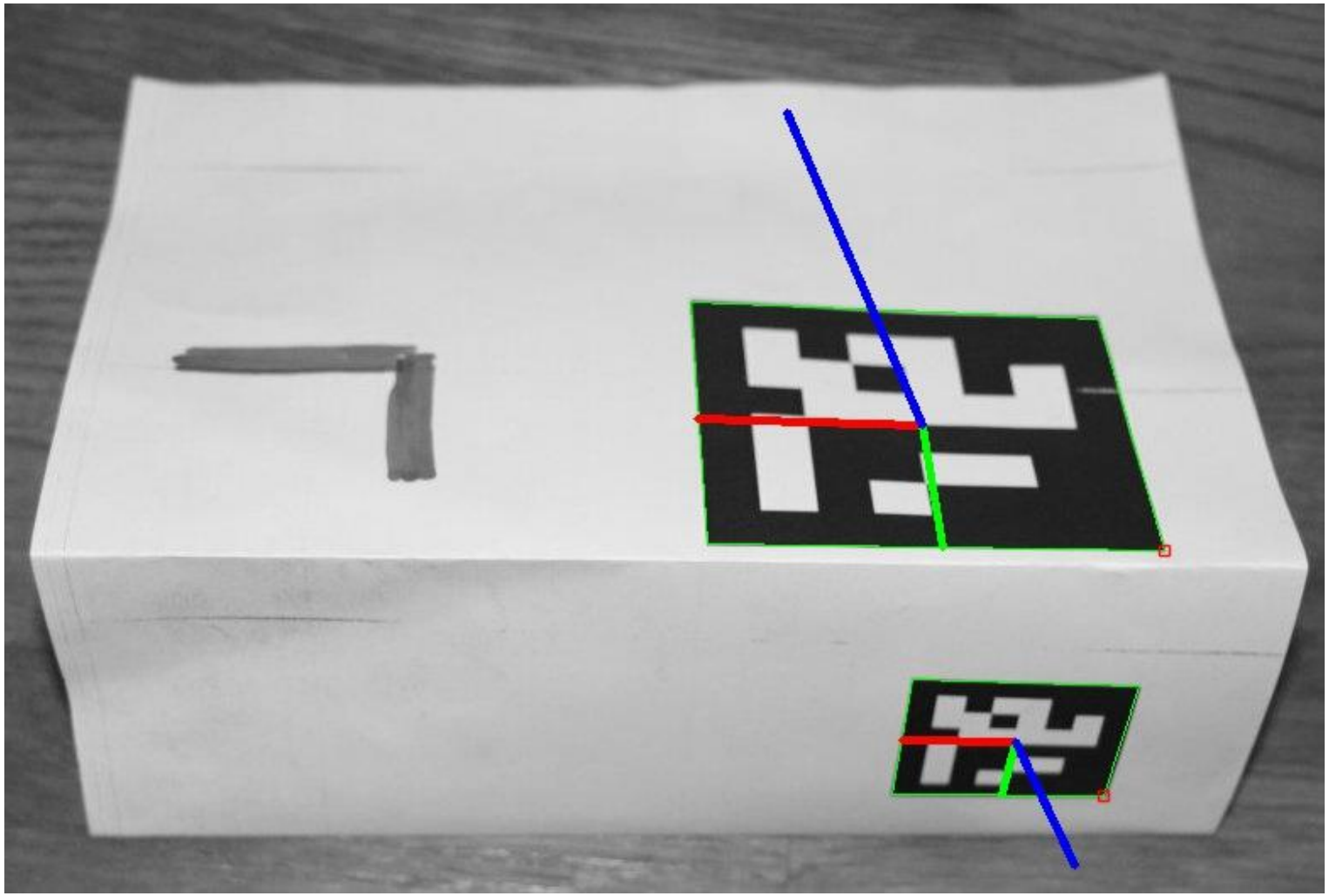
Pose estimation



11. Aruco



Aruco



Aruco

```
def demo_aruco_01(camera_matrix,dist):

    cap = cv2.VideoCapture(0)
    aruco_dict = aruco.Dictionary_get(aruco.DICT_6X6_250)

    while (True):
        ret, frame = cap.read()
        gray = cv2.cvtColor(frame, cv2.COLOR_BGR2GRAY)
        corners, ids, rejectedImgPoints = aruco.detectMarkers(gray, aruco_dict)

        if len(corners) > 0:
            frame = aruco.drawDetectedMarkers(frame, corners,ids)

            rvec, tvec, _ = aruco.estimatePoseSingleMarkers(corners[0], 0.05, camera_matrix,dist)
            aruco.drawAxis(frame, camera_matrix, dist, rvec[0], tvec[0], 0.1)

        cv2.imshow('frame', frame)
        if cv2.waitKey(1) & 0xFF == 27:
            break


    cap.release()
    cv2.destroyAllWindows()


    return
```

12. Augmented reality

Augmented Reality

```
frame = cv2.imread(filename_in)
frame, rvec, tvec = tools_aruco.detect_marker_and_draw_axes(frame, marker_length, cameraMatrix, dist)

glClear(GL_COLOR_BUFFER_BIT | GL_DEPTH_BUFFER_BIT)
glDisable(GL_DEPTH_TEST)
glDrawPixels(frame.shape[1], frame.shape[0], GL_BGR, GL_UNSIGNED_BYTE, cv2.flip(frame, 0).data)
glEnable(GL_DEPTH_TEST)

glMatrixMode(GL_PROJECTION)
glLoadIdentity()

left = -principalX / fx
right = (image_shape[1] - principalX) / fx
bottom = (principalY - image_shape[0]) / fy
top = principalY / fy
glFrustum(left, right, bottom, top,near, far)

if numpy.count_nonzero(rvec)>0:
    glMatrixMode(GL_MODELVIEW)
    glLoadMatrixf(tools_aruco.compose_GL_MAT(rvec, tvec))
    tools_aruco.draw_native_axis(marker_length/2)
    glPushMatrix()
    tools_aruco.draw_cube(size=marker_length/4)
    glPopMatrix()

glutSwapBuffers()
glutPostRedisplay()
```

Augmented Reality