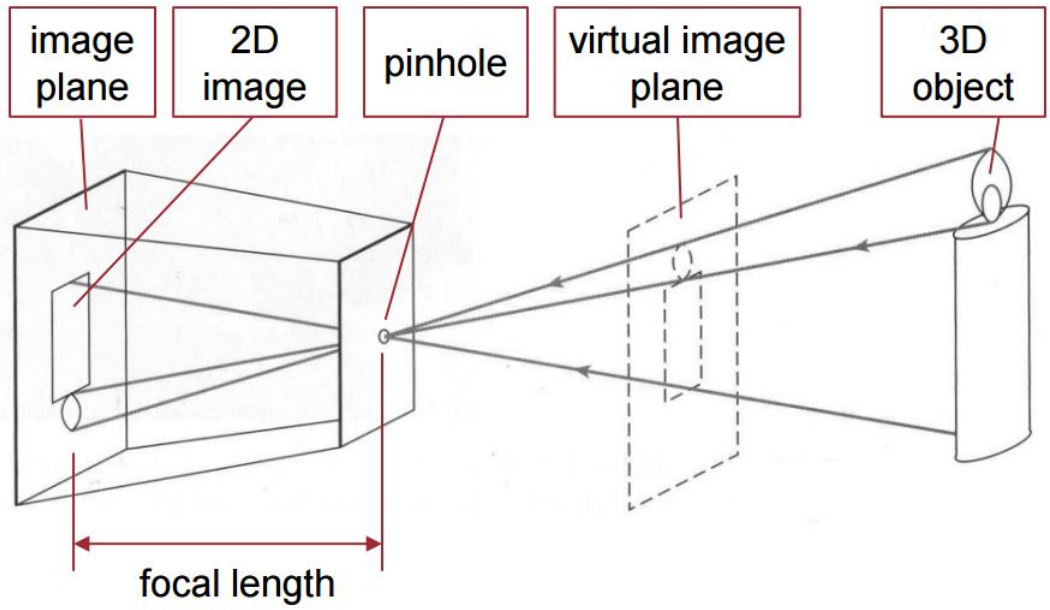
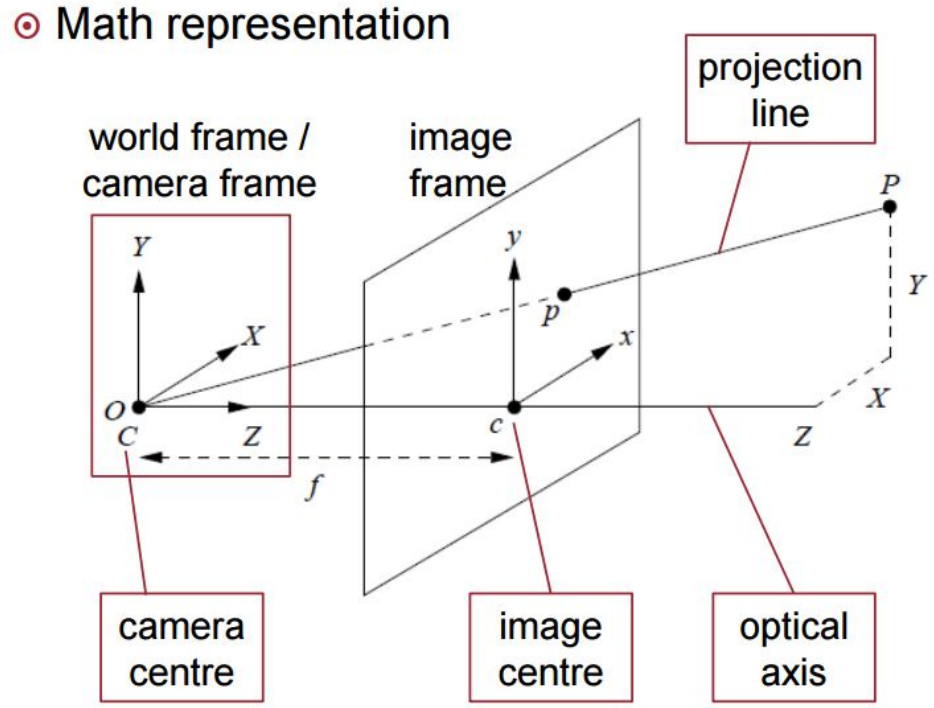
Robotics : Assignment 3

Group 2 : r05922008 丁柏文 r05922084 韓翔宇
r05922146 葉興宇 b03902062 董文捷

1. **The physical meaning of the intrinsic parameters**
   The intrinsic parameters for *Xiaomi 5* with *Camera FV-5 Lite app* is
   $f_x = 5.2527901518613203e+02 \quad f_y = 5.2423050665947335e+02$
   $c_x = 3.3348261217425255e+02 \quad c_y = 2.3490390416419061e+02$

   In Camera calibration With OpenCV, the calibration is done with the help of the `cv::calibrateCamera` function, which finds the camera intrinsic and extrinsic parameters from several views of a calibration pattern. The intrinsic parameters f_x, f_y, c_x, and c_y is stored in the output 3x3 floating-point `cameraMatrix` with the form $\texttt{cameraMatrix} = \begin{bmatrix} f_x & 0 & c_x \\ 0 & f_y & c_y \\ 0 & 0 & 1 \end{bmatrix}$.
   Those intrinsic parameters have their significant physical meanings in the camera model. We first consider a simple geometry camera model, *pinhole camera model*, which describes the mathematical relationship between the coordinates of a 3D point and its projection onto the image plane.





By similarity of the triangles, we can get $\frac{x}{f} = \frac{X}{Z} \rightarrow x = f\frac{X}{Z}$

Same relation holds for y, too. $\frac{y}{f} = \frac{Y}{Z} \rightarrow y = f\frac{Y}{Z}$

Ideally, principal point c, the intersection point of the optical axis and the image plane, should be the center of the image. However, due to assembly error of the camera, the position of c in image plane may located at (c_x, c_y).

Therefore, the relations become $x = f[\frac{X}{Z}] + c_x \quad y = f[\frac{Y}{Z}] + c_y$

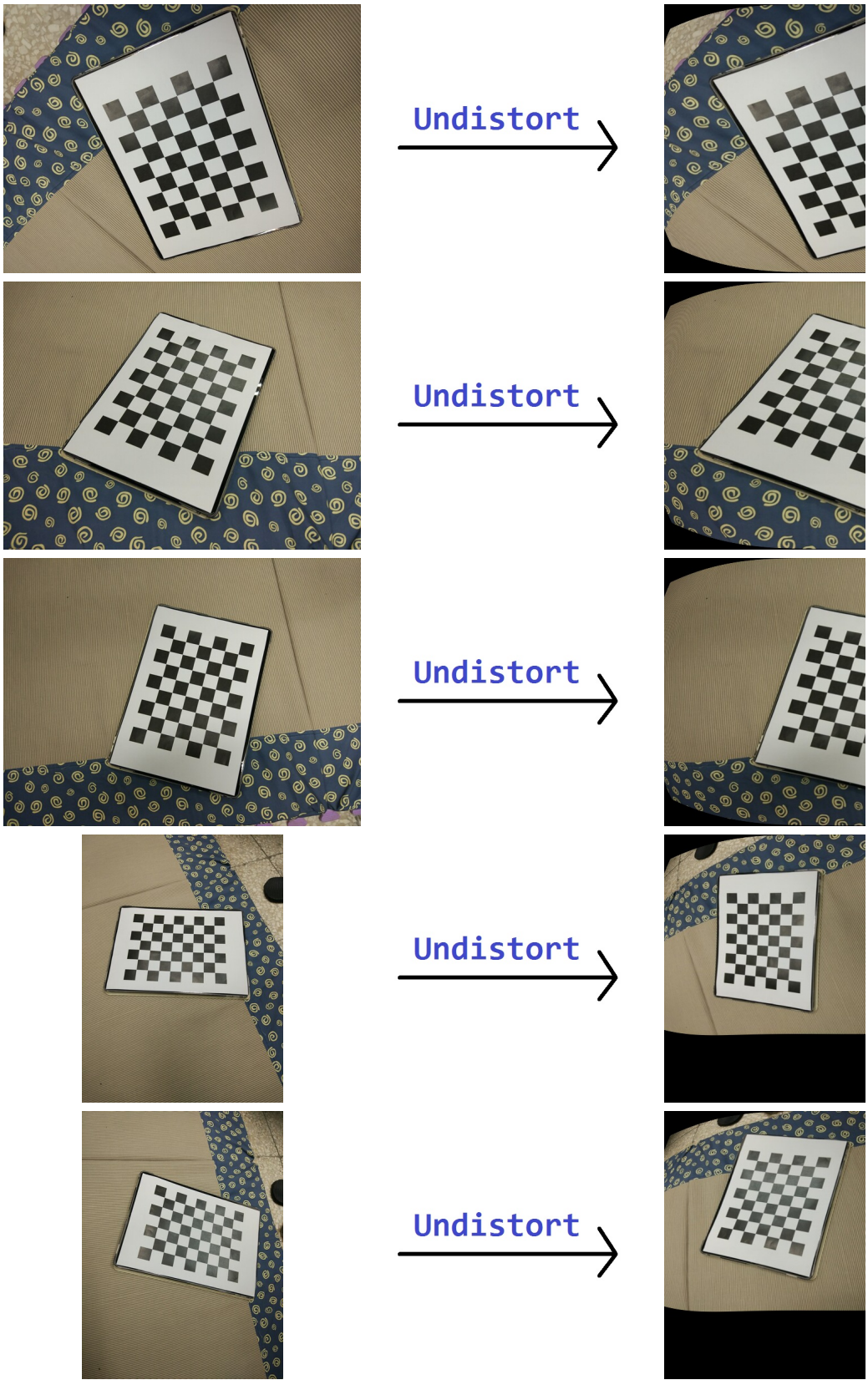
Furthermore, since we need to use pixel as a unit in the image plane, and the aspect ratio of a pixel may not be 1, that is to say, a pixel is a rectangle rather than a square, we use s_x and s_y to rewrite the relation as

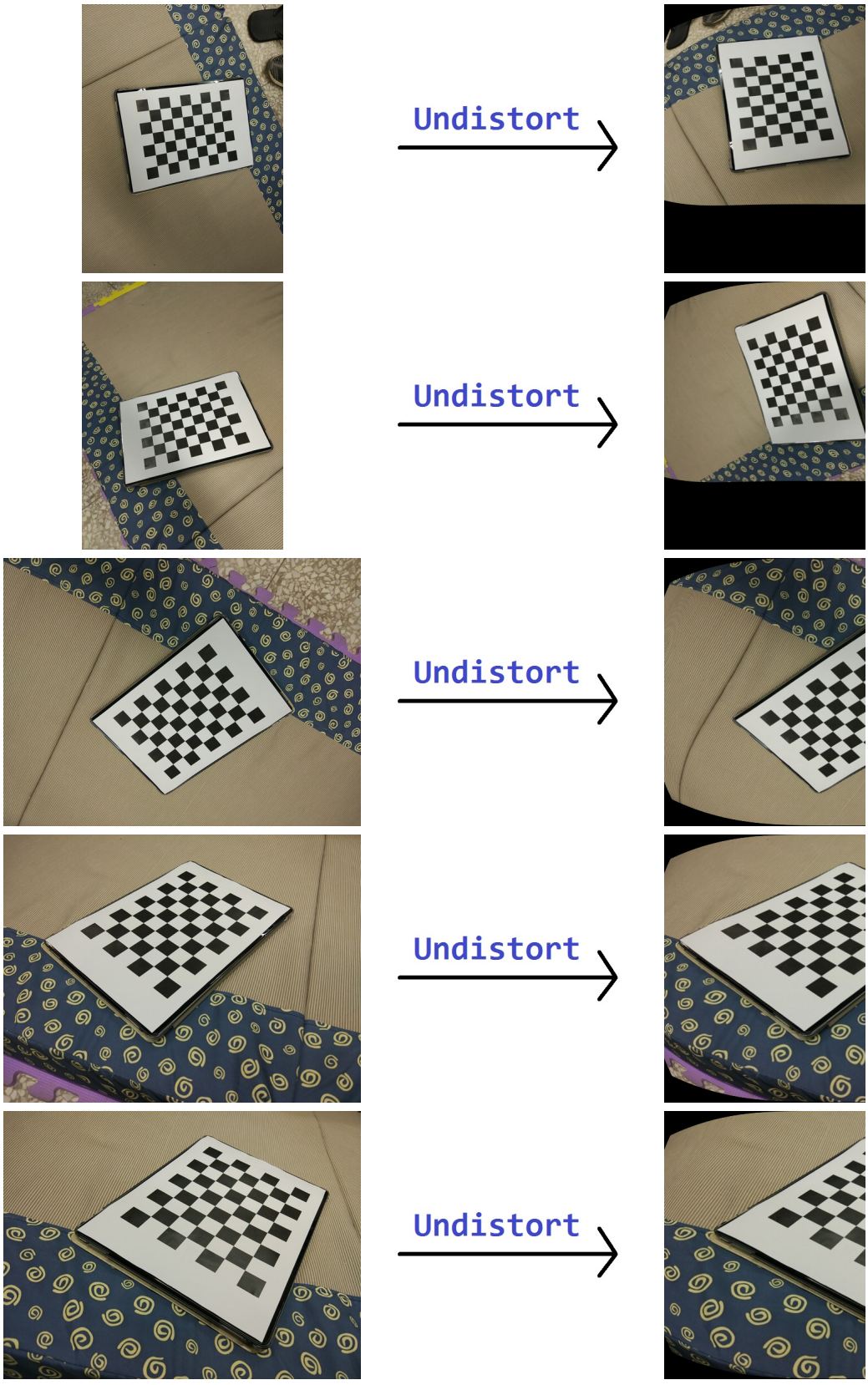
$x = f[\frac{X}{Z}] \cdot s_x + c_x \quad y = f[\frac{Y}{Z}] \cdot s_y + c_y$

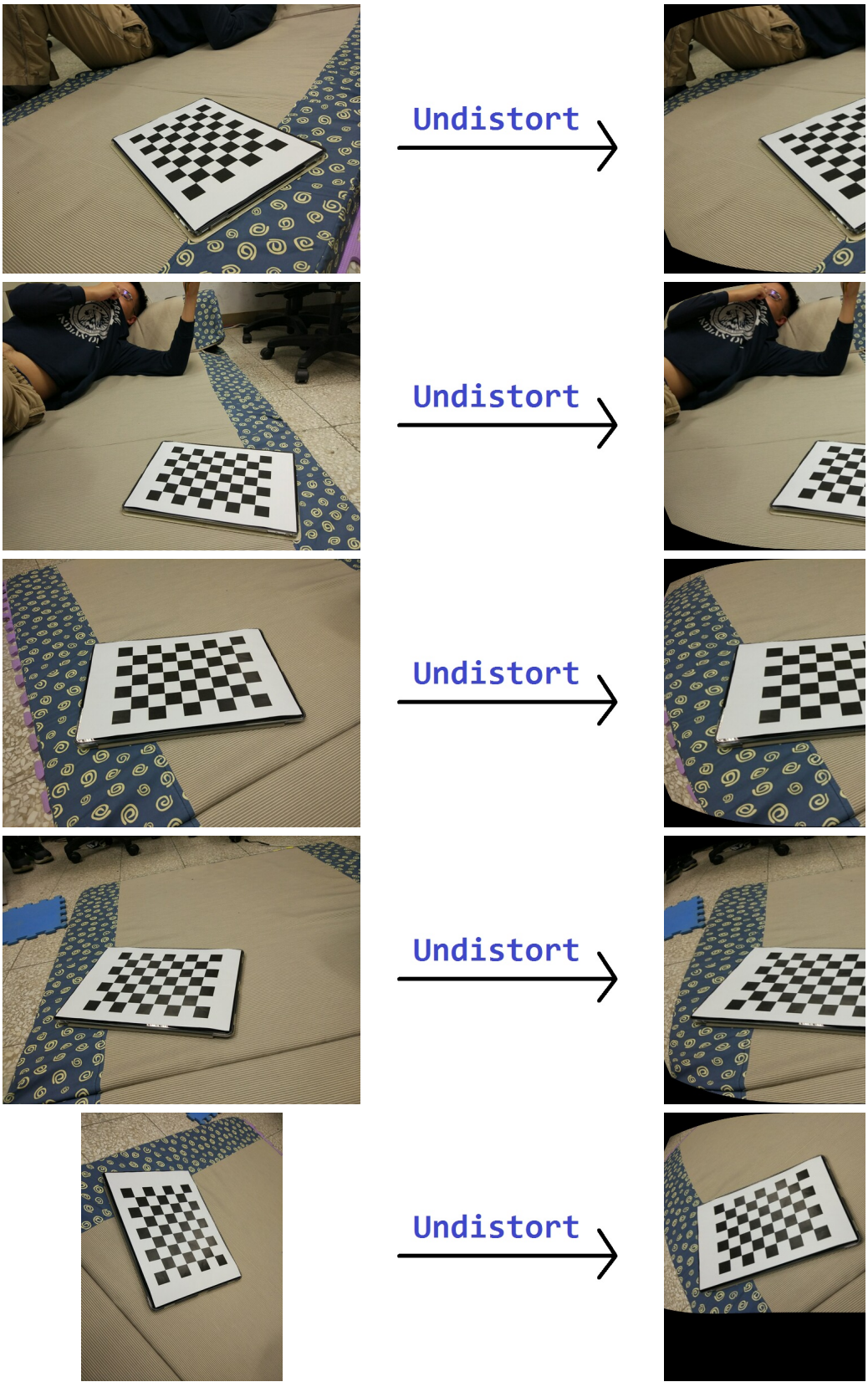
Let $f \cdot s_x = f_x$ and $f \cdot s_y = f_y$, we finally get $x = f_x[\frac{X}{Z}] + c_x \quad y = f_y[\frac{Y}{Z}] + c_y$

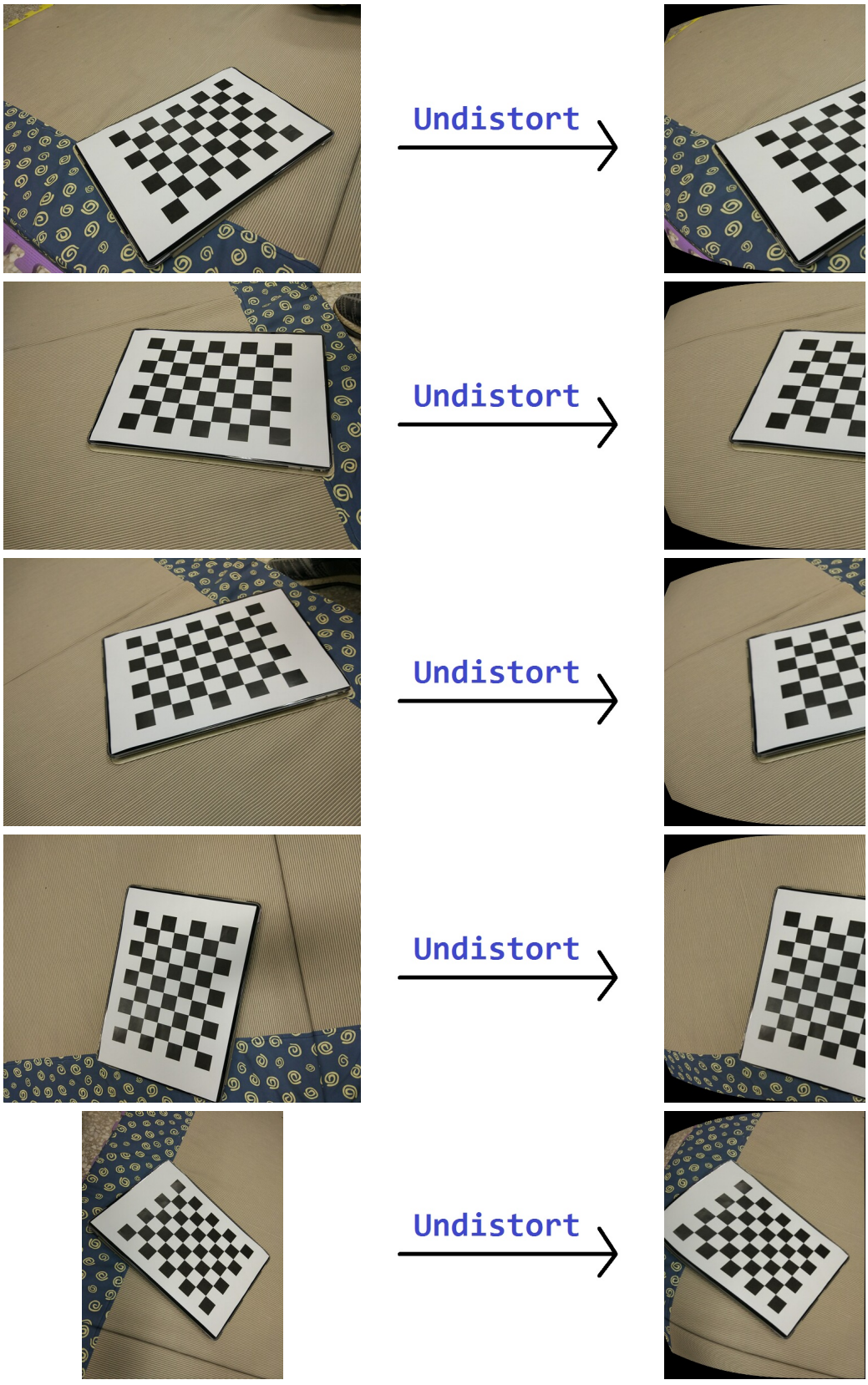
2. **The effect of `cv::undistort`**

   In *pinhole camera model*, the camera aperture is described as a point. Nevertheless, we use lenses to focus light and reduce the exposure time in reality. Lenses can distort images, especially at short focal length.


Undistort
Undistort
Undistort
Undistort
Undistort


Undistort
Undistort
Undistort
Undistort
Undistort


Undistort
Undistort
Undistort
Undistort
Undistort


Undistort
Undistort
Undistort
Undistort
Undistort

For the distortion `OpenCV` takes into account the radial and tangential factors. Radial distortion occurs when light rays bend more near the edges of a lens than they do at its optical center, most visible when taking pictures of vertical structures having straight lines which then appear curved. For the radial factor `OpenCV` uses the following formula
$x_{distorted} = x(1 + k_1 r^2 + k_2 r^4 + k_3 r^6)$ $y_{distorted} = y(1 + k_1 r^2 + k_2 r^4 + k_3 r^6)$
On the other hand, tangential distortion occurs because the image taking lenses are not perfectly parallel to the image plane. It can be represented via the formulas
$x_{distorted} = x + [2p_1 xy + p_2(r^2 + 2x^2)]$ $y_{distorted} = y + [p_1(r^2 + 2y^2) + 2p_2 xy]$
The distortion coefficients are also calculated in `cv::calibrateCamera`, presented as `distCoeffs` $= (k_1\ k_2\ p_1\ p_2\ k_3)$. With `cameraMatrix` and `distCoeffs`, `cv::undistort` is able to transform an image to compensate for lens distortion. In our result, we have $k_1 = 7.5350825654120113e-01$, $k_2 = -6.8824480883938541e+00$, $p_1 = 0$, $p_2 = 0$, $k_3 = 1.6336663151773003e+01$. The undistorted images are obviously concave, trying to fix the radial distortion.

3. **The division of work within our team**

   - r05922008 資工碩一 丁柏文: **Part B** program.
   - r05922084 資工碩一 韓翔宇: **Part A** program.
   - r05922146 資工碩一 葉興宇: Report **Part A (5)**.
   - b03902062 資工三 董文捷: Report **Part A (4)**.

4. **Environment**
   `ubuntu 16.04`, `OpenCV 3.1`

5. **References**

(1) Figures from Camera Models and Imaging
(2) 攝像頭校正 camera calibration - part 1 camera model
(3) 攝像頭校正 camera calibration - part 2 calibration
(4) What Is Camera Calibration?