A Stereo Machine Vision System for measuring three-dimensional crack-tip displacements when it is subjected to elastic-plastic deformation

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1. Aims

The aims of this project is to:

- design and manufacture a Stereo Machine Vision System (SMVS) to measure a crack tip displacement in x, y and z direction simultaneously.

- Keep a low cost in manufacturing SMVS while maintain the accuracy within a acceptable margins.

2. Background

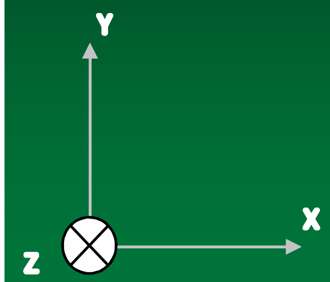
- To study complex behaviour of mixed-modes I,II and III a pair of grips have specially been designed. Using a universal Instron machine and these grips a cracked specimen would go under simultaneous in and out-of-plane (mixed-mode I,II and III) displacement.

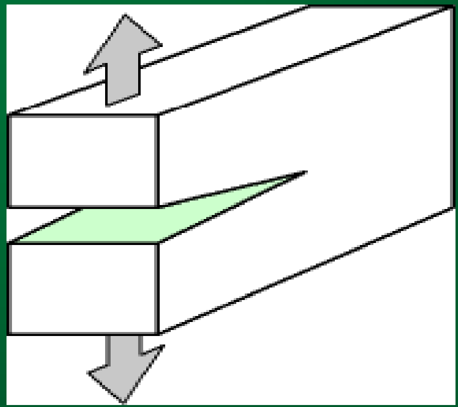
- Mechanical displacement measurement sensors such as clip gauge is used to measure the y-displacement and two Linear Variable Displacement Transducers (LVDT) are used to measure the displacement in x and z direction.

2. Background

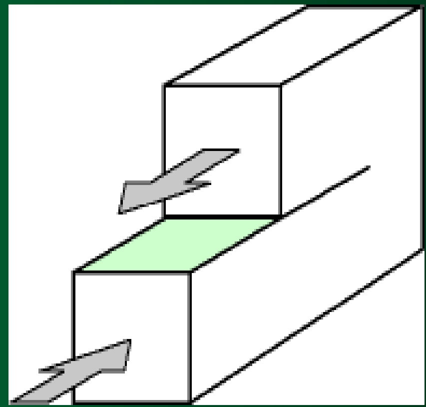
- Because of the compound geometry of the grips not all of the mechanical sensors are able to physically fit around the crack tip to measure the displacement.

- This is where the importance of a non-contactable measurement device such as SMVS become evident.

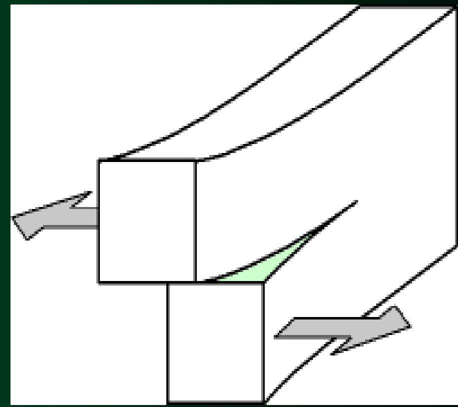




Mode I
(Tension, Opening)

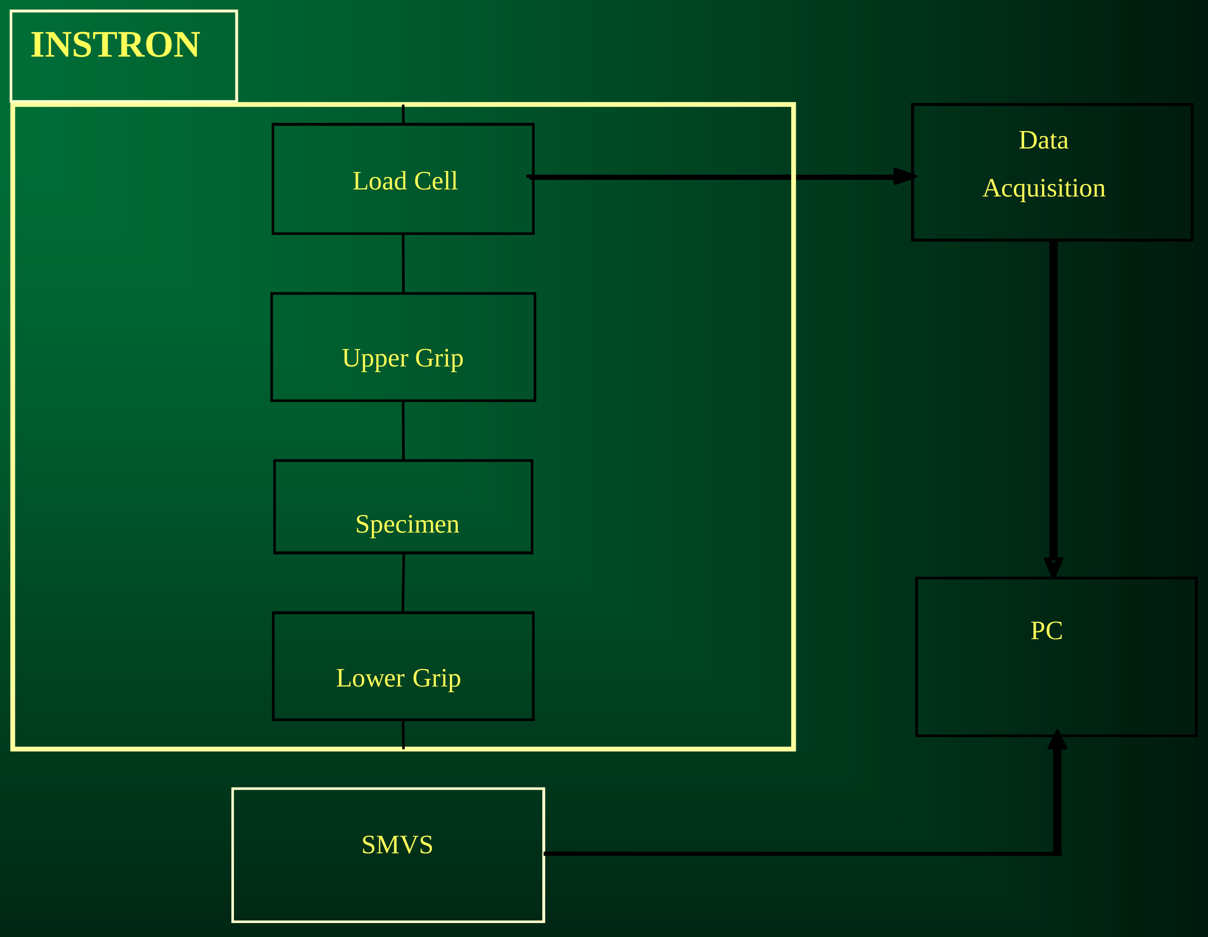


Mode II
(In-plane shear, Sliding)

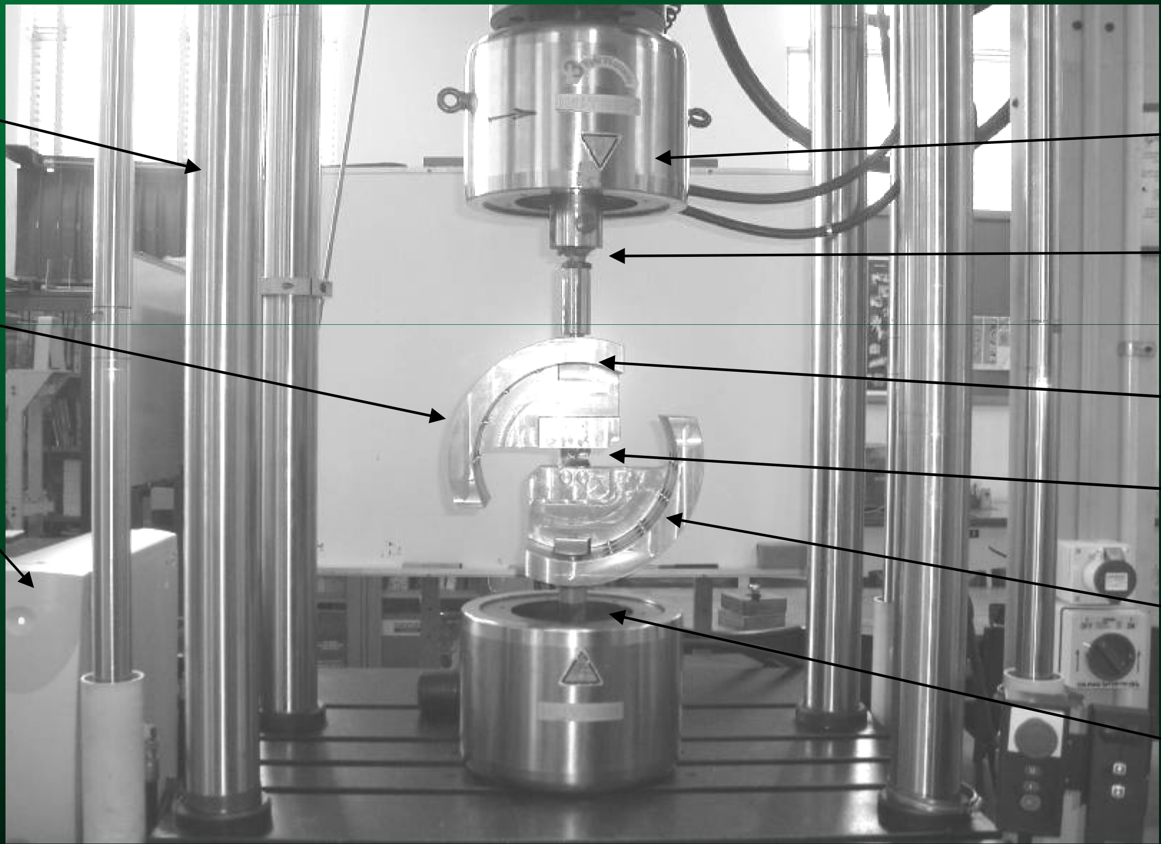


Mode III
(Out-of-plane shear, Tearing)

3. System Set Up - Hardware



3. System Set Up - Hardware



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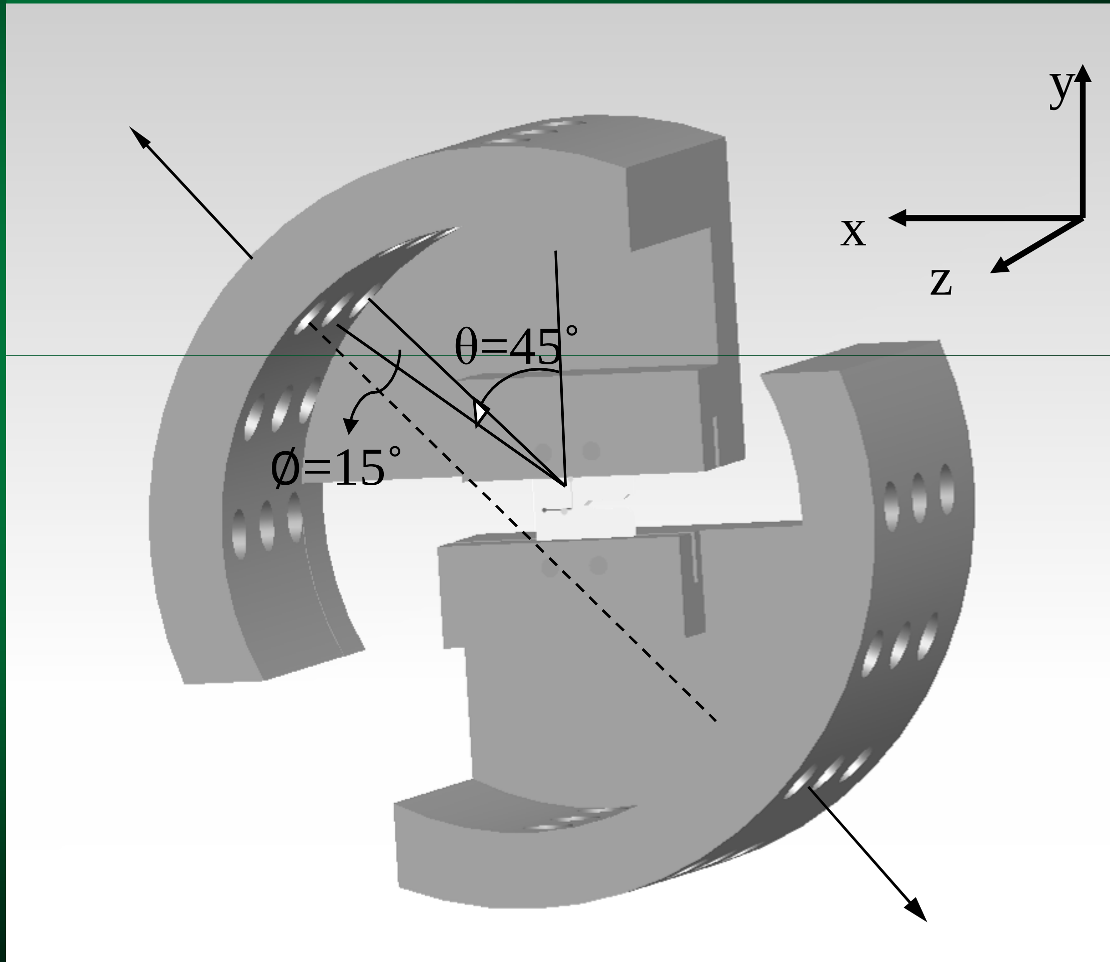

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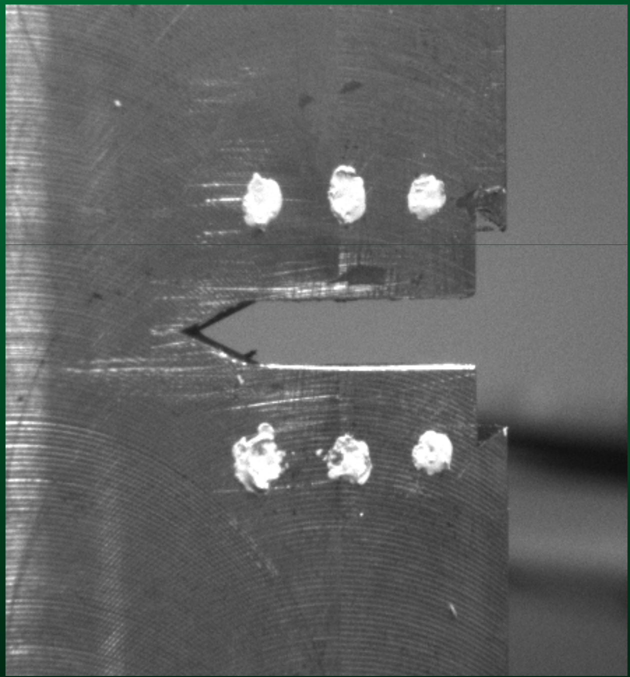

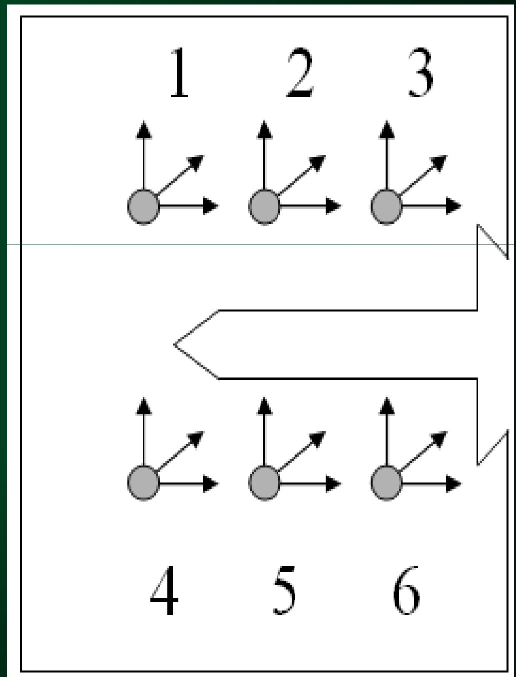

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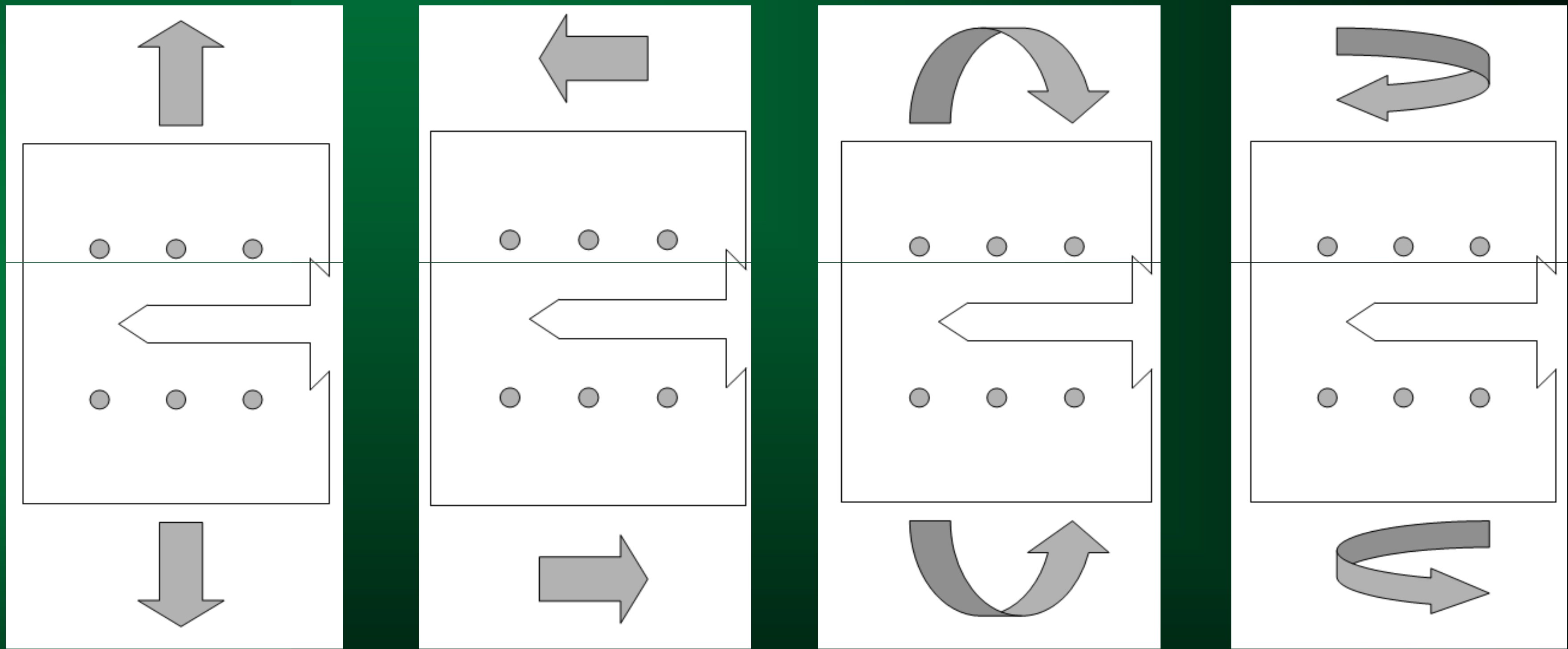

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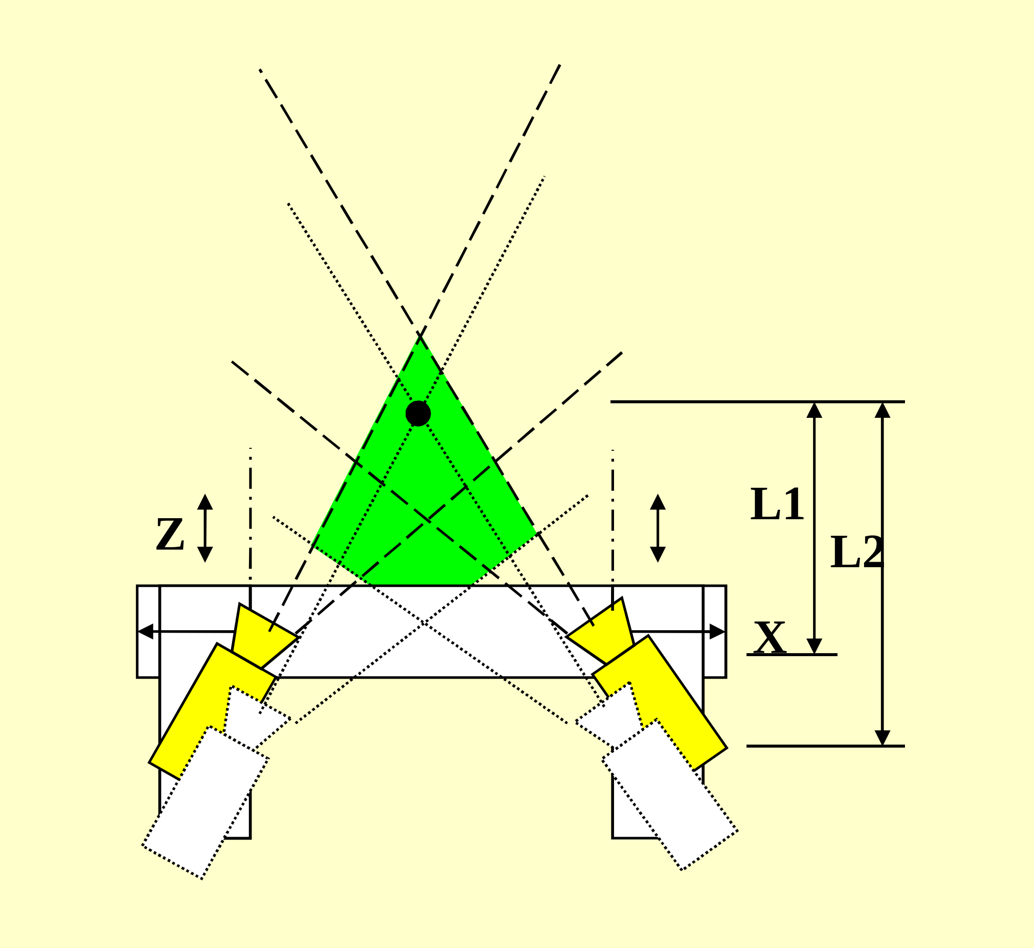

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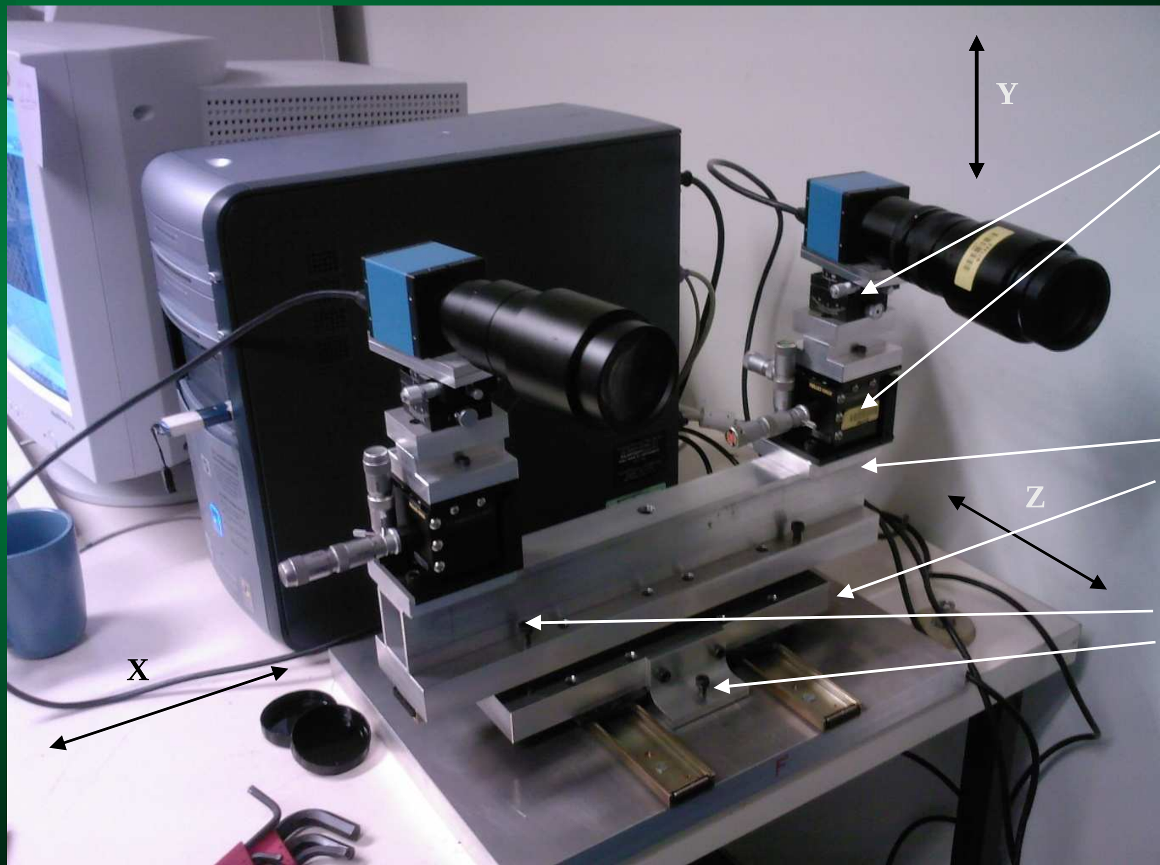


Micro Positioners

Macro Positioners

Locking Cap Screws

3. System Set Up - Hardware

- The machine vision consists of:

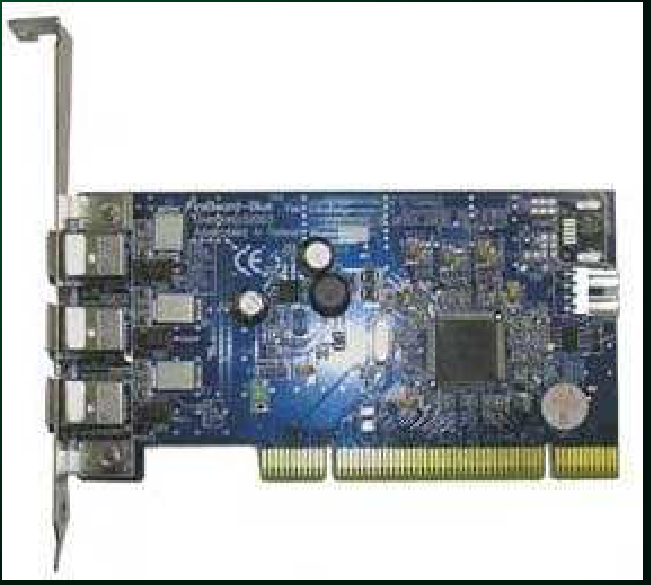
1-Firewire Cameras:

Two DMK 21AF04 firewire cameras

3. System Set Up - Hardware

2-Image Processing Card:

Fireboard-Blue™ 1394a PCI adapter



3. System Set Up - Hardware

3-Micropositioner:

Mellet Geriot 5 axis manual.

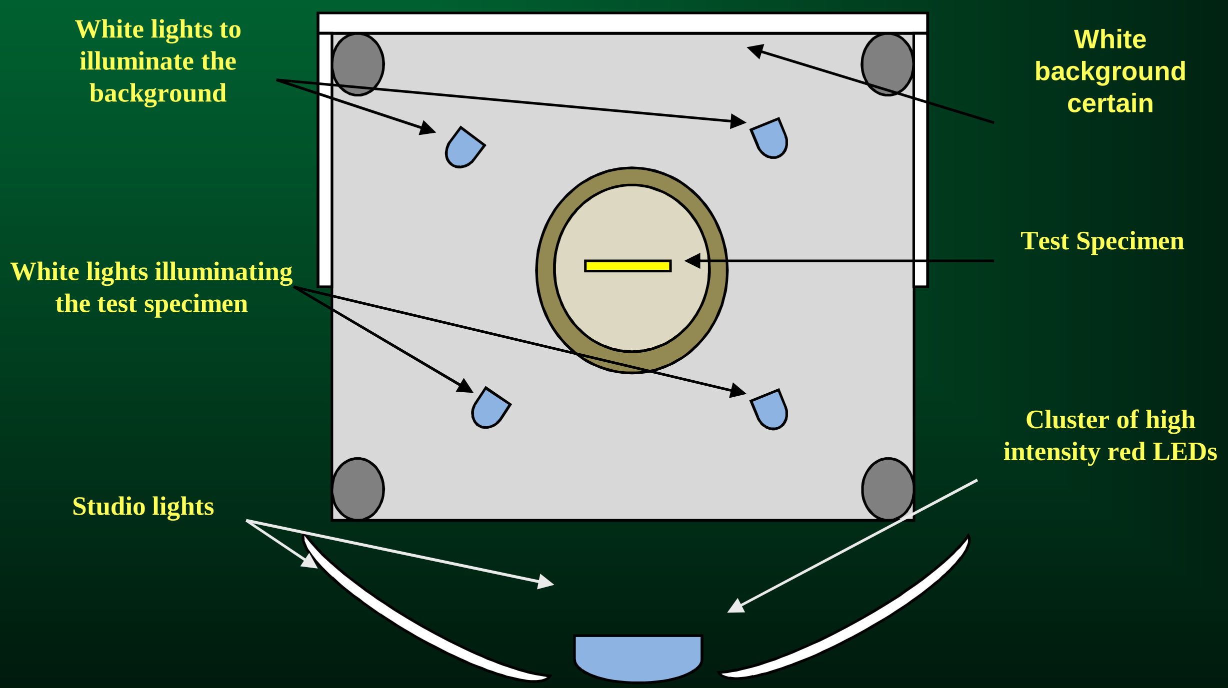
4-Macroptioner:

Lateral and Transversal linear bearings

5- Navitar Zoom Lenses :

The Zoom 7000 offers a 6:1 zoom ratio

3. System Set Up - Hardware



4. Calibration

Camera calibration is the process of identifying the camera’s optical parameters and its position and orientation with respect to a pattern frame.

- Intrinsic parameters: focal length, pixel spacing and distortion of lens.
- Extrinsic parameters: incorporate rotation of cameras, distance between cameras and angle of the cameras.

4. Calibration

- 1. Calculating the homograms for all points in a series of images. A homogram is a matrix of perspective transformation between the checkerboard (i.e., our calibration pattern plane in SMVS) and the camera view plane.
- 2. Initializing the intrinsic (including distortion) parameters to zero.
- 3. Finding extrinsic parameters for each image of the pattern.
- 4. Optimizing by minimizing error of projection points with all parameters.

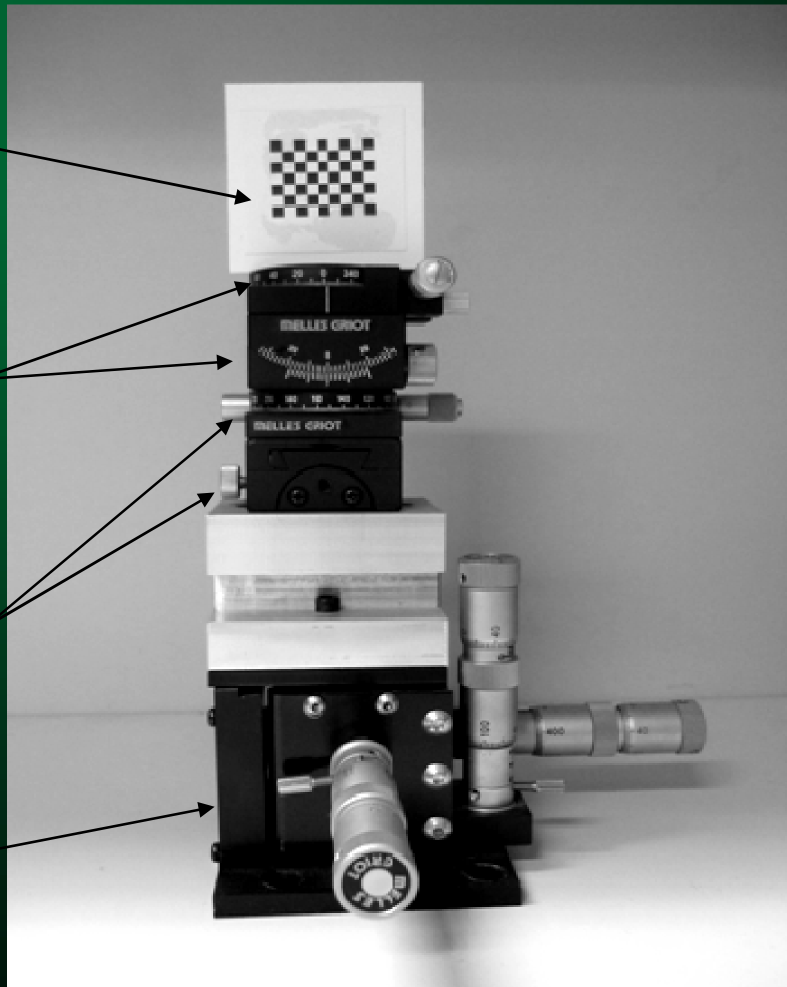
4. Calibration

Checkerboard
pattern

Rotation and
Goniometers (tilt)
unis

Second rotation
and tilt unit

Translation (x,y,z)
unit

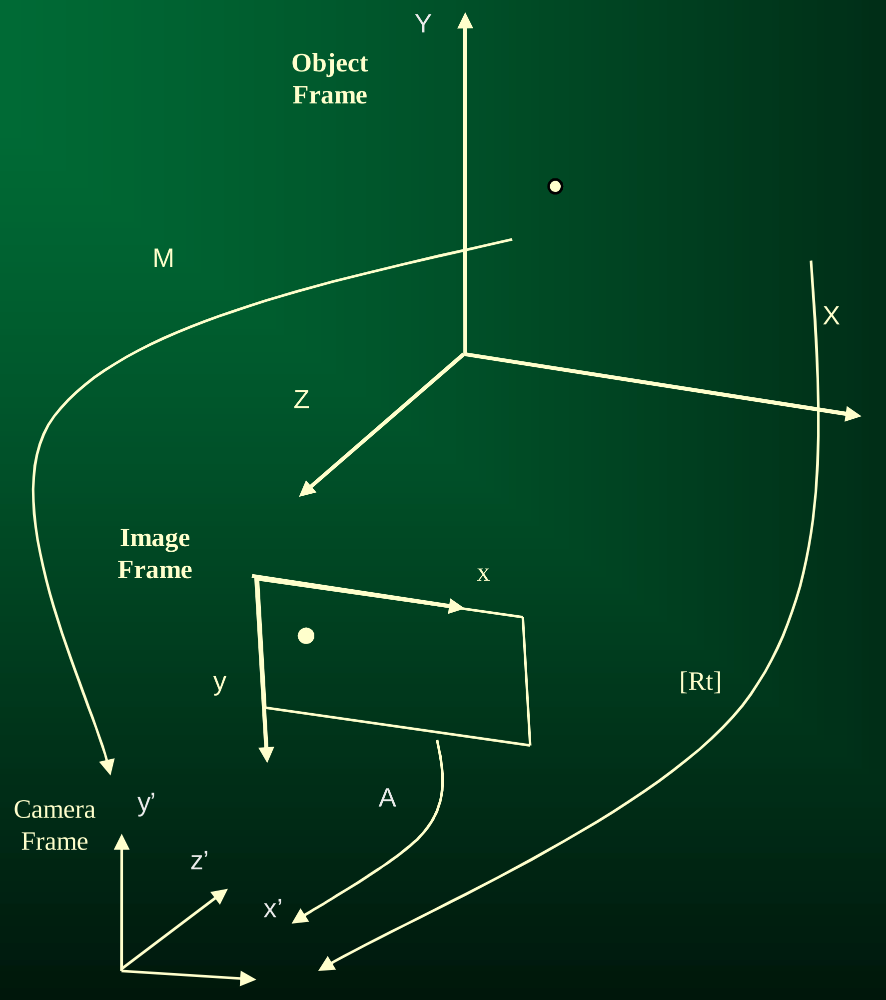


4. Calibration

- Assuming a pinhole camera is used, a 3-D point on specimen surface which is defined as $\{M\} = [X, Y, Z]^T$
- , corresponds to a point on the projected image defined as $\{m\} = [x, y]^T$. During the estimation process, 16 frames from randomly selected angles are captured. The homogram relation between {m} and {M}

$$\{m\} = [A][R]\{t\}\{M\}$$

4. Calibration



4. Calibration

$$[R]=\begin{bmatrix} r_{11} & r_{12} & r_{13} \\ r_{21} & r_{22} & r_{23} \\ r_{31} & r_{32} & r_{33} \end{bmatrix}, \{t\}=\begin{bmatrix} t_1 \\ t_2 \\ t_3 \end{bmatrix}$$

$$[A]=\begin{bmatrix} f_L & \gamma & c_x \\ 0 & f_R & c_y \\ 0 & 0 & 1 \end{bmatrix}$$

4. Calibration

- Looking at the homography between the model plane {M} and its image we can assume that the model plane is on $Z = 0$ of the world coordinate system.
- Assuming $Z = 0$ sets the world coordinate system for that particular frame on the model plane. Orientation of the coordinate system changes with the angle which the model plane is set to for that shot.

4. Calibration

If i^{th} column of a rotation matrix [R] is denoted as r_i then,

$$\begin{bmatrix} x \\ y \\ 1 \end{bmatrix} = [A][r_1 \quad r_2 \quad r_3 \quad t]\begin{bmatrix} X \\ Y \\ 0 \\ 1 \end{bmatrix} = [A][r_1 \quad r_2 \quad t]\begin{bmatrix} X \\ Y \\ 1 \end{bmatrix}$$

Therefore a model plane {M} and its image {m} is related by homography [H]:

$$\{\tilde{m}\} = H\{\tilde{M}\}$$

Which [H] is:

$$\begin{bmatrix} h_1 & h_2 & h_3 \end{bmatrix} = \lambda A \begin{bmatrix} r_1 & r_2 & t \end{bmatrix}$$

4. Calibration

Where λ is an arbitrary scalar. Knowing r_1 and r_2 are orthonormal (orthogonal vectors with magnitude of 1, then we have,

$$h_1^T A^{-T} A^{-1} h_2 = 0$$

$$h_1^T A^{-T} A^{-1} h_1 = h_2^T A^{-T} A^{-1} h_2$$

$[A]^{-1}[A]^{-T} = [B]$ is called the "absolute conic".

$$[B] = [A]^{-T}[A]^{-1} = \begin{bmatrix} B_{11} & B_{12} & B_{13} \\ B_{21} & B_{22} & B_{32} \\ B_{31} & B_{32} & B_{33} \end{bmatrix}$$

4. Calibration

$$
= \begin{bmatrix}
\dfrac{1}{f_L^2} & -\dfrac{\gamma}{f_L^2 f_R} & \dfrac{c_x\gamma - c_y f_R}{f_L^2 f_R} \\
-\dfrac{\gamma}{f_L^2 f_R} & \dfrac{\gamma^2}{f_L^2 f_R^2} + \dfrac{1}{f_R^2} & -\dfrac{(c_x\gamma - c_y f_R)}{f_L^2 f_R^2} - \dfrac{c_y}{f_R^2} \\
\dfrac{c_x\gamma - c_y f_R}{f_L^2 f_R} & -\dfrac{(c_x\gamma - c_y f_R)}{f_L^2 f_R^2} - \dfrac{c_x}{f_R^2} & -\dfrac{(c_x\gamma - c_y f_R)^2}{f_L^2 f_R^2} + \dfrac{c_x}{f_R^2} + 1
\end{bmatrix}
$$

4. Calibration

$$c_x = \frac{(B_{12}B_{13} - B_{11}B_{23})}{(B_{11}B_{22} - B_{12}^2)}$$

$$\lambda = \frac{B_{33} - [B_{13}^2 + c_x(B_{12}B_{13} - B_{11}B_{23})]}{B_{11}}$$

$$f_L = \sqrt{\frac{\lambda}{B_{11}}}$$

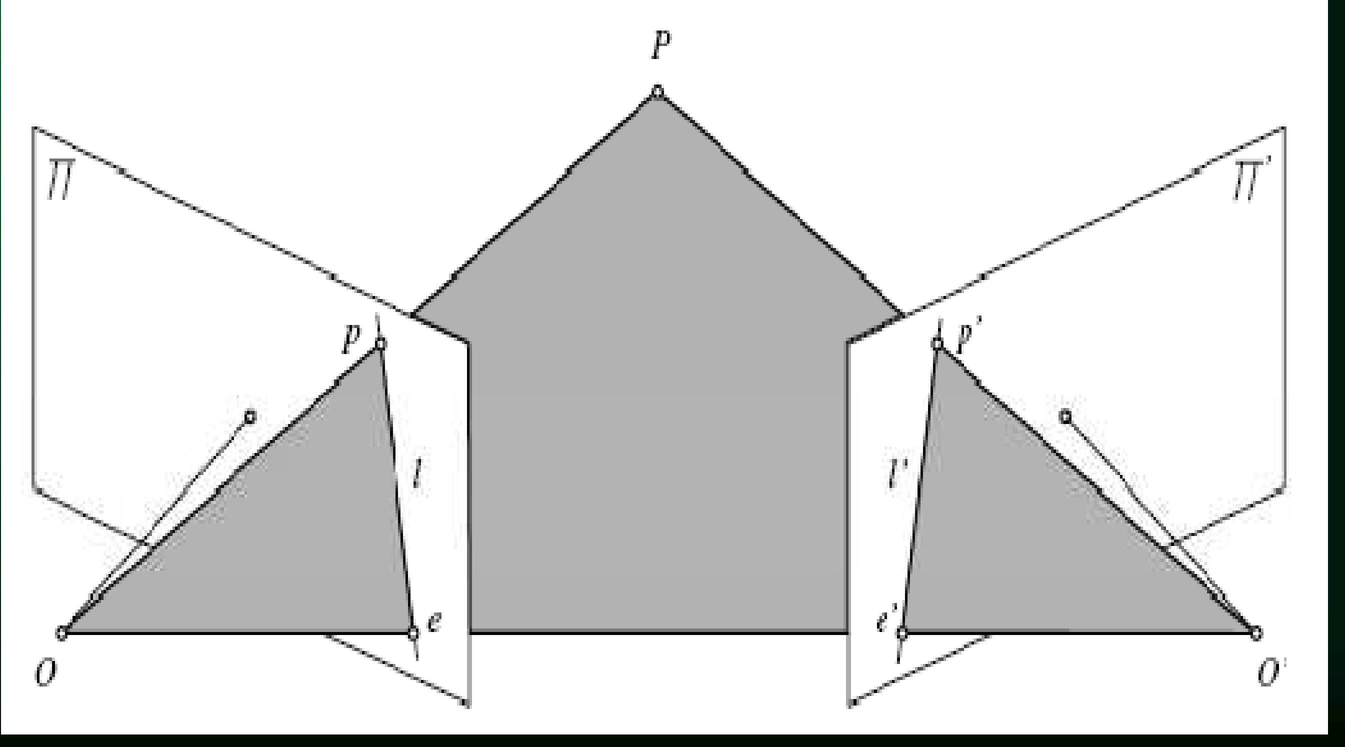
$$f_R = \sqrt{\frac{\lambda B_{11}}{(B_{11}B_{22} - B_{12}^2)}}$$

$$\gamma = \frac{-B_{12} f_L^2 f_R}{\lambda}$$

$$c_y = \frac{\gamma c_x}{f_L} - \frac{B_{13} f_L^2}{\lambda}$$

4. Calibration

- Epipolar geometry: the point P, the optical centres O and O’ of the two
  cameras, and the two images p and p’ of P all lie in the same plane.



$$\begin{pmatrix} X \\ Y \\ Z \end{pmatrix} = \begin{pmatrix} x \\ y \end{pmatrix} \begin{bmatrix} \text{Intrinsic \&} \\ \text{extrinsic} \\ \text{parameters} \end{bmatrix}$$

4. Calibration

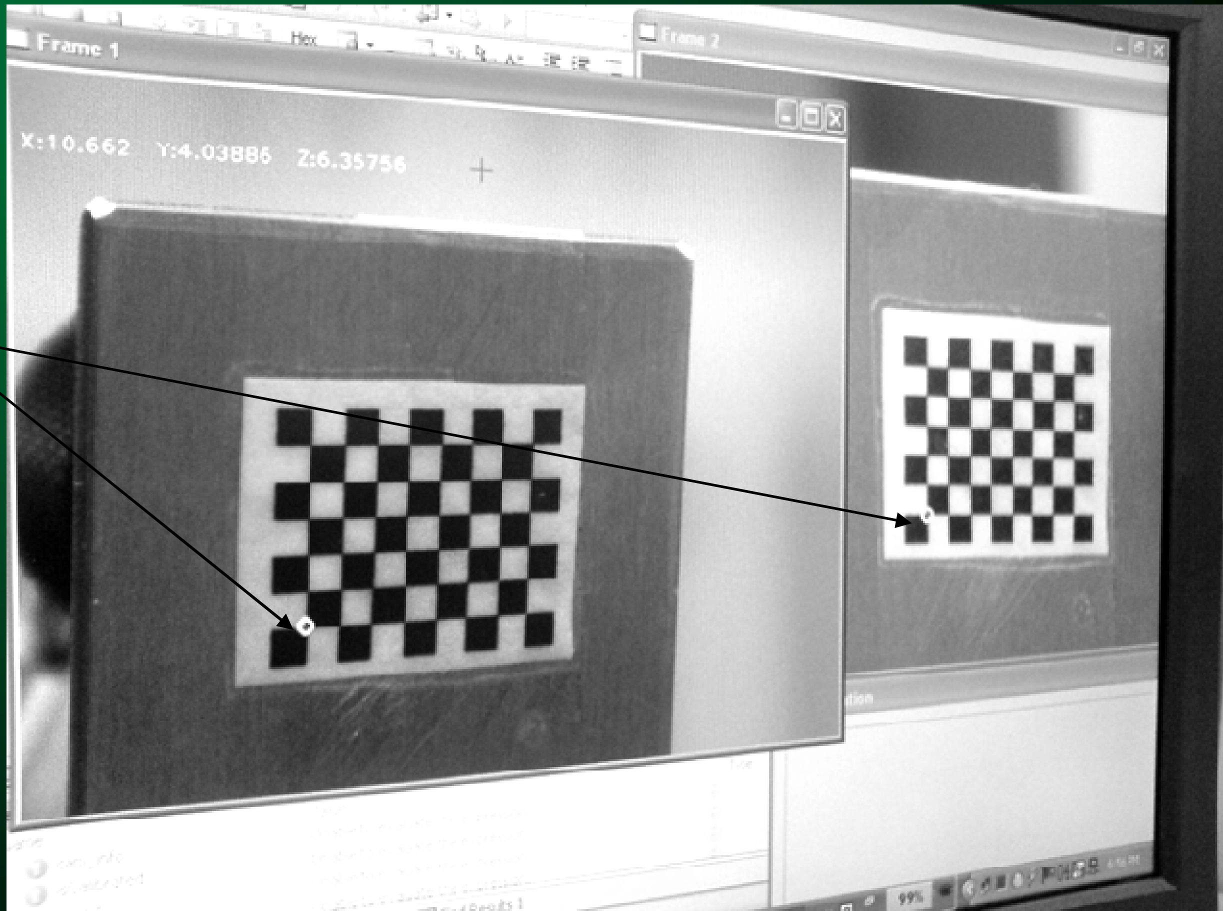
- Epipolar geometry depends uniquely on the parameters and geometry of the two cameras and not on the geometry of the scene.
- A matrix called the "fundamental matrix", [F], exists, which is the algebraic representation of the epipolar geometry and which therefore relates an epipolar line to the point it has generated

$$\{m^T\}[F]\{M\} = 0$$

$$\begin{pmatrix} X \\ Y \\ Z \end{pmatrix} = \begin{pmatrix} x \\ y \end{pmatrix} \begin{bmatrix} \text{Intrinsic \&} \\ \text{extrinsic} \\ \text{parameters} \end{bmatrix}$$

4. Calibration

A pair of corresponding points



4. Calibration

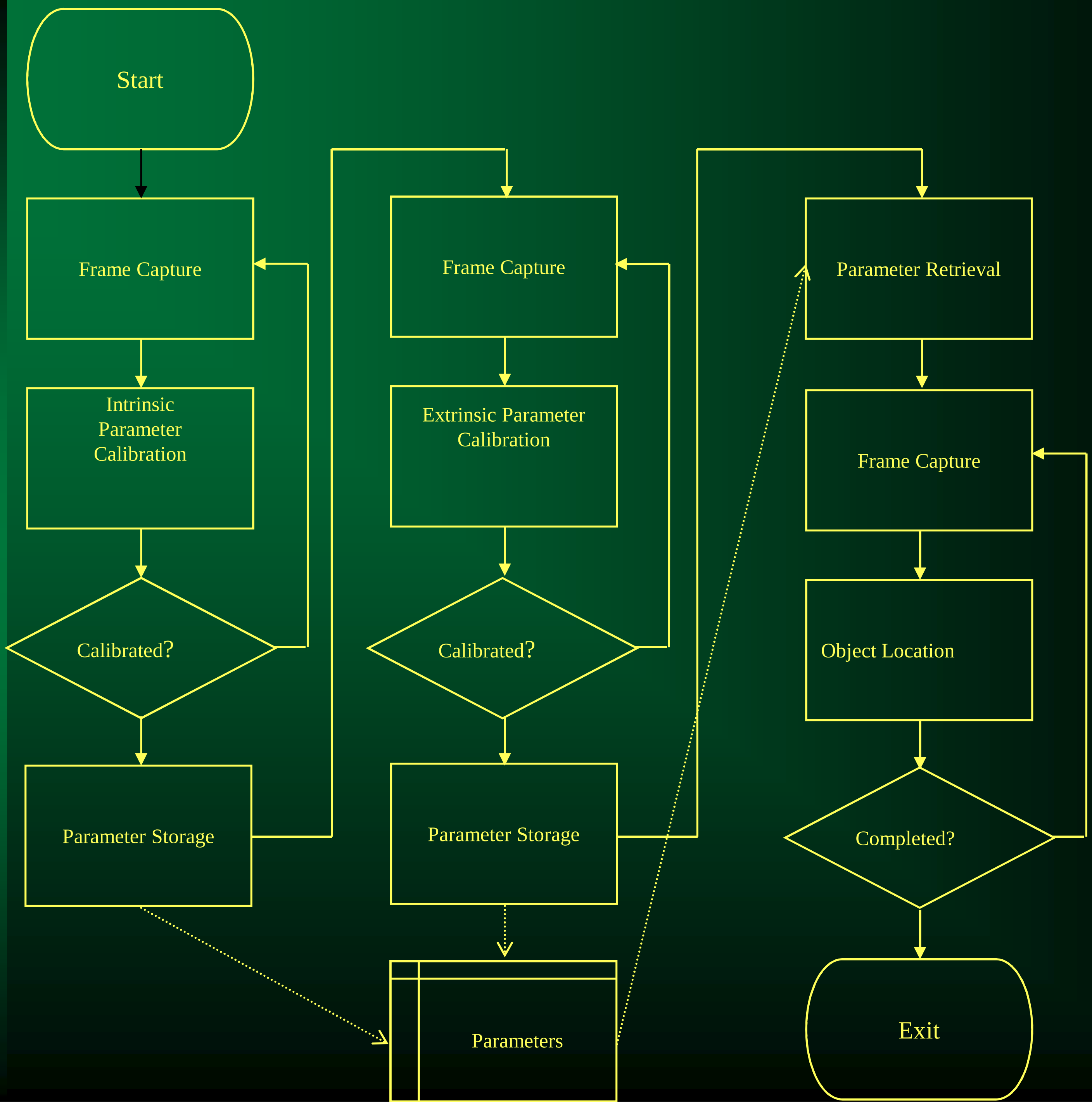
- Once we had a corresponding object pair, we could compute the depth (z value) of the detected object. To do that, we could use the following simple formulas

$$z_{object} = \frac{(B \cdot f)}{(d \cdot PS)}, d = x_L - x_R$$

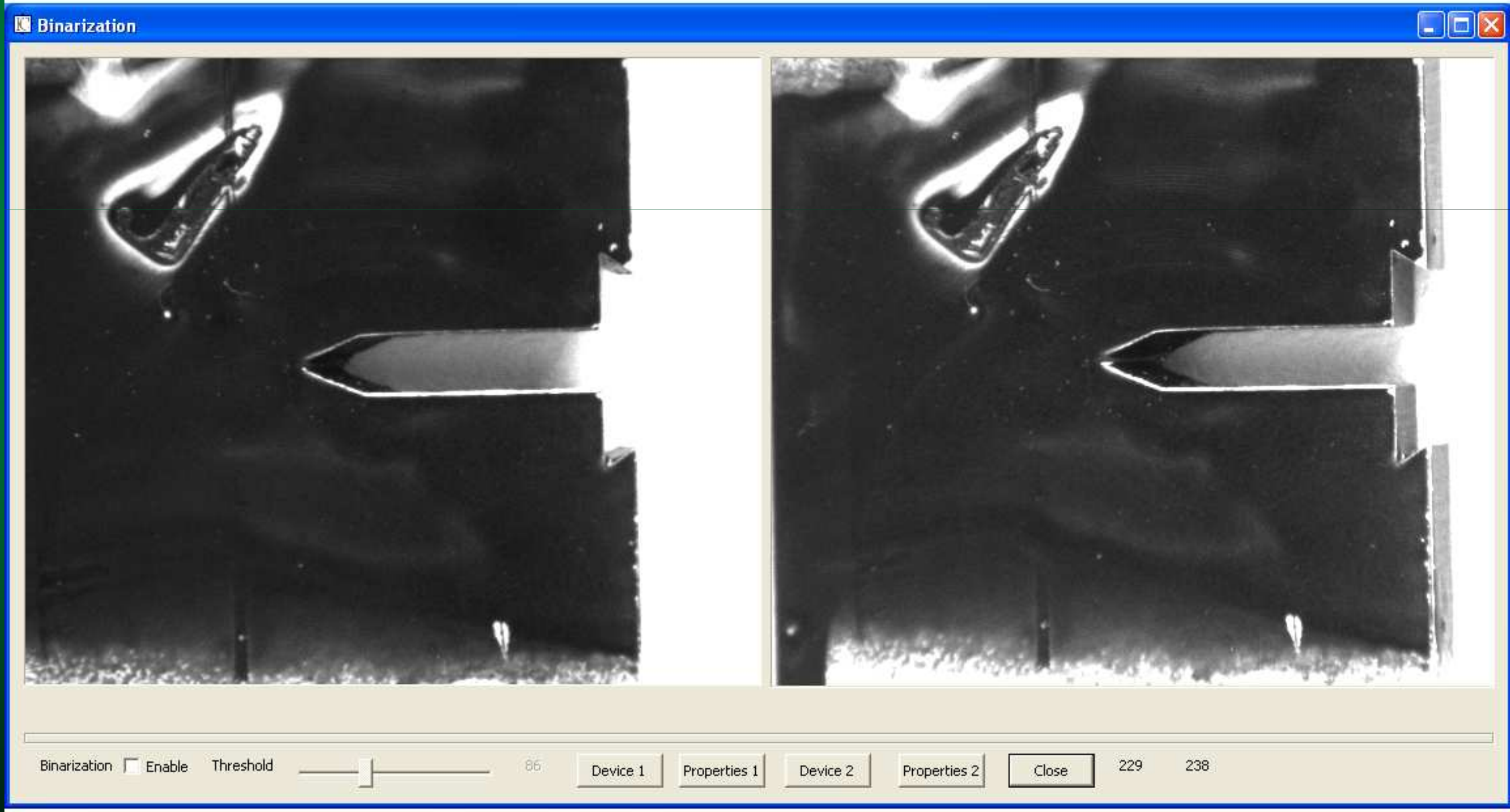
$$x_{object} = \frac{x_{image} \cdot PS \cdot z_{object}}{f} - (B/2)$$

$$y_{object} = \frac{y_{image} \cdot PS \cdot z_{object}}{f}$$

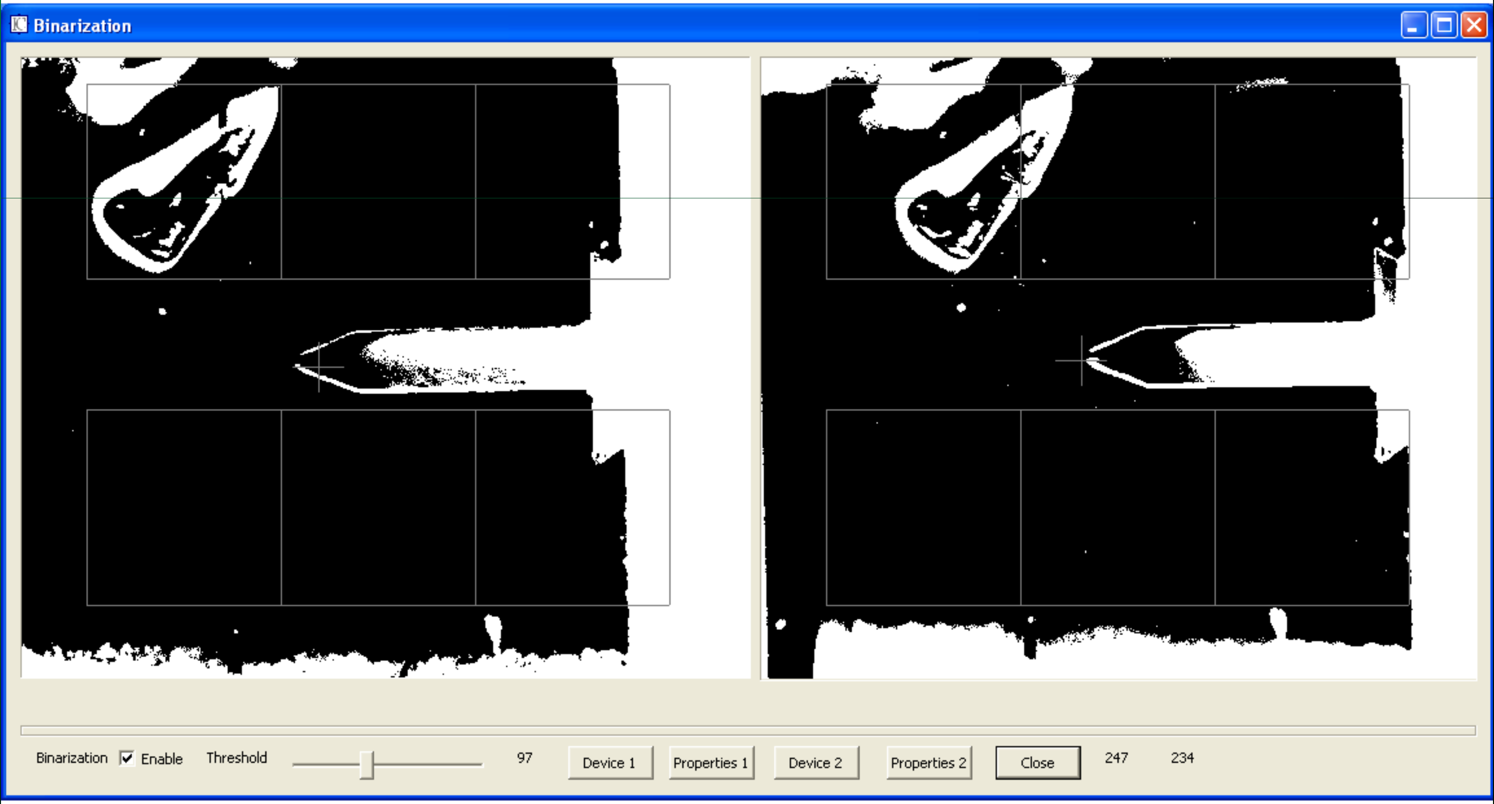
where d is the disparity (difference between x-values in image plane), B the baseline (distance between cameras) and f is the focal length. PS is the size of one pixel


Start
Frame Capture
Intrinsic Parameter Calibration
Calibrated?
Parameter Storage
Frame Capture
Extrinsic Parameter Calibration
Calibrated?
Parameter Storage
Parameters
Parameter Retrieval
Frame Capture
Object Location
Completed?
Exit

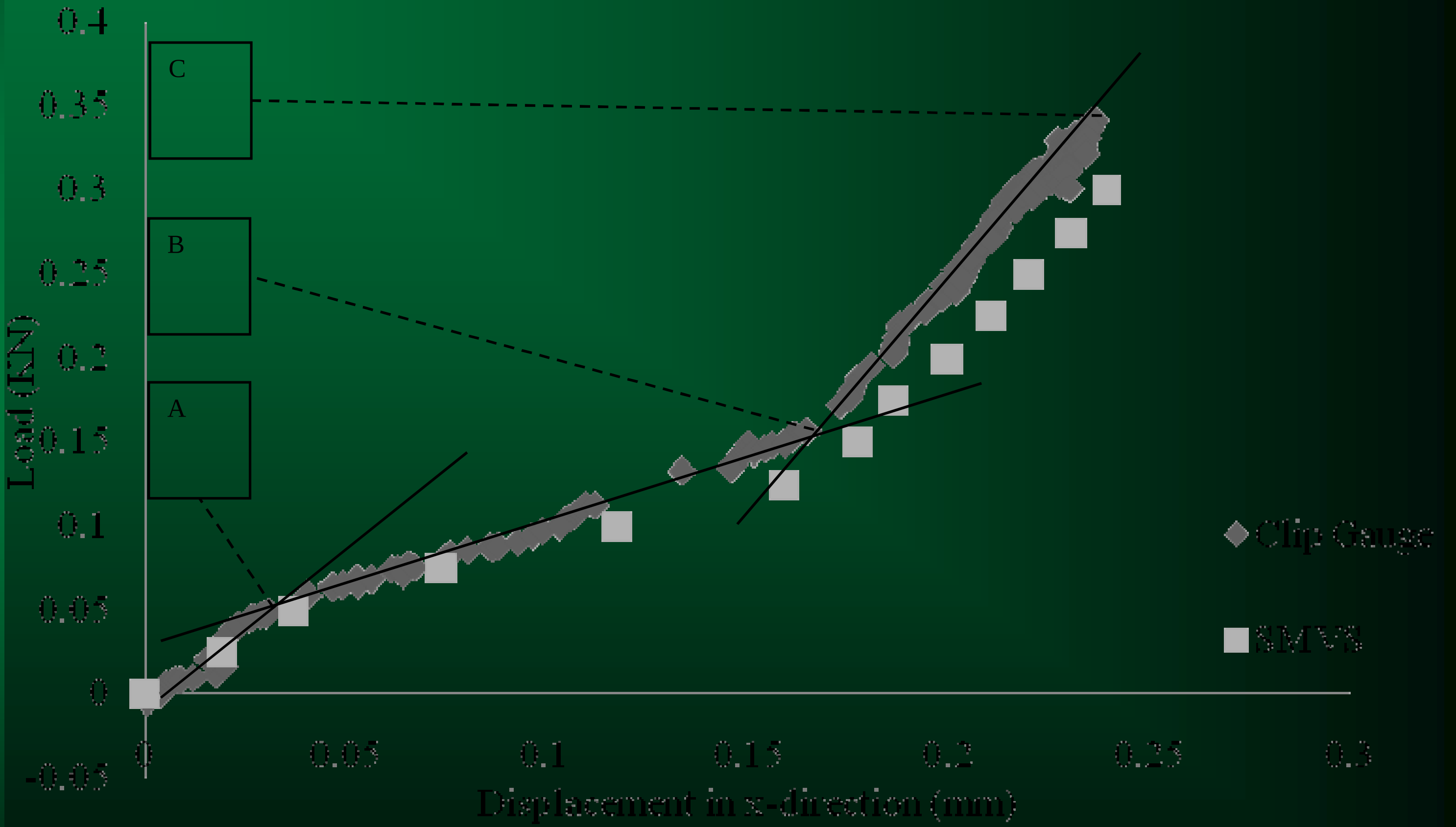
4. System Set Up - Software



4. System Set Up - Software

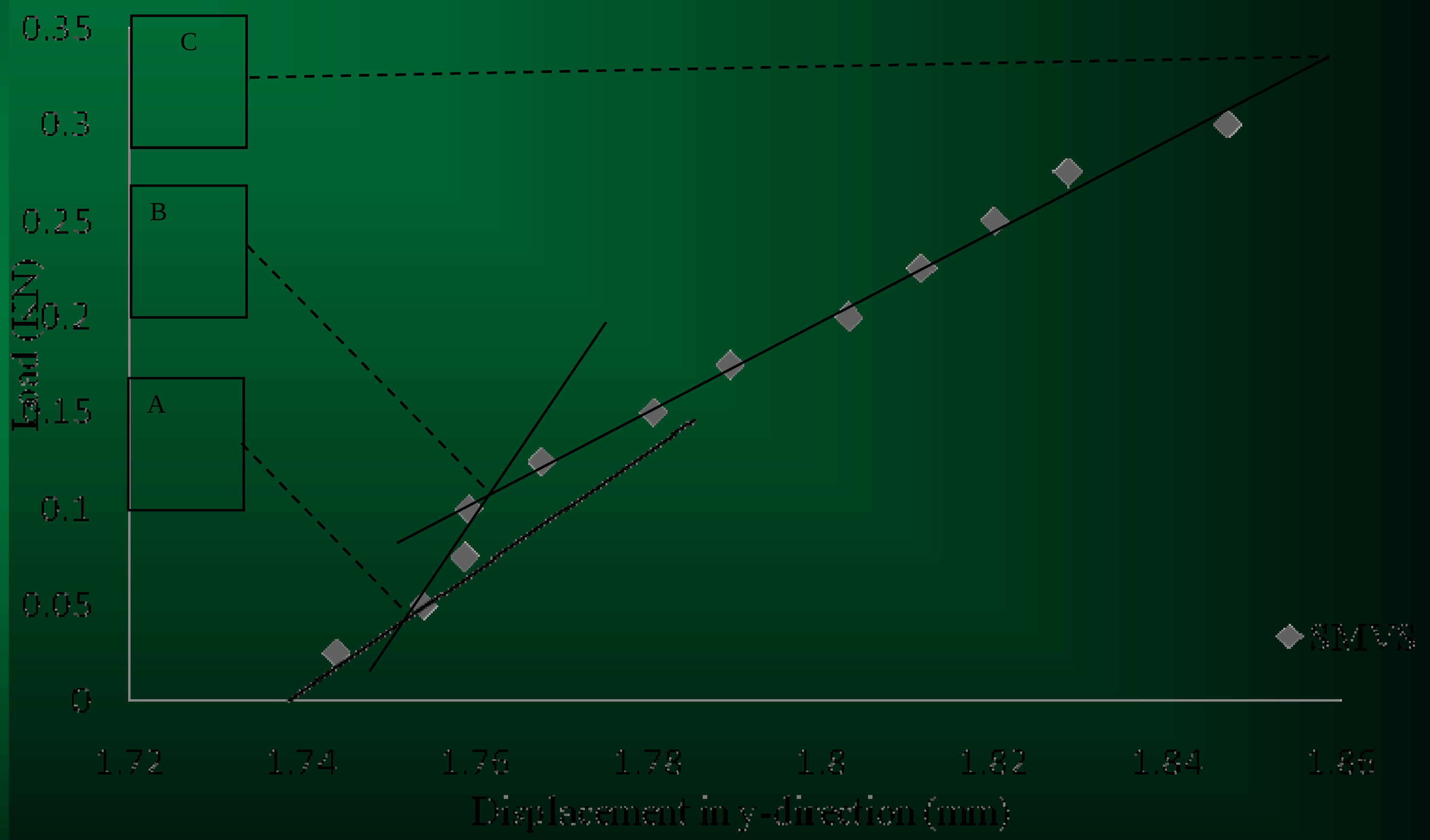


5. Results



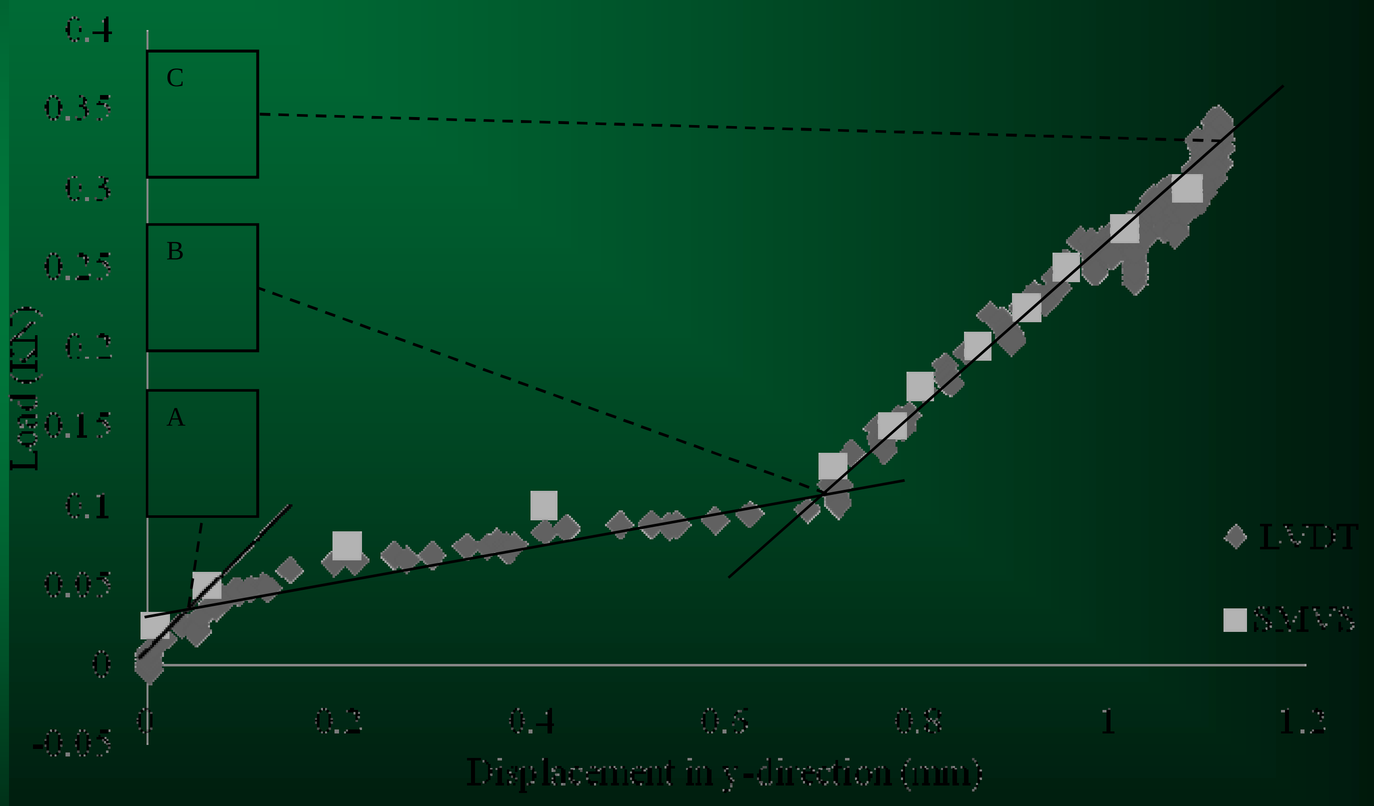
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
-0.05
Load (KN)
C
B
A
0
0.05
0.1
0.15
0.2
0.25
0.3
Displacement in x-direction (mm)
Clip Gauge
SMVS

5. Results



0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
Load (KN)
C
B
A
1.72
1.74
1.76
1.78
1.8
1.82
1.84
1.86
Displacement in y-direction (mm)
SMVS

5. Results



C
B
A
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
-0.05
Load (KN)
0
0.2
0.4
0.6
0.8
1
1.2
Displacement in y-direction (mm)
LVDT
SMVS

Thank you

Questions?