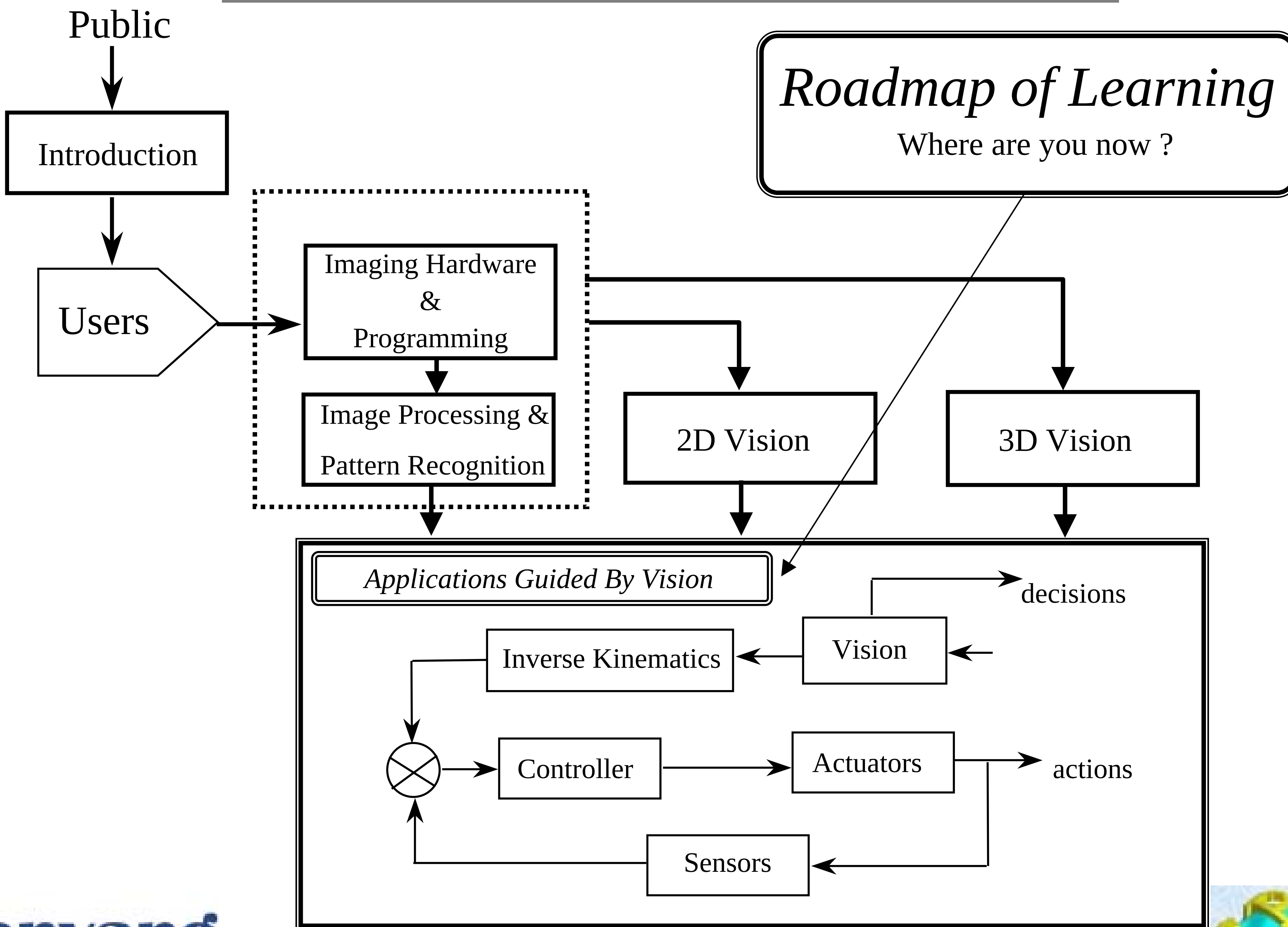

Roadmap of Learning
Where are you now ?
Public
Introduction
Users
Imaging Hardware & Programming
Image Processing & Pattern Recognition
2D Vision
3D Vision
Applications Guided By Vision
decisions
Vision
Inverse Kinematics
Controller
Actuators
actions
Sensors

CONTENT

Chapter 9: Machine Vision Applications

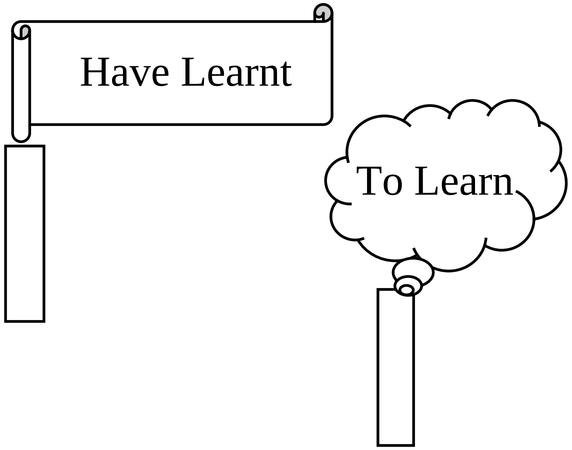
9.1 Visual Inspection

9.2 Visual Guidance of Robot Manipulator

9.3 Visual Guidance of Robotic Head

9.4 Visual Guidance of Vehicle

9.5 3D Model Acquisition



What can be done with a machine vision system ? (A Review)

ANSWER:

Visual Guidance:

To obtain a geometric (full or partial) description of a scene necessary to the safe planning and control of the movement of machine (eg, robot).

Visual Inspection:

To obtain photometric and/or geometric measurement of goods or parts or machined outputs (like printing) for the sake of ensuring the highest quality if possible.

Visual Measurement:

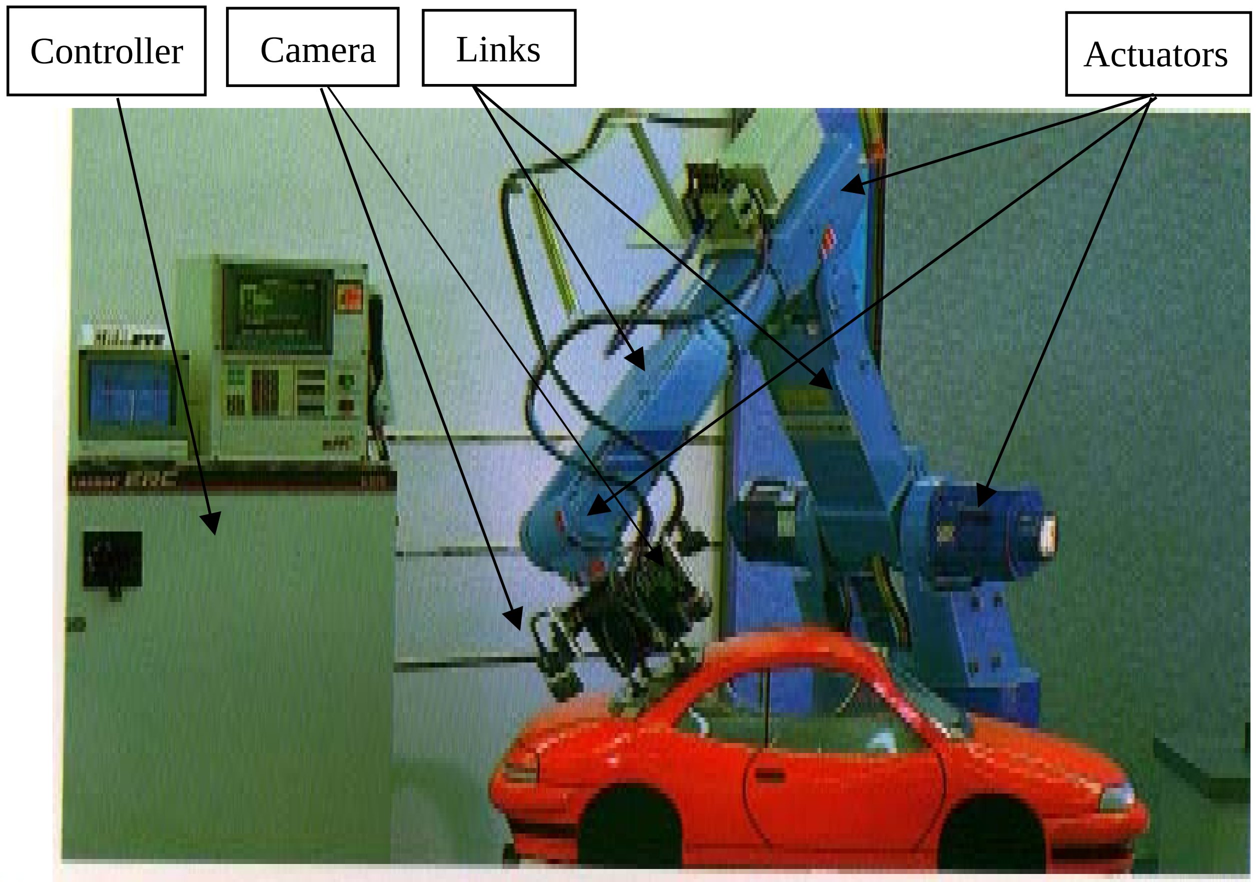
To obtain photometric and/or geometric measurement of machined outputs for different purposes (inspection, surveillance, etc)

Visual Identification:

To obtain metric features from images for the sake of identifying the belonging of objects under the viewing.

Visual Guidance of Robot Manipulator

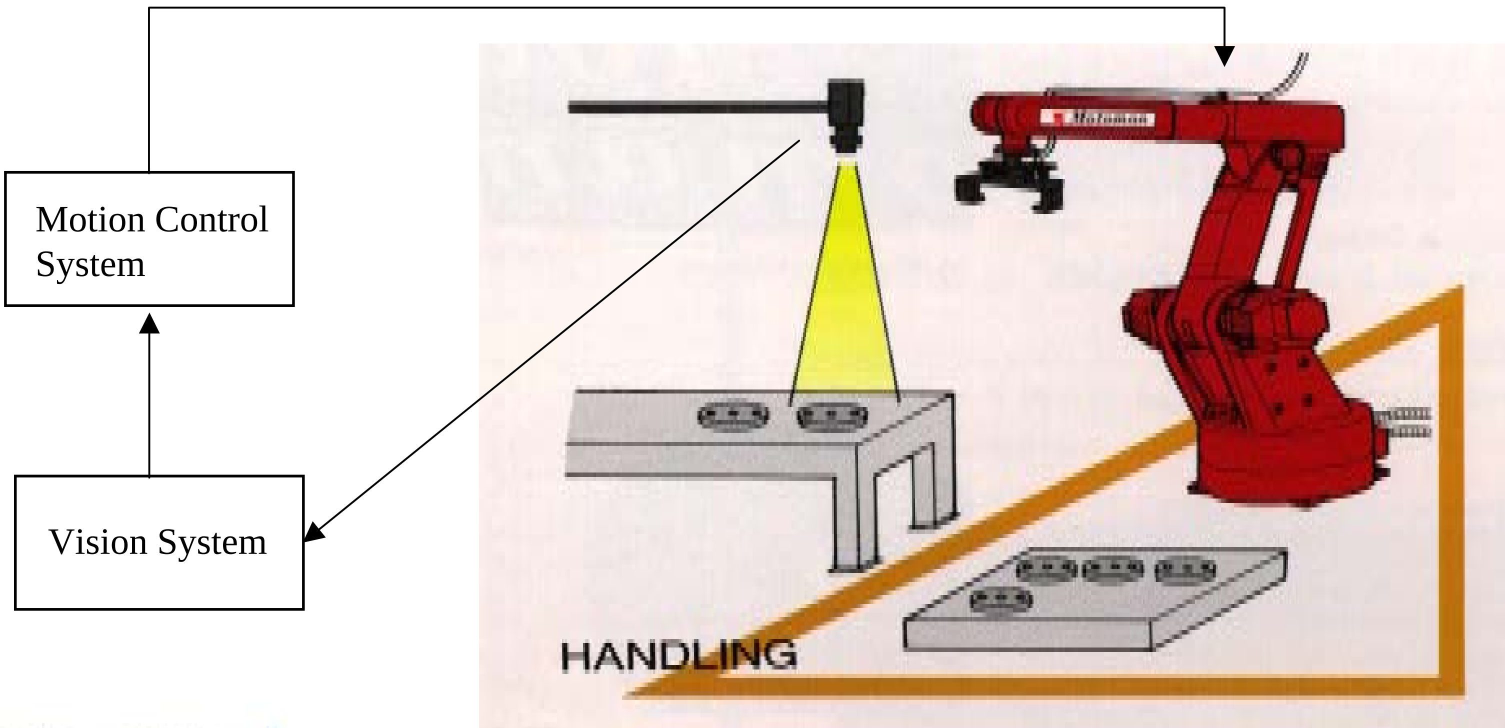
1. Illustration:



Visual Guidance of Robot Manipulator

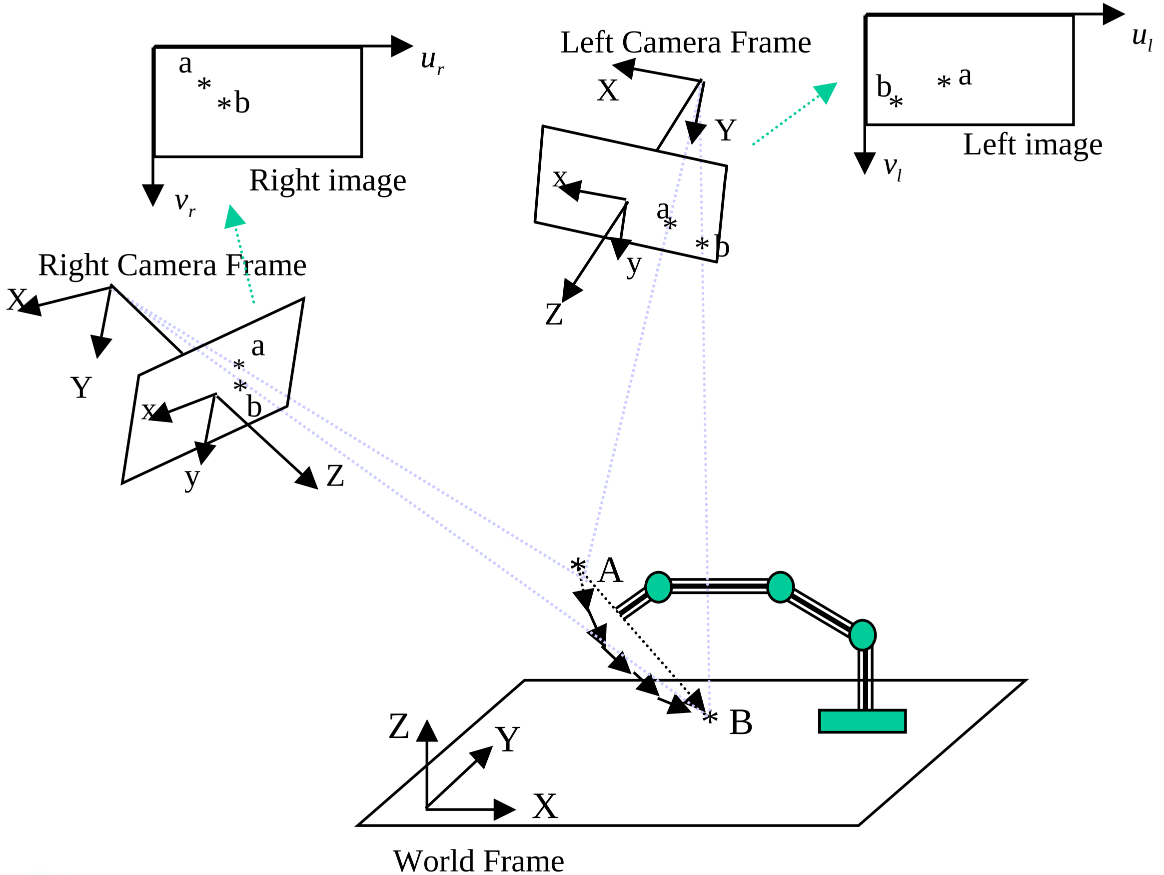
2. Problem Statement:

How to use images to guide the arm/hand's motion
from an initial position A to a destination position B ?



Visual Guidance of Robot Manipulator

3. Problem Analysis:



Visual Guidance of Robot Manipulator

3. Problem Analysis:

Step 1: Assume that we use two cameras.

Step 2: We define a world coordinate system.

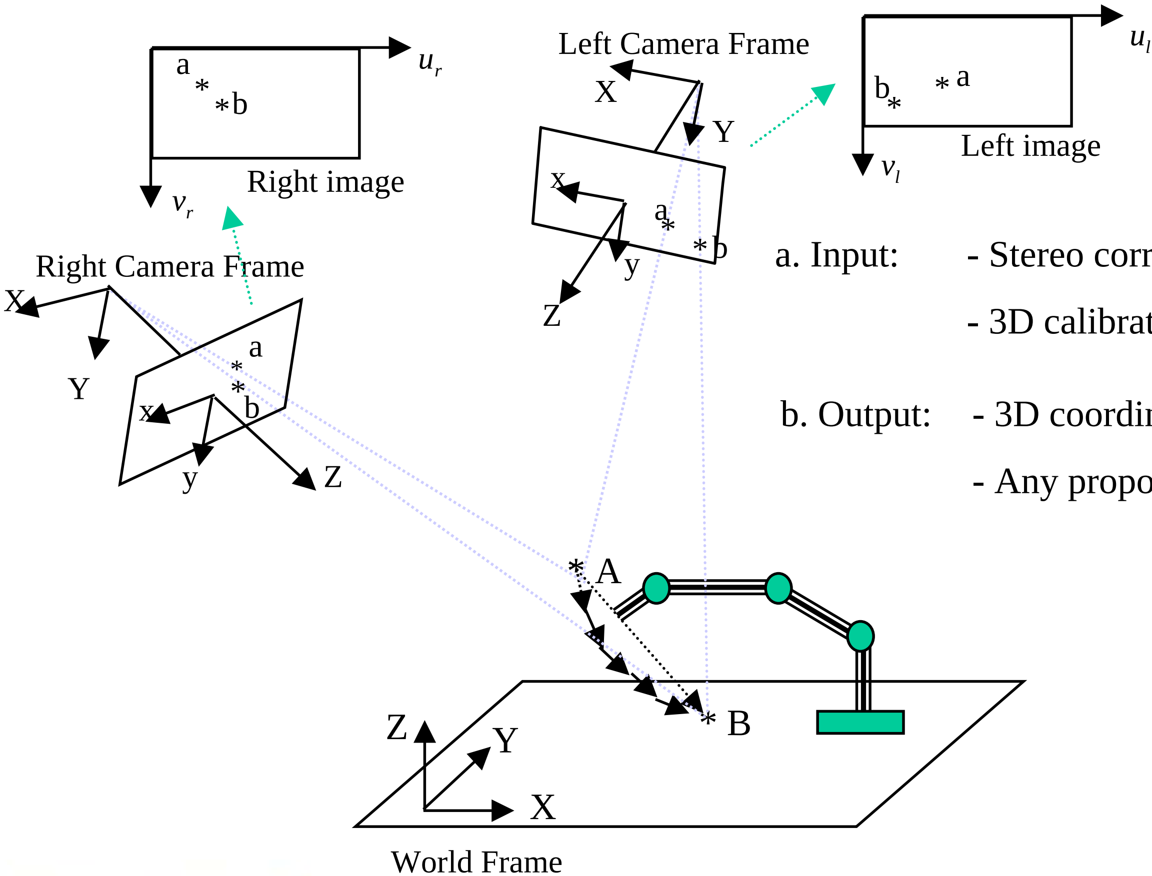
Step 3: The position (A, B) are unknown in the world frame.

Step 4: Assume that the motion control system of the arm/hand accepts a moving vector in the world frame as input.

Step 5: The problem becomes “how to compute the moving vector(s) in the world frame from images ?”

Visual Guidance of Robot Manipulator

4. Vision Techniques: Calibrated Stereo Vision (Deterministic Solution)



a. Input: - Stereo correspondence of A’s and B’s images

- 3D calibration matrices of the stereo cameras

b. Output: - 3D coordinates of A and B

- Any proposed trajectory linking A to B.

c. Description of solution:

Left image coordinates: (u_l, v_l)

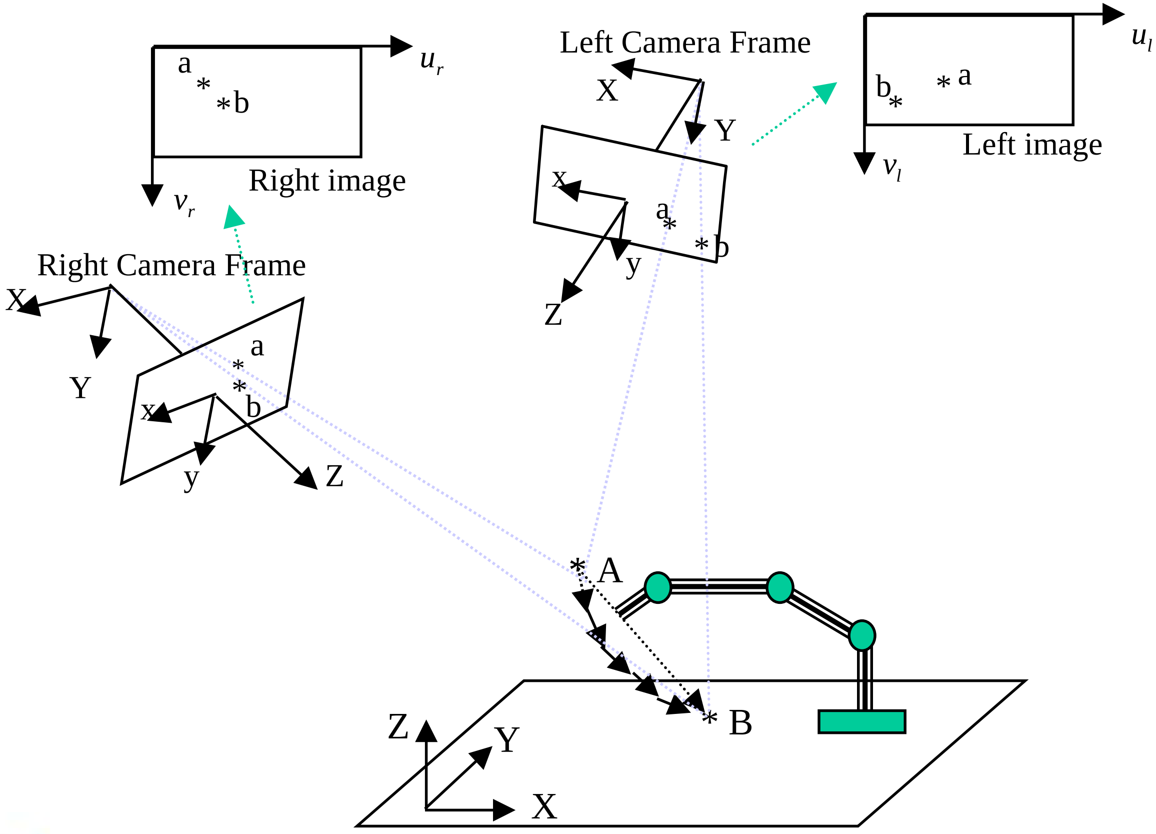
Right image coordinates: (u_r, v_r)

3D calibration matrices:

$$M_l = \{m_{li}, i = 1,2,...,12\}$$
$$M_r = \{m_{ri}, i = 1,2,...,12\}$$

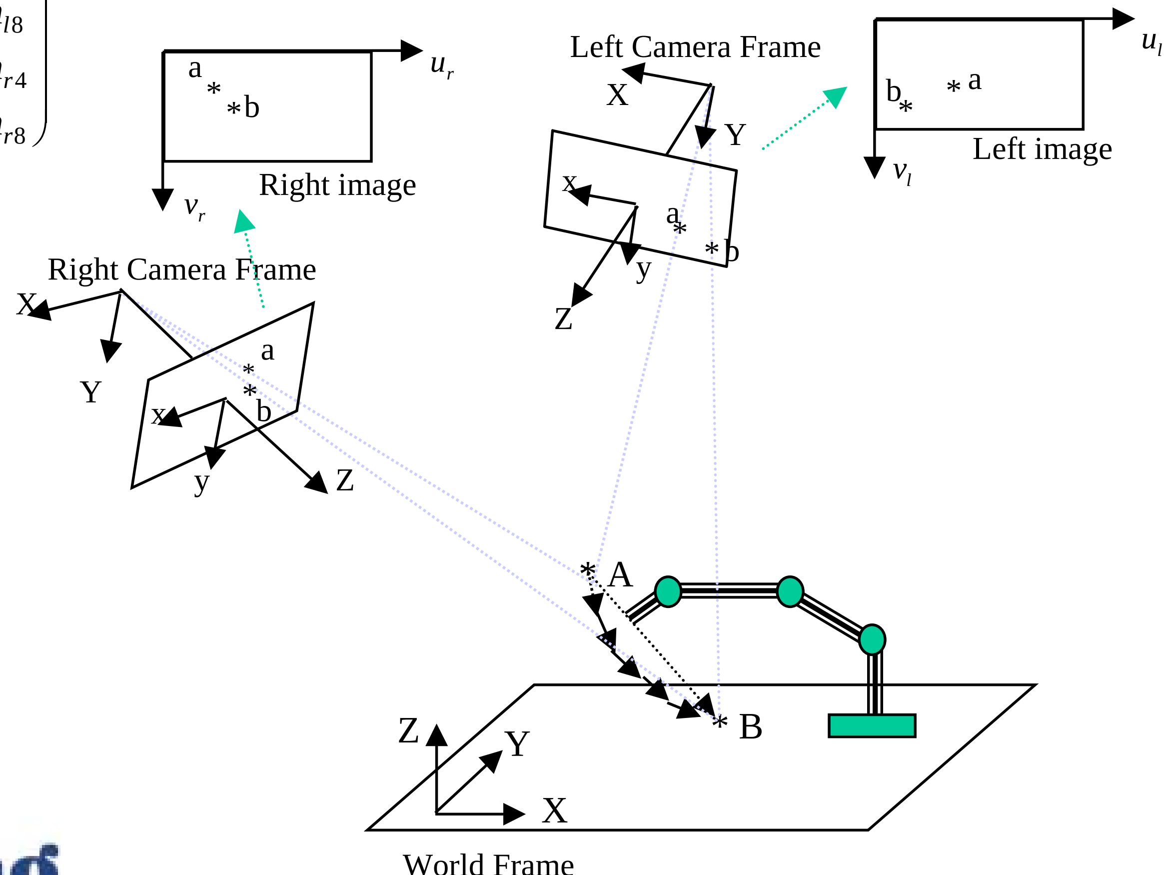
3D coordinates of A or B in world frame:

$$({}^wX, {}^wY, {}^wZ)$$



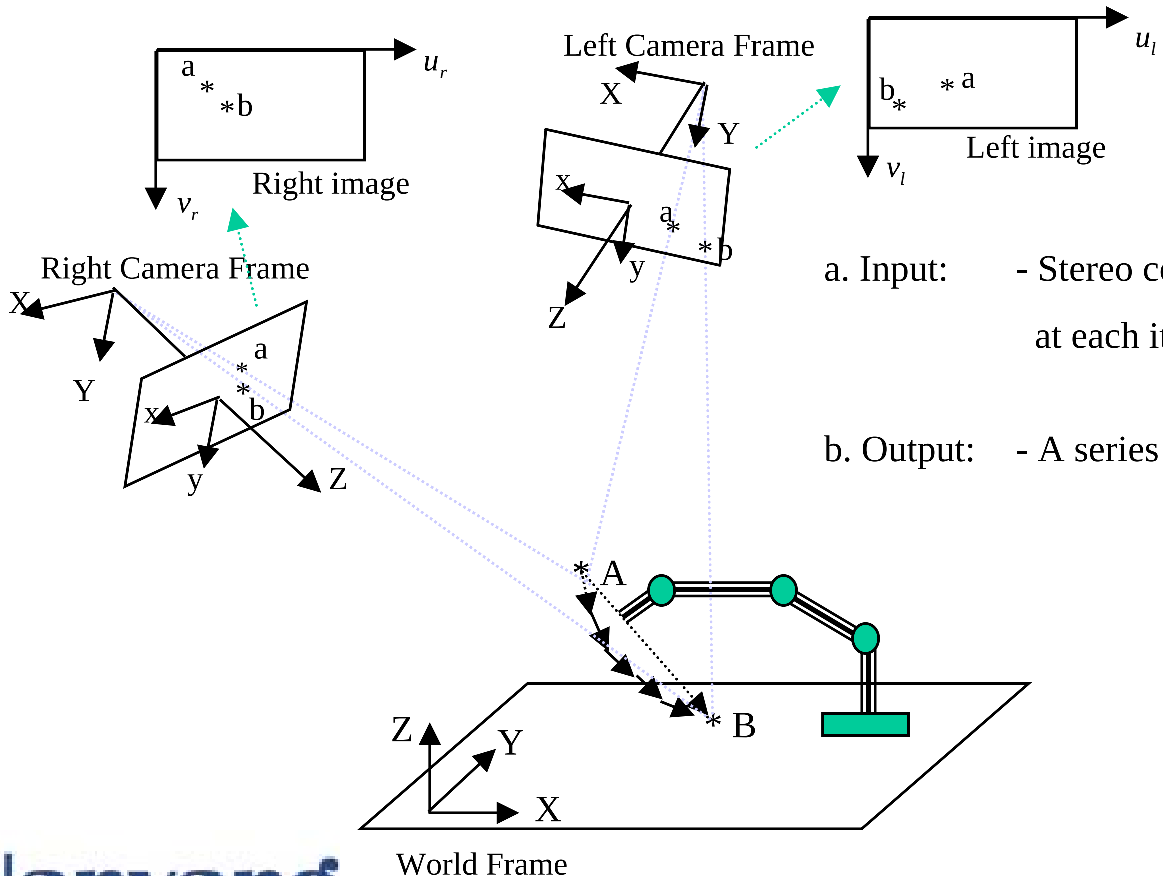
$$\begin{pmatrix} {}^{w}X \\ {}^{w}Y \\ {}^{w}Z \end{pmatrix} = (H^t \bullet H)^{-1} \bullet (H^t \bullet Q). \quad \text{with:} \quad H = \begin{pmatrix} (m_{l1} - m_{l9} \bullet u_l) & (m_{l2} - m_{l10} \bullet u_l) & (m_{l3} - m_{l11} \bullet u_l) \\ (m_{l5} - m_{l9} \bullet v_l) & (m_{l6} - m_{l10} \bullet v_l) & (m_{l7} - m_{l11} \bullet v_l) \\ (m_{r1} - m_{r9} \bullet u_r) & (m_{r2} - m_{r10} \bullet u_r) & (m_{r3} - m_{r11} \bullet u_r) \\ (m_{r5} - m_{r9} \bullet v_r) & (m_{r6} - m_{r10} \bullet v_r) & (m_{r7} - m_{r11} \bullet v_r) \end{pmatrix}$$

$$Q = \begin{pmatrix} u_l - m_{l4} \\ v_l - m_{l8} \\ u_r - m_{r4} \\ v_r - m_{r8} \end{pmatrix}$$



Visual Guidance of Robot Manipulator

4. Vision Techniques: Un-calibrated Stereo Vision (Iterative Solution)



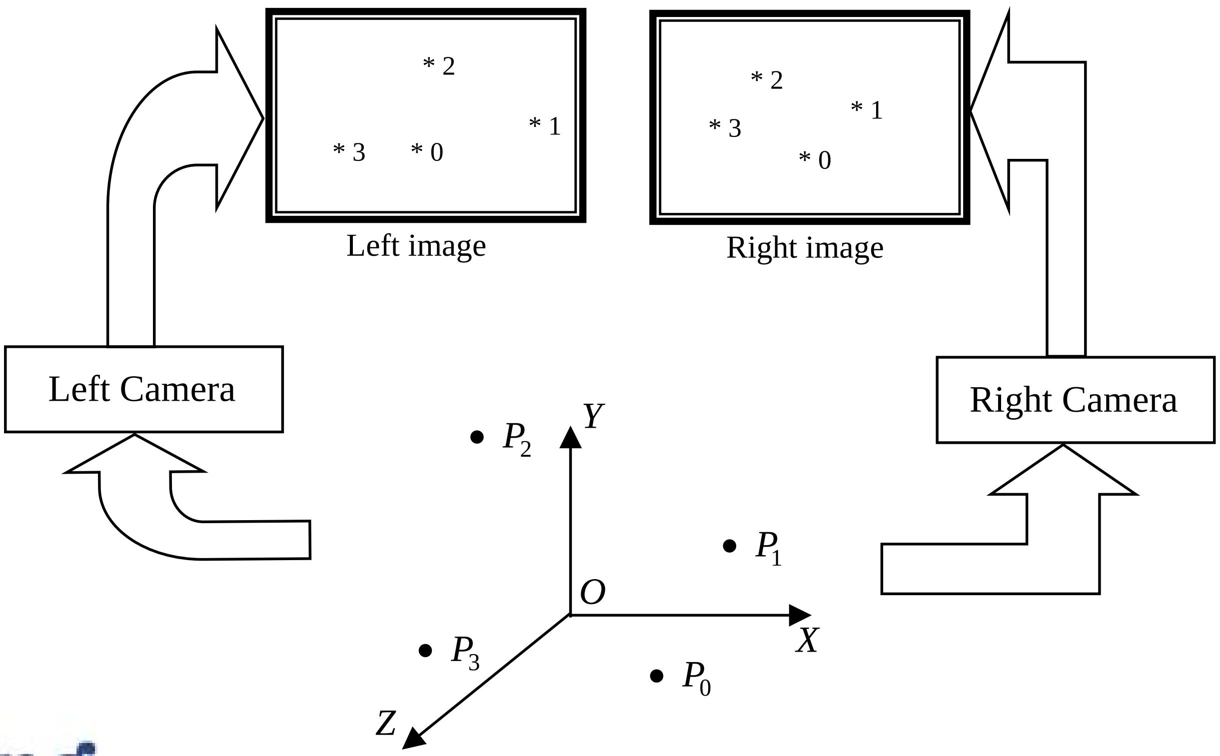
a. Input: - Stereo correspondence of A's and B's images at each iteration.

b. Output: - A series of moving vectors that link A to B.

c. Description of the "Projective Reconstruction Method":

Step 1: At the initialisation stage, we select four pairs of image points:

$$\{{}^{l}I_i = (u_{li}, v_{li}), \mathrm{i} = 0,1,2,3\}$$
$$\{{}^{r}I_i = (u_{ri}, v_{ri}), \mathrm{i} = 0,1,2,3\}$$

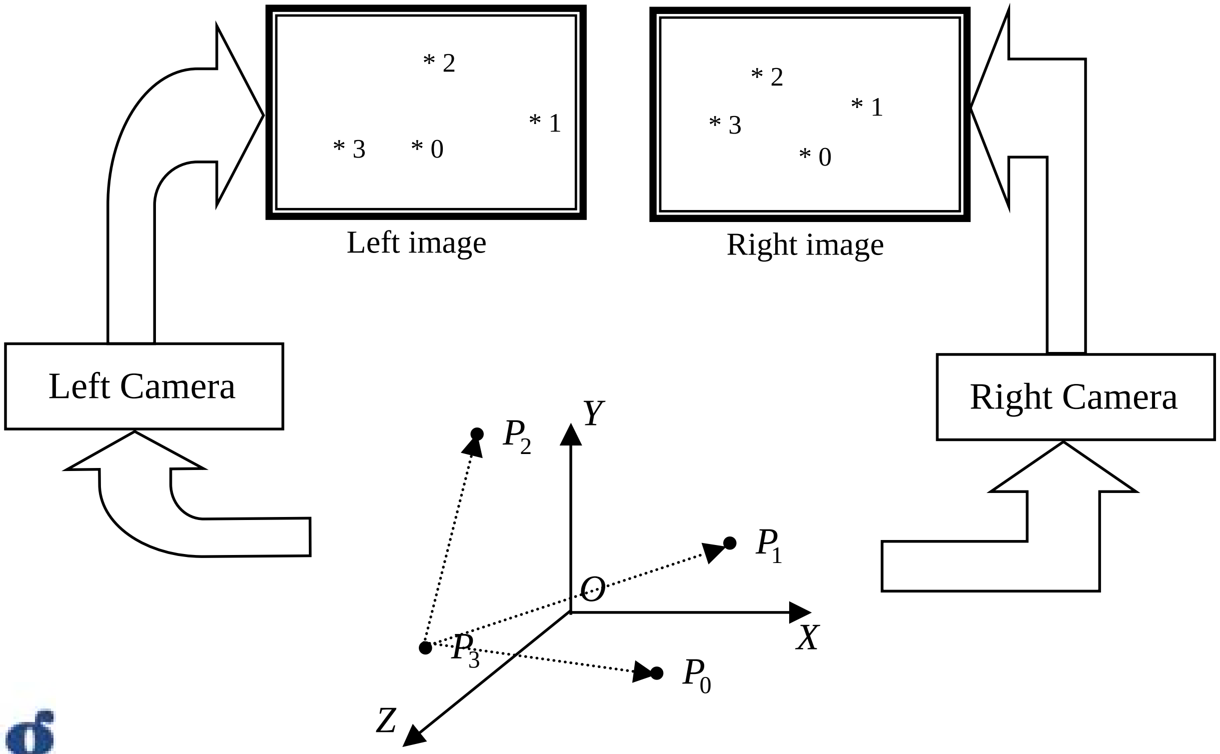


Step 2 : These four pairs of image points correspond to four 3D points : (P_0, P_1, P_2, P_3) in a 3D Cartesia space. We arbitrarily use these four points to define a non - orthogonal coordinate system O - ABC.

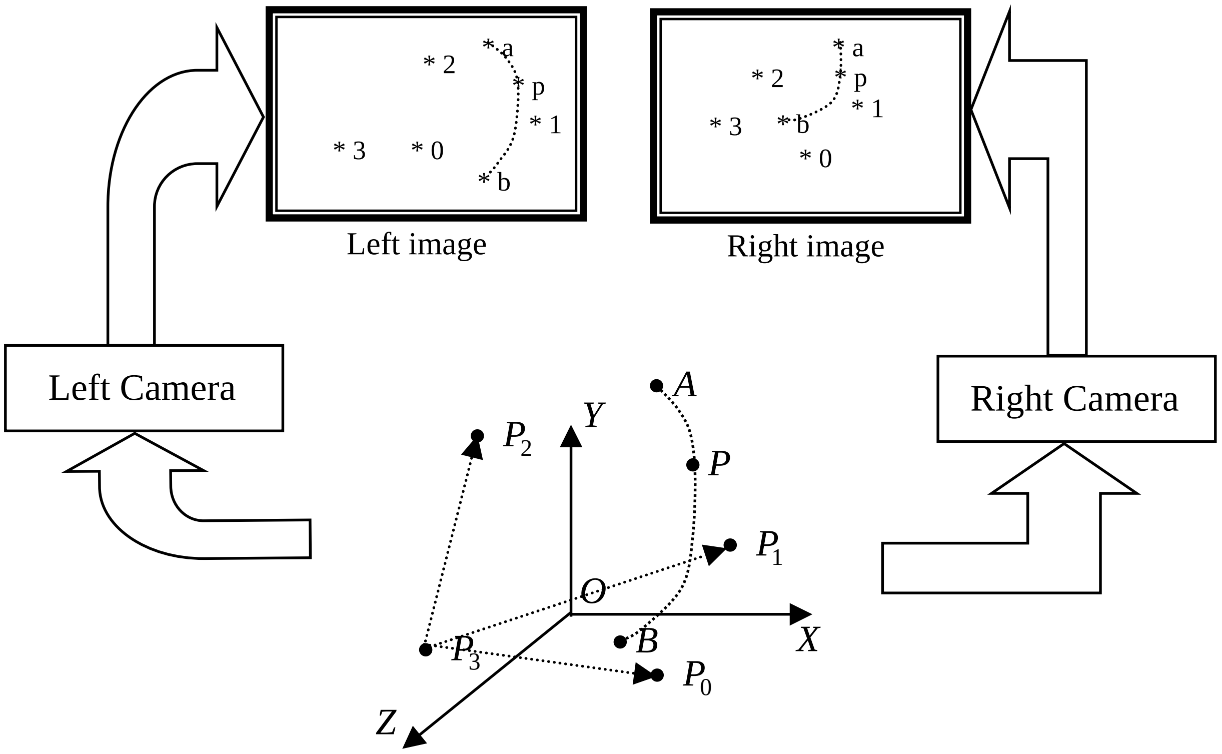
In O - ABC coordinate system, the coordinates of the four points are assigned to be :

$$^{abc}P_o = (a,b,c,1)^t = (1,0,0,1)^t \qquad ^{abc}P_1 = (a,b,c,1)^t = (0,1,0,1)^t$$

$$^{abc}P_2 = (a,b,c,1)^t = (0,0,1,1)^t \qquad ^{abc}P_3 = (a,b,c,1)^t = (0,0,0,1)^t$$



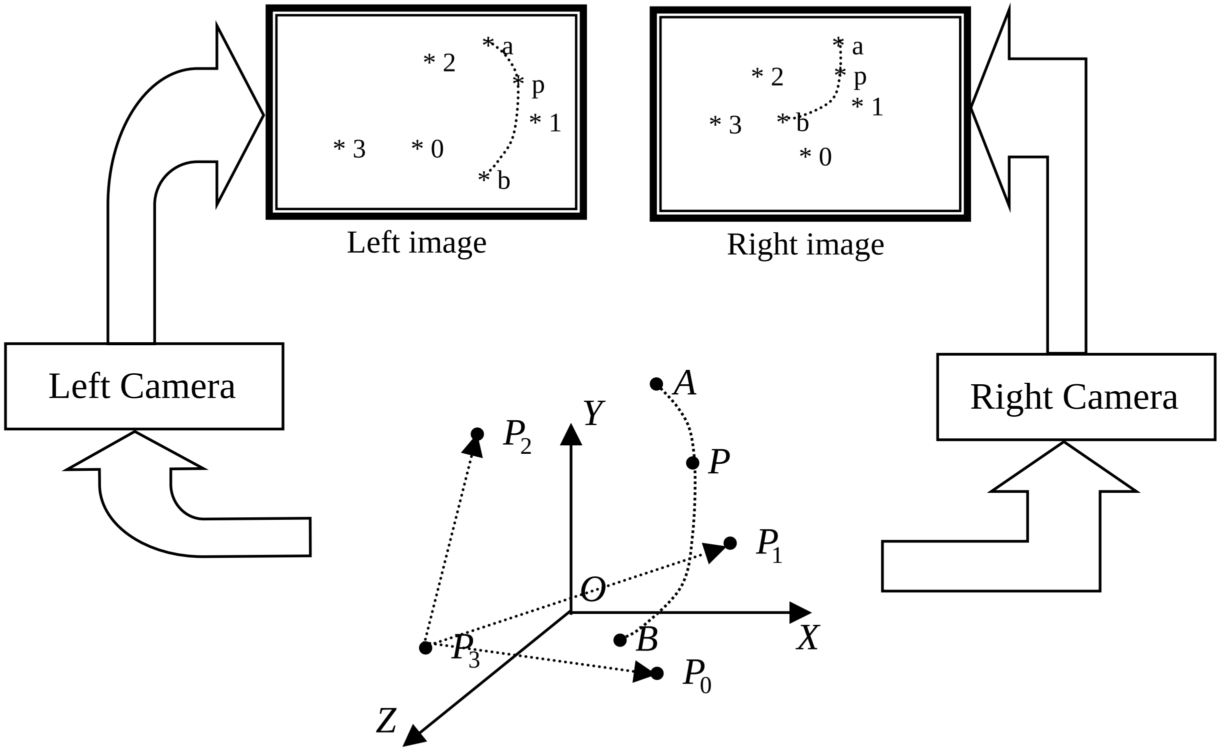
Step 3: Let ${}^{xyz}P = (X, Y, Z, 1)^t$ be the coordinates of a 3D point P in the O - XYZ coordinate sytem and ${}^{abc}P = (a, b, c, 1)^t$ be the coordinates of the same point P in the O - ABC coordinate system.



Assume that ${}^{xyz}H_{abc}$ describes the mapping from O - XYZ to O - ABC. Then, we have :

$$\begin{cases} {}^{l}I = (u_l, v_l, 1)^t = M_l \bullet {}^{xyz}P \\ {}^{r}I = (u_r, v_r, 1)^t = M_r \bullet {}^{xyz}P \\ {}^{xyz}P = {}^{xyz}H_{abc} \bullet {}^{abc}P \end{cases}$$

$$\begin{cases} {}^{l}I = (u_l, v_l, 1)^t = (M_l \bullet {}^{xyz}H_{abc}) \bullet {}^{abc}P = {}^{abc}M_l \bullet {}^{abc}P \\ {}^{r}I = (u_r, v_r, 1)^t = (M_r \bullet {}^{xyz}H_{abc}) \bullet {}^{xyz}P = {}^{abc}M_r \bullet {}^{abc}P \end{cases}$$



Step 4: From the four pairs of $\{({}^{l}I_i, {}^{r}I_i, {}^{abc}P_i), i = 0,1,2,3\}$, we can form the following equations:

$$\begin{cases} {}^{l}I_i = {}^{abc}M_l \bullet {}^{abc}P_i \\ {}^{r}I_i = {}^{abc}M_r \bullet {}^{abc}P_i \end{cases} \qquad i = 0,1,2,3$$

By solving for $({}^{abc}M_l, {}^{abc}M_r)$, we have the solutions below:

$${}^{abc}M_l = \begin{bmatrix} u_{l0} - u_{l3} & u_{l1} - u_{l3} & u_{l2} - u_{l3} & u_{l3} \\ v_{l0} - v_{l3} & v_{l1} - v_{l3} & v_{l2} - v_{l3} & v_{l3} \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$${}^{abc}M_r = \begin{bmatrix} u_{r0} - u_{r3} & u_{r1} - u_{r3} & u_{r2} - u_{r3} & u_{r3} \\ v_{r0} - v_{r3} & v_{r1} - v_{r3} & v_{r2} - v_{r3} & v_{r3} \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Step 5: Combining the following two systems of equations:

$$\begin{pmatrix} u_l \\ v_l \\ 1 \end{pmatrix} = \begin{bmatrix} u_{l0}-u_{l3} & u_{l1}-u_{l3} & u_{l2}-u_{l3} & u_{l3} \\ v_{l0}-v_{l3} & v_{l1}-v_{l3} & v_{l2}-v_{l3} & v_{l3} \\ 0 & 0 & 0 & 1 \end{bmatrix} \bullet {}^{abc}P$$

$$\begin{pmatrix} u_r \\ v_r \\ 1 \end{pmatrix} = \begin{bmatrix} u_{r0}-u_{r3} & u_{r1}-u_{r3} & u_{r2}-u_{r3} & u_{r3} \\ v_{r0}-v_{r3} & v_{r1}-v_{r3} & v_{r2}-v_{r3} & v_{r3} \\ 0 & 0 & 0 & 1 \end{bmatrix} \bullet {}^{abc}P$$

we have:

$$I = \begin{pmatrix} u_l \\ v_l \\ u_r \\ v_r \end{pmatrix} = \begin{bmatrix} u_{l0}-u_{l3} & u_{l1}-u_{l3} & u_{l2}-u_{l3} & u_{l3} \\ v_{l0}-v_{l3} & v_{l1}-v_{l3} & v_{l2}-v_{l3} & v_{l3} \\ u_{r0}-u_{r3} & u_{r1}-u_{r3} & u_{r2}-u_{r3} & u_{r3} \\ v_{r0}-v_{r3} & v_{r1}-v_{r3} & v_{r2}-v_{r3} & v_{r3} \end{bmatrix} \bullet {}^{abc}P$$

Then, the difference equation will be:

$$\Delta I = \begin{pmatrix} \Delta u_l \\ \Delta v_l \\ \Delta u_r \\ \Delta v_r \end{pmatrix} = \begin{bmatrix} u_{l0}-u_{l3} & u_{l1}-u_{l3} & u_{l2}-u_{l3} \\ v_{l0}-v_{l3} & v_{l1}-v_{l3} & v_{l2}-v_{l3} \\ u_{r0}-u_{r3} & u_{r1}-u_{r3} & u_{r2}-u_{r3} \\ v_{r0}-v_{r3} & v_{r1}-v_{r3} & v_{r2}-v_{r3} \end{bmatrix} \bullet {}^{abc}\Delta P$$

Step 6: We approximate the above relationship be replacing ${}^{abc}\Delta P$ with ${}^{xyz}\Delta P$. The computation of the differentiation yields:

$$\Delta I \cong N_{4\times3} \bullet {}^{xyz}\Delta P$$

with

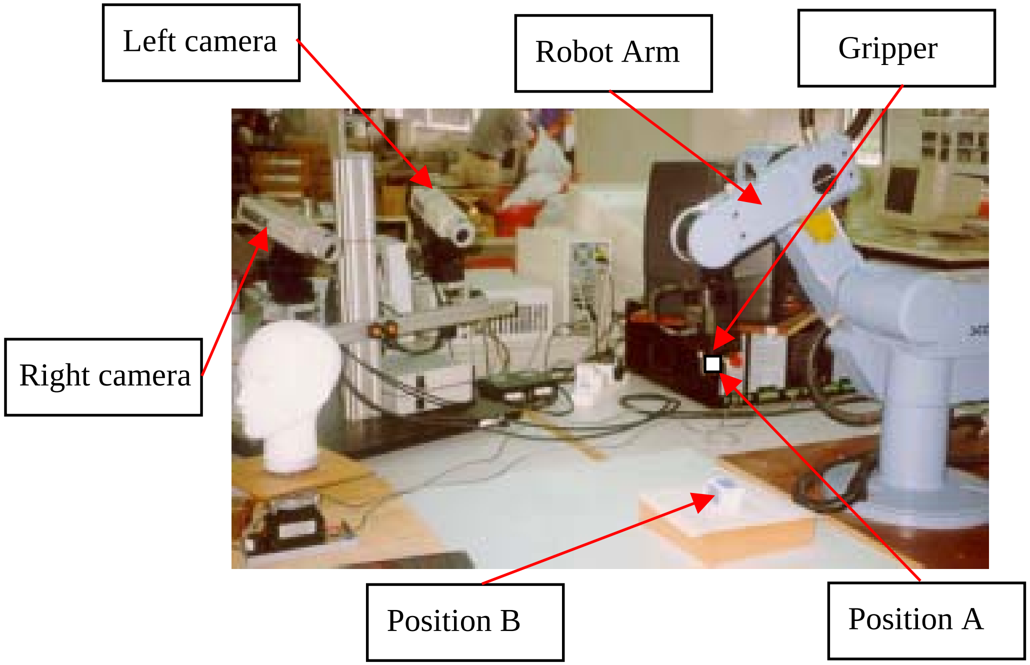
$$N_{4\times3} = \begin{bmatrix} u_{l0}-u_{l3} & u_{l1}-u_{l3} & u_{l2}-u_{l3} \\ v_{l0}-v_{l3} & v_{l1}-v_{l3} & v_{l2}-v_{l3} \\ u_{r0}-u_{r3} & u_{r1}-u_{r3} & u_{r2}-u_{r3} \\ v_{r0}-v_{r3} & v_{r1}-v_{r3} & v_{r2}-v_{r3} \end{bmatrix} \qquad \Delta I = \begin{bmatrix} \Delta u_l \\ \Delta v_l \\ \Delta u_r \\ \Delta v_r \end{bmatrix} \qquad {}^{\mathrm{xyz}}\Delta P = \begin{bmatrix} \Delta X \\ \Delta Y \\ \Delta Z \end{bmatrix}$$

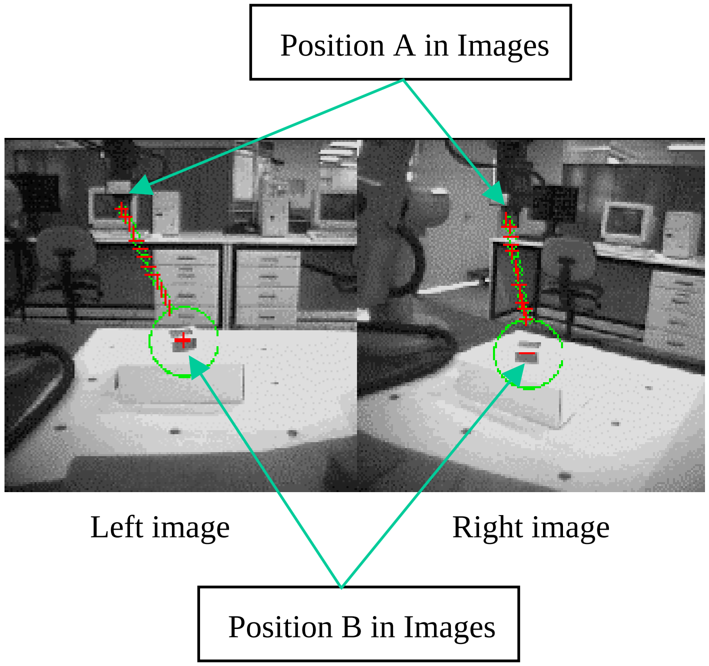
Step 7: The matrix N could be invertible. We can directly derive an iterative mapping function as follows (G is a gain matrix):

$$\begin{cases} {}^{xyz}\Delta P(k) = G \bullet [(N^t \bullet N)^{-1} \bullet N^t] \bullet \Delta I(k) \\ \Delta I(k) = [u_{lb} - u_{lp}, v_{lb} - v_{lp}, u_{rb} - u_{rp}, v_{rb} - v_{rp}]^t \\ {}^{xyz}P = A + \sum_k {}^{xyz}\Delta P(k) \end{cases}$$

Visual Guidance of Robot Manipulator

5. Experimental Results: Un-calibrated Stereo Vision




Position A in Images
Left image
Right image
Position B in Images

SUMMARY

1. Robot manipulator is composed of mechanical linkage that is powered by actuators, controlled by computer and programmed by end-users.

2. Like human hand-eye coordination behavior, it is possible to implement vision-guided manipulation with: a) robot manipulator and b) machine vision system.

3. There are two categories of solutions for vision-guided robot manipulator:

    a) Deterministic methods.
    (The standard stereo vision is just one example)

    b) Iterative methods.
    (The projective reconstruction method is one example)