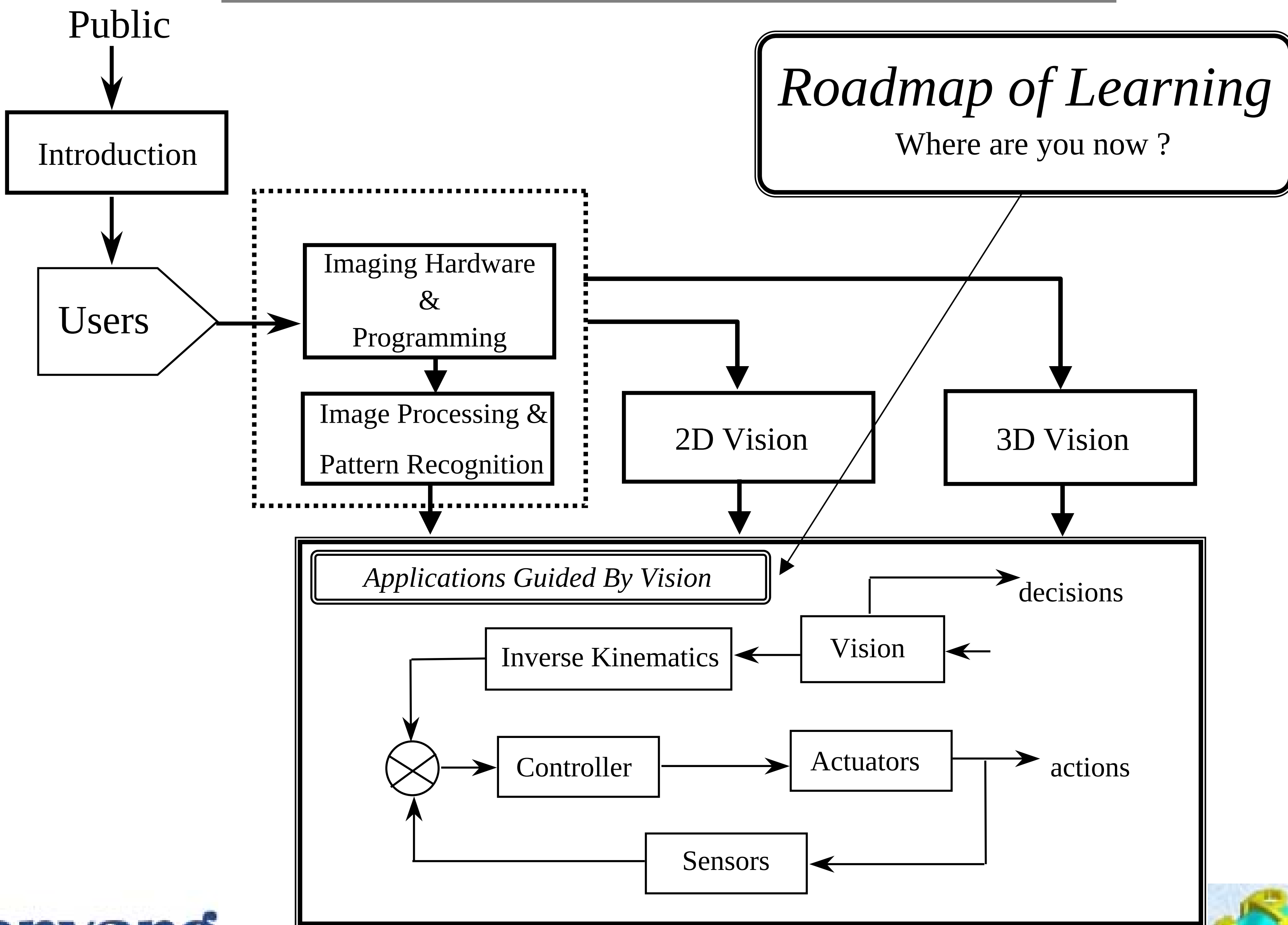

Roadmap of Learning
Where are you now ?
Public
Introduction
Users
Imaging Hardware & Programming
Image Processing & Pattern Recognition
2D Vision
3D Vision
Applications Guided By Vision
decisions
Vision
Inverse Kinematics
Controller
Actuators
actions
Sensors

CONTENT

Chapter 9: Machine Vision Applications

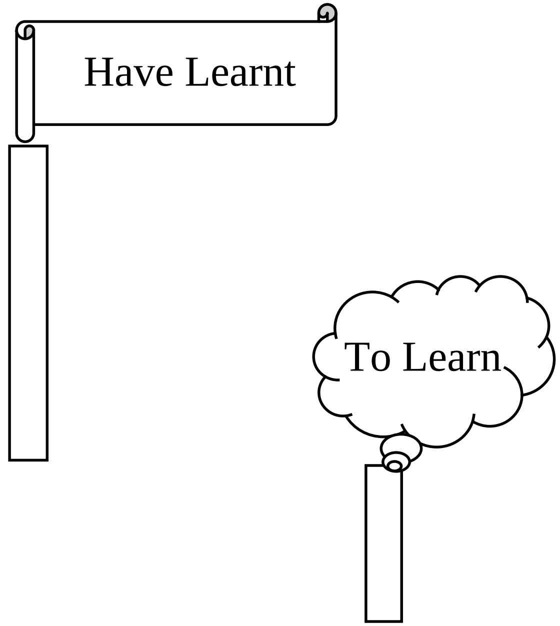
9.1 Visual Inspection

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



Nanyang Technological University

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)

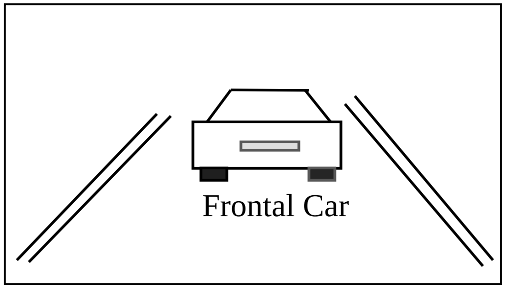
Visual Identification:
To obtain metric features from images for the sake of identifying the belonging of objects under the viewing.

Visual Guidance of Robotic Head

1. Illustrations:

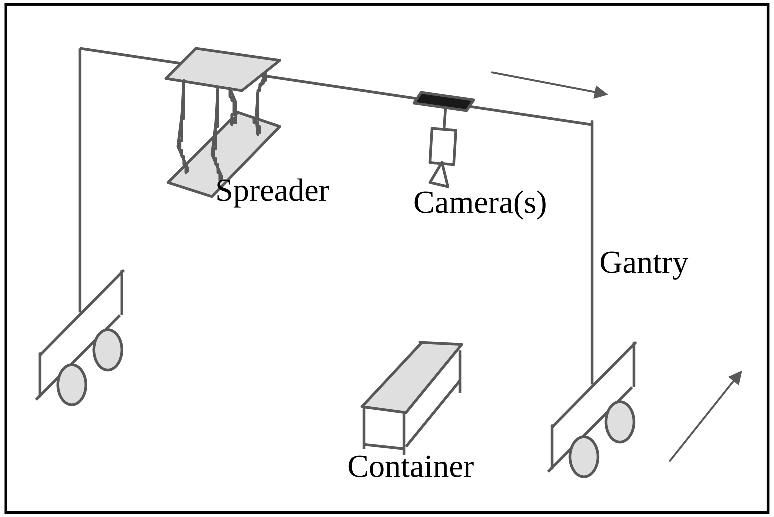
Application 1: Car Following

A vision system is mounted on our vehicle. Consider our vehicle as a robotic head. The task of following a frontal vehicle can be treated as "Head-Eye Coordination".



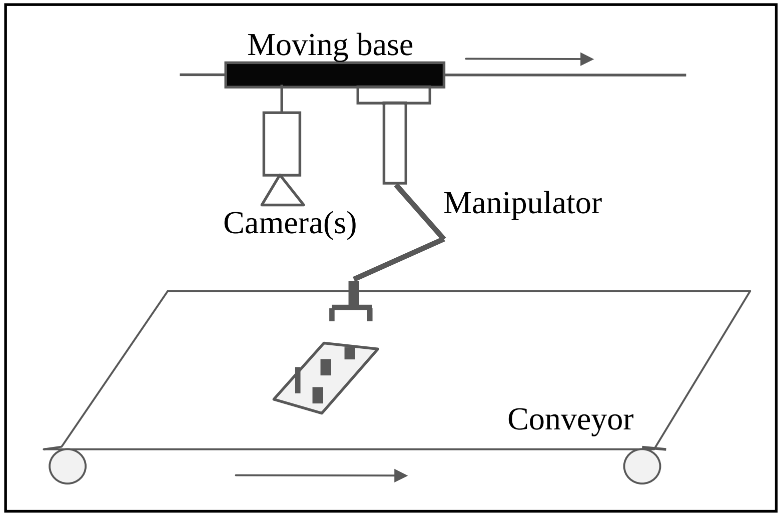
Application 2: Vision-Guided Container Loading/Unloading

Consider the spreader device as a robotic head. The task of guiding the spreader device to be positioned on top of a container can be considered as "Head-Eye Coordination" problem.

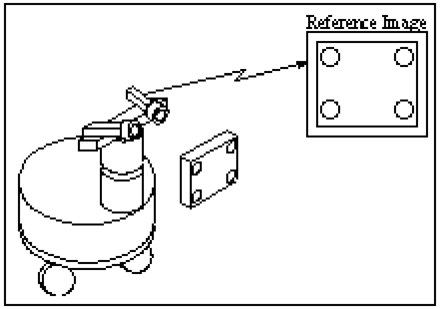


Application 3: On-fly Assembly Line

The object to be handled is moving. A vision system is mounted on the moving base of a manipulator. The task of maintaining a zero motion between the manipulator and the object is a “Head-Eye Coordination” problem.

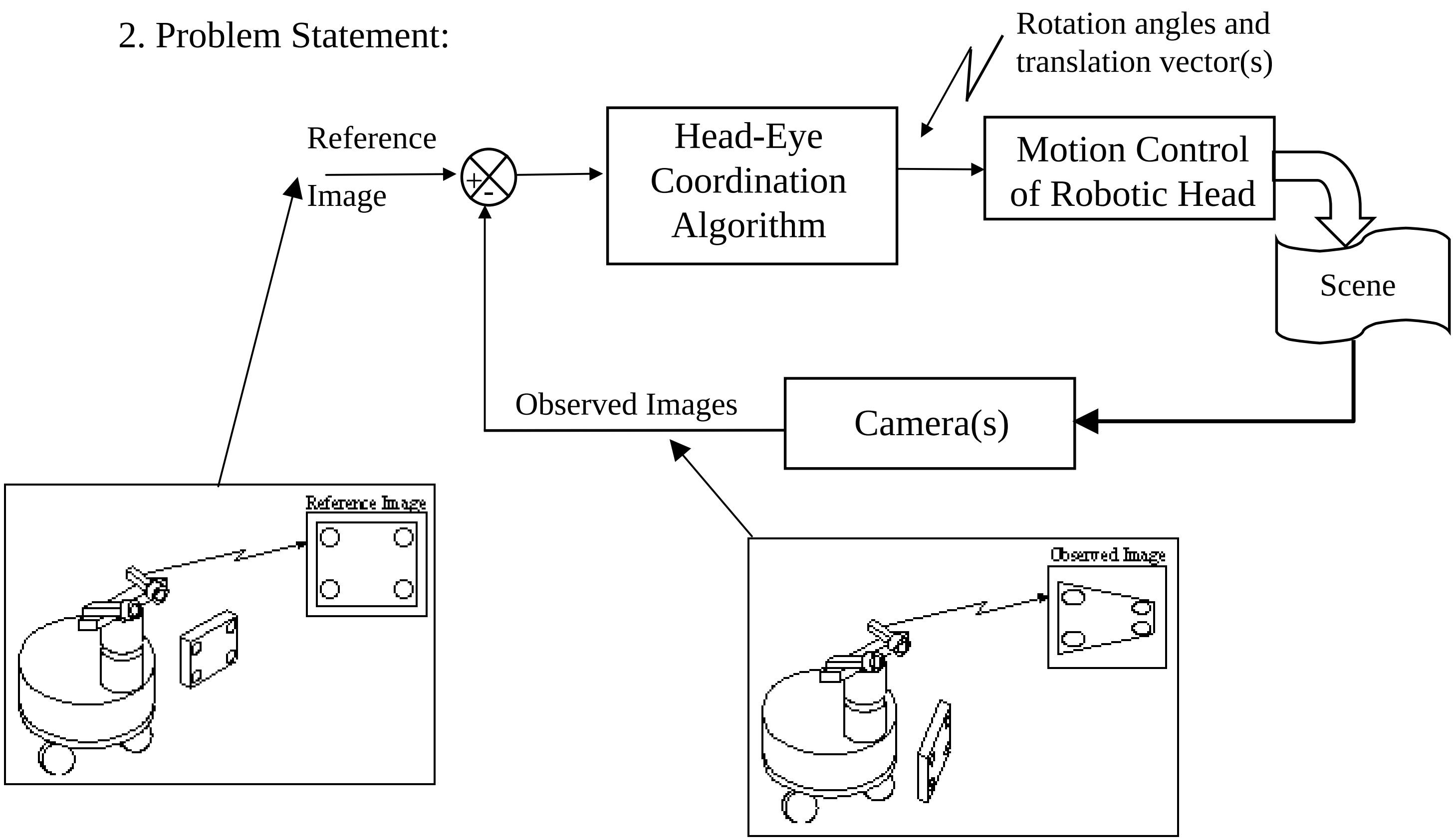


The reality is that nearly all vision systems (animal vision, human vision or machine vision) are mounted on a motion platform that can be defined as “head”.



Visual Guidance of Robotic Head

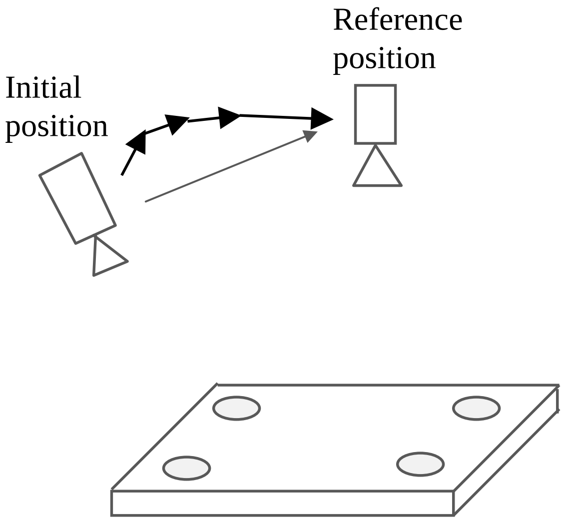
2. Problem Statement:



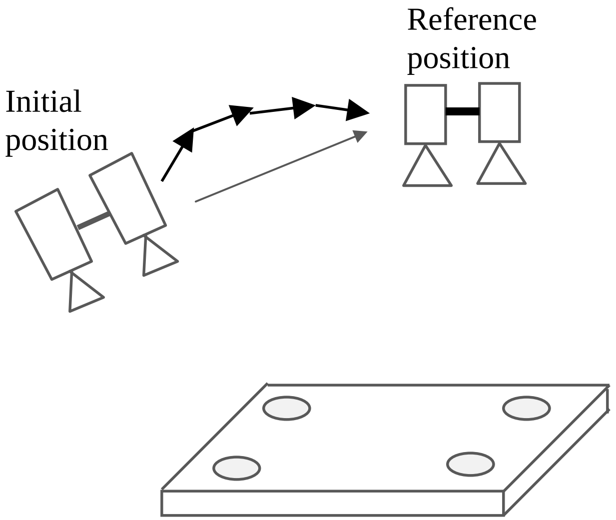
The problem of "Head-Eye Coordination" is to "how to compute head's motion that moves the head (ie, cameras) so that the observed images converge to a reference image.

Visual Guidance of Robotic Head

3. Problem Analysis:



Vision System With One Camera



Vision System With Two Cameras

Visual Guidance of Robotic Head

3. Problem Analysis:

Step 1: We have a vision system composed of one or two cameras.

Step 2: One reference image is taken at a reference pose.

Step 3: At beginning, a vision system is at an initial pose that is different than the reference pose.

Step 4: One or two images is taken at the initial pose by the vision system.

Step 5: The problem becomes “how to compute one or a series of motion transformation that brings the head (ie, cameras) from the initial pose to the reference pose ?”

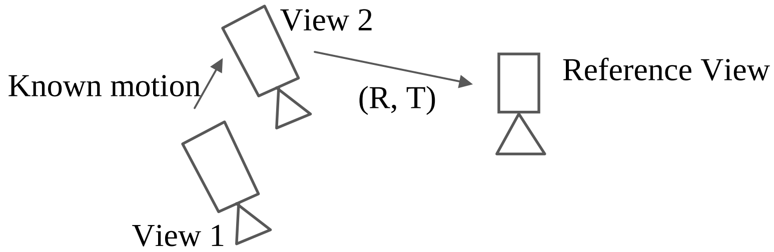
Visual Guidance of Robotic Head

4. Vision Techniques: Two-Views Method (Deterministic Solution):

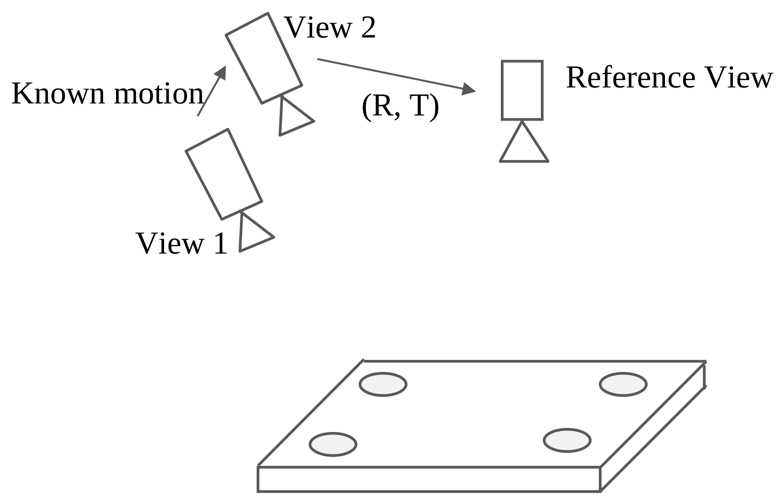
a. Input: - Two views

(These two views can be: a) the left and right views of a stereo vision, or b) the (view 1, view 2) of a moving camera with known motion)

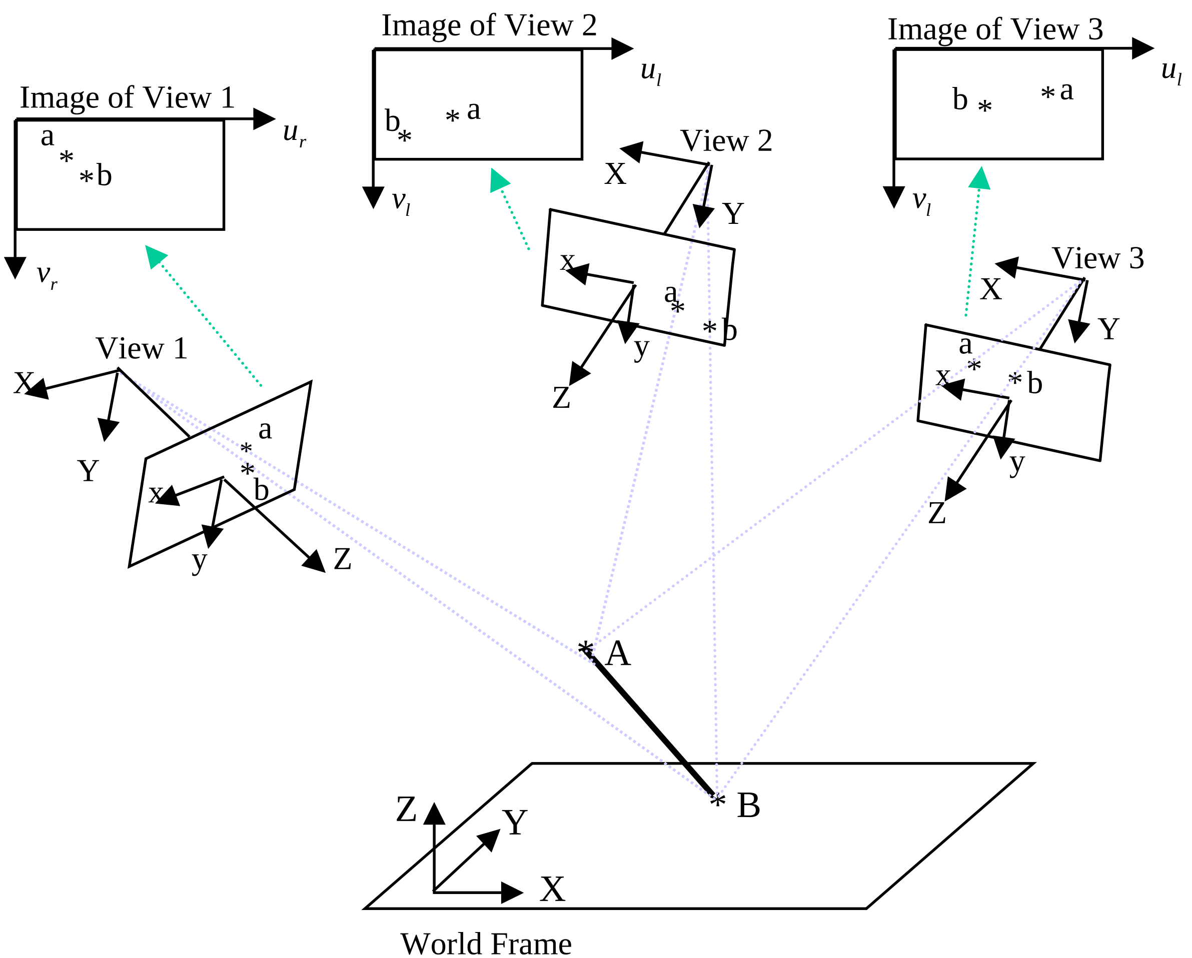
- Parameters of camera(s)
- Line segments extracted from images.



b. Output: - The final motion transformation that brings the head (ie, cameras) from its initial view to the reference view.



c. Solution description:



Step 1: Image is formed according to a perspective projection (assuming f = 1):

$$^{v}x = \frac{^{v}X}{^{v}Z} \qquad ^{v}y = \frac{^{v}Y}{^{v}Z} \tag{1}$$

Step 2: At View 3 (the reference view):

a. A 2D line segment in the reference image can be described by:

$$^{v3}a \bullet {}^{v3}x + {}^{v3}b \bullet {}^{v3}y + {}^{v3}c = 0. \tag{2}$$

b. The corresponding projection plane passing through this line is:

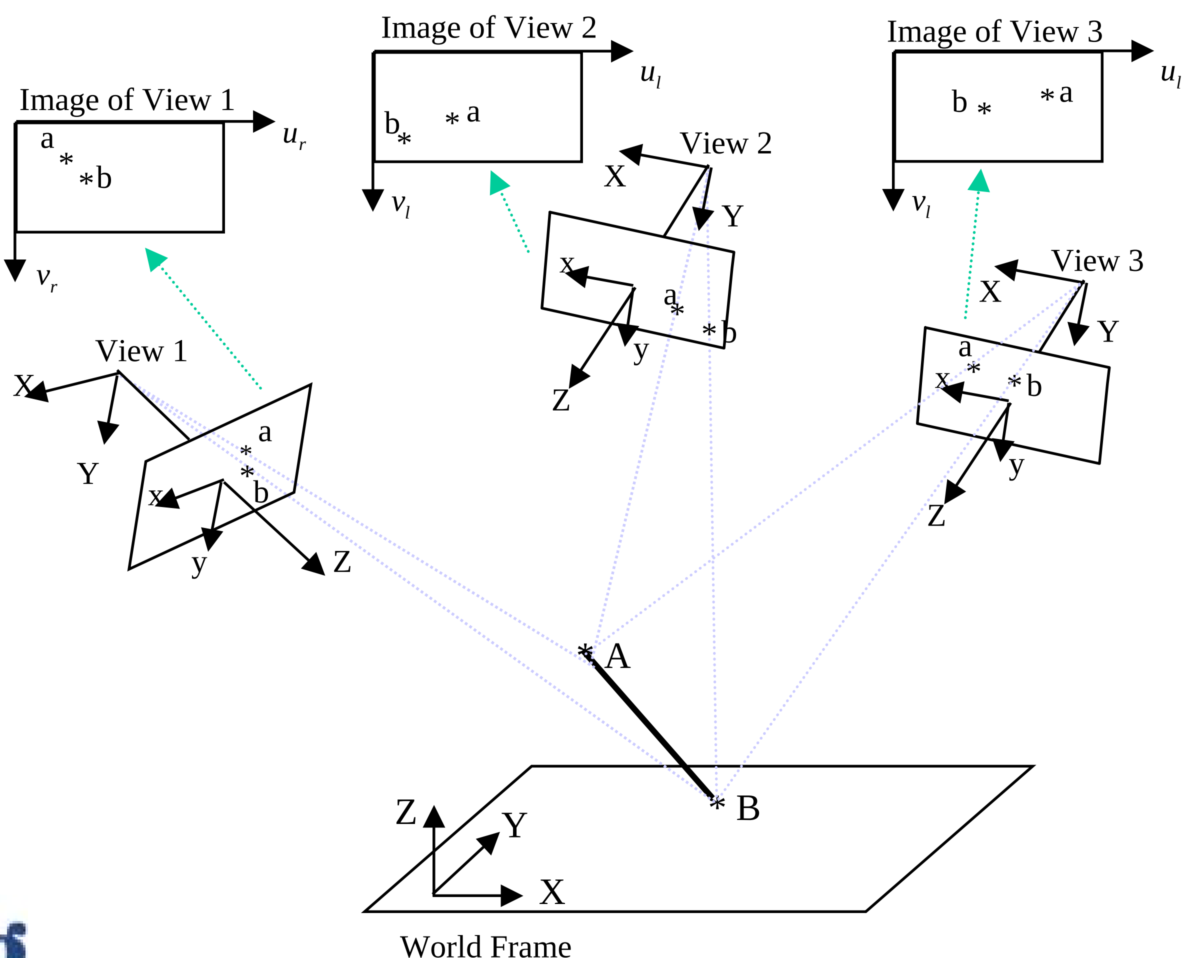
$$^{v3}a \bullet {}^{v3}X + {}^{v3}b \bullet {}^{v3}Y + {}^{v3}c \bullet {}^{v3}Z = 0. \tag{3}$$

c. If we define: $^{v3}S = (^{v3}a, {}^{v3}b, {}^{v3}c)$ and $^{v3}P = (^{v3}X, {}^{v3}Y, {}^{v3}Z)$, we have:

$$^{v3}S \bullet {}^{v3}P^{t} = 0 \tag{4}$$

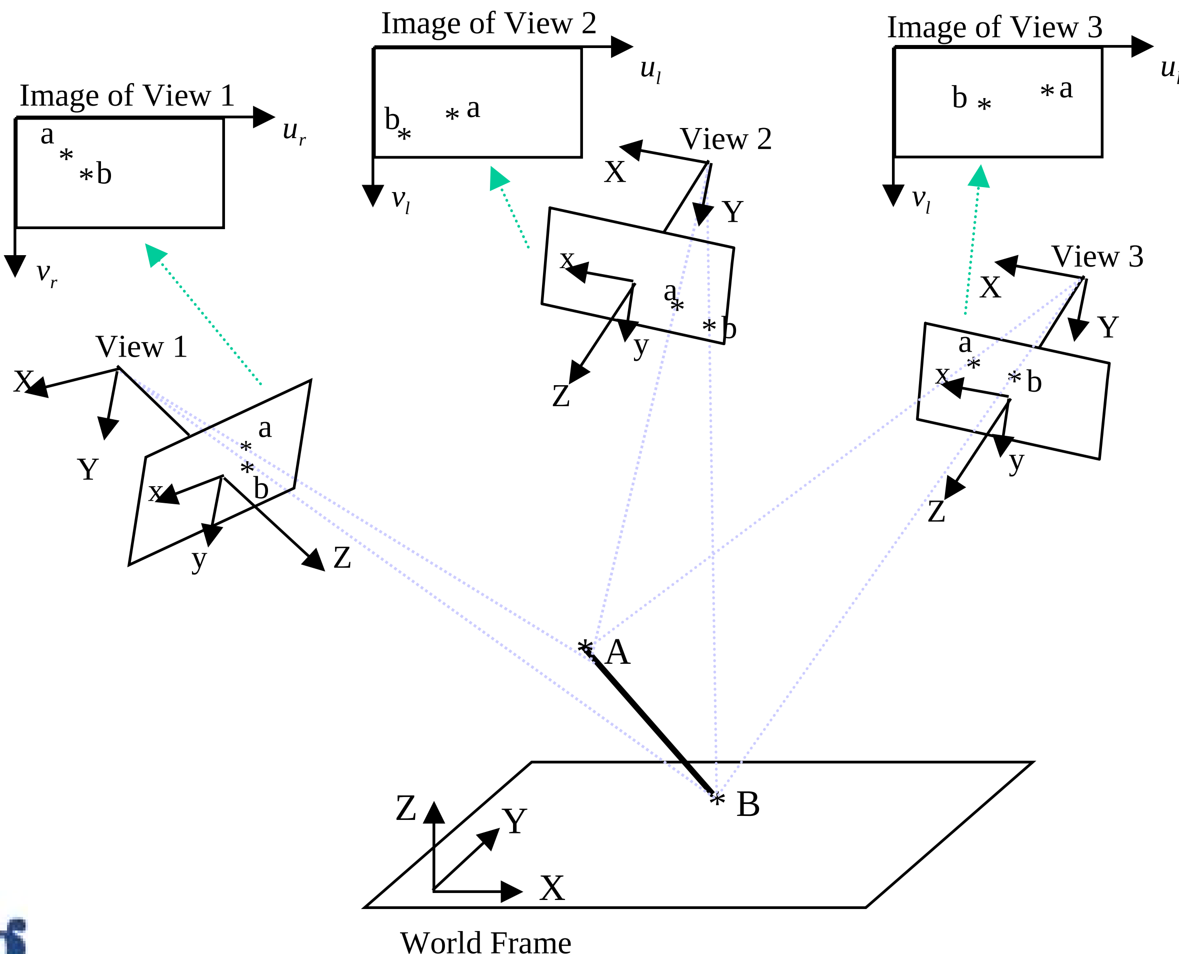
Step 3: If $({}^{v3}R_{v2}, {}^{v3}T_{v2})$ denotes the motion transformation from View 2 to View 3, we can compute the 3D coordinates of point P in View 3 from its 3D coordinates in View 2:

$$ {}^{v3}P^t = {}^{v3}R_{v2} \bullet {}^{v2}P^t + {}^{v3}T_{v2}. \quad (5) $$



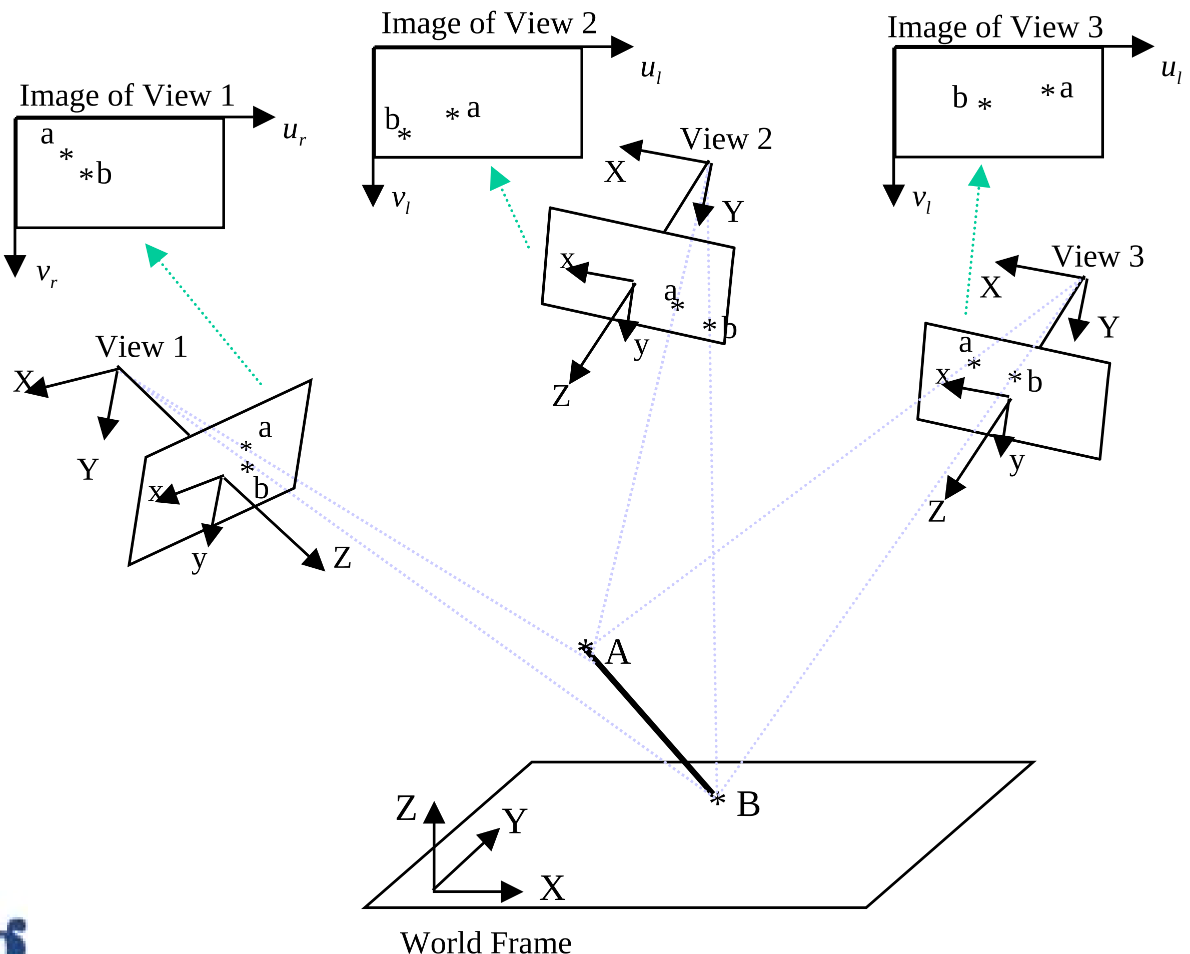
Step 4 : The combination of Eq(4) and Eq(5) yields :

$$ {}^{v3}S \bullet {}^{v3}R_{v2} \bullet {}^{v2}P^{t} + {}^{v3}S \bullet {}^{v3}T_{v2} = 0. \tag{6} $$



Step 5 : If we have two 3D points (${}^{v2}A$, ${}^{v2}B$) on a 3D line segment in View 2, we can establish the following system :

$$\begin{cases} {}^{v3}S \bullet {}^{v3}R_{v2} \bullet {}^{v2}A^t + {}^{v3}S \bullet {}^{v3}T_{v2} = 0. \\ {}^{v3}S \bullet {}^{v3}R_{v2} \bullet {}^{v2}B^t + {}^{v3}S \bullet {}^{v3}T_{v2} = 0. \end{cases} \quad (7)$$



Step 6 : The subtraction of the two equations in Eq(7) yields :

$$ {}^{v3}S \bullet {}^{v3}R_{v2} \bullet ({}^{v2}A^{t} - {}^{v2}B^{t}) = 0. \quad (8) $$

Step 7 : If we define :

$$ {}^{v2}D^{t} = ({}^{v2}A^{t} - {}^{v2}B^{t}) / \| {}^{v2}A^{t} - {}^{v2}B^{t} \| $$

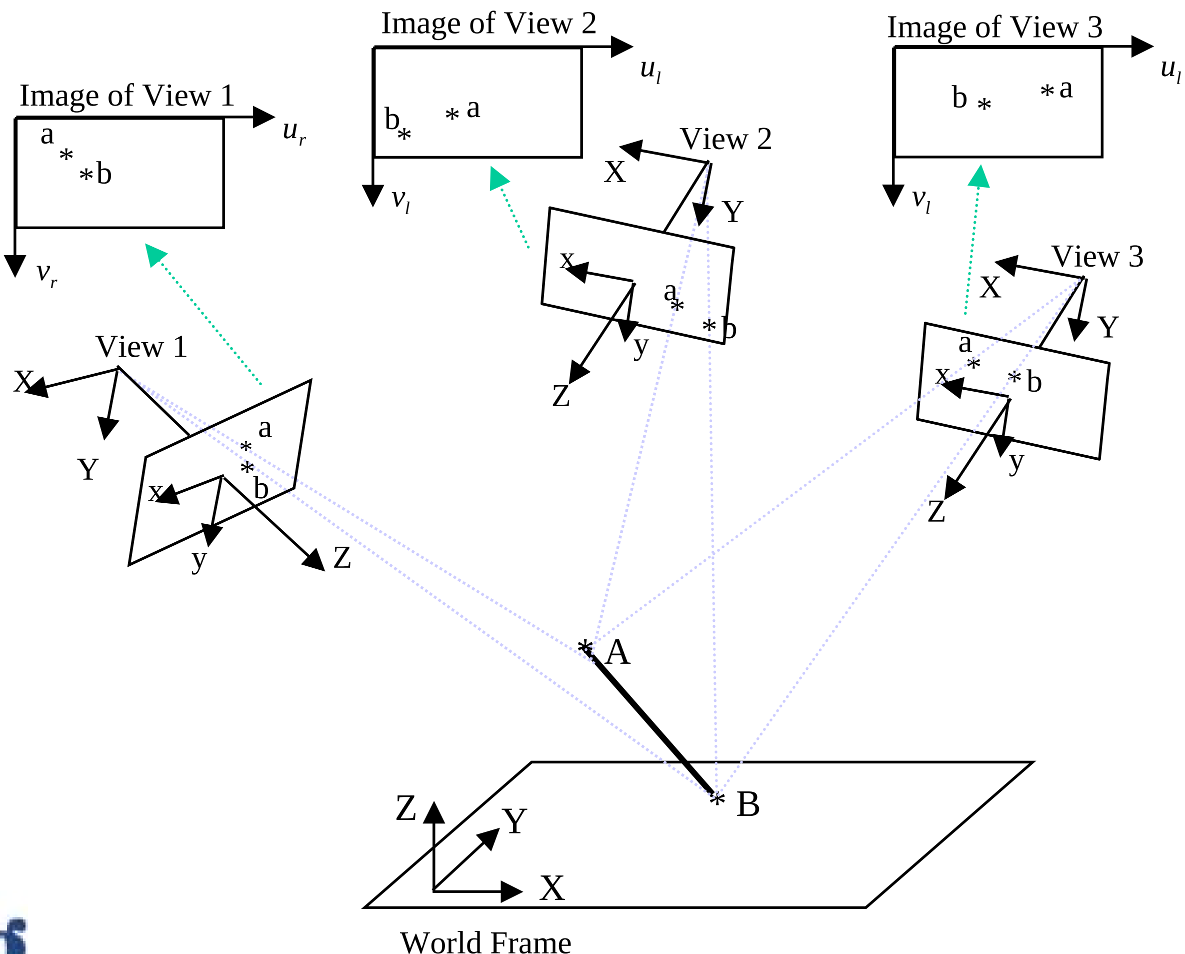
Eq(8) becomes :

$$ {}^{v3}S \bullet {}^{v3}R_{v2} \bullet {}^{v2}D^{t} = 0. \quad (9) $$

Step 8: Finally, we have the following two key equations:

$$\text{Key equation 1: } {}^{v3}S \bullet {}^{v3}R_{v2} \bullet {}^{v2}P^t + {}^{v3}S \bullet {}^{v3}T_{v2} = 0. \qquad (10)$$

$$\text{Key equation 2: } {}^{v3}S \bullet {}^{v3}R_{v2} \bullet {}^{v2}D^t = 0.$$



Five Observations:

1. 2D line segments are fully determined from images that are known in advance (as input).

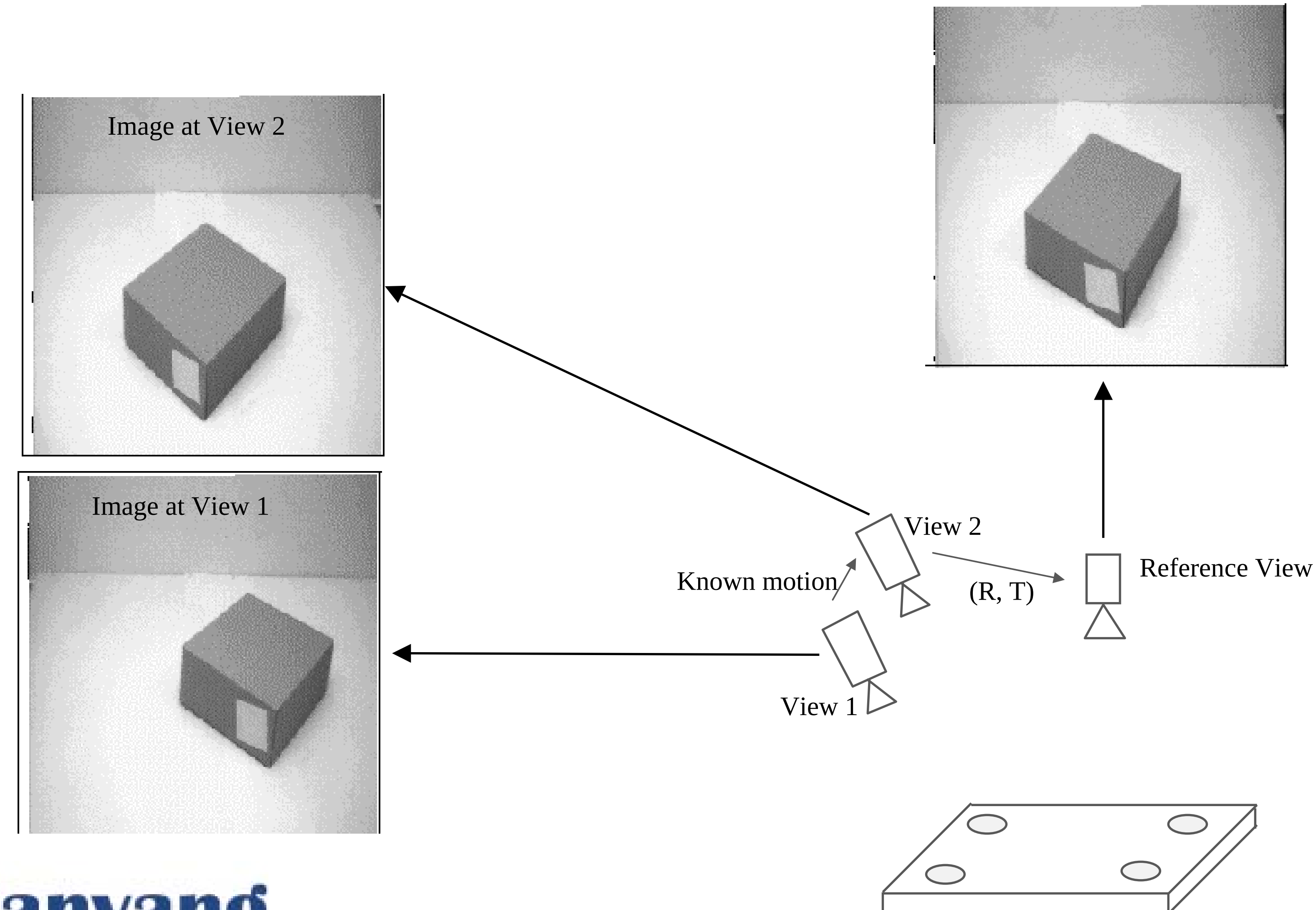
2. 3D line segments at View 2 can be fully determined from View 1 and View 2 because the motion between these two views are known in advance (calibrated stereo vision).

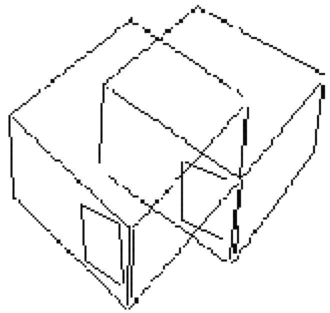
3. R is a rotation matrix that has only three independent variables. From Key equation 2, three line segments theoretically allow to estimate the rotation matrix R. But, this needs to solve three non-linear equations. This is a difficult task.

4. If we consider that R is a 3x3 matrix having eight elements (the ninth element can be set to 1), eight line segments allow to establish eight linear equations according to Key equation 2. Once the eight elements in R have been estimated, we can easily convert R into an orthonormal matrix. Knowing R, the translation vector T can be estimated from Key equation 1 with three line segments only.

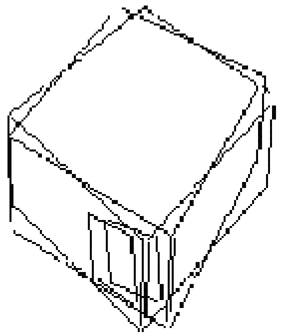
5. If using the two key equations together, six line segments are sufficient to estimate the 11 unknown elements in R and T.

d. Experimental Results:

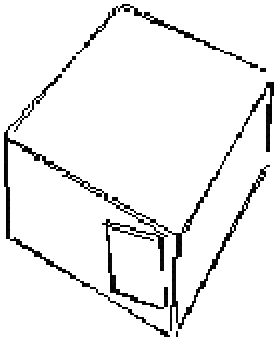




The matched 2D line segments extracted from the image taken at View 1 and the image taken at View 2.



The matched 2D line segments extracted from the image taken at View 2 and the image taken at View 3.



We apply the estimated motion transformation to the 3D line segments at View 2 to transform them into View 3. Then, we project the transformed 3D line segments onto the image plane of View 3. The photo shows the superimposition of the projected 2D line segments with the 2D line segments extracted from the image taken at View 3.

Nanyang Technological University

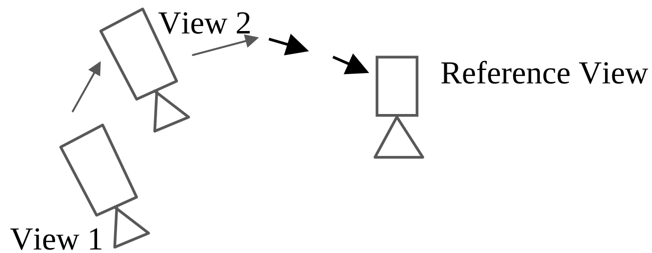
Visual Guidance of Robotic Head

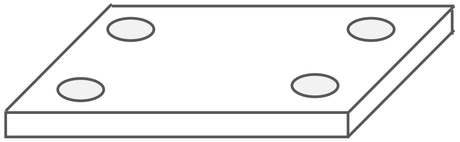
5. Vision Techniques: Planar-Rectangle Method (Iterative Solution)

a. Input: - One view at each iteration.

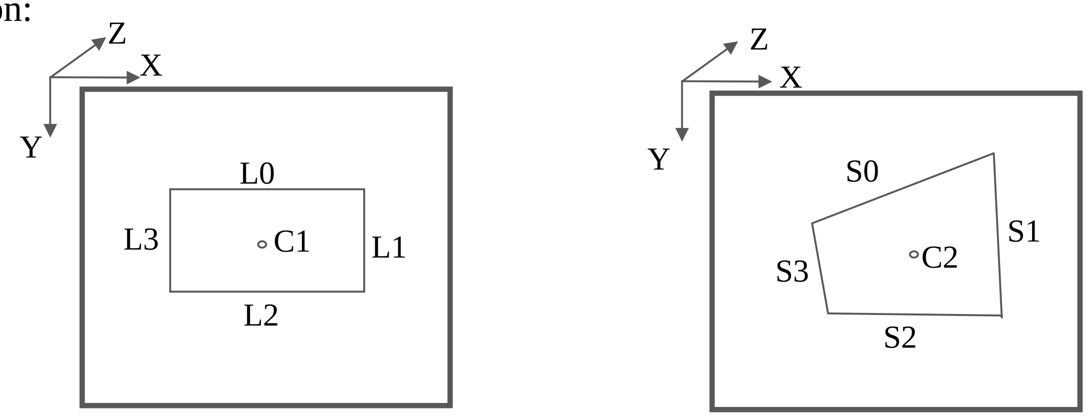
- Line segments corresponding to a planar object.

b. Output: - A series of motion transformations that bring the head (ie, camera) from the initial view to the reference view.





c. Solution description:



Step 1: Derive the equations for computing the translation vector:

$$Tx = k_1 \bullet (x_{c2} - x_{c1})$$
$$Ty = k_2 \bullet (y_{c2} - y_{c1})$$
$$Tz = k_3 \bullet (L_0 - S_0)$$

Step 2: Derive the equations for computing the three rotation angles:

$$\theta_X = k_4 \bullet [(S_0 / L_0 - 1) + (L_2 / S_2 - 1)]$$
$$\theta_y = k_5 \bullet [(S_1 / L_1 - 1) + (L_3 / S_3 - 1)]$$
$$\theta_Z = k_6 \bullet sign \bullet a\cos(S_0 \bullet L_0)$$

d. Experimental Results:

System Setup

Reference Image taken at the Reference View

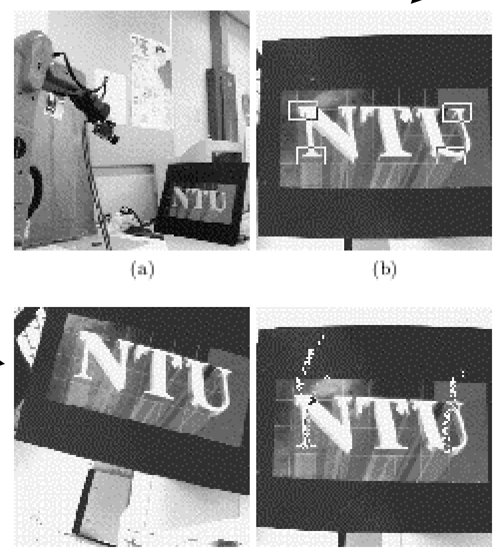


Image taken at an initial view

Image taken at the final view after moving the camera with the series of computed motion transformations.

SUMMARY

1. Head-Eye coordination is an interesting problem in industry.

2. The problem definition for Head-Eye coordination is “how to compute the head’s motion that moves the vision system so that the observed images converge to a reference image ?”.

3. There are two categories of solutions for vision-guided robotic head:

    a) Deterministic method(s).
    (The two-views method is one example)

    b) Iterative methods.
    (The planar-rectangle method is one example)