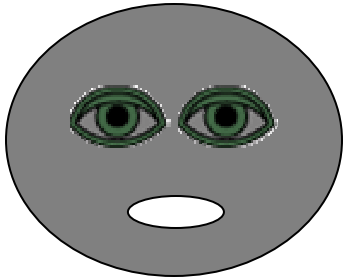
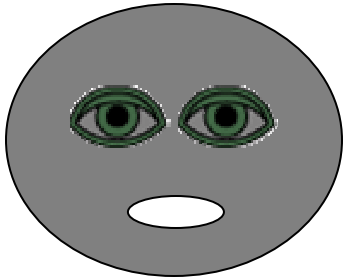


Robot Vision: A Holistic View

Behavior-based Vision



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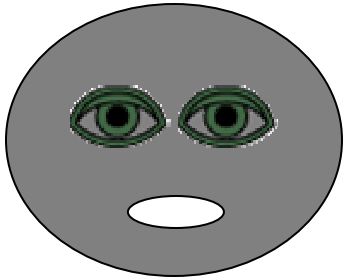
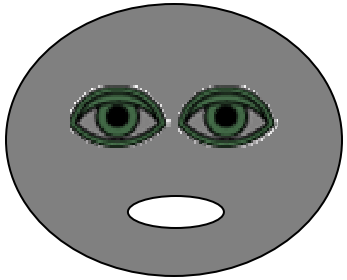


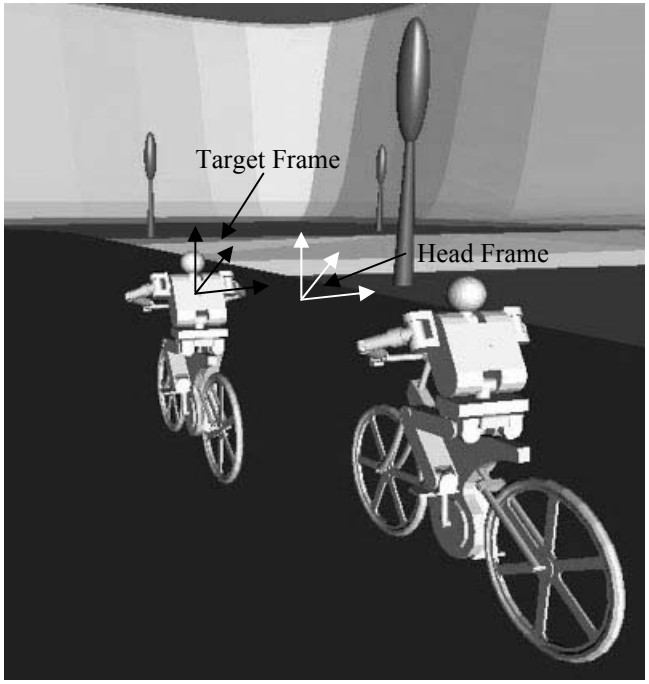
Introduction

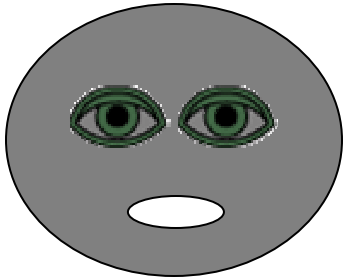
- Behavior-based vision was popularized by Shirai et al (1973), Sanderson et al (1987), Espiau et al (1992), and many others.
- Behavior-based vision studies the aspect of using vision to provide sensory feedback to a robot's control system.
- We know that vision is an effective mean to acquire signal, information and knowledge about a scene or object.
- We also know that the ultimate goal of sensing and understanding a scene is to enable decision-making and action-taking.
- Therefore, one primary objective of vision is to guide behaviors of an intelligent and autonomous agent.
- In general, there are three generic scenarios of vision-guided behaviors: (a) vision-guided positioning, (b) vision-guided manipulation, and (c) vision-guided locomotion.



Introduction

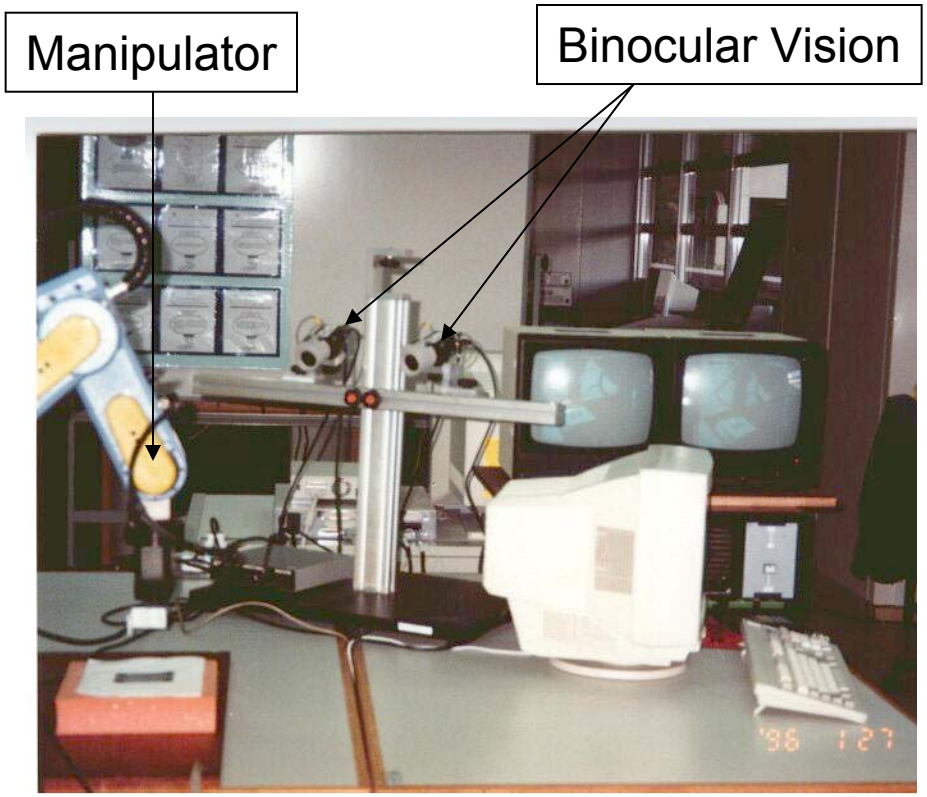
Illustration of Vision-guided Positioning





Introduction

Illustration of Vision-guided Manipulation



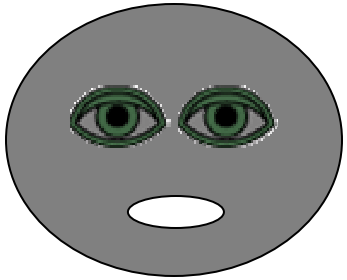


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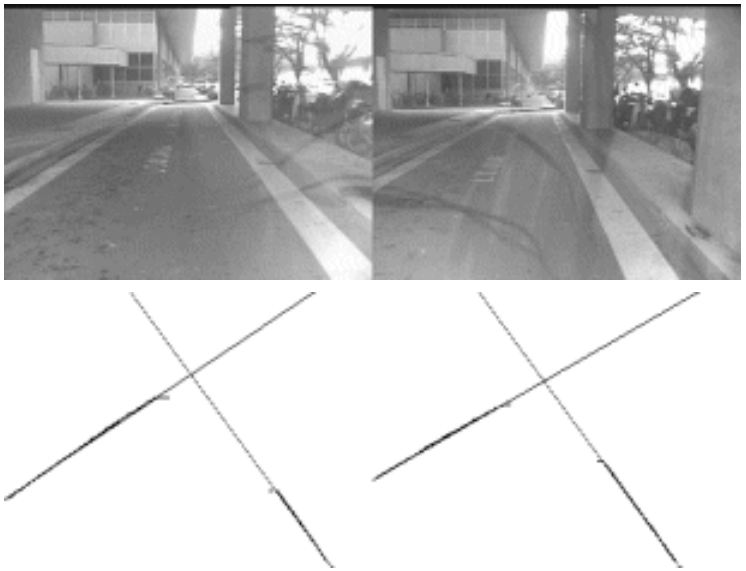
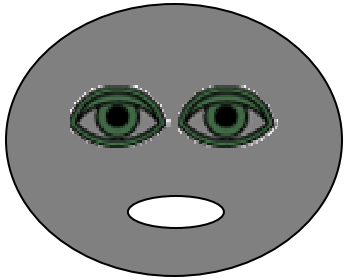
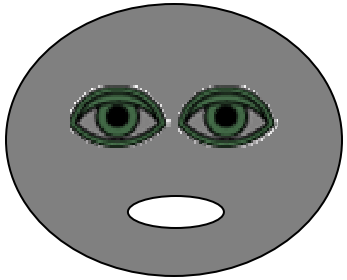
Illustration of Vision-guided Locomotion





Introduction

- In theory and practice, there are two different approaches to behavior-based vision.
- The first approach is called “inner-loop visual servoing”.
- The second approach is called “outer-loop visual servoing”.



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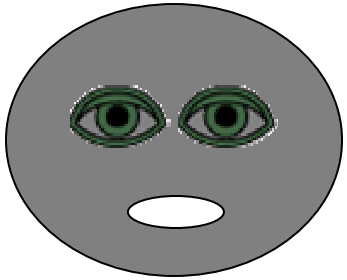
Future Challenge

Inner-loop Visual Servoing

- We have said that vision should be able to output signal, information and knowledge about a scene or object.
- At the level of signal, there are two interesting phenomena.
- The first interesting phenomenon is that the motion of a camera in operational space could be manifested in the form of velocity (or displacement) vector field in image space.
- Hence, the desirable motion in operational space could be mapped into the desirable motion in image space.
- This causality forms the basis of one type of visual servoing, called “inner-loop” visual servoing.
- In other words, it is possible to purposefully control eyes’ motion in operational space, in order to achieve the desired outcome (i.e. objective) specified in image space.
- And, the typical setting of inner-loop visual servoing is an eye mounted on a neck/body.

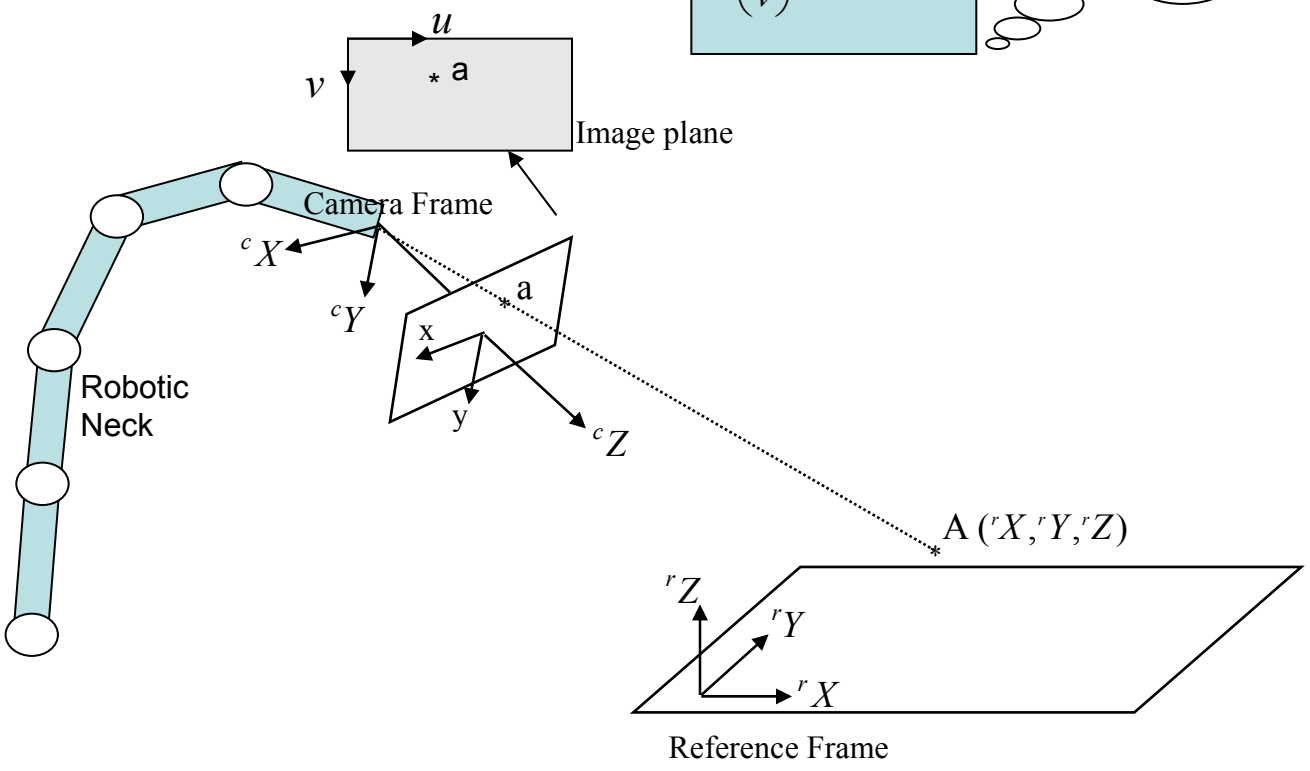


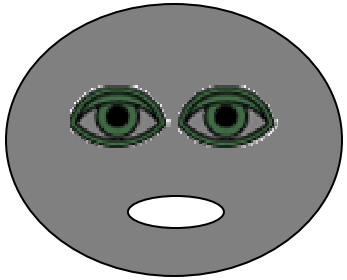
Inner-loop Visual Servoing

A General Setting

$$\begin{pmatrix} \dot{u} \\ \dot{v} \end{pmatrix} = J_{uv} \bullet \dot{q}$$

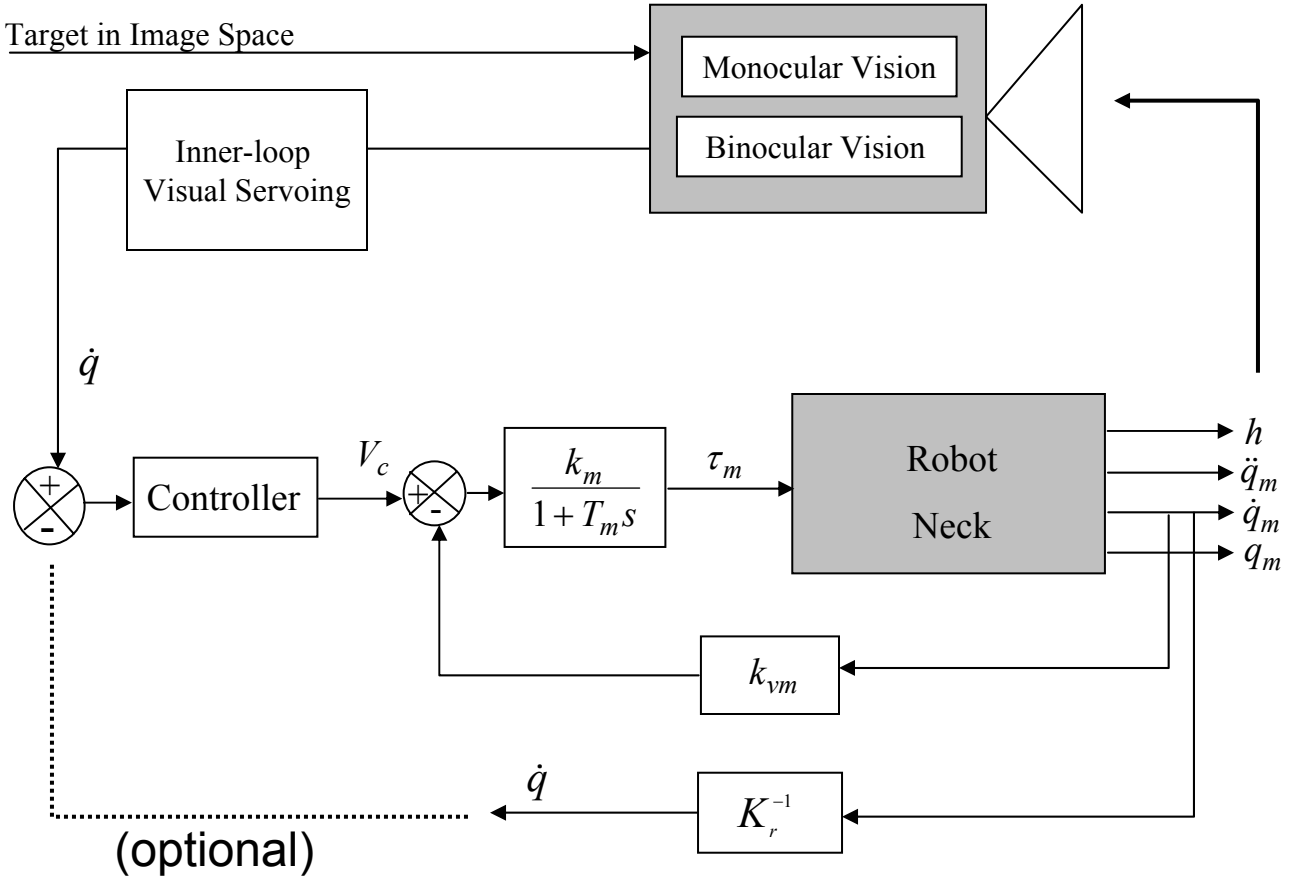
J_{uv} is called "image Jacobian"

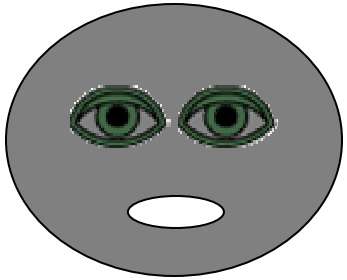




Inner-loop Visual Servoing

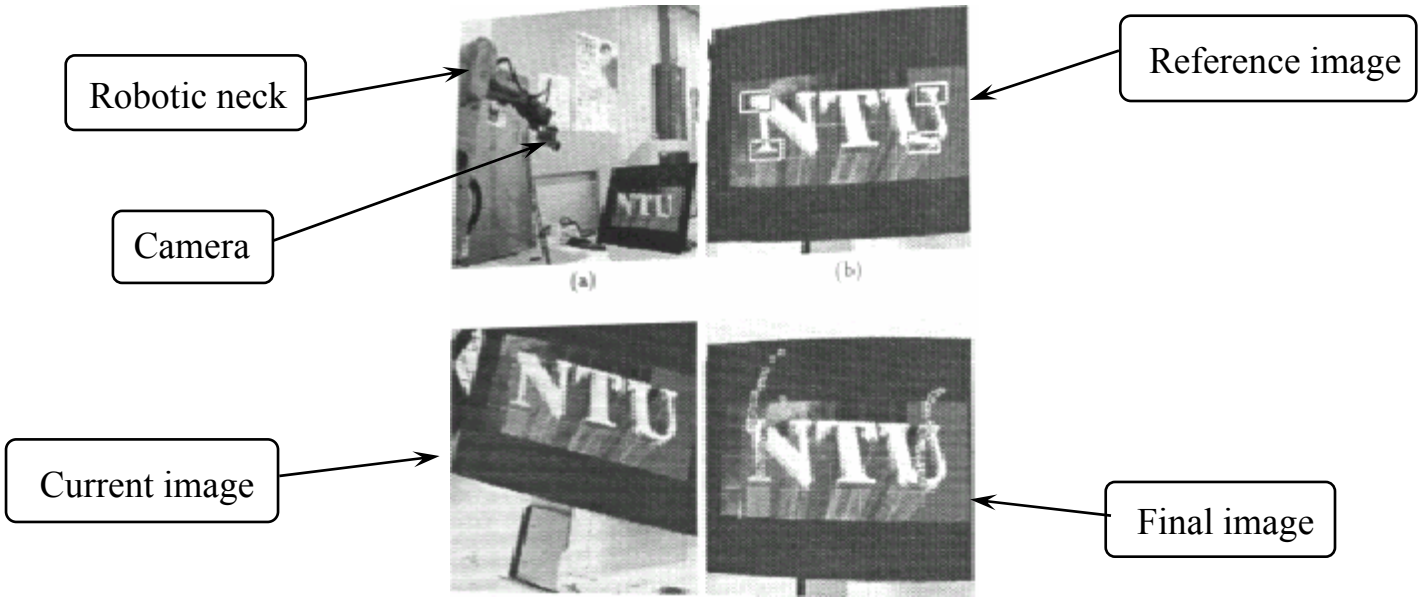
Schematic Diagram of Inner-loop Visual Servoing

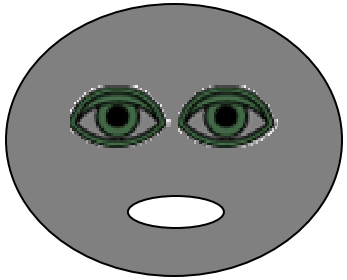




Inner-loop Visual Servoing

Example

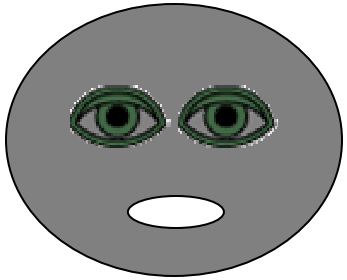




Inner-loop Visual Servoing

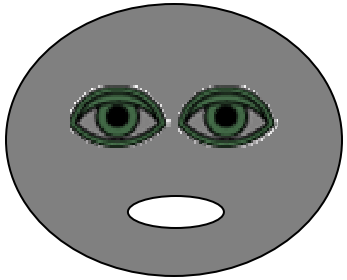
For more details, see the following reference:

Espiau, B., Chaumette and Rives, P.: **A New Approach to Visual Servoing in Robotics**. *IEEE Transaction on Robotics and Automation 8* (1992) 313--326.



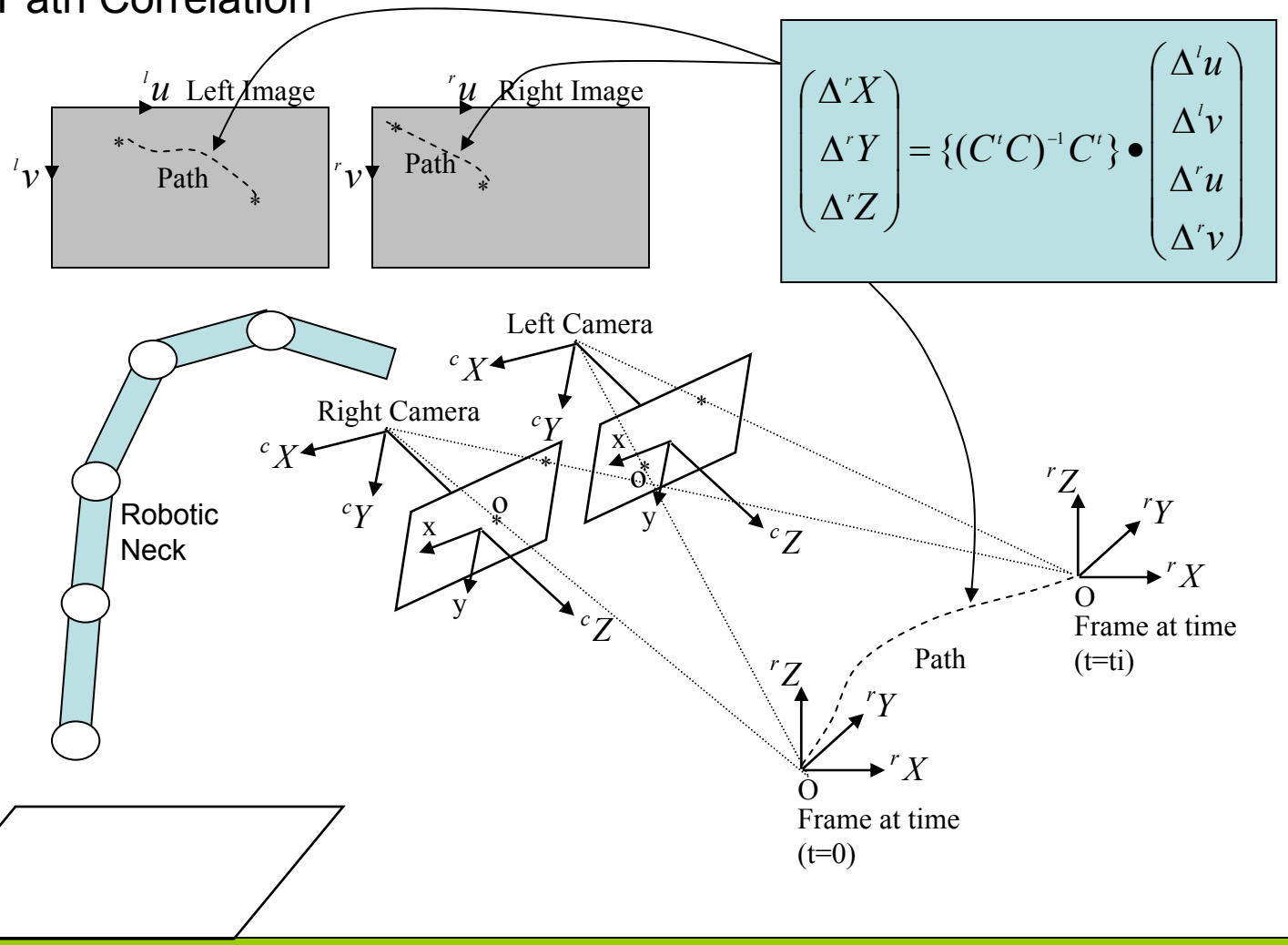
Outer-loop Visual Servoing

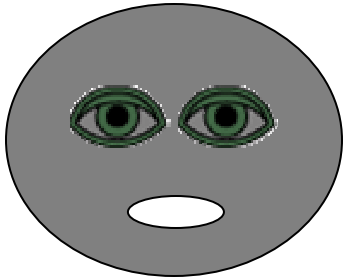
- There are two concerns about inner-loop visual servoing.
- First of all, the image Jacobian depends on many variables, including the depth, camera parameters, and robot's Jacobian matrix.
- Secondly, it is better to do visual servoing at the outer loop.
- With the setting of two cameras and the principle of qualitative binocular vision, the second interesting phenomenon of vision, at the level of signal, is that there is a simple correlation between a path in task space and a corresponding path in image space.
- This simple correlation of paths forms the basis of image-guided motion planning and control, which is also called "outer-loop" visual servoing.
- With the outer-loop visual servoing, it is possible to automate the process of planning the desired motion, followed by motion execution.
- This means that a robot could gain the autonomy at the level of motion execution (i.e. to self-specify the desired motion and to automatically achieve it).



Outer-loop Visual Servoing

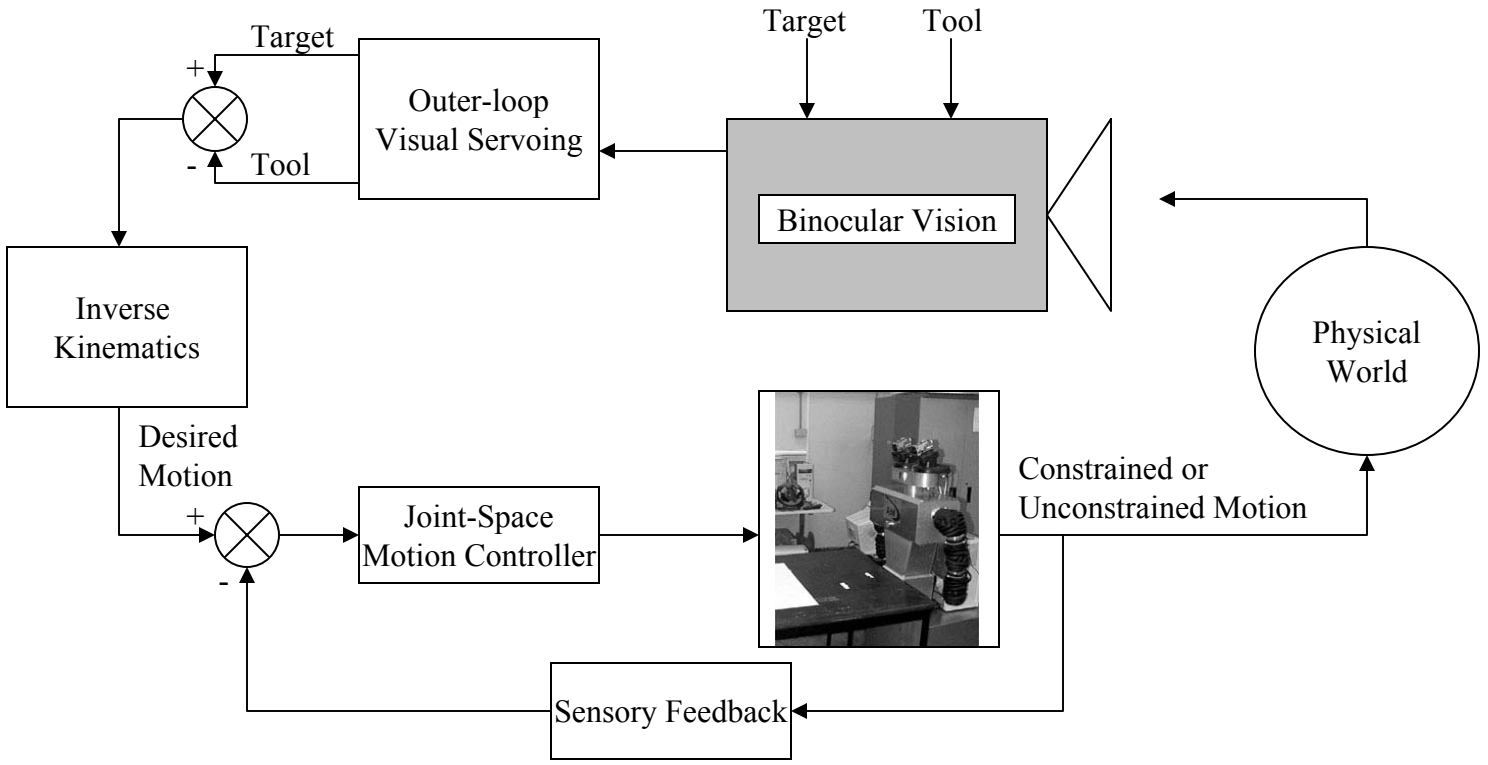
Path Correlation

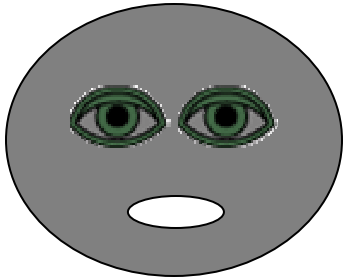




Outer-loop Visual Servoing

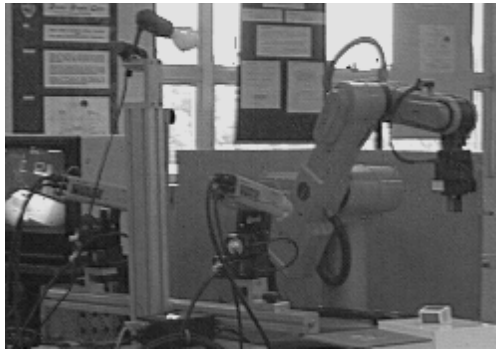
Schematic Diagram of Outer-loop Visual Servoing

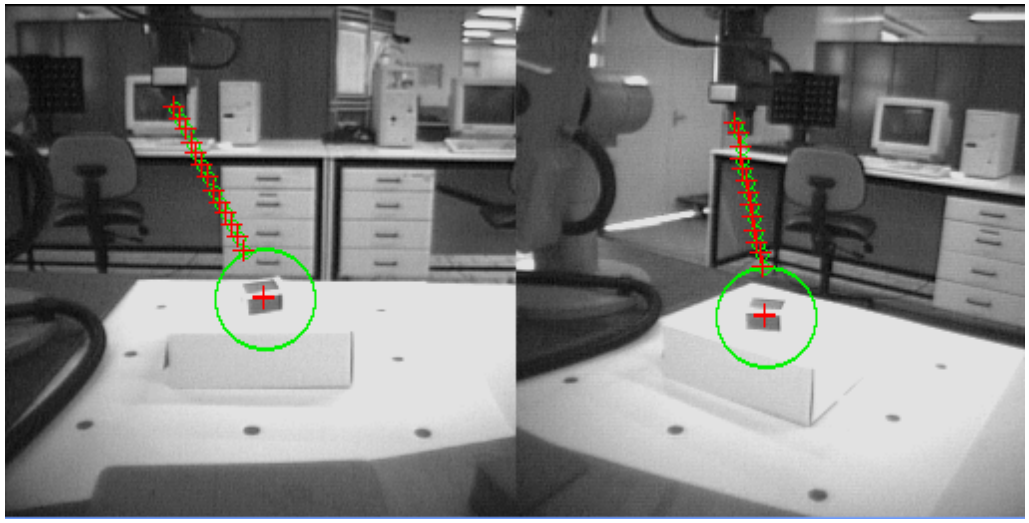




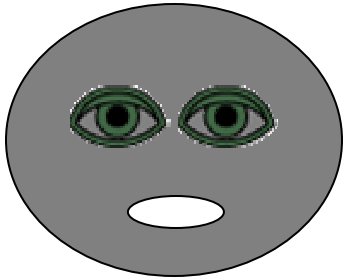
Outer-loop Visual Servoing

Example





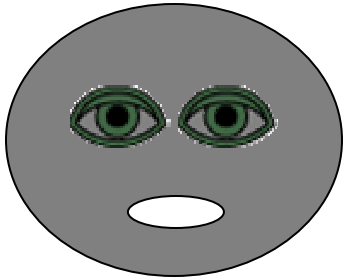
Trajectories in Image Space



Outer-loop Visual Servoing

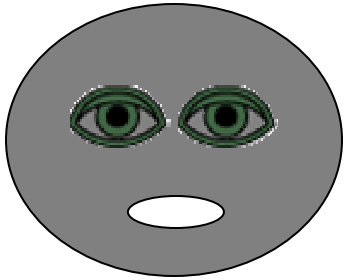
Video

Run



Future Challenge

- With the outer-loop visual servoing, a robot could achieve the autonomy at the level of motion planning and control.
- The future challenge is for a robot to achieve the autonomy at the level of action planning and control, or even task planning and control.
- This means that a robot of tomorrow should be able to understand behaviors, events, and episodes occurring in a scene.
- In other words, it is necessary for robot vision not only to process images or videos, but also to understand images or videos.
- Hence, cognitive vision is a must in robotics in future.



End of Behavior-based Vision