IVR: Visual Servoing

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informatics

Overview

- Model-based control
- Visual servoing task
- What is a Jacobian?
- Visual servoing task
- Implications for robot control

PROBLEM: Guiding a robot to a target based on images

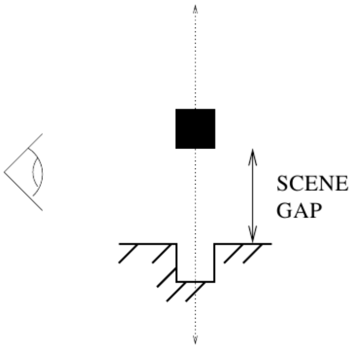
APPLICATIONS:

- Assembly robotics: Component insertion
- Mobile robotics: Docking

$\Longrightarrow$ VISUAL SERVOING THEORY

QUESTION

If only vertical robot motion possible (and sufficient) to reduce the gap:



How to get peg exactly into hole?

APPROACH 1: MODEL DRIVEN

KNOWN:

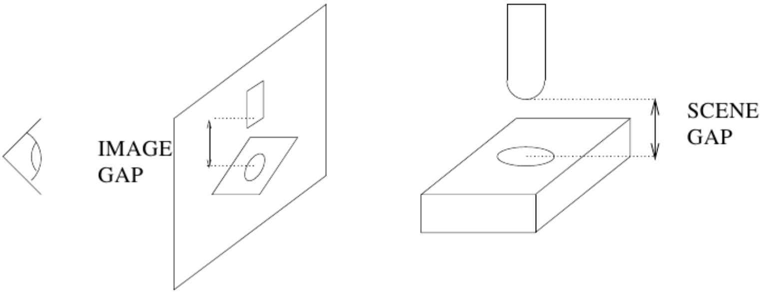
- Robot manipulation model
- Part & robot position known
- Target model
- Camera calibrated

BUT: errors exist and combine - noise, unknowns, gear backlash

SO: need very accurate calibration & mechanisms

TRY 2: VISUAL SERVOING

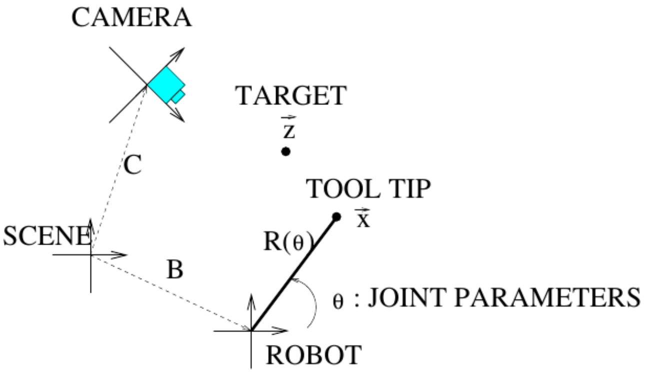
Move so that observed positions directly link to task distances



- Incrementally move to reduce image gap
- Don't know exact positions

MORE FORMAL MODEL

CONSIDER:



VARIOUS QUANTITIES

B - ROBOT POSITION WRT SCENE

C - CAMERA POSITION WRT SCENE

P - CAMERA PROJECTION MODEL

$\vec{\theta}$ - ROBOT JOINT PARAMETERS

$R\left(\vec{\theta}\right)$ - TOOL POSITION WRT ROBOT

LINKING EQUATION

IF:

- $\vec{x}$ - TOOL TIP WRT TOOL
- $\vec{z}$ - TARGET WRT SCENE
- $\vec{a}$ - IMAGE OF TOOL TIP
- $\vec{b}$ - IMAGE OF TARGET

THEN (as a concatenation of appropriate transformations):

- $\vec{a} = PC^{-1}BR(\theta)\,\vec{x}$
- $\vec{b} = PC^{-1}\vec{z}$

APPROACH 1: MODEL DRIVEN

Calibrate P, C, B, $R\left(\vec{\theta}\right)$ accurately

SOLVE: $\vec{\theta} = \vec{f}(\vec{z}, \vec{x}, P, C, B)$

Hard analytics

Not always solvable

APPROACH 2: VISUAL SERVOING

How much to move joints ($\Delta\vec{\theta}$) to reduce target error $\vec{\Delta} = \vec{a} - \vec{b}$?

Visually estimate $\vec{f}(\cdots)$ such that $\Delta\vec{\theta} \doteq \vec{f}(\vec{\Delta})$

Use $\Delta\vec{\theta}$ to partially approach target and recompute $\vec{\theta}$

Iterate

ESTIMATING $\vec{f}()$

Move robot joint i slightly from θ_i to $\theta_i + \varepsilon$

Observe tool tip moves slightly from $\vec{a}$ to $\vec{a} + \vec{\delta}_i$

Compute:

$$\frac{\partial \vec{a}}{\partial \theta_i} \doteq \frac{\left(\vec{a} + \vec{\delta}_i\right) - \vec{a}}{(\theta_i + \varepsilon) - \theta_i} = \frac{\vec{\delta}_i}{\varepsilon}$$

Repeat for all i to estimate JACOBIAN matrix

$$J = \frac{1}{\varepsilon}\left[\vec{\delta}_1, \ldots, \vec{\delta}_N\right]$$

for N joints.

USING THE JACOBIAN

Linear theory:

$$\vec{\Delta} \doteq J \Delta \vec{\theta}$$

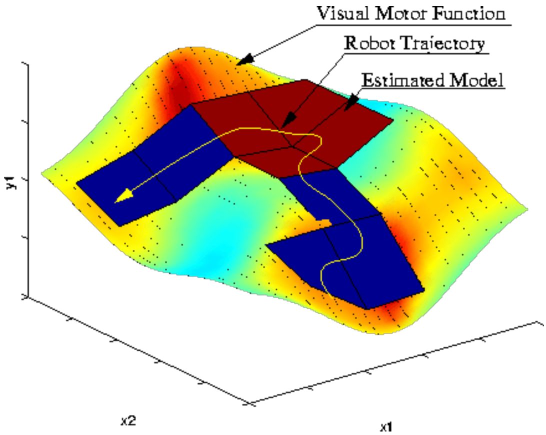
J is $2 \times N$, so use pseudo-inverse

$$\Delta \vec{\theta} = \left(J^\top J\right)^{-1} J^\top \vec{\Delta}$$

But J is only approximate and not true inverse?

So, move $\alpha \Delta \vec{\theta}$ and iterate ($\alpha < 1$)

SERVOING ALGORITHM



see Perceptual Actions: Vision Based Uncalibrated Robot Control by Martin Jägersand

SERVOING ALGORITHM

DO

Compute $\vec{\Delta}$

Estimate J

Compute $\Delta\vec{\theta}$

Move joints $\alpha\Delta\vec{\theta}$ where $0 < \alpha < 1$

WHILE $\|\vec{\Delta}\| > \tau$ pixels

$\tau > 1$? Maybe robot is 'shakey'

CONVERGENCE?

If α small enough, should always be reducing Δ

As J is linear, moving $\alpha\Delta\vec{\theta}$ should reduce position error by approximately $\alpha\vec{\Delta}$

CONVERGENCE

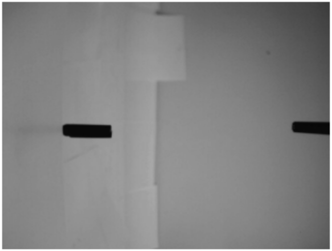
STEP	MOVEMENT	REMAINDER
1	$\alpha\|\vec{\Delta}\|$	$(1-\alpha)\,\|\vec{\Delta}\|$
2	$(1-\alpha)\,\alpha\|\vec{\Delta}\|$	$(1-\alpha)^2\,\|\vec{\Delta}\|$
	$\dots$	
n	$(1-\alpha)^{n-1}\,\alpha\|\vec{\Delta}\|$	$(1-\alpha)^n\,\|\vec{\Delta}\|$

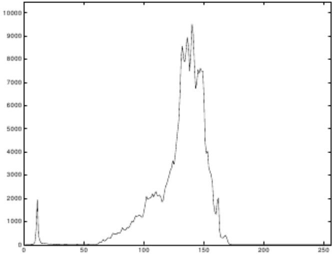
Total movement:

$$\sum_{n=1}^{\infty}(1-\alpha)^{n-1}\,\alpha\|\vec{\Delta}\| = \frac{1}{1-(1-\alpha)}\alpha\|\vec{\Delta}\| = \|\vec{\Delta}\|$$

VISUAL SERVOING RESULTS 1

Initial position and histogram (#pixels per gray level)

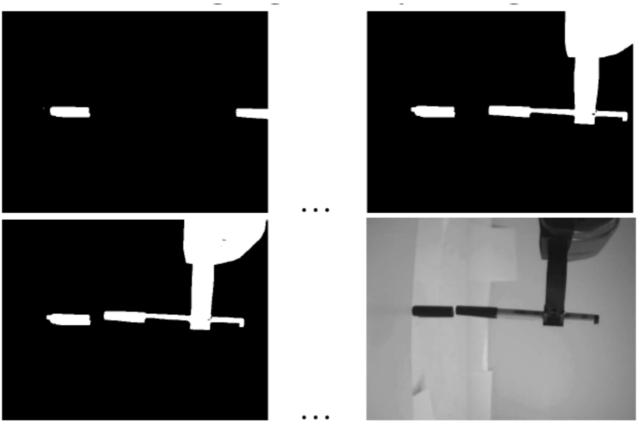




Camera on side

VISUAL SERVOING RESULTS 2

Note: changing binary images



5 iterations

Discussion

- Usually more cameras (image-based visual servoing)
- If the pose of the robot can be estimated based on a robot model a single camera may be sufficient (position-based visual servoing)
- Precision is improved by combination with force feedback
- Camera movements and other sources of errors
- Related problem: Camera positioning; track following in autonomous robots

Summary on visual servoing

- Servoing versus model based control
- Basics of visual servoing
- Linear approximations are usually safe if small steps are taken
- What about efficiency, dynamics, inertia, friction?
  $\Rightarrow$ control theory

Java-based Visual Servo Simulator:
http://www.robot.uji.es/research/projects/javiss

Further reading:

S. Hutchinson, G. D. Hager, P. I. Corke (1996) A tutorial on visual servo control. *IEEE Transactions on Robotics and Automation* **12**:5, 651-670.