Robots and Intelligent Control

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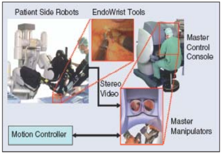
Outline

Robots

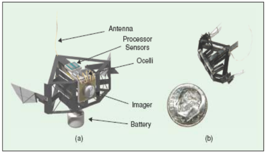
- Many definitions have been suggested for what we call a robot, ranging from a simple material handling device to a humanoid.

Industrial manipulator

Mars Rover



Surgical robot



Robotic Flies

Microrobotics

Definition

- Microrobotics include the manipulation, design, and fabrication of objects with characteristic dimensions in the millimeter to micrometer range.

Application

- Microrobotics have been proposed for numerous applications ranging from manipulation of biological cells, biomedical therapy and military reconnaissance.

Challenge

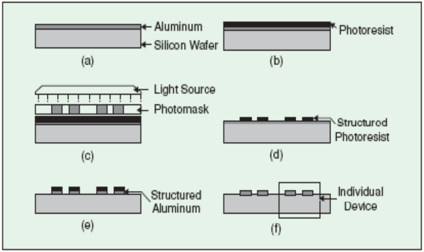
- The scaling of physical effects makes even the simplest manipulation tasks challenging. In addition, traditional fabrication and power supply method becomes unfeasible at the microscale.

Microfabrication

- Microfabrication technologies are based on fabrication processes that have been developed for the semiconductor industry.
- Traditional micro-fabrication methods are limited to planar two-dimensional (2-D). For micro-electromechanical systems (MEMS), new processes and three-dimensional (3-D) fabrication methods are continually being developed and improved.
- Devices are normally fabricated on silicon wafers, but other materials such as glass or polymer substrates are also used.

Microfabrication (Continued)

- Structures on the wafer are created by a sequence of fabrication steps performed in a clean-room facility: deposition, pattern transfer, and etching. Deposition processes are used to create thin films of a material on the wafer.



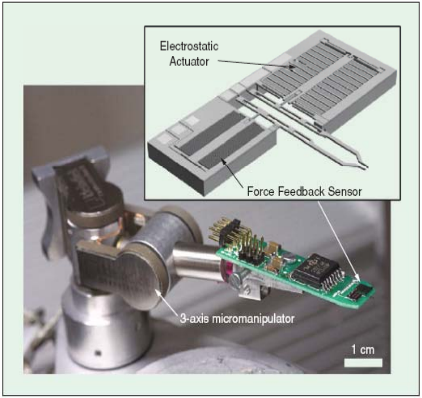
Fabrication of aluminum electrodes on a wafer.

Micromanipulation

Definition and application

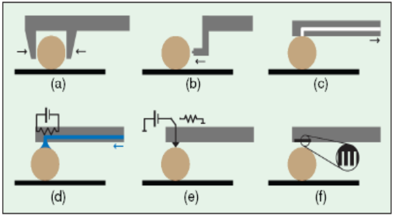
- Micromanipulation is the robotic manipulation of objects with characteristic dimensions in the millimeter to micrometer range.
- Single-axis and multi-axis micromanipulators are commercially available with a travel range of a few millimeters or centimeters and with a resolution typically better than 1μm.
- Stages are typically driven by dc motors, stepper motors, or piezo drives. Some micromanipulators provide encoders for accurate position feedback.

micromanipulation



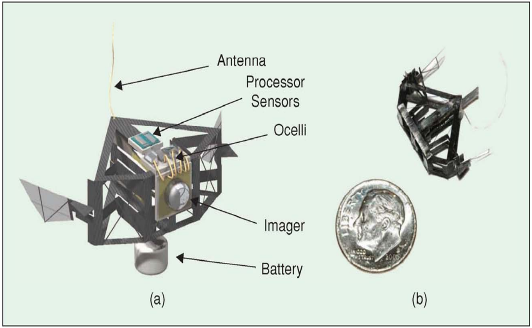
MEMS force-feedback microgripper mounted on a Kleindiek MM3A three-axis piezo-driven micromanipulator.

Microassembly



. *Strategies for gripping microparts. (a) Using traditional gripping methods, the part is released when gravity pulls it away from the gripper. (b) Impulsive forces can can be used to push the part in a desired direction. (c) A vacuum becomes efficient as scale reduces, since the weight of the part decreases relative to the surface area. (d) Surface tension due to fluids (water) can be used to hold parts. The water can be vaporized to release the part. The water can also be frozen to form a rigid connection. (e) Electrostatic charges can be used to grip parts. Grounding the charge can be used to release the part. (f) Changes in surface roughness lead to changes in van der Waals forces, since surface molecules are farther apart, on average, with rough surfaces than with smooth. A part can be gripped with a smooth portion of the gripper, and then released by rolling/sliding it to a rough portion.*

Microrobotics



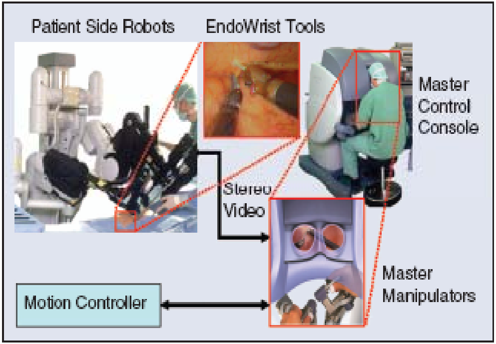
(a) Artist's conception and (b) current prototype of the micromechanical flying insect. Images courtesy Ronald S. Fearing and Robert J. Wood, University

Surgical Assistance

Key features

- The goal of surgical robots is not to replace the physician with a machine but, rather, to provide intelligent, versatile tools that augment the physician's ability to treat patients.
- In some cases, the robot operates side by side with the physician and performs functions such as endoscope holding, tissue retraction, or limb positioning. These systems typically provide one or more direct control interfaces such as joysticks, head trackers, or voice control to assist the physician.

Technology and challenges

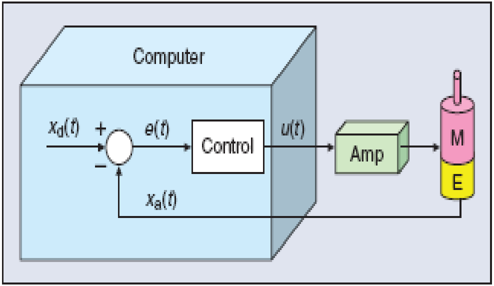


The da Vinci surgical system

Technology and challenges

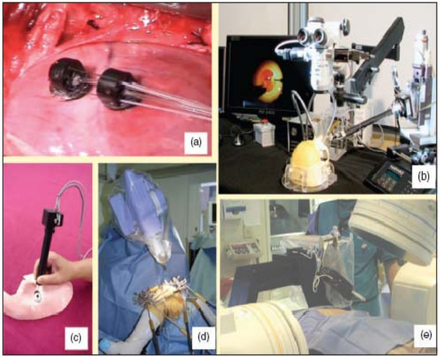
- Surgical robots present design challenges due to the requirements for miniaturization, safety, sterility, and adaptation to changing conditions.
- Surgical robots must satisfy requirements not found in industrial robotics. They must operate safely in a work space shared with humans; they generally must operate in a sterile environment; and they often require high dexterity in small spaces.

Motor control in surgery robot



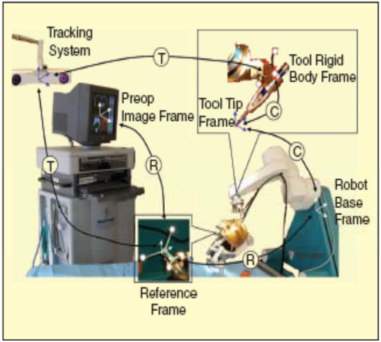
Computer control of a robot joint, showing Motor(M), Encoder(E), and Power amplifier(Amp).

Examples of surgery robots



Robots for surgical assistants. (a) The Heartlander [37].
(b) The JHU steady-hand robot for retinal surgery. (c) Carnegie Mellon University (CMU) micron. (d) Acrobot for knee surgery. (e) JHU remote center of motion (RCM) robot for nerve and facet blocks in clinical trial at Georgetown University.

Tracking and Registration

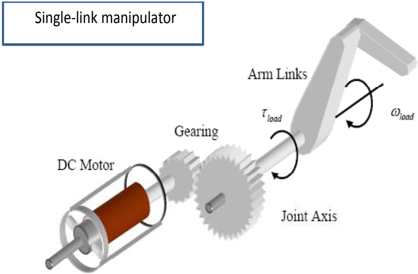


Coordinate transformations for a sample image-guided robot system

Robot dynamics

The dynamics of a single-link manipulator with friction is

$$I\ddot{\theta} = \tau - \tau_f, \tag{1}$$



Robot dynamics

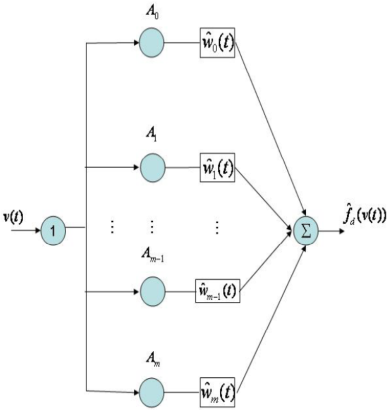
For control designs, the exponential model given below retains relatively simple form while being able to capture essential features of sliding friction

$$\tau_f(\alpha, v) = [\alpha_0 + \alpha_1 \mid v \mid + (\alpha_2 - \alpha_0) e^{-|v/v_s|^{\alpha_3}}] \cdot \mathrm{sgn}(v) + d_m(t) \quad (2)$$

Motivation

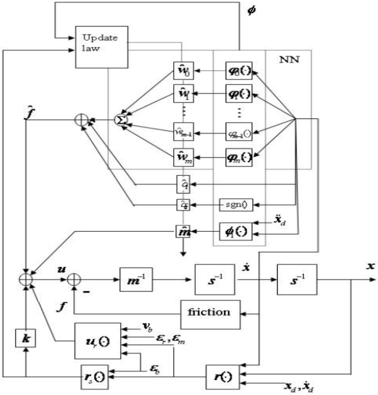
Since the friction is generally unknown and nonlinearly parameterized, neural networks can be invoked for its approximation.

Robot dynamics



Single-layer Neural network

Robot dynamics

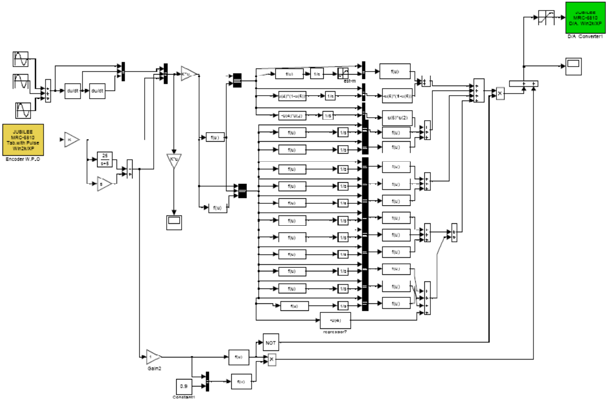


Close-loop diagram

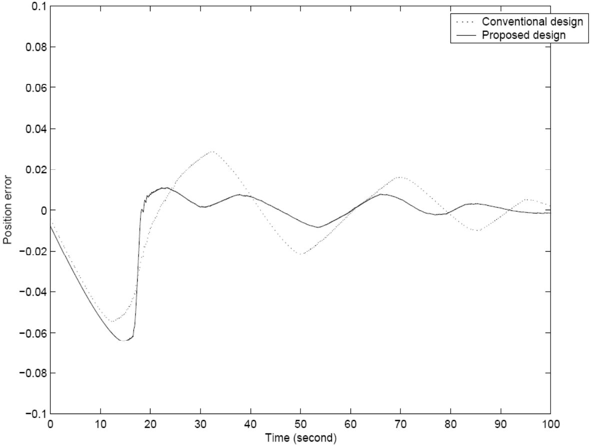
Robot dynamics

Matlab-based robot manipulator

Robot dynamics

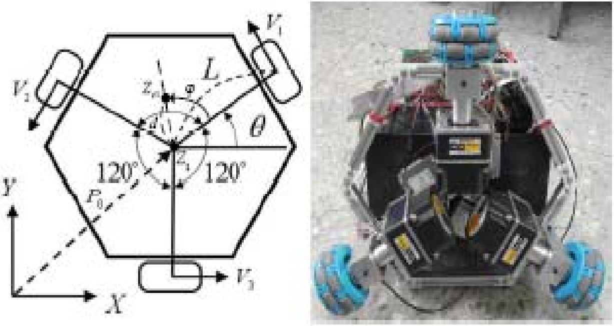


Simulink program



Tracking results

What is wheeled mobile robot and why is it important?



Three-wheel mobile robot

Application of wheeled mobile robot

Applications

- Space robot.
- Factory automation.
- Service robot.

Methods

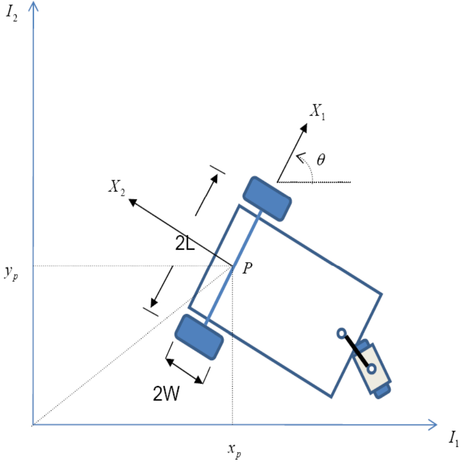
- Intelligent control.
- Robust control.
- Adaptive Backstepping control.

Control Approaches

Implementation

- PC-based Scheme (Matlab xPC tool).
- DSP chip (TI F2407A).
- FPGA (Altera, etc).

Schematic diagram



Two drive-wheel robot

Mathematical model

The constraint kinematics and dynamics can be respectively written as follows

$$\dot{q} = \begin{bmatrix} -\sin\theta \\ \cos\theta \\ 0 \end{bmatrix} v_1(q) + \begin{bmatrix} 0 \\ 0 \\ 1 \end{bmatrix} v_2(q), \tag{3}$$

and

$$\begin{bmatrix} m & 0 & 0 \\ 0 & m & 0 \\ 0 & 0 & I_0 \end{bmatrix} \begin{bmatrix} \ddot{x}_p \\ \ddot{y}_p \\ \ddot{\theta} \end{bmatrix} = \frac{1}{W} \begin{bmatrix} -\sin\theta & -\sin\theta \\ \cos\theta & \cos\theta \\ L & -L \end{bmatrix} \begin{bmatrix} \tau_1 \\ \tau_2 \end{bmatrix} + \lambda \begin{bmatrix} \cos\theta \\ \sin\theta \\ 0 \end{bmatrix} \tag{4}$$

Controller

The proposed virtual controllers are given by

$$\begin{aligned}
\alpha_1 &= 0, \\
\alpha_2(\bar{e}_2, u_{d,1}) &= -k_{z,2} u_{d,1}^{\bar{n}} z_2, \\
\alpha_j(\bar{e}_j, \bar{u}_{d,1}^{(j-2)}) &= -z_{j-1} - k_{z,j} u_{d,1}^{\bar{n}} z_j + \sum_{k=1}^{j-1} \frac{\partial \alpha_{j-1}}{\partial e_k} e_{k+1}, \\
&\quad + \frac{1}{u_{d,1}} \sum_{k=0}^{j-2} \frac{\partial \alpha_{j-1}}{\partial u_{d,1}^{(k)}} u_{d,1}^{(k+1)} \quad 3 \leq j \leq n-1 \\
u_{b,1} &= u_{d,1} + \eta, \qquad (5)
\end{aligned}$$

$$u_{b,2} = u_{d,2} - u_{d,1} z_{n-1} - k_{z,n} z_n + u_{d,1} \sum_{k=1}^{n-1} \frac{\partial \alpha_{n-1}}{\partial e_k} e_{k+1} + \sum_{k=0}^{n-2} \frac{\partial \alpha_{n-1}}{\partial u_{d,1}^{(k)}} u_{d,1}^{(k+1)}, \tag{6}$$

where $\bar{n} = 2k + 1, k \geq n - 3$ and $\eta \in R$ is a dynamic variable obeying

$$\dot{\eta} = -k_0 \eta - h_1 \tag{7}$$

with

$$h_1 = z_1 + \sum_{j=2}^{n-1} z_j \Big(y_{j+1} - \sum_{k=1}^{j-1} \frac{\partial \alpha_{j-1}}{\partial e_k} y_{k+1} \Big) - z_n \sum_{k=1}^{n-1} \frac{\partial \alpha_{j-1}}{\partial e_k} y_{k+1} \tag{8}$$

The torque input is specified as

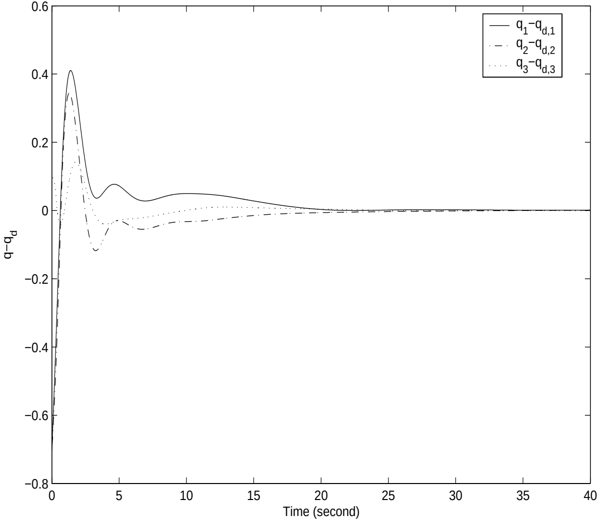
$$
\begin{aligned}
\tau &= \tau_a + \tau_r, \\
\tau_{a,i} &= \begin{cases} 0, & \text{when } \xi^T \hat{\mathcal{B}}_i = 0 \\ \frac{\rho_i \xi_i}{\xi^T \hat{\mathcal{B}}_i}(-k_a \xi_i - h_i + (\Phi \hat{\beta})_i), & \text{otherwise,} \end{cases} \quad i = 1, 2 \\
\tau_r &= -\sum_{i=1}^{2} (1 - \rho_i)[k_1 + \frac{k_2 \| h - \Phi \hat{\beta} \|}{\| \xi \|}] \mathcal{B}_s \xi, \qquad (9)
\end{aligned}
$$

The corresponding update algorithms for $\hat{\beta}$ and $\hat{\mathcal{B}}$ are given by

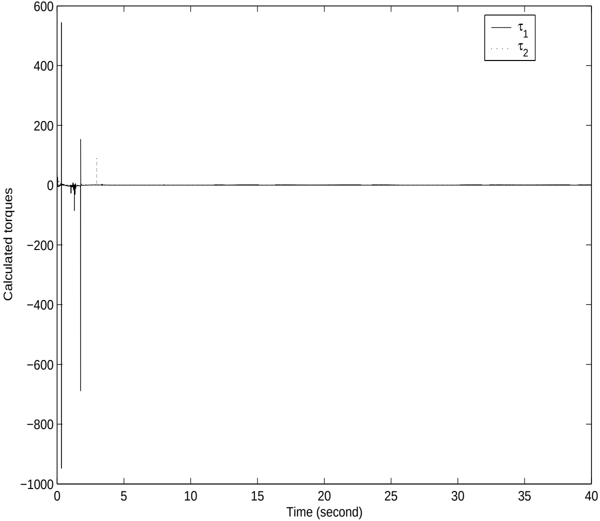
$$\begin{aligned} \dot{\hat{\beta}} &= -\gamma_a \Phi^T \xi, \\ \dot{\hat{\mathcal{B}}}_i &= \gamma_b \rho_i \frac{-\xi_i [k_a \xi_i + h_i - (\Phi \hat{\beta})_i]}{\xi^T \hat{\mathcal{B}}_i} \xi, \quad i = 1, 2 \end{aligned} \tag{10}$$

where $\gamma_a, \gamma_b > 0$ are the diagonal gain matrices.

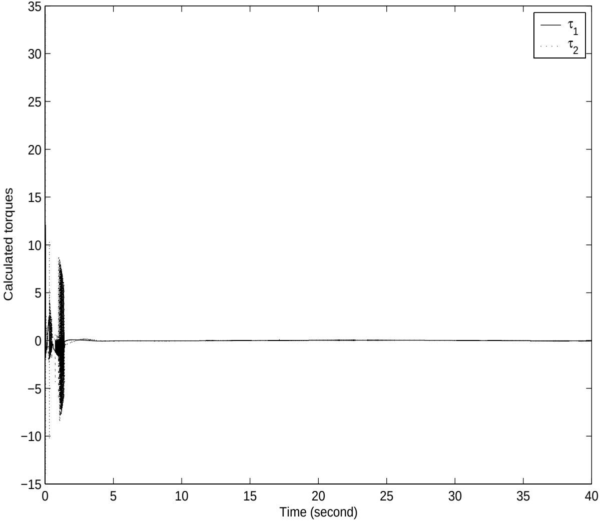
Trajectories of tracking errors



Torques of purely adaptive linearizing control



Torques of the switching adaptive control



The end!! Thank You!