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Control Grasp Force Using Tactile Feedback

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Technical Aspects of Multimodal Systems

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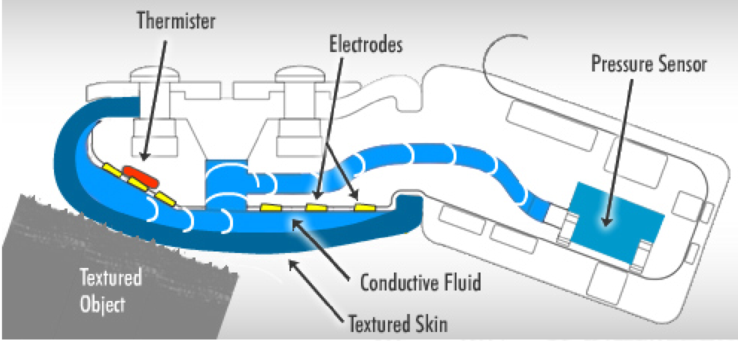
Outline

Motivation

https://www.youtube.com/watch?v=TH9i2ViM6Z4

Tactile Sensor: BioTAC

- deformable skin
- conductive fluid
- 19 electrodes
- thermister
- pressure sensor



Schematic of BioTAC sensor [1]

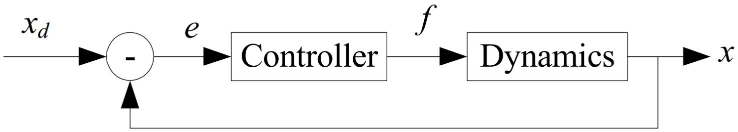
Coulomb's Law of Friction

- two contacting objects.
- friction coefficient μ_s.
- normal force F_N: orthogonal to surface.
- coulomb friction F_f: parallel to surface.
- tangential force F_t: opposite to F_f.
- slippage: F_t exceeds F_f

$$F_{t,min} > F_{f,max} = \mu_s F_N \tag{1}$$

Closed-loop Control

- desired value x_d
- current value x
- error e
- control command f



Closed-loop control circuit [2]

PID Controller

- P: proportional term with constant k_P
- I: integral term with constant k_I
- D: derrivative term with constant k_D

$$f = k_P e + k_I \int_0^t e dt + k_D \frac{de(t)}{dt} \quad (2)$$

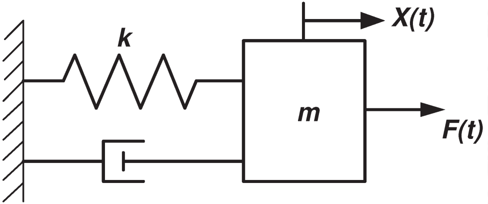
PID Controller

video

Impedance Control

- control the relationship of **force and motion**
- dynamics of interaction between robot and environment
- mass M, damping coefficient C, spring stiffness K,
- input: motion $\ddot{x}, \dot{x}, x$
- output: force F

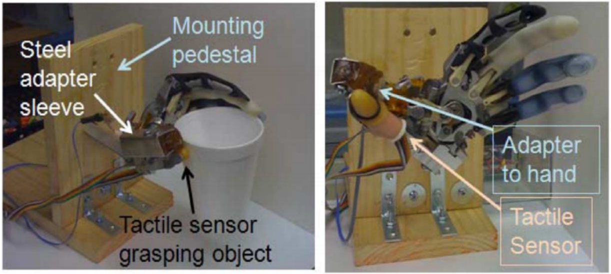
$$F = M(\ddot{x}_d - \ddot{x}) + C(\dot{x}_d - \dot{x}) + K(x_d - x) \quad (3)$$



[3]

Grip Control Using Biomimetic Tactile Sensing Systems
Nicholas Wettels, et. al, 2009

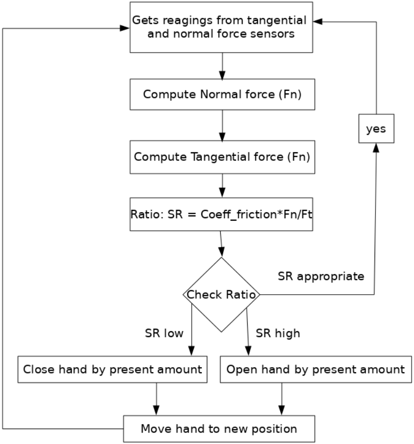
- static hand configuration with bioTac fingertips.
- grasping object with variable weights.
- determine tangential and normal forces in fingertips.
- applying Coulomb's law of friction to rank grasp force.
- controlling with proportional position controller.



Settings of experiment [4]

Force Control

- unknown friction coefficient is set to $\mu_s = 0.5$
- proportional position controller
- force too high $\rightarrow$ desired finger position x_d to a looser position
- force too high $\rightarrow$ desired finger position x_d to a tighter position

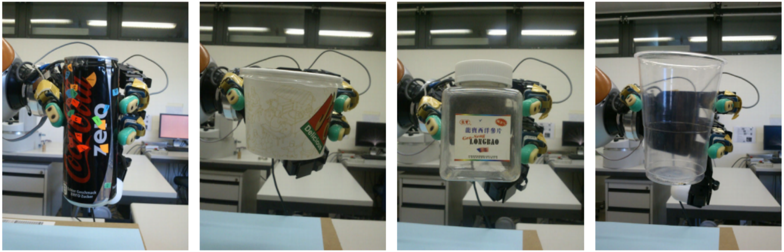


Grasp adjustment algorithm from [4]

Learning of Grasp Adaptation through Experience and Tactile Sensing

Mioa Li, et. al, 2014

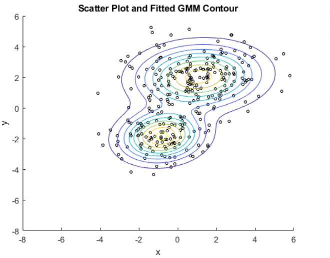
- grasping objects with variable weights
- dynamic hand configuration
- classifying grasps
- impedance controller



(a) cola can (b) food box (c) box (d) cup

Stability Estimation

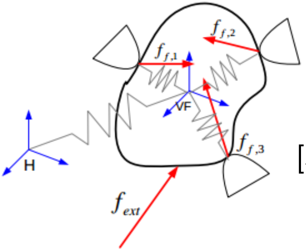
- Gaussian Mixture Model (GMM) Classifier
- one-class classification problem i.e. just positive training data
- training data consists of:
  - grasp stiffness $\{K_{g1}, K_{g2}, K_{g3}\}$
  - rest length $\{L_1, L_2, L_3\}$
  - tactile Readings $\{S_1, S_2, S_3\}$
- if new data point is classified as unstable, *Grasp Adaptation* is triggered



[6]

Impedance Controller for Grasp Stability

- Virtual Frame (VF): center frame of the object with position p_o
- stiffness K_i at each contact point i
- rest length L_i is the desired length between fingertip i and origin of VF
- p_i: current position of fingertip i
- $\Delta p_i = p_o - p_i$



[5]

$$f_{f,i} = K_i(||\Delta p_i|| - L_i)\frac{\Delta p_i}{||\Delta p_i||} \quad (4)$$

Grasp Adaptation

- distance d_{GM} between current grasp and each Gaussian component
- if $d_{GM} <$ *thresh Impedance Adaptation*
  - Adaptation of neighbours stiffness $K_{gi,n}$
  - increasing/decreasing K_{gi} in impedance controller increases/decreases contact force f_{gi}
- if $d_{GM} >$ *thresh Adaptation of Grasp Configuration*
  - Adaptation of neighbours rest length $L_{1,n}$
  - Idea: local exploration of object surface
  - Finger 1 tries to find a surface position that satisfies new rest length $L_{1,n}$
- `https://www.youtube.com/watch?v=UsPwmrYszbU&index=10&list=PLs3zEsp7m08VuXUhyf6z8q3jf-FRna5zO`

Overview: Slippage Detection methods

approach	slippage detection method
Wettels et al, 2009 [4]	*via Coulomb law of Friction* + based on physic background - object uncertainties are not handled $\rightarrow$ μ_s chosen approximately
Li et al, 2014 [5]	*via Gaussian Mixture Model* + handling of object uncertainties - Training $\rightarrow$ representative data has to be captured

Overview: Force Control methods

approach	controlling method
Wettels et al, 2009 [4]	*via position P-controller* + easy controller - incremental position control not reliable - proportional term leads to rest error
Li et al, 2014 [5]	*via object-based impedance controller* + relation of force and motion is considered

[1] SynTouch, "Overview of BioTac Sensory Technology," https://www.youtube.com/watch?v=W_O-u9PNUMU, 2012, [Online; accessed 26-Nov-2017].

[2] R. N. Jazar, *Theory of Applied Robotics: Kinematics, Dynamics, and Control*. Springer Publishing Company, Incorporated, 2007.

[3] MDPI, "Cluster Data from Mixture of Gaussian Distributions," http://www.mdpi.com/1099-4300/17/9/6289, 2015, [Online; accessed 09-Dec-2017].

[4] N. Wettels, A. R. Parnandi, J. H. Moon, G. E. Loeb, and G. S. Sukhatme, "Grip control using biomimetic tactile sensing systems," *IEEE/ASME Transactions on Mechatronics*, vol. 14, no. 6, pp. 718–723, Dec 2009.

[5] M. Li, Y. Bekiroglu, D. Kragic, and A. Billard, "Learning of grasp adaptation through experience and tactile sensing," in *2014 IEEE/RSJ International Conference on Intelligent Robots and Systems*, Sept 2014, pp. 3339–3346.

[6] MathWorks, "Cluster Data from Mixture of Gaussian Distributions," https://de.mathworks.com/help/stats/cluster-data-from-mixture-of-gaussian-distributions.html, 2017, [Online; accessed 26-Nov-2017].