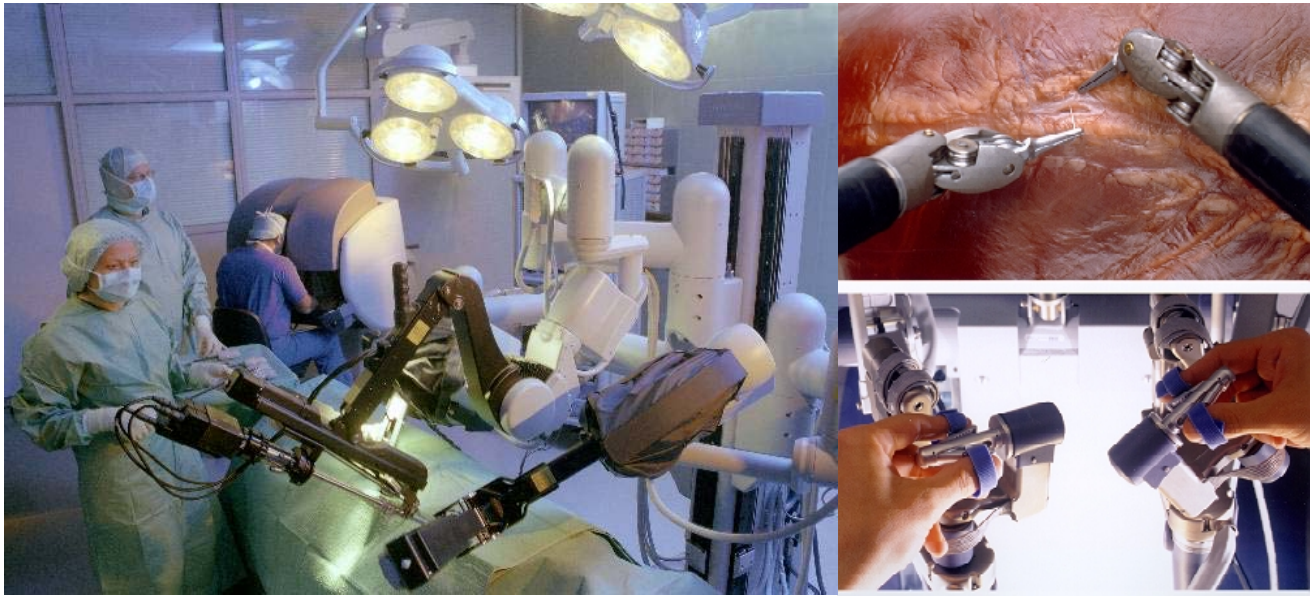
Contact Force Estimation in Teleoperated Robotic Surgery



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Interventional Centre

Rikshospitalet-Radiumhospitalet Medical Centre

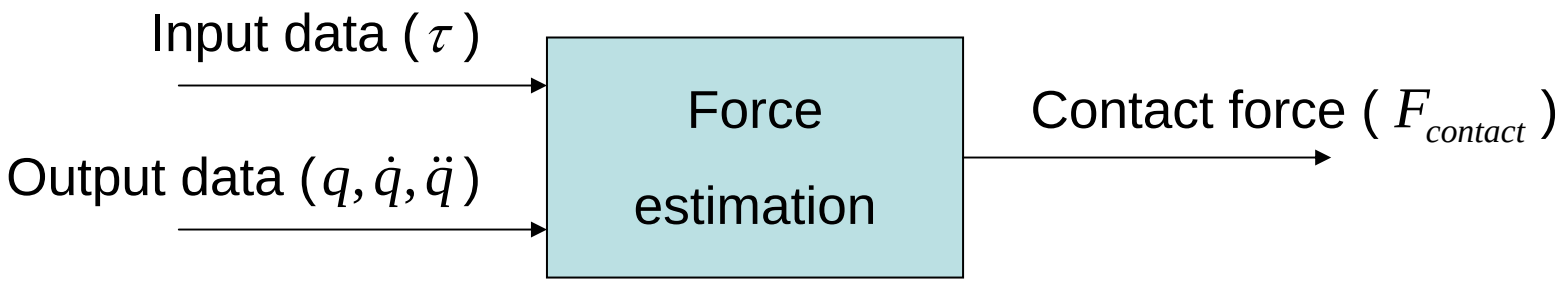
The Interventional Centre

- Established in 1996 as an R&D department at the Rikshospitalet University Hospital in Oslo
- Employs both clinical and technical personnel
- Link between technological institutions (both academic and commercial) and the clinical environments in the hospitals within the fields of minimally invasive and image guided therapy
- Four research areas:
  - MRI-guided therapy
  - Other image-guided therapy (CT, x-ray, ultrasound, video)
  - Robotics and simulators
  - Patient monitoring and telecommunication

Rikshospitalet University Hospital, Oslo, Norway

Estimating Robot-Environment Contact Forces

- Represents an alternative to *measuring* the contact force, which requires a force sensor
- Force sensor drawbacks:
  - Expensive (at least more expensive than not buying one)
  - Hard to make small enough to fit at the tip of a surgical instrument
  - Introduces additional electronics and cables
  - Must be sterilizable for clinical applications
- Instead, utilize the robot's input and output data to estimate the contact force



Robot Dynamics

- Force estimation with input/output data requires an accurate dynamic model of the robot

$$M(q)\ddot{q} + C(q,\dot{q})\dot{q} + N(q) + \tau_f(\dot{q}) = \tau$$

- Challenge: how do we model the friction?

$$\tau_f = ?$$

- The main part of the dynamic equation can be linearly parameterized

$$\underbrace{M(q)\ddot{q} + C(q,\dot{q})\dot{q} + N(q)}_{Y(q,\dot{q},\ddot{q})\theta} + \tau_f(\dot{q}) = \tau$$

- We would like a friction model on the same form

$$\tau_f(\dot{q}) = Y_f(\dot{q})\theta_f$$

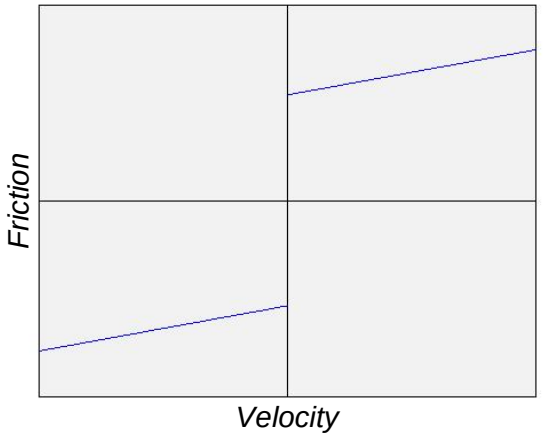
The Coulomb+viscous Friction Model

- The most common friction model in engineering

$$\tau_f(\dot{q}) = c_{Coulomb}\,\mathrm{sgn}(\dot{q}) + c_{viscous}\,\dot{q}$$

- Linear in the parameters

$$\tau_f(\dot{q}) = \begin{bmatrix}\mathrm{sgn}(\dot{q}) & \dot{q}\end{bmatrix}\begin{bmatrix}c_{Coulomb}\\ c_{viscous}\end{bmatrix} = Y(\dot{q})_f\,\theta_f$$



- Does there exist a friction model, in principle as simple as the Coulomb+viscous model, but with better performance?
  - Main requirement: linearity in the model parameters
  - Main assumption: friction can be sufficiently modeled as a static function of velocity

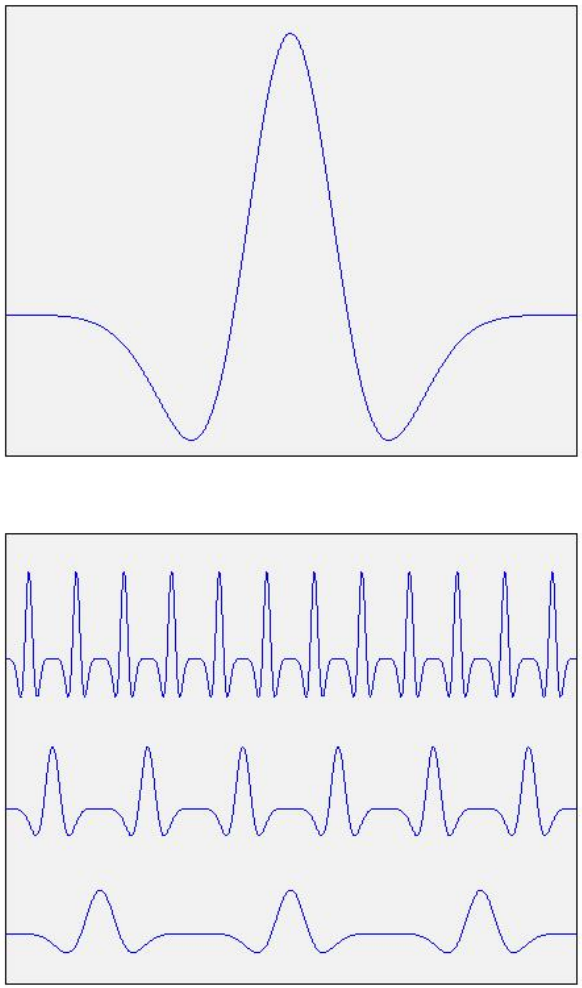
The Wavelet Network Friction Model

- A wavelet is a function $\psi(x)$ which is local in both frequency and space/time
- The Mexican hat is a common wavelet function
- Wavelet theory says that a family of wavelets $\psi_i(x)$, generated from wavelets with different frequency and space content can reconstruct a function $f(x) \in L^2$

$$f(x) = \sum_i c_i \psi_i(x)$$

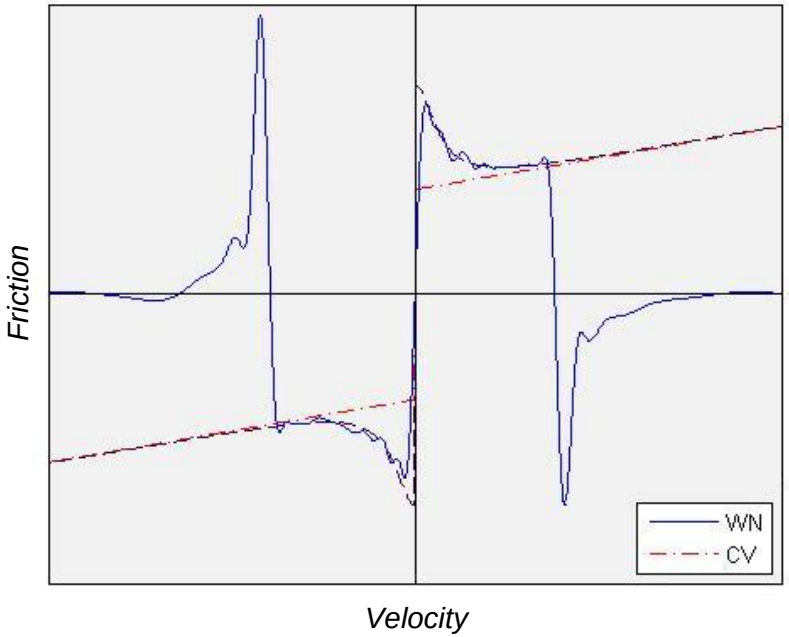
- The function f can be a friction map

$$\tau_f(\dot{q}) = \begin{bmatrix} \psi_1(\dot{q}) & \psi_2(\dot{q}) & \cdots \end{bmatrix} \begin{bmatrix} c_1 \\ c_2 \\ \vdots \end{bmatrix}$$

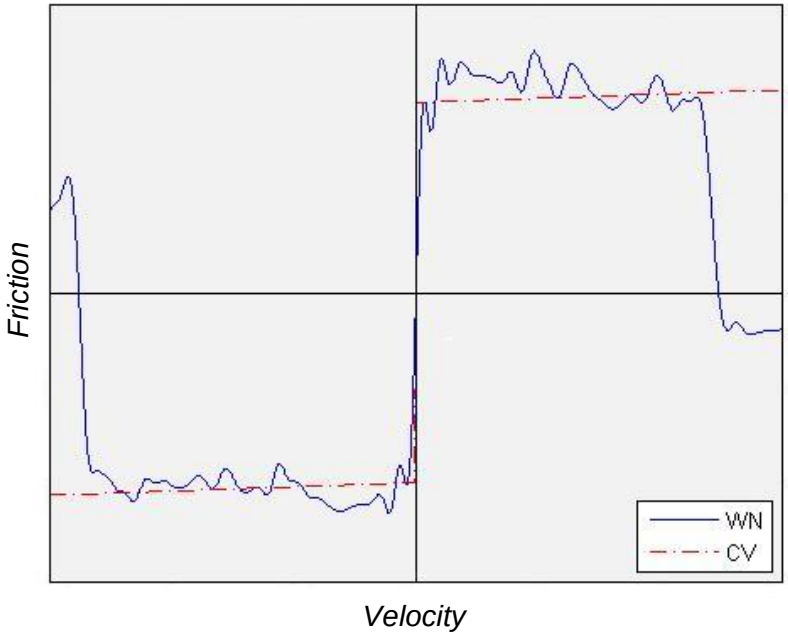


Simulations and Experiments with the PHANTOM Omni

Simulation



PHANTOM Omni



Computing the Contact Force from the Dynamic Equation

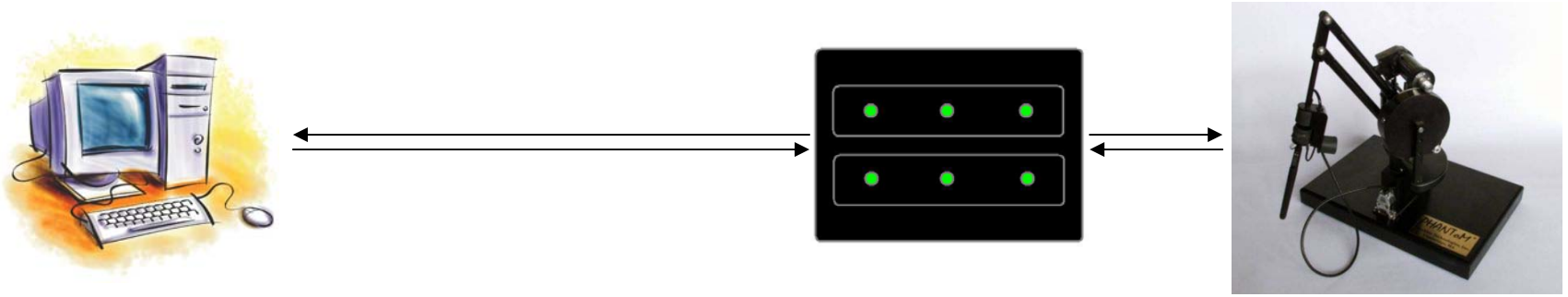
- When the robot is interacting with the environment:

$$Y(q,\dot{q},\ddot{q})\theta + Y_f(\dot{q})\theta_f = Y_{tot}(q,\dot{q},\ddot{q})\theta_{tot} = \tau + J^T F_{contact}$$

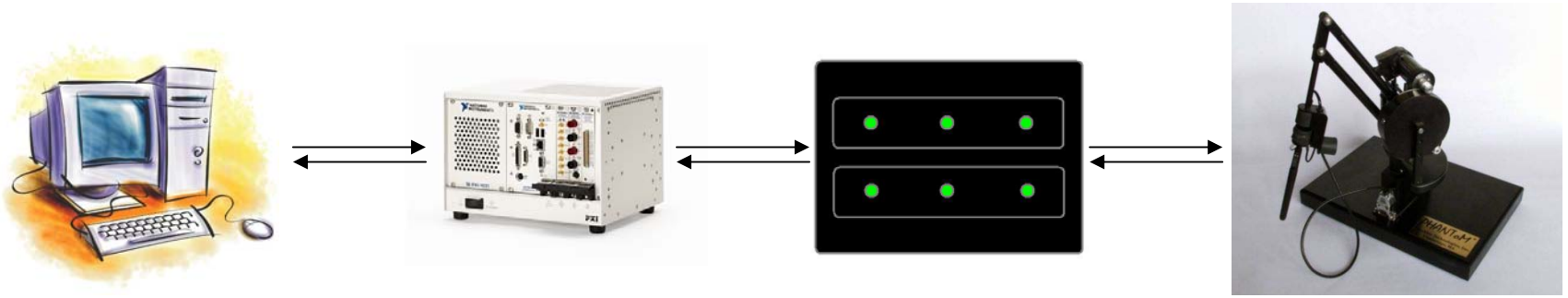
$$\Rightarrow F_{contact} = J^{-T}\left(\tau - Y_{tot}(q,\dot{q},\ddot{q})\theta_{tot}\right)$$

LabVIEW Real-Time Control System (PHANTOM Premium)

- Original control system



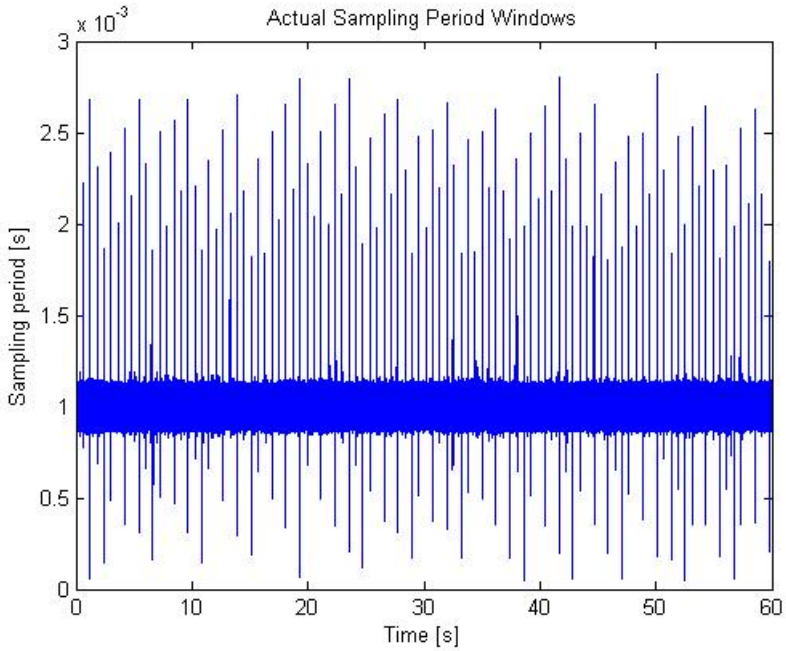
- New control system

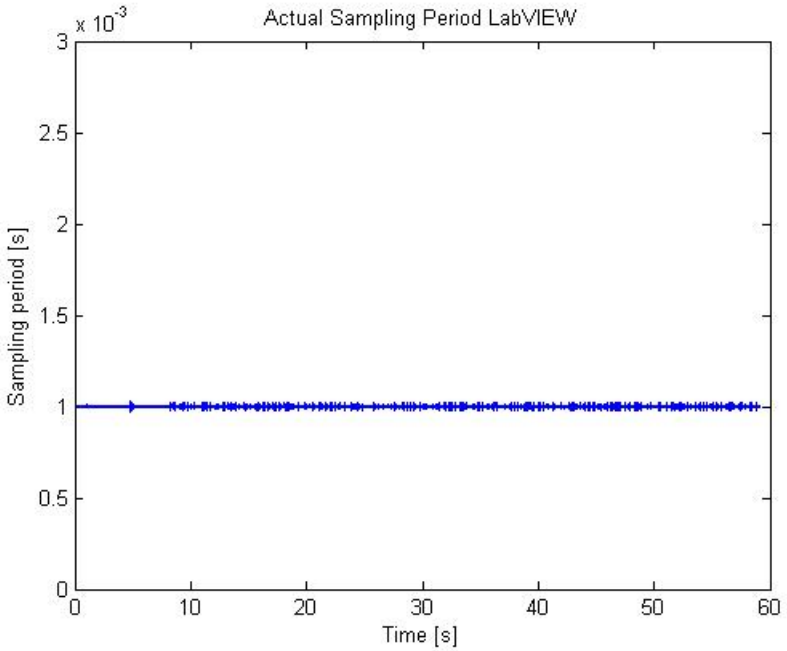


Windows Computer *NI LabVIEW PXI* *PHANTOM Amplifiers* *PHANTOM*

Windows vs. Real-Time

- Real-time: ability to maintain a constant sampling rate





Conclusion

- In theory: contact force estimation can be done perfectly
- In practice: we are limited by the accuracy of the dynamic model
- Next step: contact force estimation in a master-slave scheme