Research and Development in Homecare Robotics

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Plan of the Presentation

- Rationale for Homecare Robotics
- State of the Art
- Two Modes of Operation:
  Autonomous Operation
  Haptic Teleoperation
- Technical Issues and Challenges
- Possible Solutions and Directions

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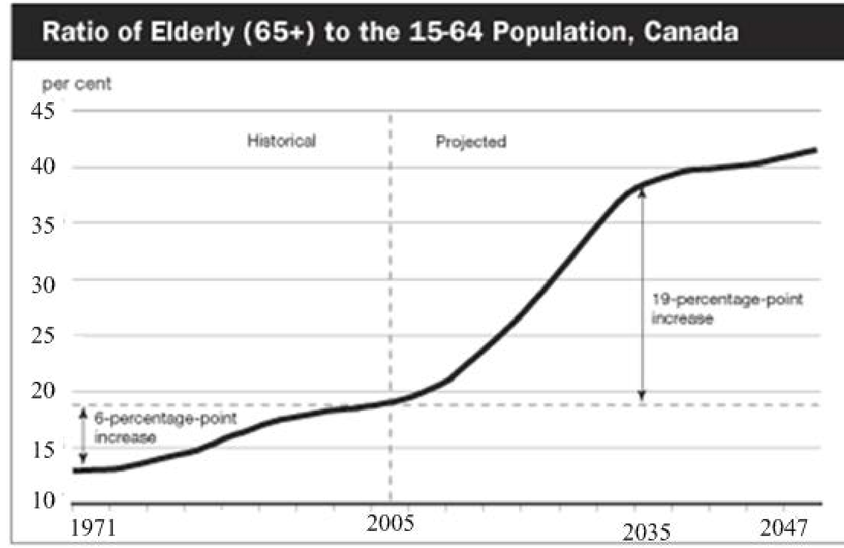
Rationale for Homecare Robotics

Rationale

➢ Quality-of-Life and Economics

- ❖ Elderly/Younger ratio in Canada will > double next 50 years
- ❖ Disabled ~10% of population
- ❖ People prefer to be independent (and are happier) in their own homes
- ❖ Canadian government spends > $10 billion/year on disabled care (basic care at home ~ $10,000/person/month)
- ❖ Cost of elderly care: much more
- ❖ Cost has increased by > 20% / year
- ❖ A homecare system can improve quality of life at reduced cost

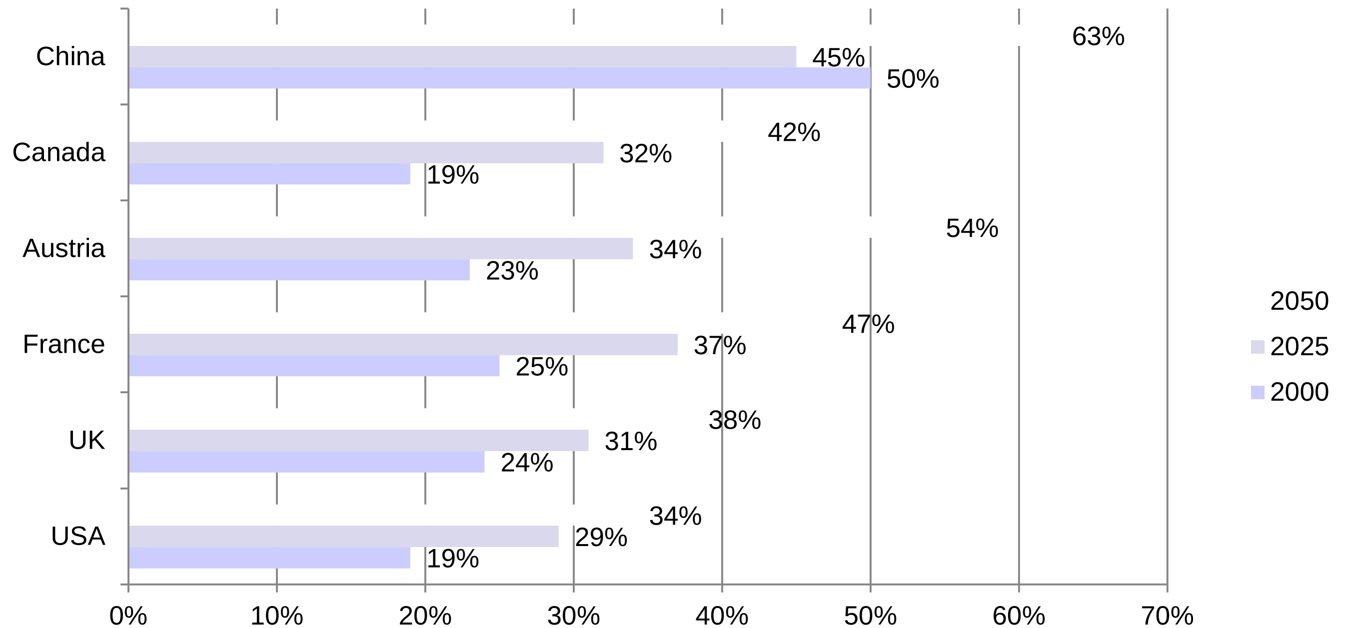


[Source: Department of Finance, Canada]

Rationale (Cont'd)

➢ **Quality-of-Life and Economic Factors**

Ratio: Elderly (> 65) / Working-age (16-65)



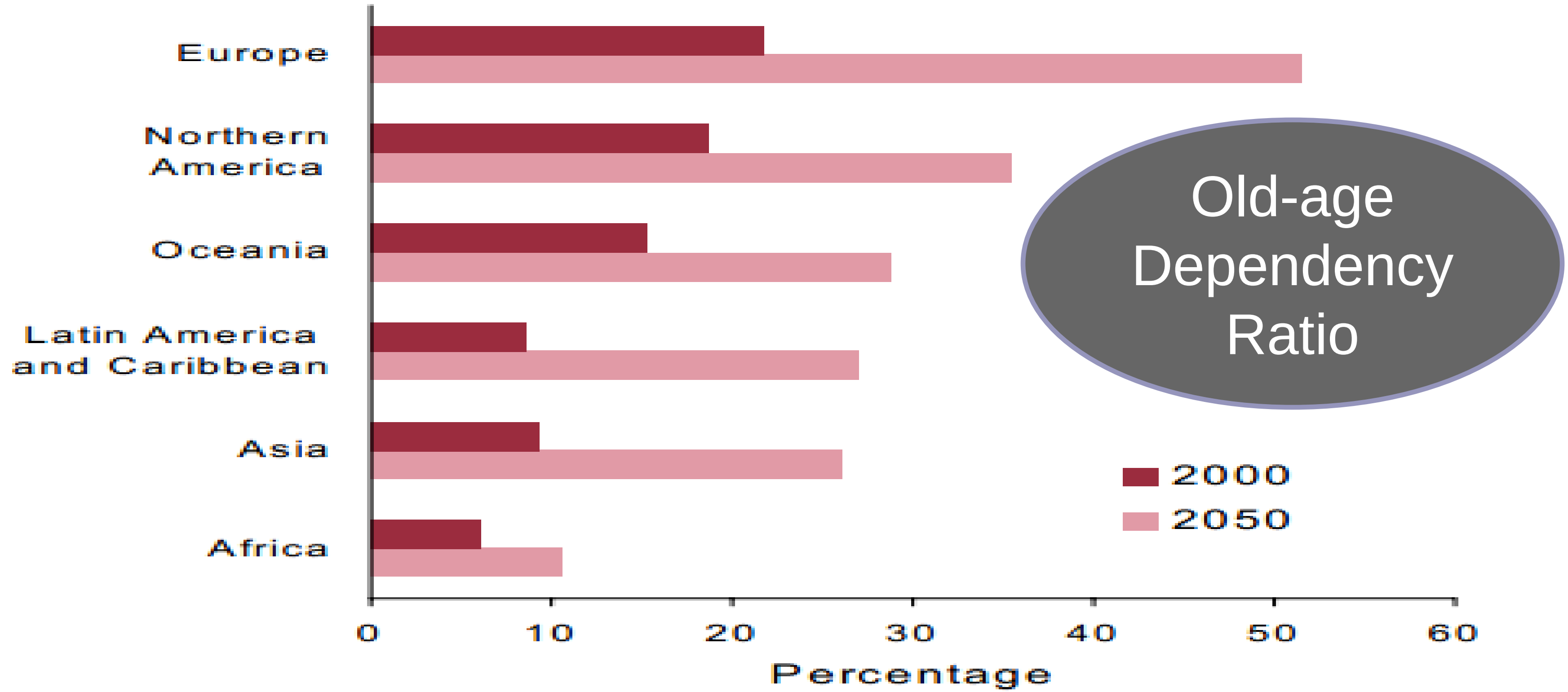
Source: UN Population Division (2009)

❖ **Situation in other regions: Comparable to Canada**

❖ **Situation will double in 50 years**

Rationale (Cont'd)

➢ **Quality-of-Life and Economic Factors**



- ❖ **Chart: % of elderly who rely on public funds (government) for survival**
- ❖ **Situation in other regions: Comparable to Canada**
- ❖ **Situation will double in 50 years**

Rationale (Cont'd)

➢ **Quality-of-Life and Economic Factors**

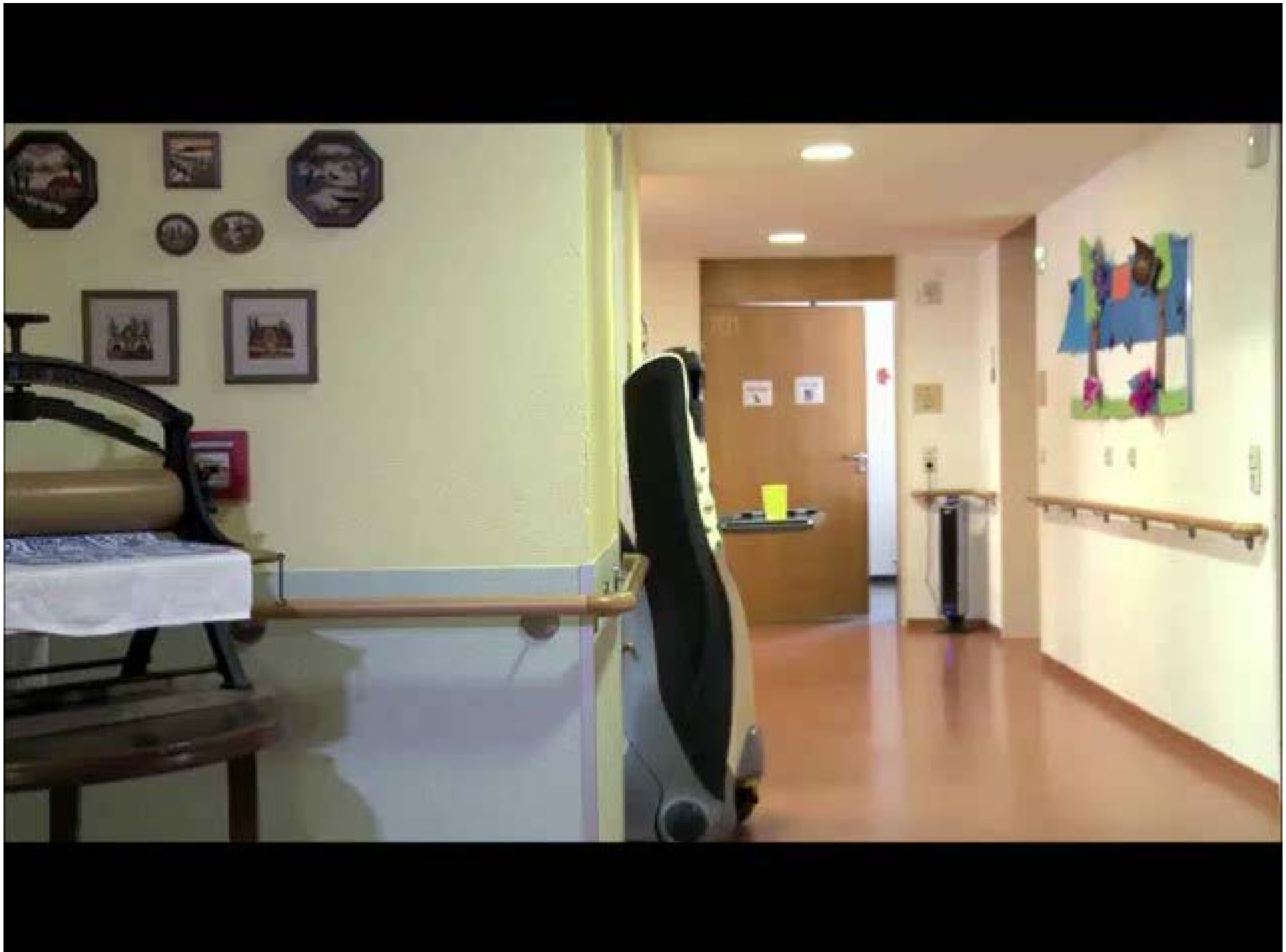
Summary of Rationale

- Improved quality of life
- Round-the-clock, consistent/repeatable and reliable care
- No invasion of privacy
- Increased flexibility and comfort in familiar home environment
- Other family members will have increased freedom and peace of mind (pursue their normal activities: employment, education, etc.)
- Government spending will be more uniform, fair, and cost effective

State of the Art; Operational/ Technology Needs

University of Tokyo's IRT (Information and Robot Technology

Shadow Robotic System (SRS Care-O-bot) Consortium: Germany, UK, USA, etc.)



Honda ASIMO

Some General features of the State of the Art

- Visual and verbal communication with humans
- Operation of existing appliances
- Picking and carrying of objects

Some Obvious Shortcomings

- Poor human-like interaction
- Slow speed
- Poor dexterity in grasping and handling (e.g., hand slowly moved to object, next fingers are closed; no conformal and compliant grasping as with human hand)
- Possible safety problems for humans (due to the nature of robotic mechanical components)

Safety in Human-Robot Interaction

Robot-inflicted Injuries to Humans

Accidents involving:

- Sharp objects and tools
- Large forces
- Fast motions and quick changes of magnitude and direction
- Malfunctions

Operational Needs

- **Faster yet safe operation**
- **More human-friendly, human-like interaction and communication**
- **More autonomous operation for 24-hr, routine, basic care (bathing, dressing, toileting, meal preparation, providing medicine, etc.)**
- **Effective detection of emergency situations**
- **Adequate emergency help (through remote monitoring, teleoperation) until regular help arrives**

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Two Modes of Operation

Two Modes of Operation

- More autonomous operation for 24-hr routine basic care (bathing, dressing, toileting, meal preparation, providing medicine, monitoring and seeking external help, etc.)

- Remote monitoring and haptic teleoperation in emergency situations (until regular help arrives—ambulance, paramedics, police, fire fighters, etc.)

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Autonomous Operation for Routine Basic Care

Autonomous Operation for Routine Basic Care

Typical Tasks:

- **Verbal and visual communication**
- **Identifying/grasping/handling of needed objects properly/safely**
- **Safely and quickly navigating in the presence of obstacles (static and dynamic)**
- **Sensing/monitoring of objects and conditions for carrying out tasks (under normal and emergency situations)**
- **Operating household appliances**

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Autonomous Operation for Routine Basic Care

Needs:

- Greater robotic intelligence (for autonomous operation in dynamic, partially structured, and partially known environment)
- Greater accuracy, speed, dexterity, etc.
- Increased safety (accident avoidance, obstacle avoidance, etc.)
- More human-friendly, human-like communication and operation
- Redesign of household appliances for easy operation by robots (and humans)

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Possible Directions for Advancing the State-of-the-Art

- **Improved intelligence (for more autonomous operation)**
- **Improved dexterity of handling (e.g., conformal and compliant grasping)**
- **Improved robot-human interaction (working "with" a human rather than working "for" a human)**
- **Improved speed, robustness, reliability, and safety**
- **Improved sensing under normal and abnormal conditions (dynamic sensor network, intelligent sensor fusion)**

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Haptic Teleoperation in Emergency Situations

Hospital Control Room

Homecare Environment

Dedicated Network

A homecare robot can provide first-aid until ambulance arrives

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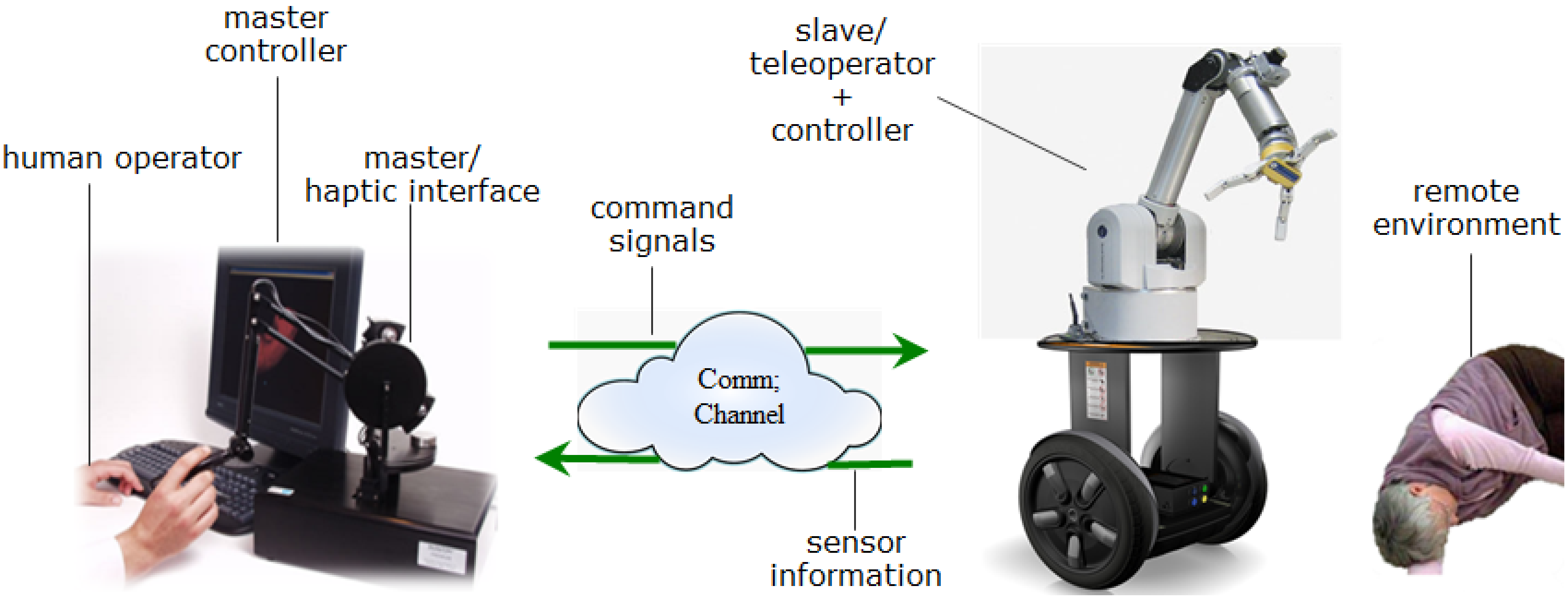
Haptic Teleoperation in Emergency Situations



Challenges: **Stability, Transparency, Accuracy, Reliability, Robustness, Remote Robot's Capabilities**

Haptic Teleoperation in Emergency Situations

Source:

Healthcare Robotics Lab, Georgia Institute of Technology

Note:

- **Time delay**
- **Low dexterity**
- **Low stability**
- **Low transparency**

Haptic Teleoperation in Emergency Situations

Typical Tasks:

- **Moving body to a more comfortable position**
- **Resuscitation and massaging**
- **Stopping of bleeding**
- **Cleaning a body area**
- **Dressing a wound**

Haptic Teleoperation in Emergency Situations

Practical Needs:

- Capability to perform emergency tasks effectively
- Safe operation (won’t harm the human)
- True “feel” of the remote activity by operator (transparency)
- Speed, accuracy, stability, reliability, and robustness (including that of communication link)

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Possible Directions for Advancing the State-of-the-Art

- **Improvements to autonomous robotics (mentioned before)**
- **Improved transparency (better/faster tactile/visual/auditory feedback to remote human operator)**
- **Stability under (and compensation for) time delay**
- **Impedance control (for more human-like manipulation)**
- **Design and control for accuracy, speed, robustness, reliability, and safety**
- **3-D virtual reality for remote operator**

Some Resrach Issues Studied in Our Lab

- Integrated Sensing, Object Sensing, and Autonomous Manipulation (Roland Lang)
- Robotic Intelligence (Nancy Du, Lili Meng)
- Robotic Navigation (Shawn Zhang, Pegah Maghsoud)
- Haptic Impedance Control (Edward Wang)
- Stable Haptic Teleoperation Under Time Delay (Mohmmed Tufail)
- Abnormal Condition Sensing and Telemedicine (Shan Xiao)
- Machine Health Monitoring and Design Automation (Shujun Gao, Min Xia)

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Our Laboratory Environment

Equipment:

- Sensable Phantom 6DoF master
- Pioneer PowerBot mobile platform
- Robosoft Robu-Arm
- Barrett WAM arm
- Barrett BH8 hand with tactile sensors
- Pentium 4

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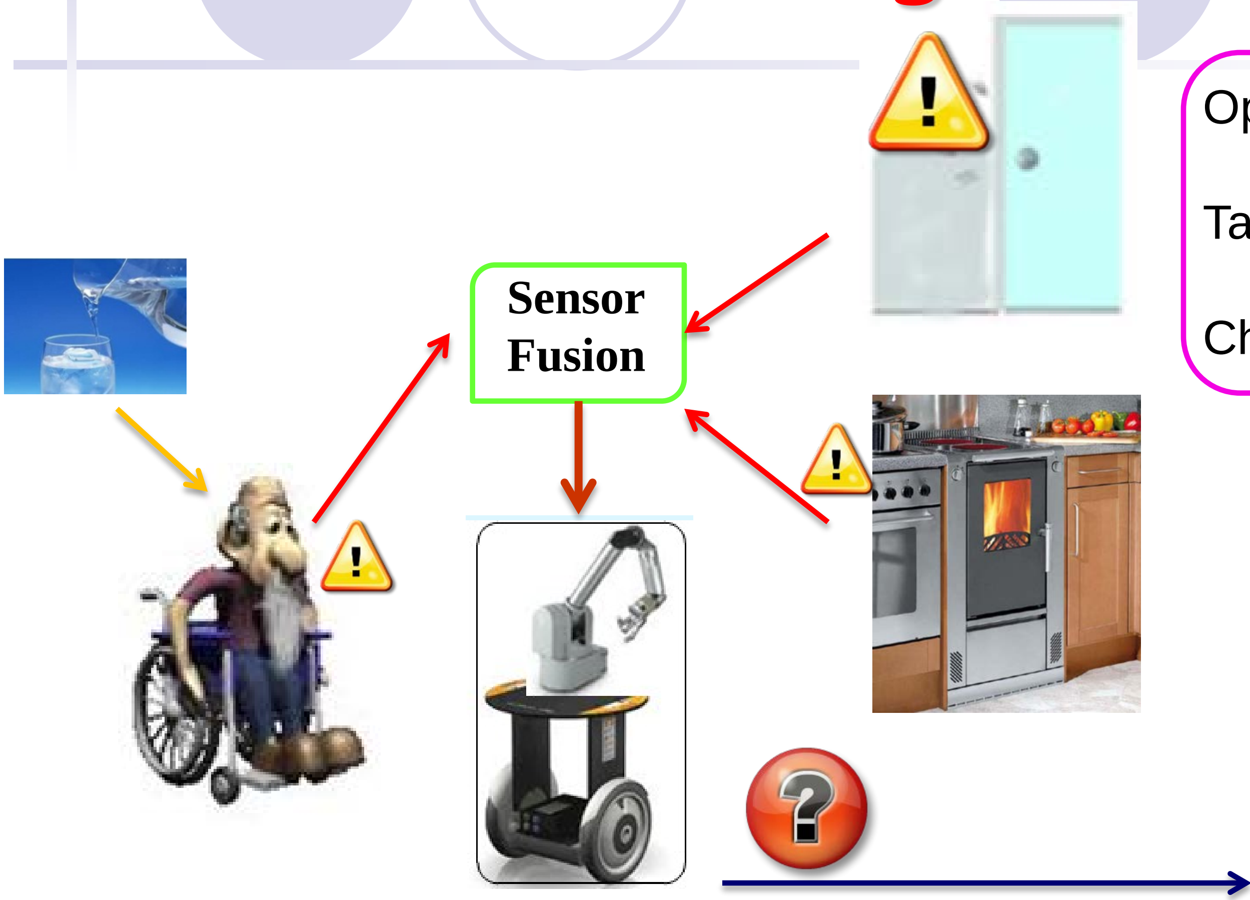
Technical Problems and Directions for Resolution

A Scenario of Home Robotic Intelligence



Decision/
Action

Open the door?

Take water to the person?

Check the food in the oven?

Sensor State

Robot's Primary Role

Capabilities

Level of Intelligence

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Characteristics and Capabilities of Intelligence

- Sensory perception
- Pattern recognition
- Learning and knowledge acquisition
- Inference from incomplete information
- Inference from qualitative or approximate information
- Ability to deal with unfamiliar situations

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Characteristics and Capabilities of Intelligence (Cont'd)

- Adaptability to new, yet related situations (through "expectational" knowledge)
- Inductive reasoning
- Common sense
- Display of emotions
- Inventiveness

→ **Self-awareness is important**

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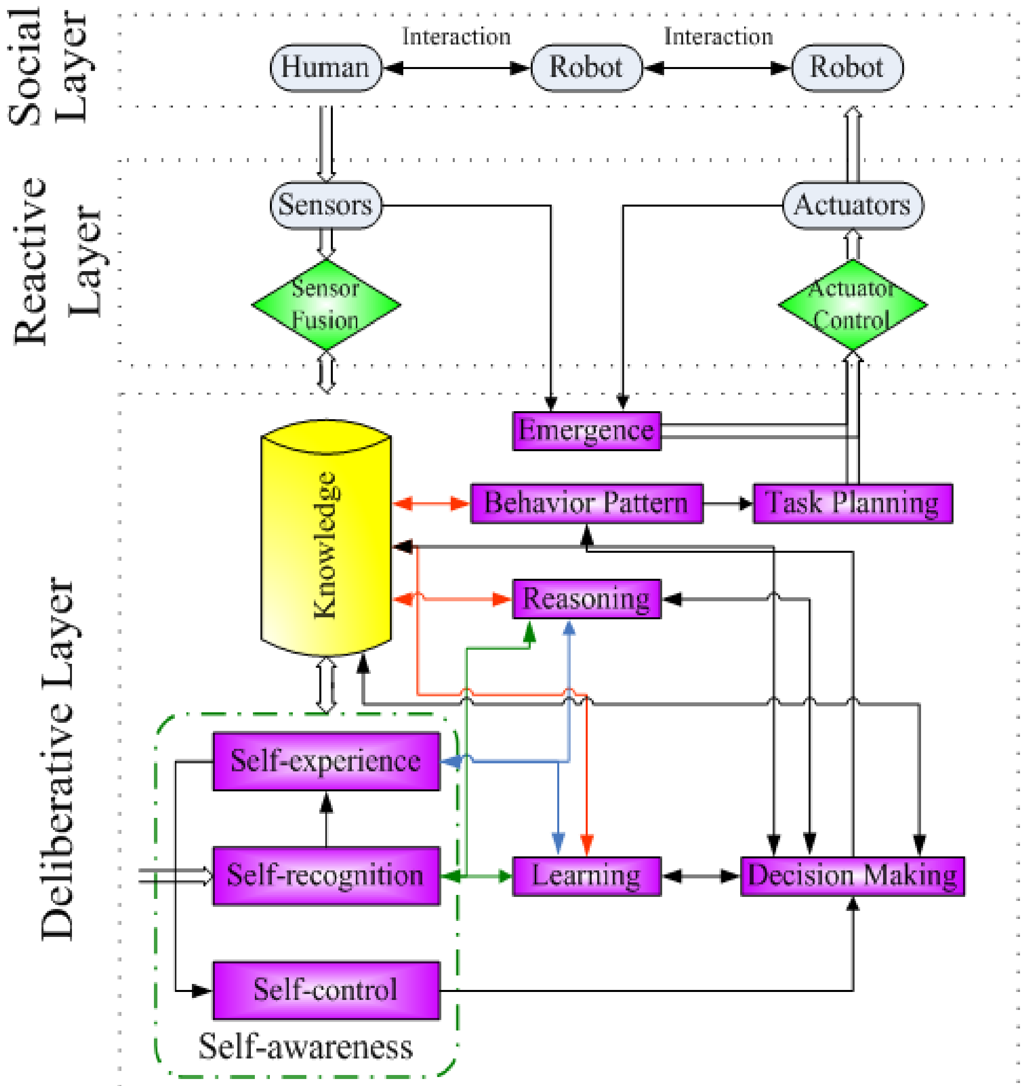
Multi-agent Hybrid Architecture with Self-awareness for Homecare Robots



Features:

- **Sensing**
- **Intelligent decision making (based on: role, capabilities, needs, etc.)**
- **Action**
- **Self-assessment and improvement**

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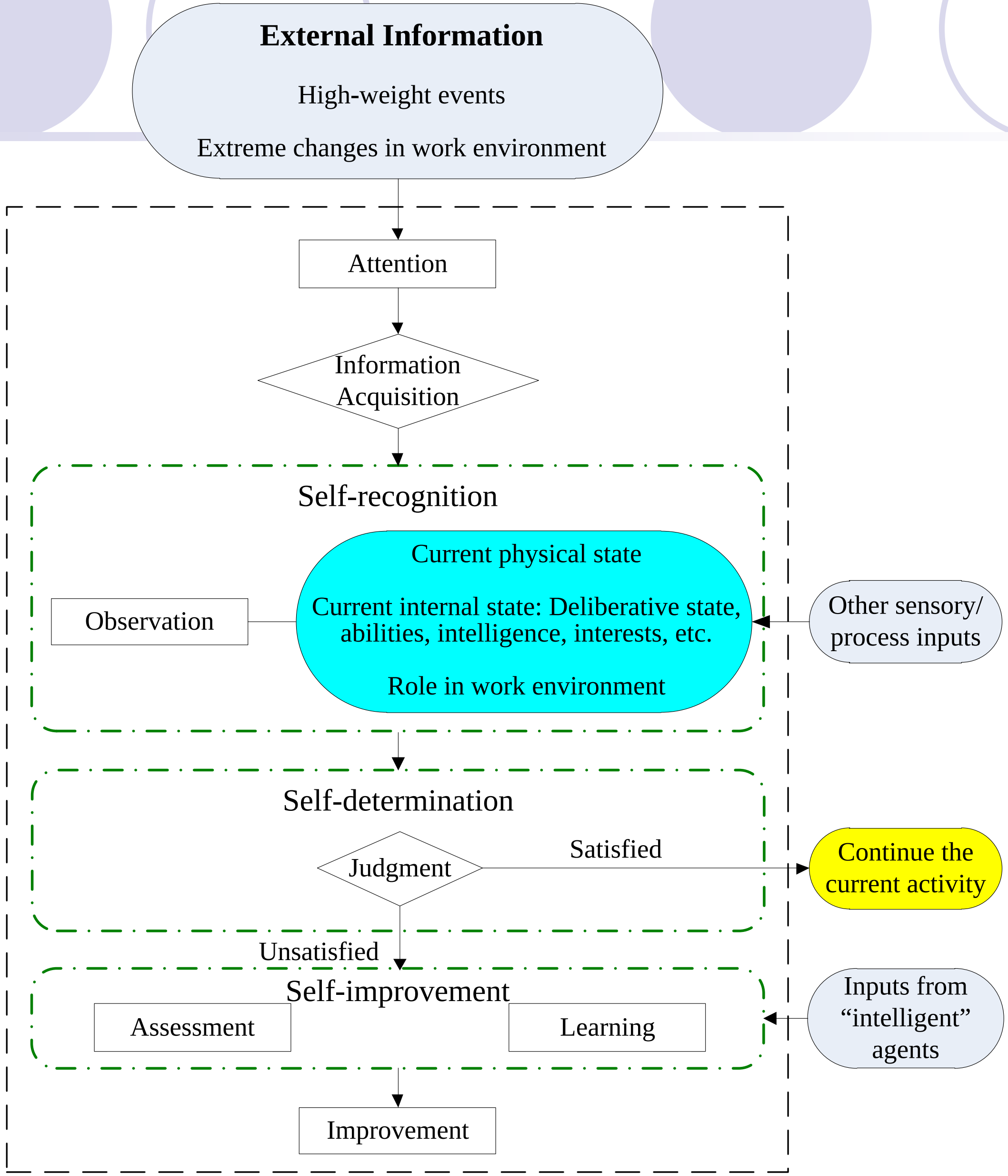
Self-awareness Model



Possible Technologies for Self-awareness Module

- **Knowledge Acquisition for Modeling and Assessment:** Experimentation with a human in place of robot
- **Knowledge Representation and Decision Making:** Soft computing (fuzzy-neural-evolutionary); Symbolic, object-oriented, AI and Expert Systems
- **Learning:** Reinforcement (Q-learning), Fuzzy-neural (learn rules, modify rules, modify membership functions etc.)

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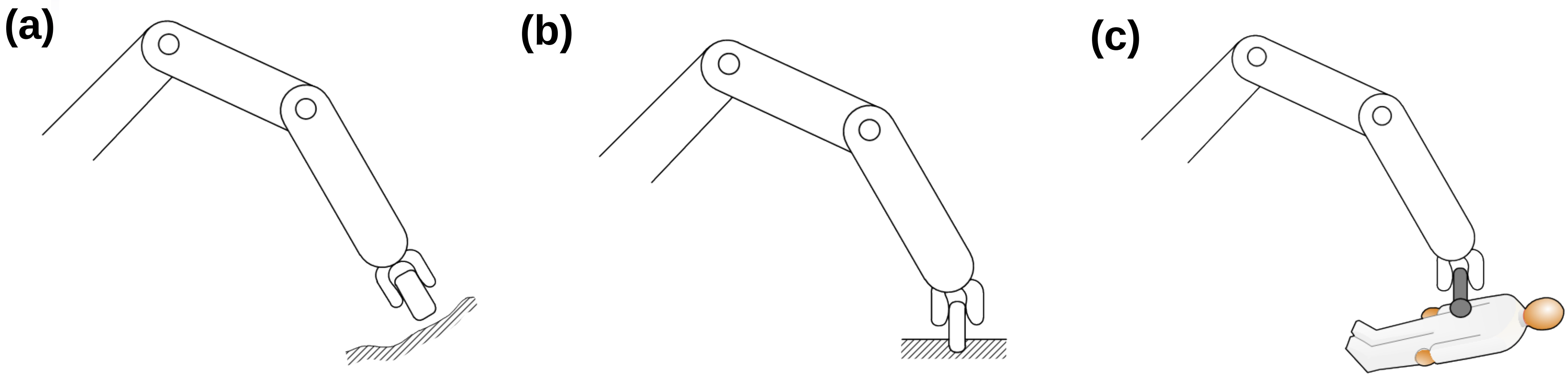
A Research Avenue in Impedance Control

Importance of Impedance Control

- For proper execution of a robotic task, both force and motion may have to be sensed and control
- In a given DoF, precise control of both simultaneously may be contradictory
- Better, human-like manipulation would be possible through impedance control

Mechanical Impedance = Force/Velocity

When is Impedance Control Appropriate?



(a) Non-contact Seam Inspection (Motion Control)
(b) Machining, Joining, Pushing, etc. (Force Control)
(c) Delicate Flexible Manipulation (Impedance Control)

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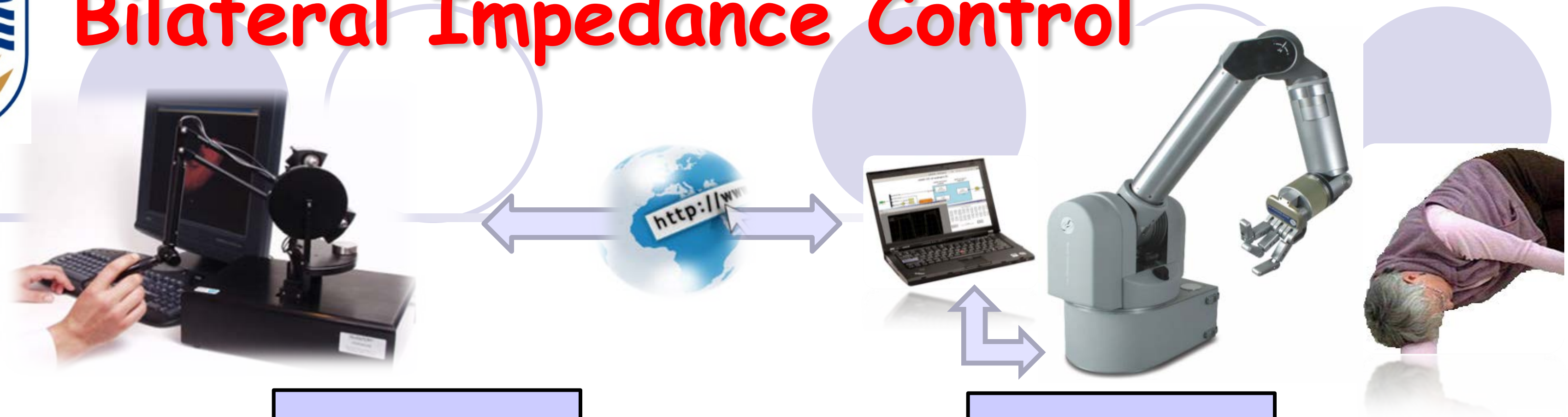
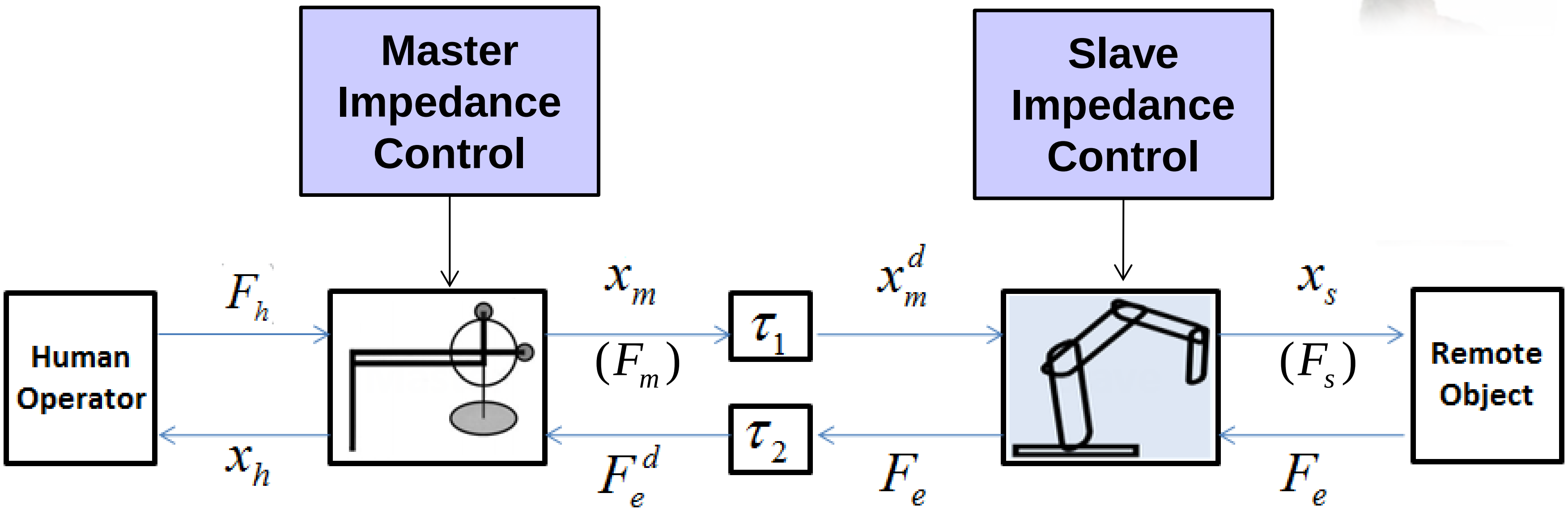
Some Mechanical Transfer Functions

Transfer Function	Definition (Laplace or Frequency Domain)
Dynamic Stiffness	Force/Displacement
Receptance, Dynamic Flexibility, Compliance	Displacement/Force
Impedance (Z)	Force/Velocity
Mobility (M)	Velocity/Force
Dynamic Inertia	Force/Acceleration
Accelerance	Acceleration/Force
Force Transmissibility (T_f)	Transmitted Force/Applied Force
Motion Transmissibility (T_m)	Transmitted Velocity/Applied Velocity

The choice of controlled transfer function (e.g., impedance or mobility?) is of practical (not analytical) importance (e.g., causality, physical realizability).

Bilateral Impedance Control





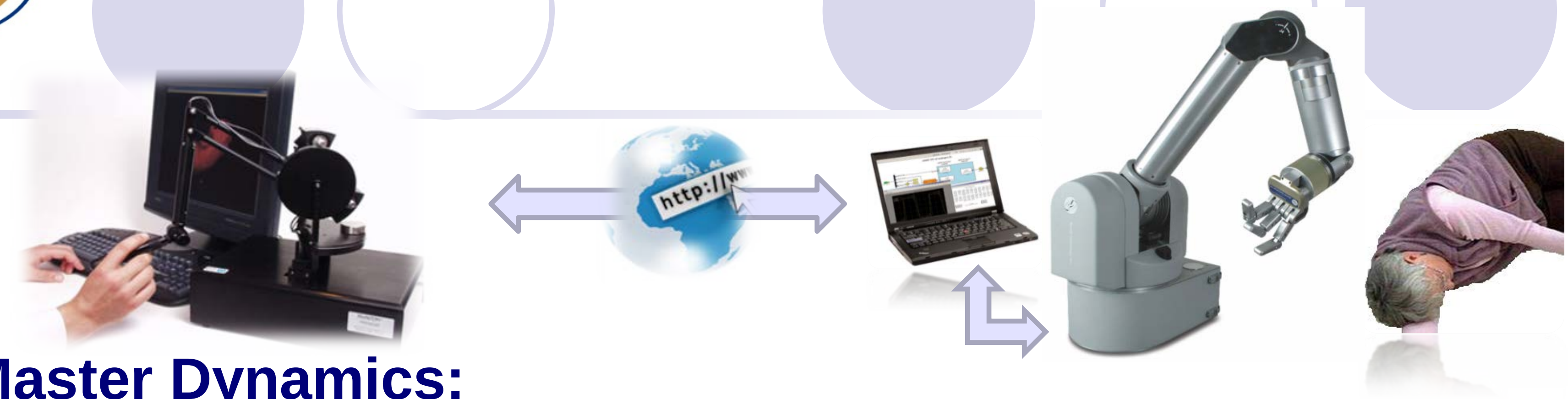
F_m = forces/torques generated by master manipulator actuators

F_s = forces/torques generated by slave manipulator actuators

F_h = forces applied by human operator (to master manipulator)

F_e = forces applied to task environment (by slave manipulator)

Impedance Control Goals



Master Dynamics:

$$\boldsymbol{M}_m(\boldsymbol{X}_m)\ddot{\boldsymbol{X}}_m + \boldsymbol{B}_m(\boldsymbol{X}_m, \dot{\boldsymbol{X}}_m)\dot{\boldsymbol{X}}_m + \boldsymbol{K}_m(\boldsymbol{X}_m)\boldsymbol{X}_m = \boldsymbol{J}_m{}^T\boldsymbol{F}_h + \boldsymbol{F}_m$$

Slave Dynamics:

$$\boldsymbol{M}_s(\boldsymbol{X}_s)\ddot{\boldsymbol{X}}_s + \boldsymbol{B}_s(\boldsymbol{X}_s, \dot{\boldsymbol{X}}_s)\dot{\boldsymbol{X}}_s + \boldsymbol{K}_s(\boldsymbol{X}_s)\boldsymbol{X}_s = \boldsymbol{F}_s - \boldsymbol{J}_s{}^T\boldsymbol{F}_e$$

Typical Measurements: F_e , X_s , and X_m

Objective 1 (Performance): Task execution at Slave according to the "desired impedance"

Objective 2 (Transparency): Generate F_m by Master actuators such that: Impedance felt by operator = actual task impedance

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Desired Impedance Specification (Desired Impedance Model)

Based on:

- **Task requirements (quality), as determined by professionals: Desired levels of applied forces, deflections, and manipulation speeds; their limits**
- **Heuristic relations (e.g., Desired impedance inversely proportional to the environmental impedance)**
- **Degree of error tolerance**

Constraints:

System capabilities and limitations, environment, nature of controller, safety limits, human operator at master, etc.

Impedance Control Strategies

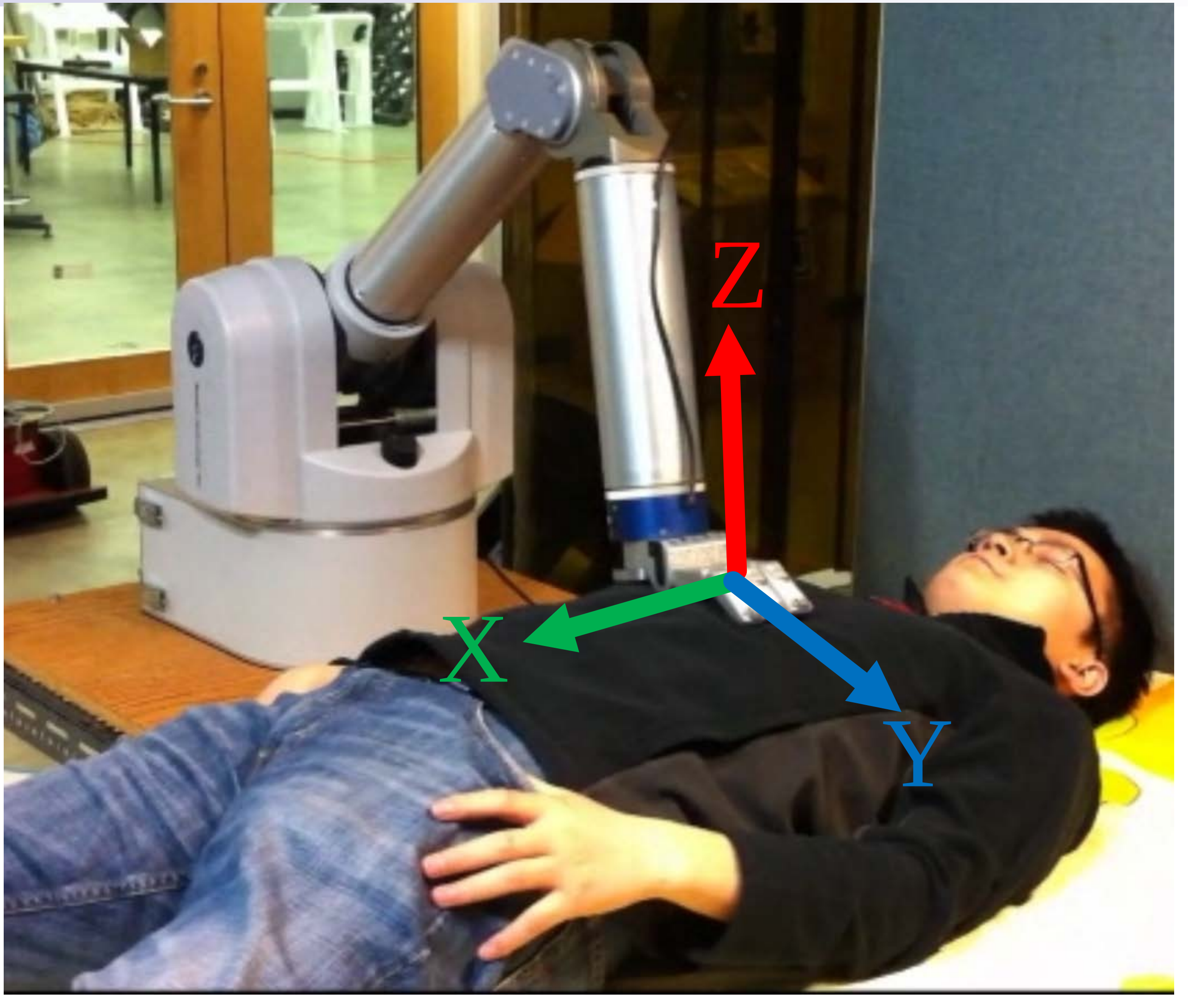
(a)Model referenced adaptive control with Reference Model = Desired Impedance Model

(b)Linearizing feedback control with a self-tuning controller tuning to the desired impedance model

(c)Sliding mode control with a sliding surface based on the desired impedance model

Performance Comparison

Robot Hand Coordinates



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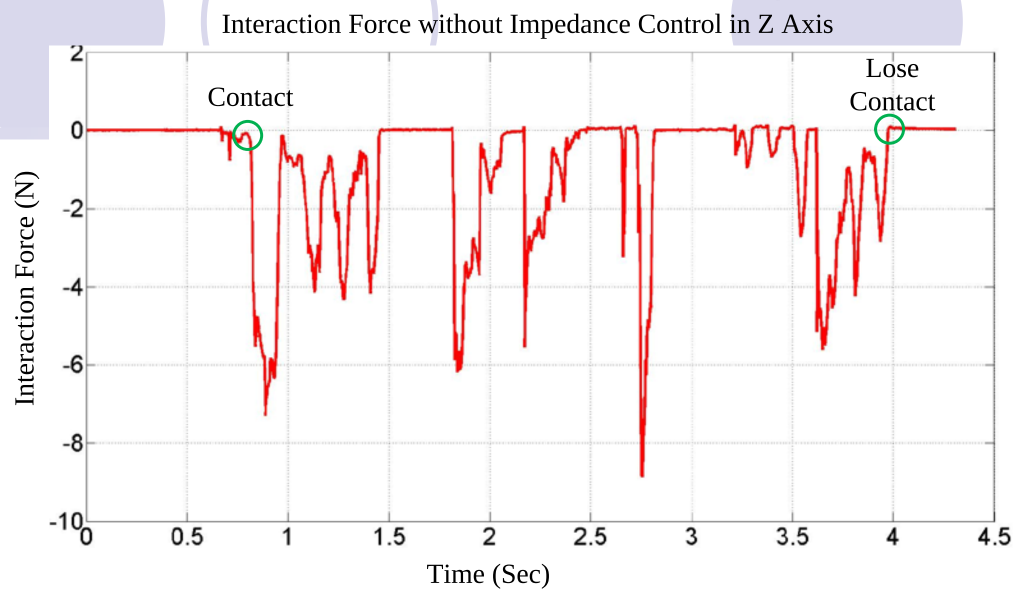
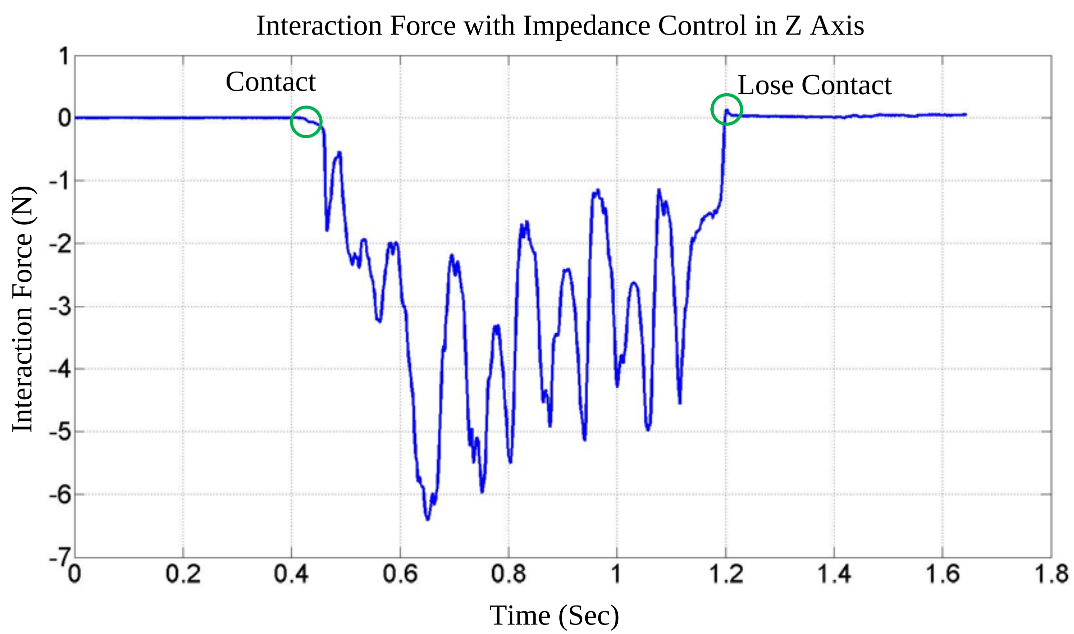
Performance Comparison (Z-axis)





Conclusion

- Homecare robotics can play an important role in today's society
- Significant progress has been made in research and development of homecare robotics
- More technological progress is needed before common household use

Thank you!

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- Tier 1 Canada Research Chair (CRC 1)
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