Design and Control of a Bio-Inspired Human-Friendly Robot

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Abstract

The increasing demand for physical interaction between humans and robots has led to the development of robots that guarantee safe behavior when human contact occurs. However, attaining established levels of performance while ensuring safety poses formidable challenges in mechanical design, actuation, sensing and control. To achieve safety without compromising performance, the human-friendly robotic arm has been developed using the concept of hybrid actuation. The new design employs inherently-safe pneumatic artificial muscles augmented with small electrical actuators, human-bone-inspired robotic links, and newly designed distributed compact pressure regulators with proportional valves. The experimental results show that significant performance improvement can be achieved with hybrid actuation over a system with pneumatic muscles alone. The simulation result of the safety of the new robot arm demonstrates that the safety characteristics surpass those of previous human-friendly robots.

Introduction

Performance

For high bandwidth and high payload,

High Stiffness
High Torque Actuation

⇩

Stiff Transmission
Powerful Motor
High Gear Reduction

⇩

Increased Weight
High Reflected Inertia
High Backdrive Friction

Safety

For low impedance output and low reflected inertia,

High Compliance
Light Structure / Drivetrain

⇩

Elastic Components
Regulated Power
Low Gear Reduction

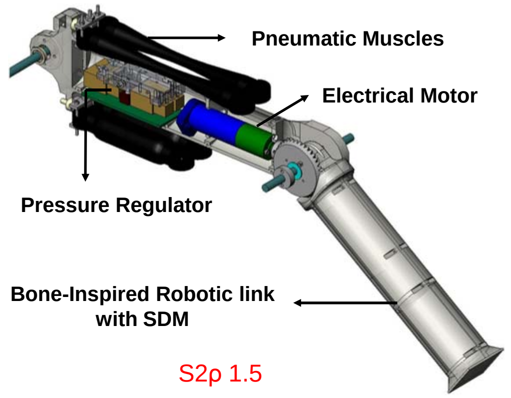
⇩

Low Control Bandwidth
Low Payload

State of the Arts

DLRIII (DLR) | SEA (MIT) | PaCMMA (MIT) | DM² (Stanford) | VST (U of Pisa)

Design for Human-Friendly Robot

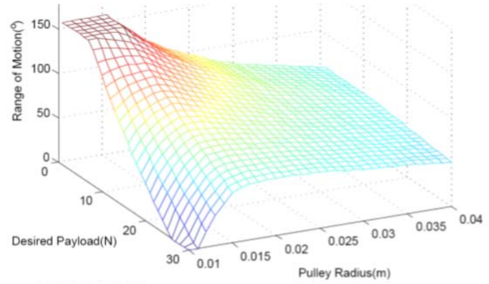


Pneumatic Artificial Muscles
- High Power-to-weight Ratio
- Inherent Compliance

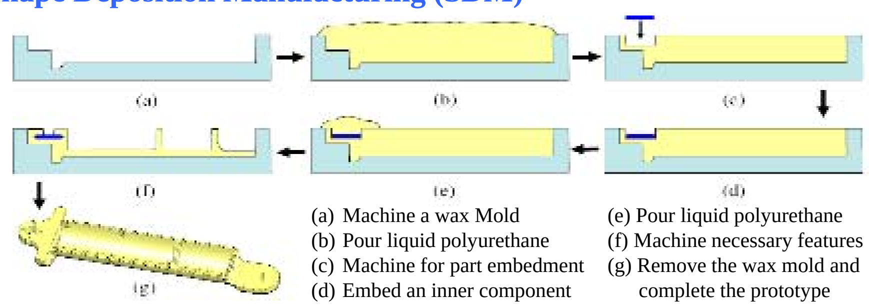
Embedded Pressure Regulator
- Proportional Valves
- Light and Compact Structure

Bone-Inspired Robotic Link
- Actuators Cavity
- Integrated Features by Shape Deposition Manufacturing (SDM)

Design Optimization
- Variable-Radius Pulley (Payload vs. Range of Motion)
- Mini Actuator Size (Response vs. Effective Inertia)
- Initial Muscle Tension (Response vs. Range of Motion vs. Safety)



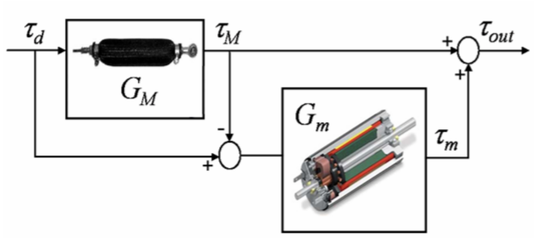
Shape Deposition Manufacturing (SDM)



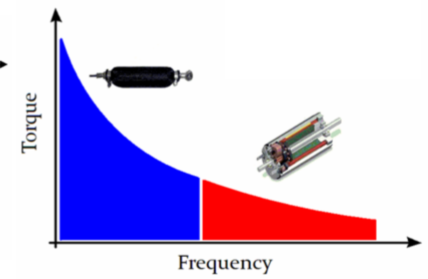
(a) Machine a wax Mold
(b) Pour liquid polyurethane
(c) Machine for part embedment
(d) Embed an inner component
(e) Pour liquid polyurethane
(f) Machine necessary features
(g) Remove the wax mold and complete the prototype

Control Strategy of Hybrid Actuation

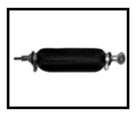
Control Scheme



Macro-Mini Torque Partitioning

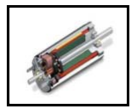


Macro Actuation



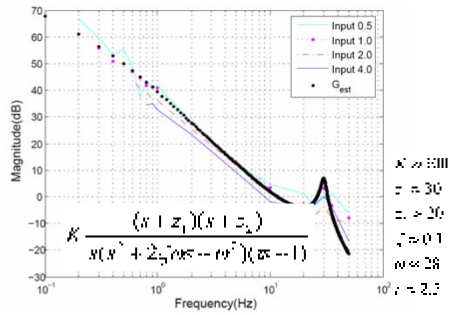
- Pneumatic Muscles
- Low-frequency Actuation
- Adaptive Force Feedback Ctrl

Mini Actuation



- Electrical Motor
- High-frequency Actuation
- Open-Loop Controller

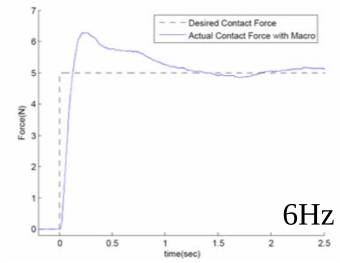
System Identification (Macro)

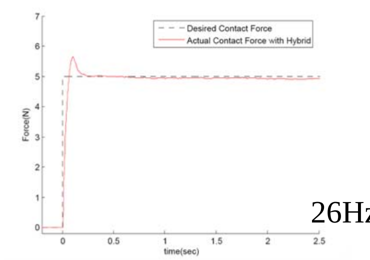


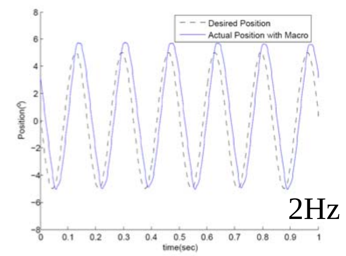
Results and Conclusion

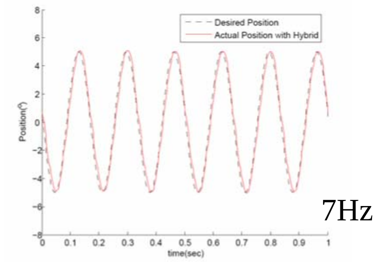
Performance Comparison (Contact Force and Position Tracking)

Macro Actuation (Pneumatic Muscles) | Mini Actuation (Muscles + Motor)

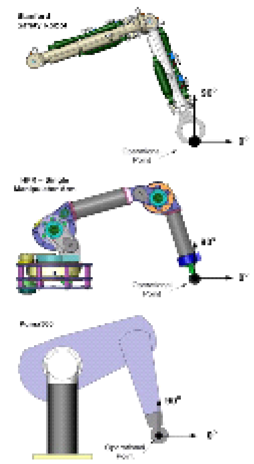








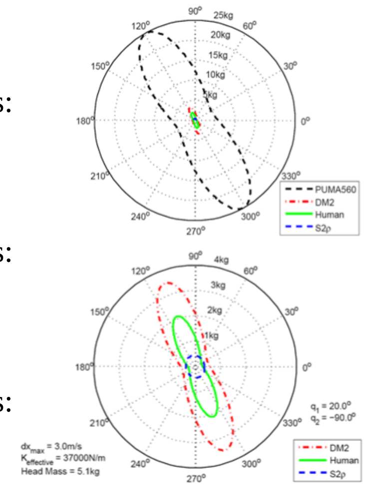
Safety Comparison (Effective Mass)



S2p
Effective Mass: 0.4Kg

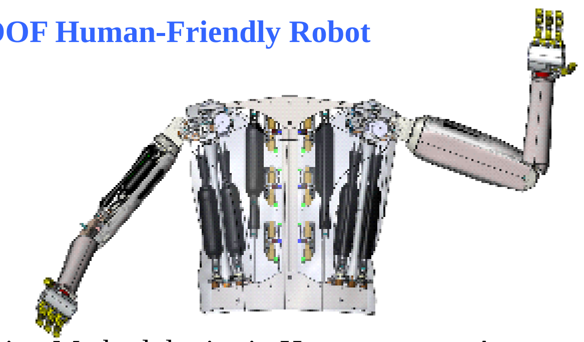
DM²
Effective Mass: 3.5Kg

PUMA560
Effective Mass: 25Kg



Future Work

7 DOF Human-Friendly Robot



- Design Methodologies in Heterogeneous Actuator Combination
- Unified Criteria for Performance and Safety
- Fiber-Reinforced Robotic Arm
- Sensor Embedded Complaint Skin/ Dexterous Hands