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

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Summary. 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 that can be achieved with hybrid actuation over a system with pneumatic artificial muscles alone. The paper evaluates the safety of the new robot arm and demonstrates that the safety characteristics surpass those of previous human-friendly robots.

1 Introduction

There is a growing interest in human-friendly robotics involving close physical interaction between robots and humans. With the ability to support a variety of commercial uses, applications for human friendly robots have emerged in medicine, home care, manufacturing and entertainment. A major challenge in such applications is safety: How can robots be sufficiently fast, strong, and accurate to do useful work while also being inherently safe for physical interaction?

Robots have traditionally relied on electromagnetic actuators, which offer excellent controllability but poor power-to-weight ratios compared to pneumatic muscles. Even more limiting is their inability to exert large sustained forces without high transmission ratios between the motor and the load. The high transmission ratios result in robot arms with high mechanical impedance, which are inherently less safe than their biological counterparts when unexpected contacts occur. Previous efforts to increase the safety of robot arms while maintaining control performance have included relocating the actuators to the base and powering the joints with cables [9, 4], designing links with high-strength composite

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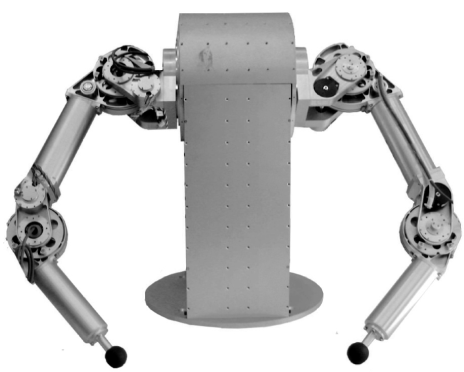
materials to minimize inertia [1], and employing a series elastic actuator [8]. Other works have employed variable compliance [2] and/or compliant, energy-absorbing layers and proximity sensors to detect impending collisions [6].

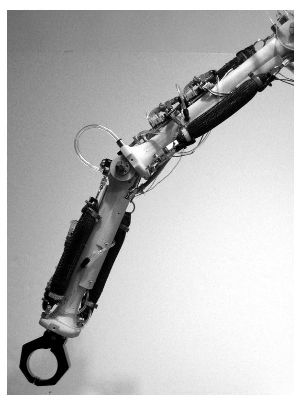
1.1 Previous Work

Distributed Macro-Mini (DM^2) actuation provides a combination of high power, low impedance, and precise control as shown in the Fig. 1 (a) [11]. Large (macro), low frequency actuators are located at the base of the robot arm as the main source of mechanical power; mini actuators are located at the joints for fast response. Although the DM^2 design approach achieves a significant increase in the control bandwidth and reduction in the effective inertia, the poor power density of electrical actuators still requires high gear ratios, which result in a heavy and bulky system. Furthermore, cable transmissions increase the complexity of the design and assembly.

To address these design issues, the Stanford Safety Robot, $S2\rho$, employs hybrid actuation, combining powerful pneumatic actuators with small electrical actuators in a parallel configuration at each joint as shown in Fig. 1 (b) [10]. Key features embodied in the $S2\rho$ include: replacement of heavy electrical actuators with compliant pneumatic muscles; utilization of compact pressure regulators within the links; and integration of valves, actuators and electronics around a sculpted, bone-like structural element. The pneumatic muscle enables the prototype arm to be light, compact, and compliant due to its high force-to-weight ratio and air compressibility. The distributed compact pressure regulators decrease air flow resistance and reduce the complexity of the arm by being located adjacent to the actuators. The human-bone-inspired robotic link further reduces the inertia and simplifies design and manufacturing. However, the discovered limitations of the $S2\rho$ robotic arm are as follows: a restricted joint motion and torque that result from limited contraction ratio of the artificial muscles; relatively slow pneumatic response caused by restricted air flow rates in the valves; and limited strength-to-weight ratios for the bone structures.



(a) 3DOF Human Friendly Robot



(b) First-generation $S2\rho$