Body Integrated Programmable Joints Interface

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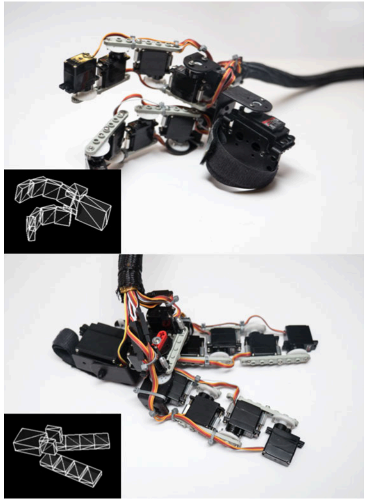

Figure 2: Our hardware. 11 motors are linked using LEGO parts, each of them with 180 degrees motion range. The wireframe diagrams illustrate the overall structure. Cables from each motor are connected to an Arduino controller.

Abstract
Physical interfaces with actuation capability enable the design of wearable devices that augment human physical capabilities. Extra machine joints integrated to our biological body may allow us to achieve additional skills through programmatic reconfiguration of the joints. To that end, we present a wearable multi-joint interface that offers "synergistic interactions" by providing additional fingers, structural supports, and physical user interfaces. Motions of the machine joints can be controlled via interfacing with our muscle signals, as a direct extension of our body. On the basis of implemented applications, we demonstrate a desirable human-machine synergy – that enhances our innate capabilities, not replacing or obstructing, and also without enforcing the augmentation. Finally we describe technical details of our muscle-based control method and implementation of each application.

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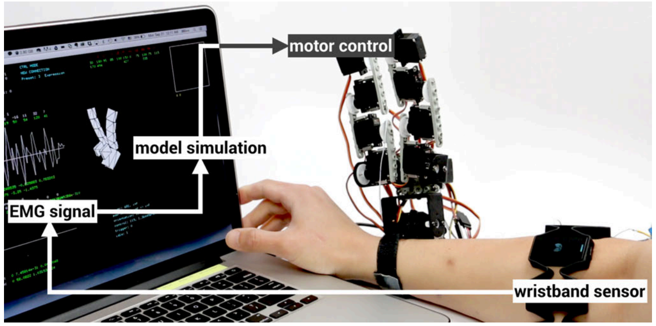

Figure 1: Sensor, control software, and the joints interface.

Author Keywords
Synergistic Interaction; Programmable Joints Interface

ACM Classification Keywords
H.5.2 User Interfaces: Input devices and strategies (e.g., mouse, touchscreen)

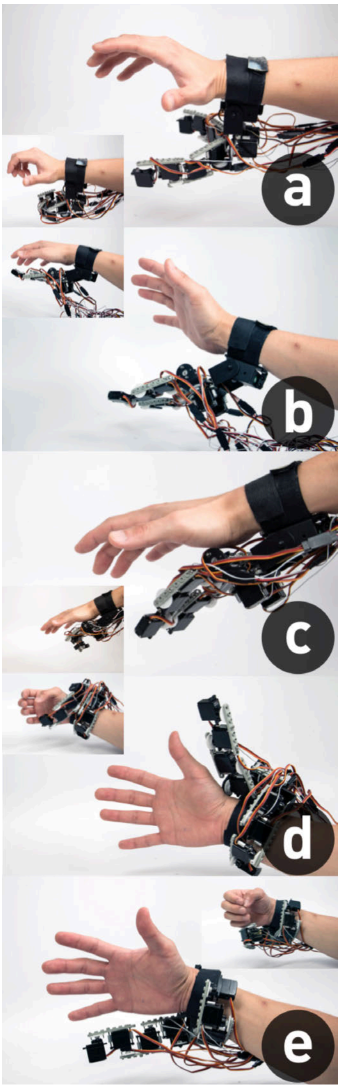

Figure 3: Different hand augmentation configurations.

Introduction

Human hands play a central role in creative endeavors as a tool for creation and the manifestation of sophisticated skills. However, advancements in digital technology and graphical user interfaces have created an artificial blockade between our hands and the world, limiting their interaction to an increasingly infinitesimal point of contact. This not only results in a disconnect from our rich kinesthetic experience, but also a potential loss of innate skills.

A similar criticism can be applied to the trans-humanistic idea of electro-mechanical prostheses, as is depicted in science fiction often as a dystopian and dehumanized element [2]. However, we speculate that the criticism has to do with a specific "possible" future where human capability is "substituted" by lifeless machines. There have been few studies that establish design guidelines for "desirable" human-machine hybrids and corresponding applications firmly based on current human needs.

In the field of robotics, exoskeletons and prosthetic limbs are closely relevant to those topics from science fictions. Exoskeletons are used for acquiring extended performance, rehabilitation, or tele-presence [6, 8]. Prostheses are designed to replace loss of body function with equivalent artificial additions, simulating sensory or functional capabilities of the human hand in the artificial limb [3]. In spite of their amplifying nature, the types of augmentation are limited to copying or linearly extending (e.g. stronger, longer) our innate ability. Recently, a more radical augmentation has been explored in research on supernumerary limbs [7, 9]. This field studies additional robotic fingers or limbs that support physical tasks by reducing load or aiding in object manipulation. These works present more synergistic collaboration between human and robot, however, their control and mechanical design are heavily focused on replicating human motions, whereas more variety in form factors and motions could open up new interaction opportunities beyond increases in number.

In this paper, we present a wrist-worn joints device that consists of 11 mechanical joints and is capable of rendering different physical form factors that suit to different tasks. We also demonstrate concrete applications illustrating the use of our device in everyday contexts. On the basis of the implemented applications we envision a synergistic electro-mechanical body extension without disregard for the natural human body and its capabilities.

System

The physical design of our joints device is created to maximize the rendering capability for various form factors, while maintaining a quasi-anthropomorphic setup so that a range of physical tasks can be performed [5]. Therefore, our final design (Figure 2) consists of two finger-shaped segments (each with 4 pitch servos, and one yaw servo), mounted on a bigger base servo that adjusts the angular position of the entire device. The base servo can be mounted in different ways: on the forearm or the wrist, parallel or perpendicular to the arm.

For the motor control, we used Electromyography (EMG) signals from a MYO [1] sensor worn around the arm (Figure 1). EMG signals are picked up from muscles around the elbow (brachioradialis), which can be coordinated by the user independently from normal

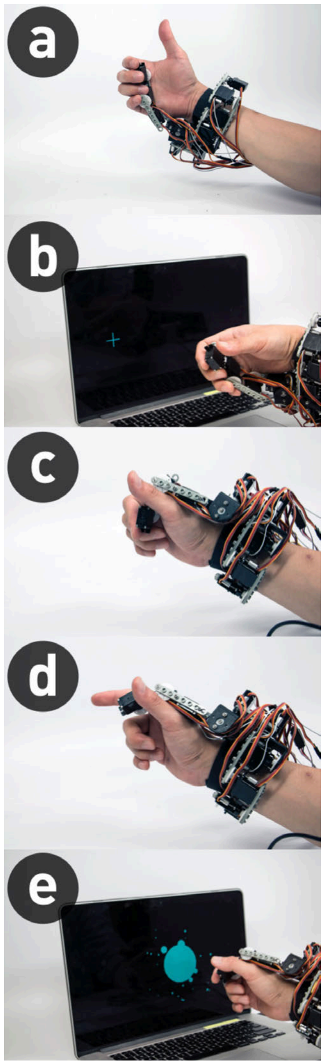

Figure 4: Our hardware configured to provide physical user interfaces.

hand movements. Therefore, we could utilize this muscle as an additional modality alongside common hand gestures. The raw EMG signal from the muscle is filtered to acquire stabilized amplitude, which is then used for control input. The motions of the robotic joints are controlled parametrically so that a sophisticated behavior can be coordinated with low-dimension control inputs.

The wearable design of our device makes it easy to switch between use and non-use. Additionally, the device can disengage from the user's context by wrapping around the arm like a wristband. This allows the wearable design of the device less interfering, coming to the foreground only when assistance is required. The multiple use cases of the device and its compact "passive" state make it attractive as a device that is worn by the user all the time, the way one wears a watch all day long.

Application: Hand Augmentation

Our biological hands and the mechanical joints can work in synergy to provide a user with increased manipulation capability. For example, a guitarist can use extra fingers to invent a phrase formerly impossible to play, or a rubik's cube can be solved by one hand – with extra fingers holding it. These capabilities are provided in addition to the user's own hands, neither substituting nor interfering with them.

We implemented various configurations: a wrist-worn gripper (Figure 3 a), a second palm that opens against a user's own palm and helps with picking up large objects (Figure 3 b), a hook tool (Figure 3 c), and extra fingers with similar function and motions as the existing ones (Figure 3 d-e). Also, the control can be driven by context-awareness, e.g. the joints rotate a doorknob while the user is unlocking the key.

More sophisticated hand gestures (via performing machine learning on the input EMG signals) can be used for high-level controls. A fist-making gesture triggers the mechanical joints to disengage by turning into the idle wristband configuration, thereby switching the user's hands back to their innate capability. In the idle state, wave-in/out gestures can be used to switch between different active modes.

Application: User Interface On-the-go

The device can be dynamically reconfigured to provide certain physical affordances, and utilized as a haptic User Interface (UI) on demand. In a setup similar to the extra little finger, we configured the device to be used as a joystick controller held by the user (Figure 4 a-b). By deactivating two of the servos, the joystick provides two degrees of freedom (DoF) control. Then we modified the two servos to read their potentiometer values (angle), and used those values for 2D pointer control.

Another implementation is a gun-trigger type of interface. Once the trigger is pulled, the servos get activated and provide force-feedback: "clicking" and then "recoiling" back to their original positions (Figure 4 c-e). Detailed motion parameters (recoil speed, stiffness, etc.) can be programmatically encoded to simulate different types of physical triggers. The device can also shift between states/shapes to render nested and sequential affordances [4] e.g. locking the trigger when a game player runs out of ammo and unlocking once reloaded.

Application: Passive Augmentation

Structural augmentation describes an inanimate form of machine engagement, where the control aspect of the joints device remains in the background. We implemented different passive support structures using the device in order to assist in bimanual tasks. The role of the non-dominant hand is offloaded to the passive joints structure (holding a camera lens or a note) therefore letting the user complete the tasks with one hand.

The device can also be configured to increase a user's exertion capability, e.g. help holding heavy objects like a wrist support used for bowling. An additional application is a lock mechanism that makes the user stay in a secure position e.g. locking on a bus handle.

Conclusion

In this paper we proposed a wearable and programmable joints interface that extends our physical capabilities. Through concrete applications, ranging from mechanical hand augmentation to providing physical UI on-the-go, we demonstrated synergistic interaction between our hands and the machine joints. These electro-mechanical augmentations are implemented in a way that they do not replace or obstruct our innate kinesthetic skills. In order to achieve controls of the joints independent from normal hand movements, we used EMG signals from the brachioradialis muscles. This allows intuitive extension of our innate hands, and additionally, the same signal can be used for various configurations – lowering the hurdle of user adaptation. Our wearable design allows the device to easily disengage from the user's context, providing augmentations only when they are needed rather than enforcing the continuous use of them.

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