ChiroBot: Modular-Robotic manipulation via Spatial Hand Gestures

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ABSTRACT
We introduce ChiroBot, a cyber-physical construction kit that allows users to create custom robots out of craft material, easily assemble the robots using joint modules and control them using hand gestures. These hand-crafted robots are assembled using our modules packaged with actuator, wireless communication and controller electronics. These modules eliminate the need for expertise in electronics and enable a plug and play system that directly encourages users to explore by quick prototyping. We designed a glove embedded with sensors to enable the user to control the robots using hand gestures. We present different usage scenarios to demonstrate the system's versatility such as vehicular robot, humanoid puppet, robotic arm, and other combinations. This paper describes the ChiroBot system, interaction methods, few sample creations, and proposes possible "play value".

Categories and Subject Descriptors:
H.5.2 [**Information Interfaces and Presentation**]: User Interfaces—Input devices and strategies, interaction styles; K.3.1 [**Computers and Education**]: Computers Uses in Education

General Terms
Design, Experimentation, Human Factors

Keywords
Modular robot, gestural interface, Play-Value, Constructionism

1. INTRODUCTION
Handicraft has been a way to demonstrate one's skills, knowledge, thoughts, experiences, perceptions and emotions [14]. The process of building and constructing functional prototypes has been shown to actively engage users particularly when they see their creation as an extension of their self-concept. Studies show that people relate to self-constructed robots as emotional and intellectual companions [4]. Present day technology has the potential to enable the user to combine craft and electronics to provide new affordances for creative expression. Animation of such user constructed robots can be made intuitive with the help of gestures as *"Gestures are integrated on actionable, cognitive and ultimately biological levels" (pg. 3)* [12].

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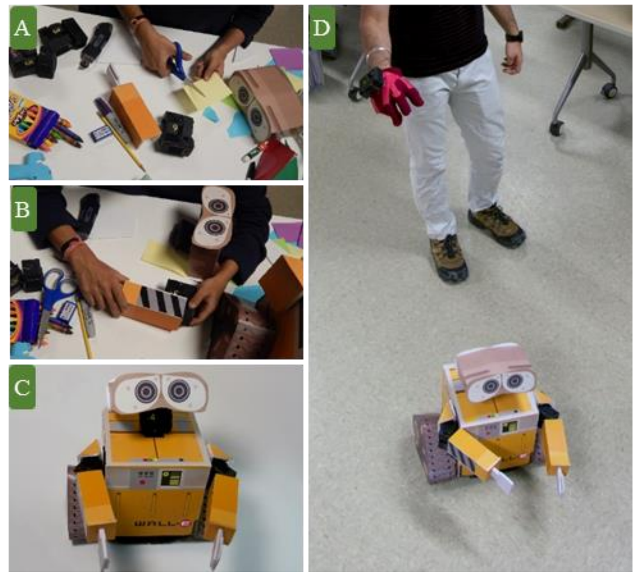

Figure 1. ChiroBot System (A) Using craft material to make robot (B) Assembly of wireless modules with craft using Velcro (C) Final robot (D) Playing with robot using hand gestures

Amalgamation of craft and technology normally require expertise in motor control, packaging, communication, wiring and programming. A simple system that takes away these complexities can allow to boost play value. To this end, we introduce ChiroBot (Chironomia + Robotics) to explore the intersections of three important trends: (1) expression of user's creativity through handicraft, (2) encapsulating the technology into modules, and (3) hand gesture as a controlling mechanism to interact with them. These robots can be crafted using materials like cardboard and foam core coupled with our designed wireless modules which provides more affordances for handicraft design. A tablet application helps the user to configure the robot they built. The robot-system is then controlled using a glove based device using hand gestures. The glove is integrated with flex sensors and inertial sensors that read signals to understand the pose of the hand. This gestural affordance engages the user by giving them an opportunity to control their play-things in a natural manner.

2. RELATED WORK
ChiroBot draws its inspiration from a multitude of fields, namely tangible interfaces, customized personal robots, puppetry and gestural interaction. Here we mention some of the influential work in these fields that motivated the ChiroBot system.

Customized robots were built using craft and lego parts and programmed via a graphical programming to create artistic robots [1]. Building robots using pre-defined shapes has been widely commercialized via Lego Mindstorms [6] and EZ-Robot[1]. Techniques have been developed to animate constructive systems and plush toys, using kinetic memory - the ability to record and playback physical motion [2, 3]. The systems in these kits are generally designed to make objects with fewer (1 – 4) motor actuated joints. The majority of these prior works have a set of predefined physical shapes and ways to assemble them that restrict design freedom. Handicraft objects on the other hand provide more freedom to explore imagination.

The control techniques in the above-mentioned kits generally uses either a graphical programming system or a record and playback technique. Some other techniques to control mobile robots have also been developed using captured gestures [11]. Capturing hand gesture using camera or sensors has now become a popular method to interact and control different virtual and tangible objects [5]. Dipietro [7] provided a comprehensive survey of the various Glove-Based Systems. Many different designs of glove based input devices have been explained, leveraging the anatomy of the hand. Some are discrete to the finger whereas others are upper limb garment prototypes. Various technologies have been used to implement the prototypes – Magnetic, Ultrasonic, Optical and Inertial. Other commercial products are also introduced in the market that use a glove-based input device e.g. Peregrine game glove and Mechdyne's Pinch glove [7].

3. ChiroBot

The design goals for ChiroBot was to convert art forms created using cardboard/craft materials into interactive robots. We attempt to take away the technical complexity and allow expansion of design, construction and creativity. The system was thus designed based on the following design goals:

DG1. *Versatile and easy connection technique:* The system should allow the user to easily attach craft material.

DG2. *Easy to use:* The system should be simple enough to be used by people of all ages specially children.

DG3. *Safe and robust:* As the system is to be used by children, the device should be safe and work reliably.

DG4. *Adequate & smooth movement:* The system should be able to recreate most motions (both fixed angle and continuous motion) smoothly to provide an enjoyable experience.

DG5. *Scalable:* In the spirit of a modular design, every individual component should be physically and computationally complete and extensible.

DG6. *Expressive*: Encourage exploration of a topic without prescribing "right" and "wrong" activities.

3.1 Early Design Phase

To achieve the goals stated earlier, we developed an initial prototype comprised of a set of actuators and basic shapes such as

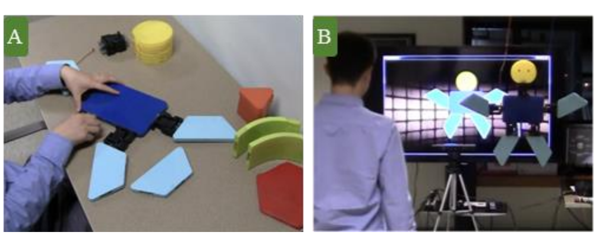

Figure 2. Initial Prototype (A) Assembly of active and passive parts (B) Control of robot with body gestures using Kinect

[1] http://www.ez-robot.com/

triangle, rectangle, trapezoid and circle. This initial prototype was controlled using body and hand gestures detected from a Kinect or Leap motion camera (Figure 2). Based on a pilot study performed with the system and after talking to different puppeteers who actively conduct workshops for kids, we found that users preferred a system that could easily be attached to pre-existing familiar material. Further, the users also showed strong inclination towards untethered systems.

We thus redesigned the system to have independent wireless modules whose position and configuration could be allotted once by the user using a mobile / tablet application. To make the control of the system mobile and gesture controlled a flex sensor and IMU (Inertial Measurement Unit) based glove was developed. To explore the versatility of the construction, we provide the user with a set of 9 such independent modules as a set.

3.2 Module Design

The joints are modules which get easily attached to the craft material using Velcro (DG1) as it is a widely popular temporary fastener among artisans and puppeteers. These modules are currently made of 3D printed material. To obtain a high torque and smooth motion Herkulex DRS-101[2] motors are used. The motor parameters are adjusted to obtain a smooth and non-jerky motion (DG4). These modules contain an XBee[3] module for wireless communication and an Arduino nano[4] (Figure 3).

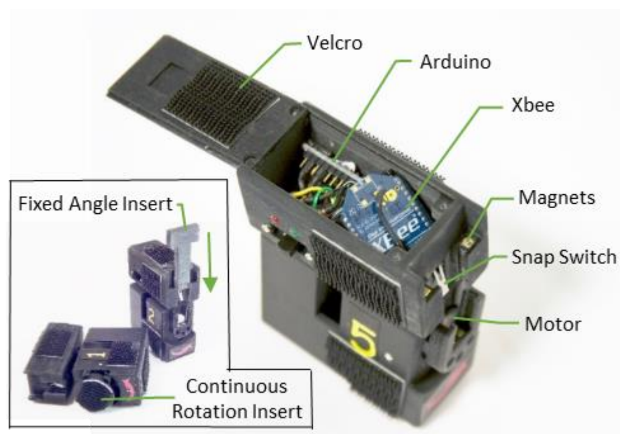

Figure 3. Electronics in the Joints and Inserts used for different types of motion

The motor, wires and electronics are enclosed in a shell like casing to make the device safe for use for kids (DG2, DG3). To allow the device to have both angular motion and continuous rotation (basic forms of one degree of freedom electric joints), an insert is used to lock the upper and lower halves of the module. These inserts are held in place with the help of magnets. A snap switch is used to prevent damage to the module in case the fixed

Table 1. LED Indication

State	Red LED	Green LED	State	Red LED	Green LED
Active Motion	● (dark red)	● (green)	Motor Error	● (red)	● (dark green)
Waiting to start	● (dark red)	● ● (dark green, green)	Wrong Insert	● ● (red, dark red)	● (dark green)

**Note: 2 LEDs in a cell indicate blinking*

[2] http://www.dongburobot.com/jsp/cms/view.jsp?code=100788
[3] http://www.digi.com/xbee
[4] http://arduino.cc/en/Main/arduinoBoardNano

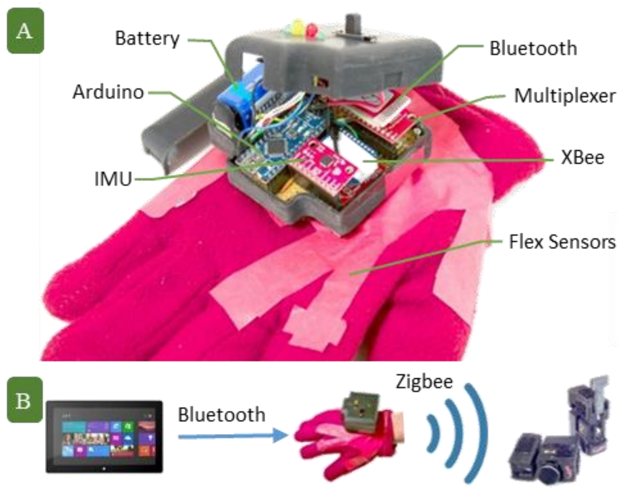

Figure 4. (A) Electronics in the Glove Controller (B) Communication Protocol

angle insert is in place but the joint is being used for continuous rotation. Two LED lights are used to provide the user with the visual feedback of the state of the device (Table 1). Each module is powered using a standard 9V battery.

3.3 Controller Design

In order for the interface to be as natural as possible, we leverage the dexterity of the user by developing a glove-based controller. There are seven flex sensors, which were multiplexed by a 16-channel CD74HC4067 MUX breakout board. These sensors are synergistically coupled with an IMU device to read the analog values which are used to capture the hand pose of the user. The flex sensors are placed on the thumb (Interphalangeal, Metacarpophalangeal joints) index and middle fingers (Proximal Interphalangeal and Metacarpophalangeal joints) due to the greater dexterity of these fingers [13]. A sensor is also placed on the pinky finger for differentiating normal control gestures from global gestures. An LED based visual feedback system is incorporated to make the user aware of the state of the IMU and controller (Figure 4A). The communication between the tablet application and the controller takes place via Bluetooth as it is compatible with tablets. XBee (Zigbee communication protocol) is used to create a Personalized Area Network for communicating between the controller and the modules. (Figure 4B).

4. Interactions

We created a sample of popular objects to explore the versatility of our system. With the help of our developed glove controller, these objects are being controlled by the means of hand gestures. The gestures can be classified as global and class-specific.

Global gestures (Figure 5A) are valid irrespective of the class of object selected by the user. The global gestures are:

Shake: This gesture is used to start the system. After shaking the hand, user is expected to keep their hand flat for 2 seconds so that the system starts from the origin position and the user has more control over it.

Closed fist: This gesture is used for an emergency stop. Whenever this gesture is performed in any orientation of the hand, the system comes to a standstill. The shake gesture is then required to restart the system.

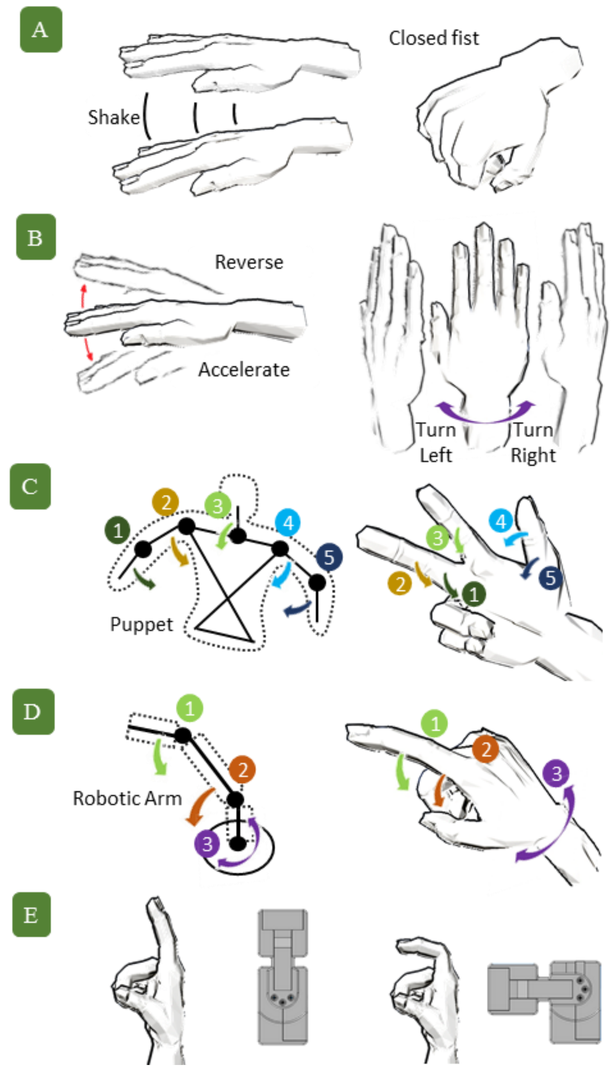

Figure 5. Control Gestures for Chirobot: (A) Global gestures (B) Gestures for controlling Vehicular Robot (C) Gestures for manipulating Puppets (D) Gestures for Robotic Arm (E) Fixed angle rotation of module mapped to PIP joint of index finger

The specific control of each class of robots is divided into the relaxed hand state where the object is in rest and active hand state where the object performs the motion based on the mapping (Figure 5E). These specific mapping is displayed to the user on the tablet interface. Some of the classes of robots created by us are:

Vehicular Robots: These types of robots consist of 2, 3 and 4 wheeled robots. The speed is mapped based on the principle of a joystick where the speed is proportional to the angular displacement of the hand from the relaxed (flat) position (Figure 5B).

Puppet Shaped Robots: The user has the freedom to control either the top or bottom of the puppet. For controlling this class, the person makes use of the thumb, index, middle finger and their hand orientation. This mapping is similar to one of the common hand mapping used for controlling hand puppets [9] (Figure 5C).

Robotic Arm: As index finger is the most decoupled from the rest of the hand, the robot arm is controlled using the index finger and hand orientation of the hand [13] (Figure 5D).

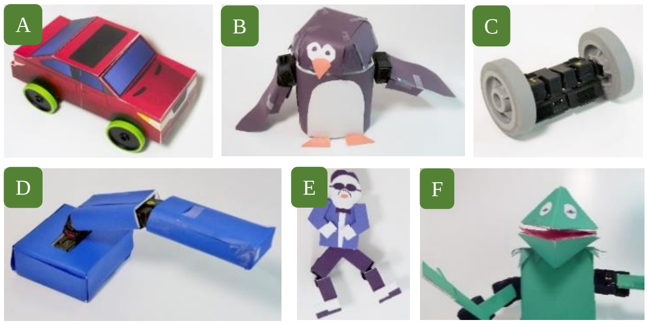

Figure 6. Robot Creations (A) Car (B) Penguin (C) 2 Wheel Car (D) Robot Arm (E) Psy – Gangam Style (F) Kermit

Other Objects: Along with these three classes, the user has the freedom to create combinations of these classes (DG5, DG6) (Figure 6).

To understand the class of the robot and joint mapping we use a tablet application. This is a simple interface where the user selects the class of the object. This operation has to be done only once at the beginning after the user constructs their object. The interface is built using Unity3D[5] game engine and can be installed on any tablet or mobile device. Seven sample class of objects have been created in this interface which is a combination of the above mentioned families.

Note that, (1) construction can be done using everyday objects, (2) the user has the freedom of both continuous and fixed rotation with the joints created, and (3) each robot family can be extended to create a multitude of robots. Thus, the possibility of objects that can be created and controlled using this system is practically limitless.

5. IMPLICATION

Play Value: Our system provides aspects like fantasy, challenge and construction to the user [10]. We predict that our system provides active involvement, aspects of free play, physically and mentally active and a socially associative involvement.

Constructionism and robotics in education: Our system enables children to learn important rudimentary engineering skills through the process of creation. Robotic technologies make it possible for children to practice and learn many necessary skills such as collaboration, cognitive skills, self-confidence, perception and spatial understanding [5], and our system supports this ideology.

Cognitive Load: In a heavy menu driven application; the user develops a 'split attention effect [8]: dividing their attention between the task and the control mechanism. By leveraging proprioception of the hardware coupled with a visual feedback (LED display), we hypothesize that the user will be more immersed in the task rather than dividing a greater attention for the control mechanism.

Potential Improvement and Future Work: Because of the size of the modules, the overall size of the robots tends to be bulky. In a more customized implementation, we could fabricate components with a smaller footprint and integrate them into a more power efficient system with a smaller form factor. We are also working on controlling multiple creations together using a single controller. We intend to determine the usability of this framework by conducting a user study.

[5] https://unity3d.com

6. Conclusion

We present the ChiroBot, a system that enables the user to craft functional electromechanical prototypes and control them using hand gestures. The demonstrated system, we believe, is an instance of a more general framework that will allow users to creatively build and explore electromechanical systems without the need for expertise in underlying complex electronics. Our immediate goal is to evaluate the performance of our system in terms of responsiveness and intuitiveness of gestural control. Our broad overarching intent is to investigate and understand how our framework can facilitate creative thinking in an educational setting.

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