HandiMate: Create and Animate using Everyday Objects as Material

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ABSTRACT
The combination of technological progress and a growing interest in design has promoted the prevalence of DIY (Do It Yourself) and craft activities. We introduce HandiMate, a platform that makes it easier for people without technical expertise to fabricate and animate electro-mechanical systems from everyday objects. Our goal is to encourage creativity, expressiveness and playfulness. The user can assemble his or her hand crafted creations with HandiMate's joint modules and animate them via gestures. The joint modules are packaged with an actuator, a wireless communication device and a micro-controller. This modularization makes quick electro-mechanical prototyping, just a matter of pressing together velcro. Animating these constructions is made intuitive and simple by a glove-based gestural controller. Our study conducted with children and adults demonstrates a high level of usability (system usability score - 79.9). It also indicates that creative ideas emerge and are realized in a constructive and iterative manner in less than 90 minutes. This paper describes the design goals, framework, interaction methods, sample creations and evaluations of our framework.

Author Keywords
Gestural interface; Play-Value; Constructionism; Handicraft; Creativity

ACM Classification Keywords
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

INTRODUCTION
The easy accessibility of information and electronic technology has resulted in the availability of cheap and powerful electronic tools. This is encouraging hobbyists and tinkerers to invent and prototype, growing the culture of learning through doing [21]. A similar trend is also seen in robotics as it is becoming a popular pedagogical method. One reason for the educational appeal of robotics, is that in the process of designing and programming robots, students indirectly learn important engineering, math, and computer science concepts [7]. On the other hand handicraft, objects made completely by hand or by using only simple tools, have served as a medium to express and demonstrate skills, knowledge, thoughts, experiences, perceptions and emotions [22]. 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 [9].

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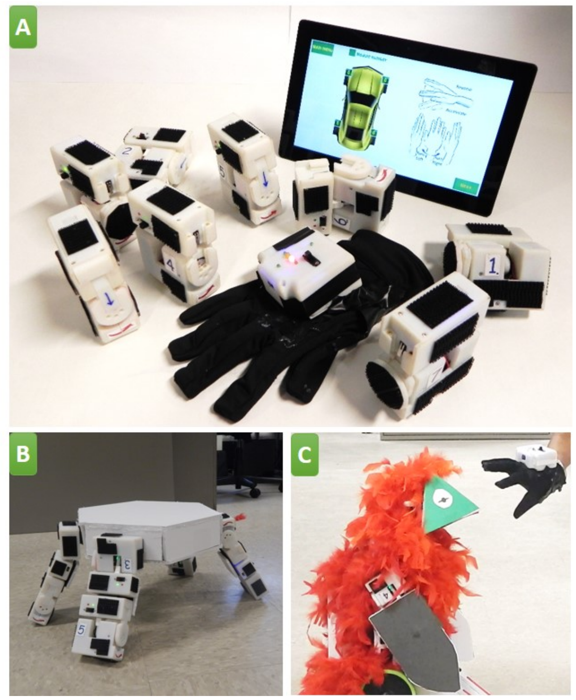

Figure 1. (a) HandiMate Kit (b) Sample creation (c) Gesture control of robot

Marvin Minsky explains in his book "Just as we learn to interpret certain types of changes as representing motions of objects in the physical realm, we learn to classify other types of changes as signifying mental events; these are what we call gestures and expression" [16], implying that gesture is a natural language of the brain. This suggests that a gestural user interface is an intuitive command methodology. Hence we have developed a gestural control device allow intuitiveness in controlling the user constructions.

Our goal was to create a kit that allowed the user to easily build and animate objects. This would allow the user to create robots using the values encouraged by handicrafting. HandiMate explores the intersection of three important trends: (a) expression of user creativity through craft, (b) animation of everyday objects, and (c) gestural interaction with portable and personal devices. The animated toys are created using everyday objects (like spoons, cardboard box, milk cartons, etc) as material coupled with modules we have designed, using velcro. The modules are equipped with microcontroller, actuator, wireless communication and a battery. So they are extensible, and independent of each other. A tablet application helps the user configure the object built. The object is animated using hand gestures through a glove based input device. The glove is integrated with flex and inertial sensors that read signals to understand the pose of the hand. This way HandiMate eliminates the need for expertise in technology like motor control, packaging, communication, wiring, and programming is by moving them to the background. This encourages the user to explore and create and at the same time broadens the age range of participation.

RELATED WORK

HandiMate draws its inspiration from crafts, configurable robots, and gestural interactions. Here we mention some of the prominent works in these fields that influenced our design rationale.

Crafting & Creativity

Crafting and making decorative articles by hand, have been given a variety of definitions, from the desire to do a job well for its own sake [25] to the celebration of social and creative explorations of material [15] . Today's crafts have been combined with DIY activity in creative subcultures across America. These DIY communities (Instructables, Dorkbot, Craftster, Ravelry, Etsy, and Adafruit) have been shown to emphasize open sharing, learning, and creativity [14]. Such discussions of the intricacies of the work, telling stories around craft, and describing the processes for others to remake or modify, has prompted further customization, creativity and reuse.

Inspired by the DIY and maker movement, we developed a platform that can allow children and adults to quickly construct and animate toys made using virtually any material.

Configurable Robots

Many researchers have explored different types of configurable robots for purposes such as smart machines capable of locomotion and transformation [19], educational tool kits that children can use to learn about programming [26], and simple toys [20]. These kits allow construction of robots using different materials such as predefined plastic shapes [2, 23], user defined plastic shapes [1], laser cut shapes [27] and a combination of craft and LEGO [24]. The control techniques in these kits generally use either a graphical programming system [2, 24], autonomous control [19] or kinetic memory - the ability to record and playback physical motion [23]. The culture of building robots using pre-defined shapes has been widely commercialized via LEGO Mindstorms [2] and EZ-Robot [1].

These kits were generally designed to make systems with few (1 to 4) motor actuated joints. A majority of these prior works tended to restrict design freedom, as they had a set of predefined physical shapes that could only be assembled in specific ways. On the other hand, crafting using everyday objects as material provides more freedom in creative exploration.

Gestural Interaction

A large amount of research has been done to exploit the idea of capturing gestures via glove-based devices. Devices implementing different sensor technologies, various patterning & placement of these sensors on the hand and multimodal systems have been explored [6]. As a result, products like Mechdynes Pinch Glove, Mattel, and Peregrines gaming glove were introduced in the market. Recently, depth cameras supported by computer vision algorithms, have been extensively used to capture user gestures (Kinect, PrimeSense, Leap Motion device). SixthSense [17] and Omnitouch [10] illustrate a wearable on-the-move system for gestural interactions. Other wrist worn depth camera devices have been developed to detect coarse motion of fingers [11]. People have also explored hand-held [18] and shoe-worn [4] systems.

As electronic sensors provide us with high fidelity sensing in mobile applications, they are reliable in robustly reading input signals. These electronics embedded in a wearable glove thereby allow capturing multiple analog values (joint bends of the hand) in a computationally efficient manner. This motivates the use of a glove-based gestural system for our kit.

DESIGN GOALS

The design goals for HandiMate are to provide a platform for the user to easily construct and animate systems using everyday objects as materials. To this end, we attempt to take away the technical complexities, while providing more design freedom and encouraging constructionism and creativity. The framework was designed based on the following design goals:

DG1. *Accessible*: The material used for constructing the objects should be easily accessible and be assembled quickly using simple and familiar techniques.

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

DG3. *Safe and robust*: As the framework is to be used by people of different age groups, the device should be safe and should 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 module should be physically and computationally complete and extensible.

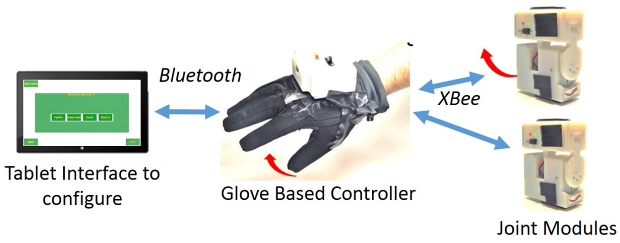

Figure 2. System overview showing flow of data

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

HANDIMATE OVERVIEW

The HandiMate consists of a tablet application, glove-based controller and joint modules (Figure 2).

Interface Design

A simple tablet application has been developed to understand the topology of constructions made and to effectively map them for gestural control. The interface is built using the Unity3D[1] game engine. The application can be installed on any tablet or mobile device. A few basic families of constructions are made available with predefined control mappings where the user has to select the position and direction of motion of the joint modules (Figure 3). The interface also allows the user to create objects different from these predefined families and to assign their own user defined mapping to the object being constructed. Once defined, these mappings are transferred to the glove-based controller using Bluetooth communication. This operation has to be done only once each time the user constructs a new object.

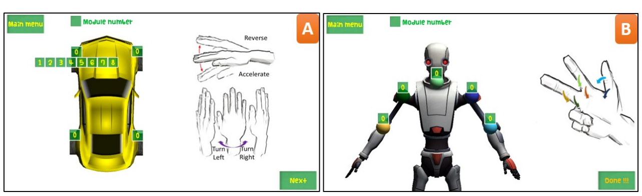

Figure 3. Tablet Interface for selecting position of the joint module (a) four wheel vehicle (b) puppet

Glove-Based Controller

The glove-based controller is used to read the hand pose of the user and control the motion of the joint modules. It consists of an Arduino Nano[2](ATmega 328, clock speed 16MHz), flex sensors[3], MPU 6050[4] (IMU), BlueSMiRF Silver[5](Baud rate 115200 bps) and XBee Series 1[6] (Baud rate 57600 bps) (Figure 4(a)). The Bluetooth device is used to receive the joint module and hand joint mapping from the tablet interface. Flex sensors are placed on the thumb (Interphalangeal, Metacarpophalangeal joints), index and middle fingers (Proximal Interphalangeal and Metacarpophalangeal joints)

[1]https://unity3d.com/
[2]http://arduino.cc/en/Main/arduinoBoardNano
[3]https://www.sparkfun.com/datasheets/Sensors/Flex/flex22.pdf
[4]https://www.sparkfun.com/products/11028
[5]https://www.sparkfun.com/products/12577
[6]https://www.sparkfun.com/products/8665

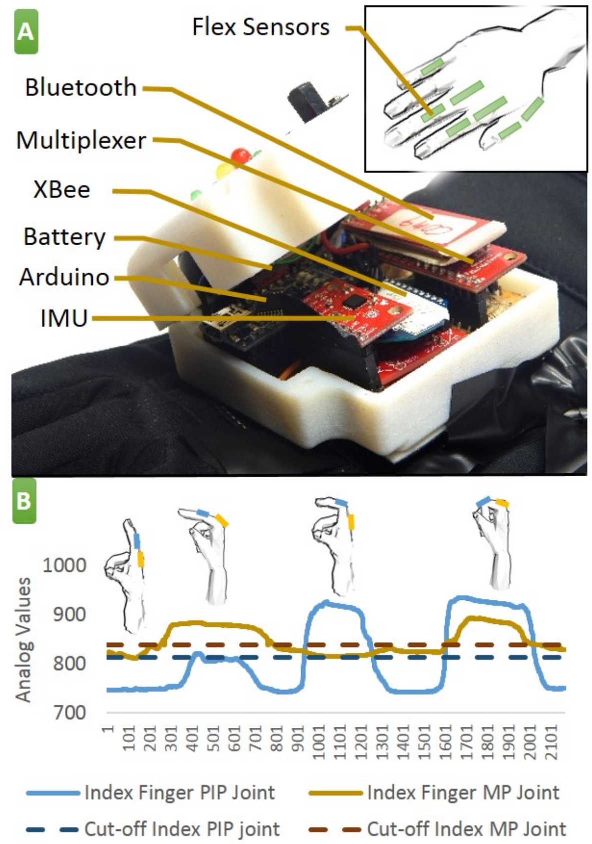

Figure 4. (a) Electronics in the Glove-based Controller (b) Analog readings of the flex sensor at Index finger PIP joint and MP joint for different finger orientations

due to the greater dexterity of these fingers from the rest of the hand [12]. A sensor is also placed on the pinky finger (Proximal Interphalangeal joint) for differentiating control gestures from start and stop gestures. The seven flex sensors, are multiplexed by a 16-channel analog multiplexer[7]. When the resistance of the flex sensor changes (34K to 67K ohms) by bending, the micro-controller picks up the voltage across the flex sensor based on a voltage divider circuit. These analog values are then converted into corresponding motor values. This mapping between the analog sensor value to the motor value is not directly based on the actual angle of the hand or finger, but is scaled to allow full rotation of the joint module within a comfortable range of motion of the hand or finger. This comfortable range was determined by doing a small pilot test with few people of different hand sizes. The flex sensors are also placed and calibrated in a way to prevent interference between the joints on the same finger (Figure 4(b)). In a similar manner the micro-controller also reads the angle values from the gyro-meter and accelerometer in the IMU device by I^2C communication and generates the motor values. The motor values are transmitted to the respective joint modules by a PAN network created by the XBee communication device.

[7]https://www.sparkfun.com/products/9056

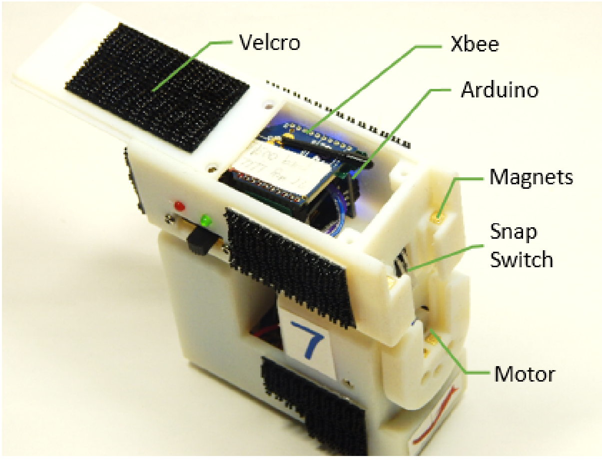

Figure 5. Electronics in the Joint Modules

For safety, these electronic components are enclosed in a shell like casing made by 3D printing. A LED based visual feedback system makes the user aware of the state of the IMU and the glove-based controller.

Joint Modules

The joints modules are used to animate the user's construction using the glove-based controller. These modules contain an XBee communication device that reads the information from the glove-based controller, a micro-controller (Arduino Nano) for interpreting this information, and Herkulex DRS-101[8] motors for motion (Figure 5). The parameters of acceleration - time ratio and power input were adjusted to obtain a smooth and non-jerky motion of the motor. The motor, wires and electronics are enclosed in a shell like casing to make the device safe for use. Each module is powered using a 9V lithium ion battery.

The joint modules are connected to each other and to everyday objects using velcro as it is a widely popular temporary fastener. These strips of velcro are provided on all sides to give users freedom to attach objects at different orientations.

[8]http://www.robotshop.com/en/herkulex-drs-0101-robot-servo.html

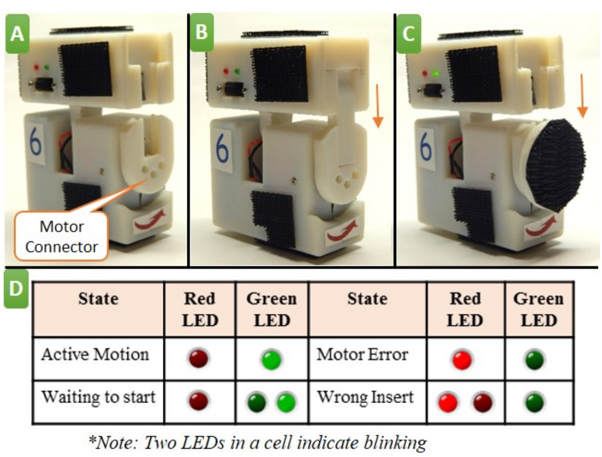

Figure 6. (a) Joint module without any insert (b) Joint module with fixed angle insert (c) Joint module with continuous rotation insert (d) LED Indication

To allow the device to have both fixed angle and continuous rotation motions (basic forms of motion by a one degree of freedom electric joint), inserts are used. These inserts are held in place with the help of magnets. The fixed angle insert allows for rotation from -90° to 90°. It snaps into the motor connector and locks the upper and lower halves of the module. The continuous rotation insert allows a wheel like continuous motion. It is attached to the motor connector and provides a large surface area for attaching objects (Figure 6(a,b,c)). A snap switch is used to prevent damage to the module in case the fixed angle insert is in place when the joint is being used for continuous rotation. Two LED lights are used to provide the user with visual feedback of the state of the device (Figure 6(d)).

INTERACTIONS

With the help of our glove-based controller that provides us with eight analog input values, the constructions are controlled by means of hand gestures. These gestures can be classified as global and construction control.

Global Gestures

Global gestures are valid regardless of the construction made by the user (Figure 7(a)). 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 100 milli-seconds. This allows the construction to always start from rest and the user has good 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 complete standstill. The shake gesture is then required to restart the system.

Construction Control Gestures

These sets of gestures are used for animating the construction. The general control of each type of construction is divided into the relaxed hand state (close to a flat hand position) where the object is at rest and active hand state where the object performs the motion based on the mapping. The constructions made by the user can be of three main categories:

Articulated

The constructions of this type has fixed angle of rotation motions. They are further sub divided into:

Puppet Shaped Constructions: For controlling this type, the user makes use of the thumb, index and middle finger. This mapping is similar to one of the common hand mapping used for controlling hand puppets [8] (Figure 7(b)). When the user moves their fingers from the rest position, the corresponding joint modules move.

Robotic Arm: As the index finger is the most decoupled finger from the rest of the hand, the robot arm is controlled using the index finger and orientation of the hand [12](Figure 7(c)). Similarly, when the user moves his hand and finger from the rest position, the respective joint modules move.

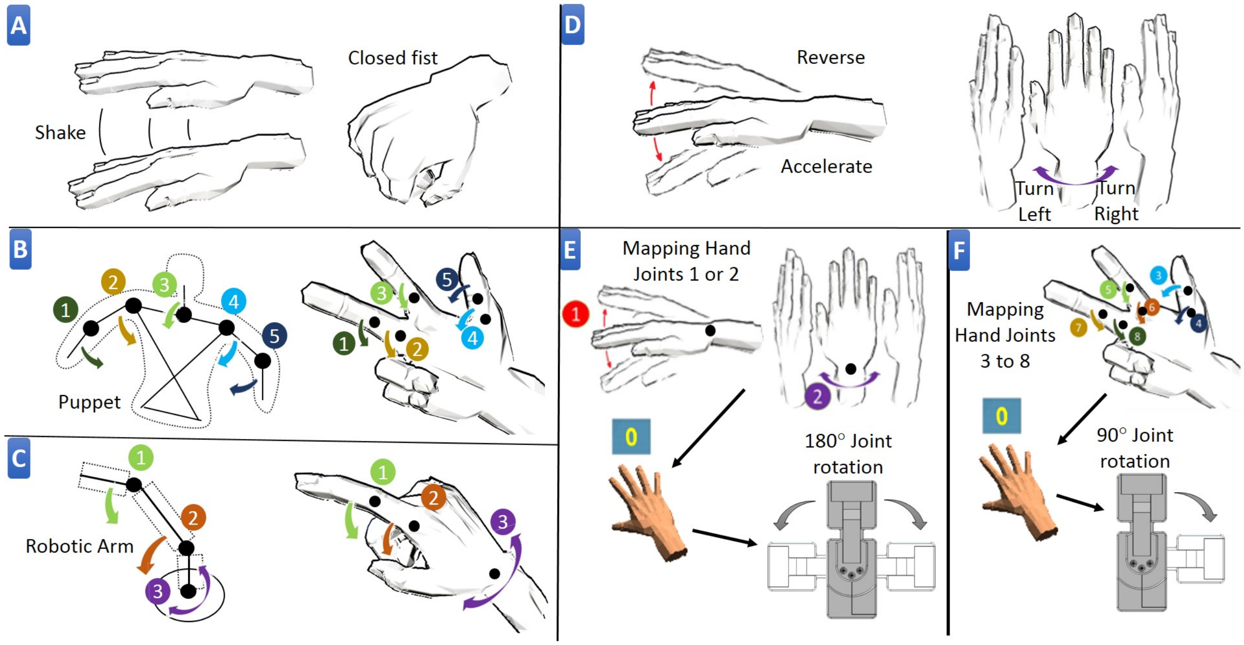

Figure 7. Interaction methods: (a) Global Gestures; Gestures for (b) Puppet Shaped Constructions (c) Robotic Arm shaped constructions (d) Vehicular constructions; User Defined gesture mapping for custom robots (e) Hand joints 1 or 2 (f) Hand joints 3 to 8

Vehicular

This type of construction consists 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 7(d)). The steering mechanism for the vehicle is executed by spinning wheels on the two sides of the vehicle in opposite directions. The user is also given the option of adding the different articulated constructions mentioned above, over the vehicle (Figure 8(g,p,t)).

Custom Robots

The previous two categories had predefined mappings for the control technique. This category does not have any fixed mapping, but allows the user to explore and experiment with different mapping techniques, and select one which they feel is more natural. The user is given the option of choosing the modules being used, and their desired motion, like fixed angle clock wise (CW), fixed angle counter clock wise (CCW), continuous rotation (CW), or continuous rotation (CCW). Once they select the modules, they have the option of choosing the hand joint number and mapping the hand joint to the respective joint module (Figure 7(e,f)). The user has the option of mapping multiple joint modules to the same hand joint. To avoid inconsistency and confusion, the option of mapping multiple hand joints to the same joint module is not available.

As hand joints 1 and 2 allow a 180° angle hand rotation (Figure 7(e)), the joint modules controlled by these joints move from -90° to 90° when in fixed angle mode. Since joints 3 to 8 are finger controlled, the joint modules mapped to them can rotate from 0° to 90° or -90°(Figure 7(f)). When the joint module is in continuous rotation mode, the user can control the speed of the joint module rotation based on the deflection from the relaxed (flat) hand position. Joints 1 and 2 allow bi-directional speed control whereas joints 3 to 8 allow unidirectional speed control.

USER STUDY

We conducted a user study to determine the usability of our framework, observe the variety of constructions made by the user, and various control mappings used by them. The participants were explained the framework and given freedom to build and construct on their own. Feedback was obtained from them for evaluating the framework and to obtain suggestions for improvements and possible future directions.

Procedure

We recruited nineteen participants by distributing flyers at the university. We had twelve participants who were graduate and undergraduate students aged between 20 and 29 years. Seven participants were school going kids aged between 10 and 15 years of age. The participant pool consisted of six females and thirteen males; seventeen right handed and two left handed individuals. All participants had no prior experience of using the framework. The user study was conducted in two different settings.

Setting 1

This study was conducted in a closed environment with the raw materials provided by us. The raw materials consisted of kitchen ware, such as spoons, fork and pans, and craft material such as construction paper, multi-colored thread, colored craft sticks, assorted feather collection, crayons, markers, tape, glue gun, knifes, googly eyes, scissor and foam core board. For quick prototyping, precut basic 2D and 3D shapes such as rectangles, circles, triangles, hexagon, cubes, rectangular prisms, triangular prisms, etc of foam core board were also provided. The user was also given the option of cut-

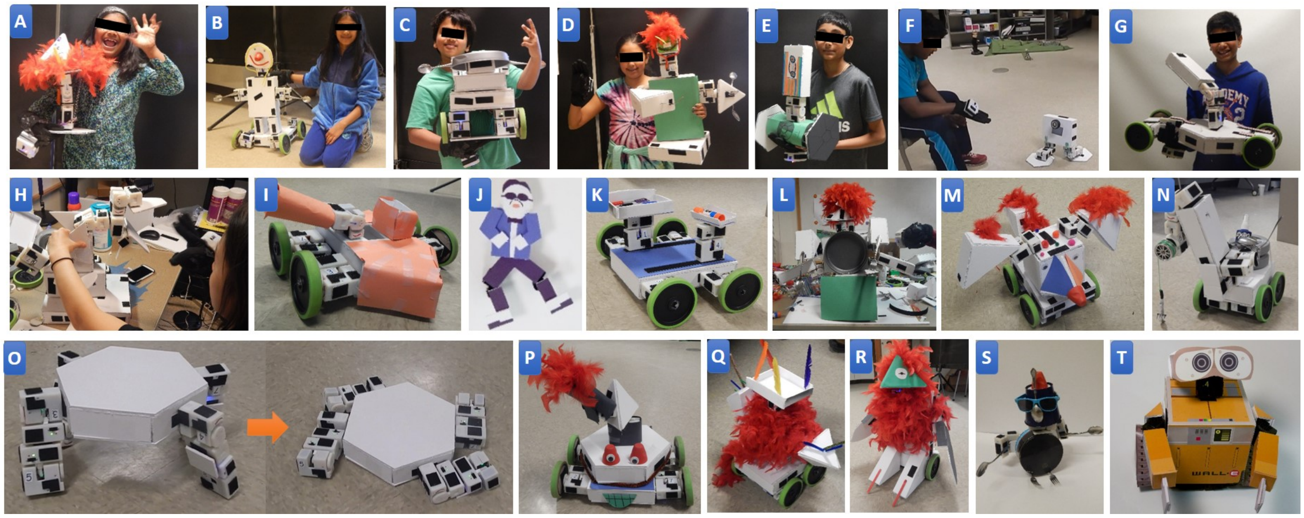

Figure 8. Different objects constructed (a) Dance arm awesome (Age 8) (b) Maddie (Age 8) (c) Bat cave moving (Age 8) (d) Pinnochio Hulk (Age 11) (e) Tie Fighter (Age 11) (f) Two legged robot (Age 11) (g) Turner (Age 14) (h) Running Chicken (Age 20) (i) Small orange boat (Age 21) (j) Gangnam Style (Age 21) (k) Tooler man (Age 21) (l) Afro-Dog (Age 22) (m) Pup on wheels (Age 22) (n) Spooner bot (Age 27) (o) QuadruBot (Age 26) (p) Preston (Age 28) (q) Indi Robot (Age 28) (r) Anxious bird (Age 29); Objects made by student of the school of arts (s) Tin Man (t) Wall-E

ting any specific shape from the raw materials provided. The study with each participant lasted 60 to 90 minutes. The participant was initially made aware of the HandiMate framework and was shown some basic constructions made by us. We explained to the participant the physical structure of the joint modules, tablet interface and gestural control methods of the glove-based controller. To start with, they were allowed to test the system by making a basic construction of either a 2-wheeled car or a 2-joint robotic arm, and allowed to control their construction. After this initial familiarization with the framework, the participant was asked to build their own desired construction using the raw materials and eight joint modules provided. They were allowed to sketch their idea first and then build in steps. They tested each step as they went on, or directly completed the whole fabrication and played with the system (Figure 9).

Setting 2

This study was conducted specifically with one participant from the school of arts. The study was conducted in an open environment where we explained about the framework to the participant,and allowed him to build a small sample construction. He was given a sample joint module for dimensional reference, and a period of one week to fabricate his constructions. The participant was given complete freedom to construct using any material desired. After the period of one week, he was asked to assemble his construction using the joint modules and animate them.

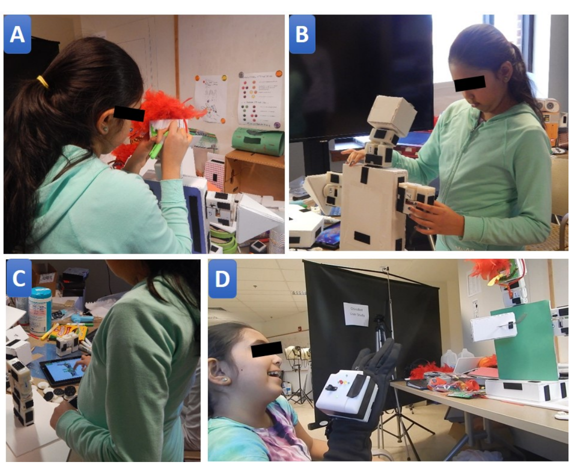

Figure 9. Steps followed during the study (a) Crafting (b) Assembly using joint modules (c) Setup on the interface (d) Play

RESULTS & DISCUSSIONS

Design Motivations

We observed that the design motivation of the construction ranged from fantasy to challenge (Figure 8). Most of the kids tried to realize their fantasy by constructing popular characters from Star Wars or Disney characters. In adults we found a mixture of fantasy and goal motivated approach towards construction. These motivations were influenced by:

- *Personal life or current professional work*: A dog motivated by her pet (The pup on wheels), anthropomorphizing a tank (Preston, he shoots red feathers out of his cannon with a constant green smile and a leopard print nose). A student who works with robots tried to create different robotic gaits using the system (QuadruBot).
- *Task Specific*: Cart to enable users to reach objects placed far away (Tooler - man), robot with a crane like mechanism to pick up spoons (SpoonerBot).
- *Creative trends*: Samurai with an insane afro hair style (Afro-Samurai), a native american chief (Indi Robot), a attention grabbing bird that flaps its wings and squawks (Anxious Bird).

This implies that the framework has aspects of play fullness as it has construction, fantasy and challenge all embedded within it [13].

Usability

The pool of our adult participants had a range of expertise in using electronics and micro-controllers. Seven people had rudimentary knowledge in these areas whereas five people

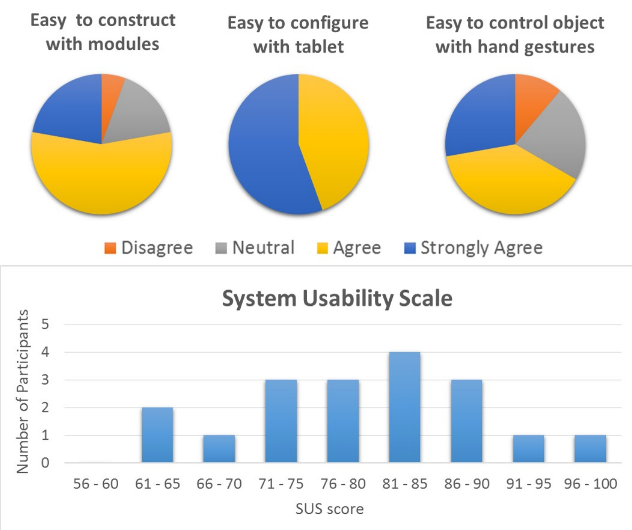

Figure 10. Results of the survey

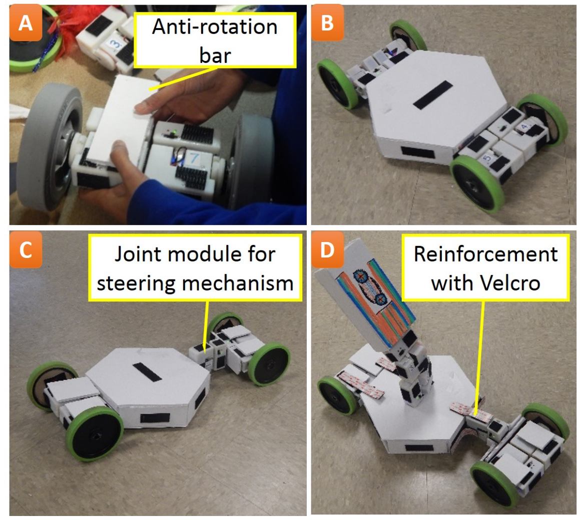

Figure 11. Learning by prototyping (a) Inserting anti-rotation bar to the two wheeled car (b) 4 wheeled car (c) 4 wheeled car with steering mechanism (d) Final 4 wheeled car with robotic arm

had extensively worked with them. We observed that all these participants were able to realize their design goals regardless of this knowledge constraint. Children as young as 8 years and above were extremely excited about animating the object as they felt amazed when they built something and brought it to life without implementing any electronic circuits. We observed that the student from the school of arts was able to create a variety of constructions and animate it. Thus we observed that when the participant was given more freedom of material and time he could create more artistic and well finished constructions.

The post study questionnaire consisted of a survey based on the system usability scale [5] (SUS) and a few questions specific to the system. For the survey conducted with children, few terms of the system usability scale were changed to simpler words like the word *'system'* was replaced by the word *'toy kit'*. For kids the average SUS score was 84.3 (SD - 4.94) and for adults it was 77.1 (SD - 11.11) giving an overall value of 79.9 (Figure 10). Based on the responses in the survey we believe this discrepancy in the value was due to the expectations of these different demographics. While kids were excited about the fact that the creation they made moved, adults expected better and precise control of the movements. Figure 10 also shows the distribution of the responses, on a Likert scale, of all the participants for specific questions about the ease of use of the system.

Learning by Doing

One 14 year old participant desired to make a robot mounted on a car using the system (Figure 11). Initially, he made a two wheeled car as a prototype. On controlling the car he observed that the car was not stable (system had no mechanism to prevent flipping of the body). He made an anti-rotation structure to constrain the flipping action. To further stabilize the car in order to attach a robot. He changed the car design to a 4 wheeled car. While testing this 4 wheeled vehicular system, he was not satisfied with its default turning mechanism as the turning was not smooth (because of the wheel skidding). He brainstormed to derive a method for a better turning mechanism by improving the design of his robot. He realized that by adding another module he could solve the problem. He went on to attach a module in between the body and the front axle of the vehicle, that could control the angle of rotation of the axle (like a steering mechanism). He tested the vehicle and was successful in efficiently maneuvering it. However when he attached the robotic arm to the main body of the vehicle he observed that the velcro in the single joint module link connecting the two bodies failed due to the overall weight of the system. He then reinforced the system using more strips of velcro. Thus he was able to learn basic engineering concepts of anti-rotation, robot steering mechanisms and structural stability.

A 11 year old participant wanted to make a robot with legs. For this he constructed a system with 4 joint modules. While testing the motion he realized that for the robot to remain stable it was necessary for the two planes of contact with the ground to remain parallel. By trial and error he configured the mapping to do so. On testing the system on the ground he observed that the robot always fell on its back. He realized that the weight distribution on the robot was not balanced and attached a wheel as a counter weight to prevent the robot from falling back. This made the robot squat only when he controlled the movement by slowly moving his hand. However, on moving the robot at high speed he observed that the robot fell erratically. He thus realized that the stability of the robot needed to be increased and he managed that by putting bigger base structures at the legs of the robot (Figure 8(f)). In this manner, he learnt about the significance of center of mass and dynamic stability of a system.

This process of designing by iterative prototyping was also observed in the user study with adults. As the system allowed independent and complete control of each joint module, many of the participants were able to divide their overall design goal into many different steps involving building and testing. One of the participants decided to take on the challenge of designing a movable robot to pick up spoons using a crane mechanism. He used the rim of one of the wheels as a pulley, the wires we had provided as rope and magnets in a pen cap as the hook. He initially tested his 3-joint crane mechanism on a base and attached appropriate counter weights to balance the cantilever structure. To firmly attach the crane to the base he also made L-brackets out of foam core and attached it to the base joint (Figure 8(n)). These are examples of constructionism by children and adults alike, in the process of reaching their goals [3]. They identified functional problems in their system, and developed design solutions to overcome them by iterative building and testing.

LIMITATIONS AND FUTURE WORK

During the user study we saw some scope for refinements in HandiMate. Because of the size of the modules, the overall size of the robots tends to be bulky. In a more customized implementation, we would fabricate components with smaller footprint and integrate them into a more power-efficient system with a smaller form-factor. We also observed some discontent among the users when they were trying to control the vehicle, as it would twist slightly while starting/stopping, due to the limited baud rate of XBee communication causing a delay in motion. By switching over to WIFI communication, this issue can be resolved. The interactions for the present system involves a glove-based controller. With the current trend of 3D cameras in everyday devices like cell phone[9], we predict that the input modality of this framework will evolve into a hands-free gesture system.

CONCLUSION

HandiMate is a cyber-physical construction kit that enables the user to craft functional electromechanical systems, and control them using hand gestures. Its framework consists of a tablet interface, glove-based controller and joint modules which package all the electronics. This allows the user to focus on designing and building. Using velcro we provide an easy technique to attach the joint modules to any crafted construction made from everyday objects. Our study conducted with both adults and kids reported a SUS score of 79.9. The diversity of creations made by the users shows that HandiMate encourages creativity and playfulness. The study also showed iterative design processes the users employed to achieve their goal by quick prototyping, thereby showcasing constructionism.

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REFERENCES

1. Ez-robot https://www.ez-robot.com/.
2. Lego mindstorms http://www.lego.com/en-us/mindstorms/.
3. Alimisis, D., and Kynigos, C. Constructionism and robotics in education. *Teacher Education on Robotic-Enhanced Constructivist Pedagogical Methods* (2009), 11–26.
4. Bailly, G., Müller, J., Rohs, M., Wigdor, D., and Kratz, S. Shoesense: a new perspective on gestural interaction and wearable applications. In *Proceedings of the 2012 ACM annual conference on Human Factors in Computing Systems*, ACM (2012), 1239–1248.
5. Brooke, J. Sus-a quick and dirty usability scale. *Usability evaluation in industry 189* (1996), 194.
6. Dipietro, L., Sabatini, A. M., and Dario, P. A survey of glove-based systems and their applications. *Systems, Man, and Cybernetics, Part C: Applications and Reviews, IEEE Transactions on 38*, 4 (2008), 461–482.
7. Druin, A., and Hendler, J. A. *Robots for kids: exploring new technologies for learning*. Morgan Kaufmann, 2000.
8. Engler, L., and Fijan, C. *Making puppets come alive: how to learn and teach hand puppetry*. Courier Dover Publications, 2012.
9. Groom, V., Takayama, L., Ochi, P., and Nass, C. I am my robot: The impact of robot-building and robot form on operators. In *Human-Robot Interaction (HRI), 2009 4th ACM/IEEE International Conference on*, IEEE (2009), 31–36.
10. Harrison, C., Benko, H., and Wilson, A. D. Omnitouch: wearable multitouch interaction everywhere. In *Proceedings of the 24th annual ACM symposium on User interface software and technology*, ACM (2011), 441–450.
11. Howard, B., and Howard, S. Lightglove: Wrist-worn virtual typing and pointing. In *Wearable Computers, 2001. Proceedings. Fifth International Symposium on*, IEEE (2001), 172–173.
12. Ingram, J. N., Körding, K. P., Howard, I. S., and Wolpert, D. M. The statistics of natural hand movements. *Experimental brain research 188*, 2 (2008), 223–236.
13. Kudrowitz, B. M., and Wallace, D. R. The play pyramid: A play classification and ideation tool for toy design. *International Journal of Arts and Technology 3*, 1 (2010), 36–56.
14. Kuznetsov, S., and Paulos, E. Rise of the expert amateur: Diy projects, communities, and cultures. In *Proceedings of the 6th Nordic Conference on Human-Computer Interaction: Extending Boundaries*, ACM (2010), 295–304.
15. Levine, F., and Heimerl, C. *Handmade nation: The rise of DIY, art, craft, and design*. Princeton Architectural Press, 2008.
16. Minsky, M. *Society of mind*. Simon and Schuster, 1988.
17. Mistry, P., and Maes, P. Sixthsense: a wearable gestural interface. In *ACM SIGGRAPH ASIA 2009 Sketches*, ACM (2009), 11.
18. Molyneaux, D., Izadi, S., Kim, D., Hilliges, O., Hodges, S., Cao, X., Butler, A., and Gellersen, H. Interactive environment-aware handheld projectors for pervasive computing spaces. In *Pervasive Computing*. Springer, 2012, 197–215.
19. Murata, S., Yoshida, E., Kamimura, A., Kurokawa, H., Tomita, K., and Kokaji, S. M-tran: Self-reconfigurable modular robotic system. *Mechatronics, IEEE/ASME Transactions on 7*, 4 (2002), 431–441.
20. Oschuetz, L., Wessolek, D., and Sattler, W. Constructing with movement: kinematics. In *Proceedings of the fourth international conference on Tangible, embedded, and embodied interaction*, ACM (2010), 257–260.
21. Papert, S. *Mindstorms: Children, computers, and powerful ideas*. Basic Books, Inc., 1980.
22. Pöllänen, S. H. Beyond craft and art: a pedagogical model for craft as self-expression. *International Journal of Education through Art 7*, 2 (2011), 111–125.
23. Raffle, H. S., Parkes, A. J., and Ishii, H. Topobo: a constructive assembly system with kinetic memory. In *Proceedings of the SIGCHI conference on Human factors in computing systems*, ACM (2004), 647–654.
24. Rusk, N., Resnick, M., Berg, R., and Pezalla-Granlund, M. New pathways into robotics: Strategies for broadening participation. *Journal of Science Education and Technology 17*, 1 (2008), 59–69.
25. Sennett, R. *The craftsman*. Yale University Press, 2008.
26. Shaer, O., and Hornecker, E. Tangible user interfaces: past, present, and future directions. *Foundations and Trends in Human-Computer Interaction 3*, 1–2 (2010), 1–137.
27. Wu, K.-J., and Gross, M. D. Topaoko: interactive construction kit. In *CHI'10 Extended Abstracts on Human Factors in Computing Systems*, ACM (2010), 3619–3624.

[9] https://www.google.com/atap/projecttango/