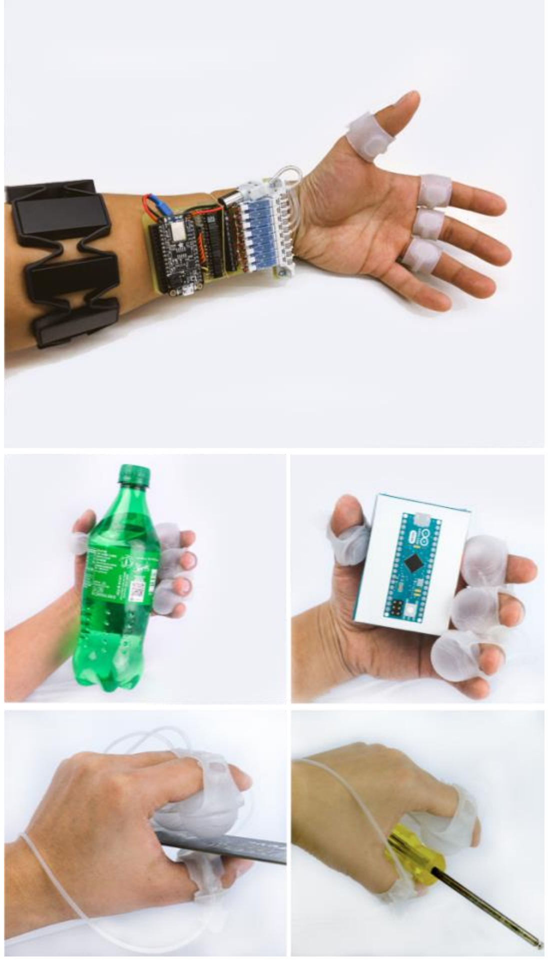

Figure 1: Demonstration of Bubble. The complete device with four uninflated units (top), and four application scenarios (underneath) of using the device to grasp a bottle of soda, a small box, a ruler, and a screwdriver.

Bubble: Wearable Assistive Grasping Augmentation Based on Soft Inflatables

Xinlei Zhang*
University of Tokyo
Tokyo, Japan
MIT Media Lab
Cambridge, MA, USA
xinleiz@media.mit.edu

Ali Shtarbanov*
MIT Media Lab
Cambridge, MA, USA
alims@media.mit.edu

Jiani Zeng
MIT
Cambridge, MA, USA
jnzeng@mit.edu

Valerie K. Chen
MIT
Cambridge, MA, USA
vkchen@mit.edu

V. Michael Bove
MIT Media Lab
Cambridge, MA, USA
vmb@media.mit.edu

Pattie Maes
MIT Media Lab
Cambridge, MA, USA
pattie@media.mit.edu

Jun Rekimoto
University of Tokyo
Tokyo, Japan
rekimoto@acm.org

ABSTRACT

We present Bubble, a pneumatically actuated wearable device that enables people with hand disabilities to use their own hands to grasp objects without fully bending their fingers. Bubble offers a novel approach to grasping, where slim, ultra-lightweight silicone actuators are attached to the fingers. When the user wishes to grasp an object, the silicone units inflate pneumatically to fill the available space around the object. The inflatable units are interchangeable, can be independently inflated, and can be positioned anywhere on the fingers in any orientation, thereby enabling a wide

---

*These authors contributed equally

CHI'19 Extended Abstracts, May 4-9, 2019, Glasgow, Scotland, UK.

ACM ISBN 978-1-4503-5971-9/19/05.
DOI: https://doi.org/10.1145/3290607.3312868

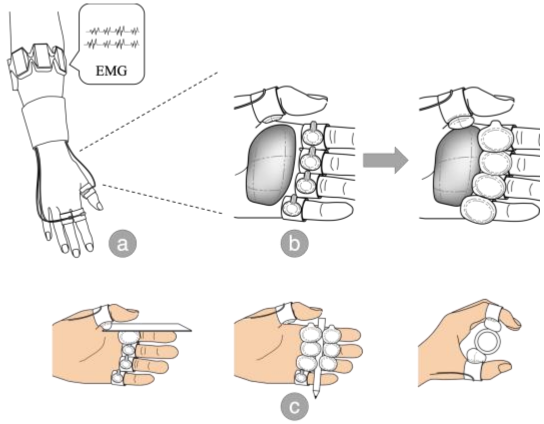

Figure 2: Concept overview of Bubble. a) Contraction of the forearm muscles is sensed and used to control inflation. b) An object is grasped using inflated units. c) Examples of grasping different objects using Bubble. From left to right: grasping a card (with the pinch gesture), a pen, a cylindrical object (e.g. water bottle).

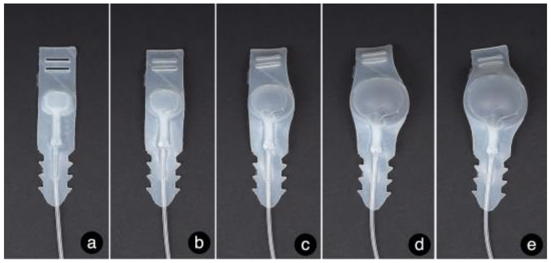

Figure 3: Demonstration of an inflatable unit at different degrees of inflation, when inflated for (a) 0s, (b) 1s, (c) 2s, (d) 3s, and (e) 4s. The mass of the unit is 5 grams.

variety of grasping gestures including the palmar grasp, pinch, etc. In this paper, we describe the implementation of our current prototype, the fabrication process of the soft inflatable units, as well as our preliminary study to evaluate our system's grasping capability.

KEYWORDS

Grasp Augmentation; Pneumatic; Wearable; Soft Materials; Soft Robot; Assistive Technology

INTRODUCTION

The ability to grasp and manipulate objects with our hands is one of the most essential human faculties. We rely heavily on our hands to perform basic daily tasks such as eating, writing, and getting dressed. However, those with diminished hand dexterity may struggle with these common tasks, resulting in a greatly reduced quality of life, or even inability to care for themselves.

Loss of hand function affects many [3], while cures can often be partial or nonexistent. For instance, sarcopenia, natural age-related decline in muscle mass, affects 5% to 13% of the elderly [9]; symptomatic hand osteoarthritis, a kind of arthritis affecting hand function with potential to cause hand disabilities, is estimated to affect 4 in 10 people in their lifetimes [7]; multiple sclerosis (MS), a common cause for impairments in hand function due to the unpredictable disruption of brain signals, affects 2.1 million people worldwide, with the number on the rise [8].

Researchers have explored a variety of wearable assistive grasping solutions. One conventional approach is a rigid hand exoskeleton, such as HandSOME [1] or HandEXOS [2]. While exoskeletons effectively bend fingers, they can often be heavy and complicated to wear. Assistive hand gloves are another solution, either tendon-driven such as Exo-glove ploy [12] and SEM Glove from Bioservo [5], or pneumatically-actuated [6, 10, 11] based on the principle of pneumatically-actuated soft grippers [4].

These approaches enable grasping by externally applying force to the fingers to bend them around the object. However, this grasping method has fundamental limitations: 1) forceful bending of the fingers may be painful for people with certain conditions (e.g. arthritis), 2) smaller objects (e.g. pills) can be more difficult to grasp than larger ones, and 3) the supported grasping gestures are very few (often limited to the palmar pinch, while other frequently used gestures such as the pinch grasp or pen grasp cannot be formed using this method).

We present a fundamentally different approach to grasping. Rather than bending the user's fingers around an object, our approach uses ultra-slim inflatable silicone chambers attached to the hand that expand dynamically to fill the space around the object. This enables grasping of various-sized objects, does not require users to fully bend their fingers around the objects, and allows for a variety of grasping gestures based on how the inflatable units are positioned and orientated. To the best of our knowledge, this approach has not been explored previously.

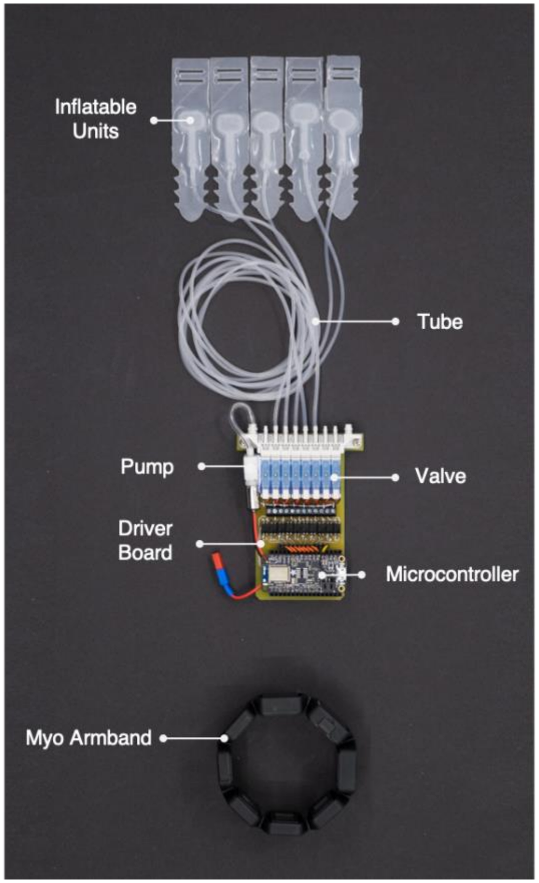

Figure 4: Components of the Bubble system. Communication between the EMG sensor, computer, and control unit occurs wirelessly via Bluetooth Low Energy (BLE).

SYSTEM OVERVIEW

Grasping an object typically involves molding one's fingers to the object's surface until the space between surface and skin is filled and the object is firmly held. Based on this principle, Bubble works by dynamically filling the space between fingers and object with inflatable units.

Bubble consists of four main parts: (1) a set of soft inflation units that attach to the hand, made to attach (depending on object size) either to the fingers or the palm, (2) a control unit powering the system and controlling the behavior of the pneumatic system, (3) an EMG sensor (Myo Armband), and (4) a computer working remotely for real-time data collection and processing. (In our current prototype, we have only attached inflation units to the fingers.)

To use Bubble, a user first attaches the EMG sensor to the forearm, and then the inflation units to the hand in the desired configuration. The control unit can be attached to the forearm using a rubber band or elastic wristband. Users decide which fingers to place units on, the number of units per finger, and the position and orientation of each unit.

To grasp an object, the user approaches it with their hand and then contracts their forearm muscles to trigger the inflation of the chambers. The inflation continues while the muscles remain contracted or until a maximum inflation threshold is reached. Once the object is properly held, the user can stop the inflation by relaxing their forearm. To release the object, the user performs a strong flexion with the wrist (moving the wrist downwards) which causes all chambers to deflate synchronously and the object to be dropped. Figure 2 illustrates the use of Bubble for object grasping, and Figure 3 shows different degrees of inflation for a soft chamber.

SYSTEM ARCHITECTURE

EMG Sensor and Neural Network

We used the Myo Armband for EMG sensing. It uses 8 stainless steel pods to collect 8-channel EMG signals at a frequency of 200Hz, which are sent to a computer using Bluetooth 4.0 protocol. For data collection and signal classification, we developed custom software in Python 3 which we ran on a MacBook Pro (2.9GHz Intel Core i7 processor with 16GB memory). For EMG signal classification, we trained a simple convolutional neural network with 2 hidden convolution layers of 30 nodes and 60 nodes, respectively. The training dataset we collected was from one of the authors, which contains 6000 records of 8-channel EMG data for each target muscle movement to be classified. Pre-processing was conducted on the data by first converting each data sample into its absolute value, and then a moving average was applied to each channel of the data using a window size of 5. The same procedure was used to process real-time incoming raw EMG data before feeding it into the trained model. We used 20% of randomly-chosen data for validation, and the training detection accuracy was 94%. The classification was performed in real-time.

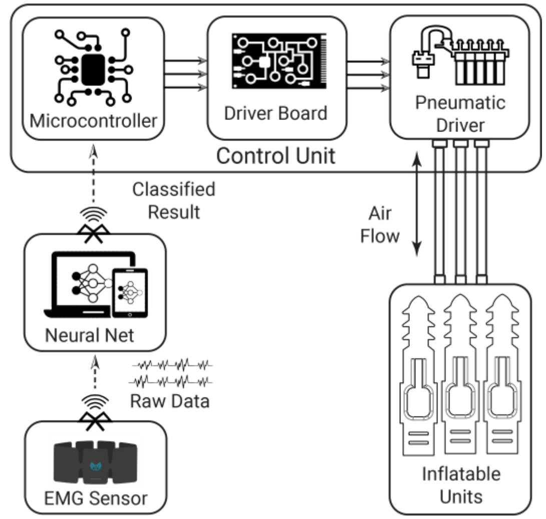

Figure 5: System architecture. EMG signals are collected and sent to a computer for analysis, and the result is then used to control the electronics and pneumatics driving the inflatable units.

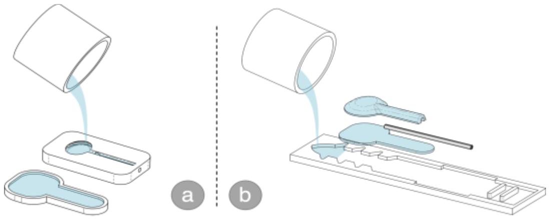

Figure 6: Casting process (a) for the inflatable chamber and (b) for the final unit.

Figure 7: Fabrication. (a) Ecoflex^{TM} 00-50 parts A and B are mixed, (b) poured into the molds, (c) and the top and bottom pieces are then assembled.

Control Unit

We used the Adafruit Feather nRF52 as the controller for our system. It has an ARM Cortex M4F processor running at 64MHz as well as built-in Bluetooth Low Energy (BLE) capability. We developed our own firmware implementing UART over BLE for communication between the controller and the computer. No obvious delay was perceived between the muscle actuation signal and device inflation.

We built our own pneumatic circuit with a micro pump and a valve array of eight two-way valves modified from 3-port valves. Each of the valves is only 5.9mm wide and weighs 4.5g, enabling fabrication of a lightweight, concise setup to improve wearability. The total mass of the controller together with 5 inflatable units is 140g.

Figure 5 shows a block diagram of the complete system architecture and signal flow.

FABRICATION PROCESS

The method of molding and casting was utilized for fabrication of the soft inflatable modules. Ecoflex^{TM} 00-50 silicone Part A and Part B were used with SLO-JO^{R} retarder to form a material with the desired stiffness and elasticity for the modules. Molds were 3D printed from CAD files at a high resolution to create silicone parts with maximally smooth surfaces. A base component and an elevated component were used to create the inflation chamber with a channel for airflow. After silicone was poured into the molds for these two parts and allowed to cure, the products were sealed together using Sil-Poxy^{TM}. Finally, the sealed structure was placed into a larger mold which was then filled with silicone to create an adjustable strap around the structure. The casting and fabrication processes are illustrated in Figures 6 and Figure 7, respectively.

PRELIMINARY GRASPING EVALUATION

Experiment

To investigate the grasping capability of Bubble, we conducted a preliminary test with one participant (27 year-old male with intact hand function) to grasp objects of different shapes, sizes, and weights. The list of objects and some example device configurations are listed in Figure 8.

Before the test, the participant first confirmed that the system behaved as expected. During the test, the participant used the device to grasp objects by first putting their hand on an object and then initiating the inflation. Four inflatable units were used in the test, placed on the thumb, index, middle, and ring fingers. Changing the position and the orientation of each inflatable unit was allowed if the participant believed it easier to grasp the object in that way. Finger contraction was not allowed during the test since some of the intended end-users of the device may not have this ability. If an object could be firmly held and the participant could freely move it around without fear of dropping it, then the object was considered possible to be grasped. The test was performed for three categories of objects: long and thin, flat, and cylindrical/cuboidal.

Figure 8: Objects used for the grasping evaluation experiment.

Table 1: Preliminary grasping test results.

Object	*Mass (g)*	*Position*	*Grasped?*
Fork	30	(m,b,b,b)	No
Pen	6	(t,m,m,m)	Yes
Toothbrush	17	(t,m,m,m)	Yes
Syringe	12	(m,m,b,m)	Yes
Screwdriver	58	(m,m,b,m)	Yes
Cup	7	(m,m,m,m)	Yes
Glue Bottle	75	(m,m,m,m)	Yes
Ecoflex Can	200	(t,t,t,t)	Yes
Spray Bottle	275	(t,m,m,m)	No
Soda Bottle	645	(t,m,m,m)	Yes
Ruler	38	(t,m,m,m)	Yes
Masking Tape	65	(t,m,m,m)	Yes
Arduino Box	17	(t,m,m,m)	Yes
Phone Box	34	(t,m,m,b)	Yes
Smartphone	180	(t,m,m,m)	No

The position column indicates whether the unit was placed on the top(t), middle(m), or bottom(b) segment of the finger for the case of the (thumb, index, middle, ring) finger.

Results

The result of the experiment as well as the device positions used for grasping each object are summarized in Table 1. Overall, the participant was able to grasp most objects (4 out of 5) in each category. The biggest and heaviest object successfully grasped was a 600ml bottle of soda (23cm long, 7cm wide and 645g in weight), and the smallest was a pen (14cm long, 0.8cm wide, and 6g in weight).

The objects that could not be grasped were a fork (18cm long and 30g in weight), a rectangular spray bottle (21.5cm x 9.5cm x 4cm in size and 275g in weight) and a smartphone (iPhone X, 14cm x 2.8cm x 7.1cm and 180g in weight). The inflated units had limited contact area with all of these test objects, so the device's ability to fill the space between hand and object was hindered.

Limitations and Future Work

Currently, to use Bubble, individuals with grasping difficulties would need help to put on the device. To address this problem, we plan to enable the inflatable units to automatically wrap themselves around a cylindrical object (i.e. finger) when pressed. This could be achieved by creating another air chamber in the structure of the inflatable unit that causes curling when inflated. The inflation would be triggered by an embedded organic pressure sensor.

In addition, as shown from the preliminary test, it is currently difficult to use Bubble to grasp objects with shapes that limit contact area (i.e. those with limited heights such as paper, cards, etc.). Thus, we plan to increase the number of units on the hand as well as develop an inflatable unit with horizontal inflation capabilities to increase possible contact area.

CONCLUSION

In this work, we have presented Bubble, a pneumatically-actuated wearable device that enables those with difficulty grasping objects to grasp things without fully bending their fingers. Bubble offers a novel approach to grasping by using silicone-based inflatable units to fill the space between the object and the hand when units are inflated. Inflation and deflation for grasping and dropping an object are controlled by forearm muscle signals (EMG) so that no finger bending is required. We have run a preliminary grasping test using common daily objects of different shapes and weights to evaluate Bubble's grasping capabilities. Our results show that Bubble can provide a firm hold for most objects tested, with the exception of objects with limited contact area. For future work, we plan to implement the capability of automatic wrapping to allow people with grasping difficulties to fasten the device independently, as well as further improve the grasping capability of the inflatable units by increasing their possible contact area.

REFERENCES

[1] Elizabeth B Brokaw, Iian Black, Rahsaan J Holley, and Peter S Lum. 2011. Hand Spring Operated Movement Enhancer (HandSOME): a portable, passive hand exoskeleton for stroke rehabilitation. *IEEE Transactions on Neural Systems and Rehabilitation Engineering* 19, 4 (2011), 391–399.

[2] Azzurra Chiri, Francesco Giovacchini, Nicola Vitiello, Emanuele Cattin, Stefano Roccella, Fabrizio Vecchi, and Maria Chiara Carrozza. 2009. HANDEXOS: Towards an exoskeleton device for the rehabilitation of the hand. In *Intelligent Robots and Systems, 2009. IROS 2009. IEEE/RSJ International Conference on. IEEE*, 1106–1111.

[3] S Dahaghin, SMA Bierma-Zeinstra, Max Reijman, HAP Pols, JMW Hazes, and BW Koes. 2005. Prevalence and determinants of one month hand pain and hand related disability in the elderly (Rotterdam study). *Annals of the Rheumatic Diseases* 64,1 (2005), 99–104.

[4] Filip Ilievski, Aaron D Mazzeo, Robert F Shepherd, Xin Chen, and George M Whitesides. 2011. Soft robotics for chemists. *Angewandte Chemie* 123, 8 (2011), 1930–1935.

[5] Mats Nilsson, Johan Ingvast, Jan Wikander, and Hans von Holst. 2012. The Soft Extra Muscle system for improving the grasping capability in neurological rehabilitation. In *2012 2nd IEEE-EMBS Conference on Biomedical Engineering and Sciences, IECBES 2012; Langkawi; Malaysia; 17 December 2012 through 19 December 2012*. IEEE, 412–417.

[6] Panagiotis Polygerinos, Zheng Wang, Kevin C Galloway, Robert J Wood, and Conor J Walsh. 2015. Soft robotic glove for combined assistance and at-home rehabilitation. *Robotics and Autonomous Systems* 73 (2015), 135–143.

[7] Jin Qin, Kamil E Barbour, Louise B Murphy, Amanda E Nelson, Todd A Schwartz, Charles G Helmick, Kelli D Allen, Jordan B Renner, Nancy A Baker, and Joanne M Jordan. 2017. Lifetime risk of symptomatic hand osteoarthritis: the Johnston County Osteoarthritis Project. *Arthritis & Rheumatology* 69, 6 (2017), 1204–1212.

[8] Mohammad Ali Sahraian, Mohammad Sahebkar, Rouhullah Dehghani, Milad Derakhshan-Jazari, Vahid Kazami-Moghaddam, and Ebrahim Kouchaki. 2017. Multiple sclerosis-A disease on a dramatically rising trend in Iran: Review of possible reasons. *Iranian journal of neurology* 16, 1 (2017), 34.

[9] Stephan von Haehling, John E Morley, and Stefan D Anker. 2010. An overview of sarcopenia: facts and numbers on prevalence and clinical impact. *Journal of cachexia, sarcopenia and muscle* 1, 2 (2010), 129–133.

[10] Hong Kai Yap, Benjamin WK Ang, Jeong Hoon Lim, James CH Goh, and Chen-Hua Yeow. 2016. A fabric-regulated soft robotic glove with user intent detection using EMG and RFID for hand assistive application. In *Robotics and Automation (ICRA), 2016 IEEE International Conference on*. IEEE, 3537–3542.

[11] Hong Kai Yap, Jeong Hoon Lim, Fatima Nasrallah, Fan-Zhe Low, James CH Goh, and Raye CH Yeow. 2015. MRC-glove: A fMRI compatible soft robotic glove for hand rehabilitation application. In *Rehabilitation Robotics (ICORR), 2015 IEEE International Conference on*. IEEE, 735–740.

[12] Sung-Sik Yun, Brian Byunghyun Kang, and Kyu-Jin Cho. 2017. Exo-Glove PM: an easily customizable modularized pneumatic assistive glove. *IEEE Robotics and Automation Letters* 2, 3 (2017), 1725–1732.