Extra Robotic Thumb and Exoskeleton Robotic Fingers for Patient with Hand Function Disability

Rifky Ismail[*], Mochammad Ariyanto
Department of Mechanical Engineering
Diponegoro University
Semarang, Indonesia
[*]Email: r_ismail@undip.ac.id

Kharisma A. Pambudi, Joshua W. Syafei, Gilar P. Ananto
Department of Mechanical Engineering
Diponegoro University
Semarang, Indonesia

***Abstract*— This paper presents the development of wearable robot to enhance and to assist people who lost the ability to grasp object. In the developing countries, most persons with hand disabilities still use manual and passive tools, especially for prosthetic and orthotic. We propose a wearable robot as an orthotic device namely extra robotic thumb and exoskeleton robotic fingers as new type of wearable robot for assisting person whose the thumb can not move anymore and the other four fingers has diminished fingers function. The motion of exoskeleton robotic finger has four DOF which each DOF represents the motion of flexion and extension on the fingers. For extra robotic thumb, it has two DOF to represent the motion of circumduction and flexion/extension on the thumb. The robot employs four linear actuators in exoskeleton robotic fingers and uses two micro servos in extra robotic thumb. The robot is designed based on 3D print technology. To assist person in Activity of Daily Living (ADL), five grip patterns are developed in this research. User can command the robot by using electromyography (EMG) sensor that attached on near healthy elbow. Based on the experimental results, the robot can successfully perform object grasping tasks by using the developed five grip modes.**

Keywords— wearable robot; four finger exoskeleton; extra robotic thumb.

I. INTRODUCTION

Currently, most persons with hand function disabilities in developing countries still use manual and passive tools, especially for prosthetic and orthotic instruments. The number of orthotic and prosthetic users based on wearable robots is still very small because only rich people can buy the products sold on the market today, usually from the United Kingdom, US, China and Europe. Because it is very expensive, many people cannot afford to buy the prosthetic or orthotic. For this reason, the research for wearable robot in the developing countries is needed especially low cost product in order to many people can buy these products.

Prosthesis is commonly utilized to replace the lost limbs of the human body. The lost limbs can be hand or foot. The research in the prosthetics hand is aimed to achieve the prosthetic more affordable, easy to maintain, and more reliable [1-4]. Commonly, low cost prosthetic hands that have been studied in universities are used 3D print technology. For prostheses that attached on the human foot, powered ankle-foot prosthesis has been successfully developed by research team from MIT [5-6]. This device enables human can walk naturally.

Exoskeletons are utilized to enhance and to give external force in order to the human joints can be moved again. Exoskeleton can be attached on the human fingers, wrist, elbow, and knee to enhance the motion of the joints. Many researches have studied the exoskeleton attached in the human is designed to restore functional hand movement or robot-assisted hand rehabilitation [7-9]. For the people who lost the ability to grasp object, exoskeleton hand can provide mechanical support and improve the grasping power that are necessary to perform grasping tasks in Activity of Daily Living (ADL).

In this reasearch, the wearable robot of exoskeleton robotic finger design was inspired by exoskeleton research using a linkage mechanism with pneumatic actuators that is developed by FESTO [10]. The motion of exoskeleton robotic fingers has four Degree of freedom (DOF) which each DOF represents the motion of flexion and extension on the fingers. While the design of extra robotic thumb using two servo motors is inspired by one of the researches at Massachusetts Institute of Technology (MIT) [11]. For extra robotic thumb design, it has two DOF to represent the motion of circumduction and flexion/extension on the thumb. For the prototype of proposed wearable robot, this research employs four linear actuators and two micro servos motors which are adjusted to hand of people who lost hand function.

For preliminary research, a prototype of wearable robot which comprises of exoskeleton robotic fingers and extra robotic thumb is developed for a male patient with hand disability on the right hand. The patient or study participant has been stung by high voltage electricity while working on the construction work. Consequently, his tendon under the wrist is broken so that his four fingers cannot be moved anymore using his muscles on the healthy remaining hand. While his thumb become stiff and cannot be moved anymore by external force.

Based on the above condition, we propose exoskeleton robotic finger to provide the patient fingers with mechanical support and enhance the grasping ability of the index, middle, little, and ring fingers. For the thumb, we proposed two DOF extra robotic thumb, because his thumb cannot be driven by external force like exoskeleton. Extra robotic thumb will work together with exoskeleton robotic fingers for object grasping tasks in ADL.

978-1-5386-0549-3/17/$31.00 ©2017 IEEE

II. Prototype Design

A. CAD Design

Before developing the 3D CAD model of extra robotic thumb and exoskeleton robotic fingers, the first step taken is the measurement of the patient's or study participant's hand size: length and width of the palms, index finger, middle finger, ring finger, and little finger. The ranges of motion boundaries in each joint of the fingers are measured to ensure the exoskeleton providing safe mechanical support for the study participant's finger.

After the measurement of the size and range of motion is complete, the design of wearable robot is sketched on the piece of paper. Then the sketch is drawn in 3D model using SolidWorks Computer Aided Design (CAD) software. SolidWorks software is selected because it is easy to use and operate. Motion study in SolidWorks is utilized to study the kinematics of extra robotic thumb and exoskeleton robotic finger. The input motion of the four fingers is the linear motion that comes from linear actuator, and the output motion is the fingertip position of exoskeleton finger. After the desired motion is conducted, then continue on the other three fingers by adjusting the length of the finger thrust links and again followed by the motion study. The next stage is design extra robotic thumb and holder for exoskeleton robotic fingers robot. The result of CAD assembly can be depicted in Fig.1.

Each part of the 3D CAD model as shown in Fig. 1 except linear actuator and servo motor is then exported to the *.STL format. The format is utilized as standard for 3D print to print the CAD model into a prototype.

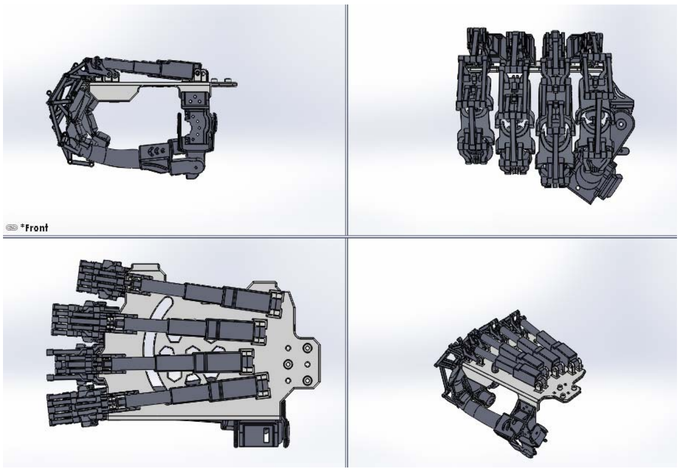
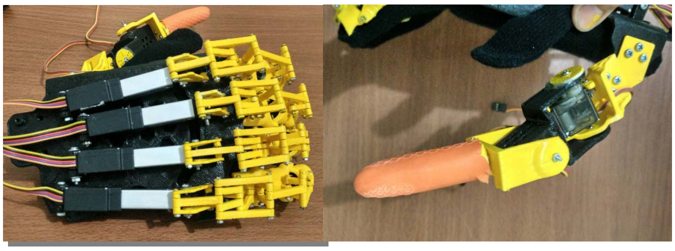


Fig. 1. 3D CAD model Assembly of the proposed wearable robot

B. Mechanical Design

The first mechanical design refers to the CAD design especially the dimensions. CAD design results are then printed by using 3D print delta type. The selected material for 3D printing is polylactic acid (PLA). Each component is then assembled and evaluated on each finger. If the dimensions and motion do not match the design target, it will be redesigned. After the evaluation result is satisfactory, the motion of exoskeleton finger is tested using linear actuator and extra robotic thumb is tested using servo motor. The linear actuator gives linear position input of stroke while the servo motor gives angular position. The test is conducted using Arduino Nano microcontroller with potentiometer to give commanded linear position for exoskeleton finger and commanded angular position for extra robotic thumb. The fingertip motion and the range of motion in each joint of exoskeleton robotic fingers are evaluated. If the resulted fingertip motion does not match with the initial design, it will be redesigned and will be printed again until the fingertip trajectory motion match with the design.

The final assembly is then performed by merging all of the four fingers on the stand for exoskeleton and then it is merged with extra robotic thumb. The final results of the proposed exoskeleton robotic fingers and extra robotic thumb can be seen in Fig.2.



(a) (b)

Fig. 2. Final assembly of the proposed wearable robot; (a) Exoskeleton robotic fingers, (b) Extra robotic thumb

C. Electrical Design

The proposed of wearable robot uses four linear actuators and two micro servos. We select linear actuator from Actuonix L12-P with 30 mm length of stroke. This type of linear actuator with the length of stroke 30 mm gives the required linear displacement input for exoskeleton robotic finger. The selected linear actuator has two pins for powering the DC motor and three pins linear potentiometer for measuring the position of stroke. The linear potentiometer pins will be used for feedback control system to regulate the position of the stroke.

The wearable robot is designed with five grip patterns. For the electric circuits, LEDs are added for motion mode to indicate the current working grip mode. We add one tactile switch for selecting the used grip pattern. A bulk converter is employed to lower the power supply voltage from 12 V to 6 V for powering four linear actuators, two micro servos, and microcontroller. The power source uses two 18650 batteries that are assembled in series with each of batteries have the capacity of 2200 mAH.

To control the stroke of the linear actuator, it is required H-bridge due to DC-based motors in linear actuator. The H-bridge system uses L293D IC which has dual H-bridge with four inputs. Furthermore, wiring diagrams are made as a rough design of the electrical circuit that will be created. Wiring diagram is created using Fritzing software as shown in Fig.3. Due to the limitations of the software some of the components used in wiring diagrams are not as they actually use such us linear actuator and the battery, but it can represent the function of those components.

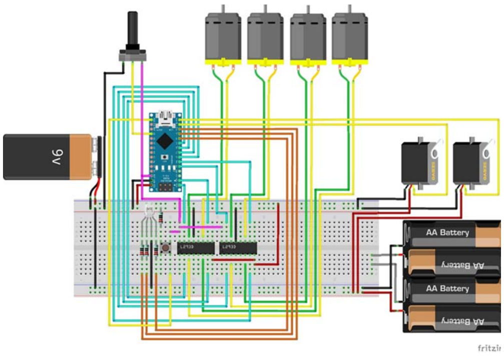


Fig. 3. Wiring Diagram of the proposed system

The used microcontroller should be able to meet the input / output requirements as follows: two analog inputs for sensors, four analog inputs for feedback control from linear actuators, eight digital outputs for H-bridges and for four linear actuators, one digital inputs for tactile switch, one digital output for actuating the LEDs, and 1 pair of TX / RX for serial communication (optional). The dimensions of the required microcontroller must be small, and the microcontroller can be interfaced with Matlab/Simulink environment for embedded control. Based on the previous requirements, we select an Arduino Nano V.3 as a microcontroller. Furthermore, the Printed Circuit Board (PCB) is designed as small as possible using Cadsoft EAGLE software. The final resulted PCB design for our wearable robot can be seen in Fig. 4.

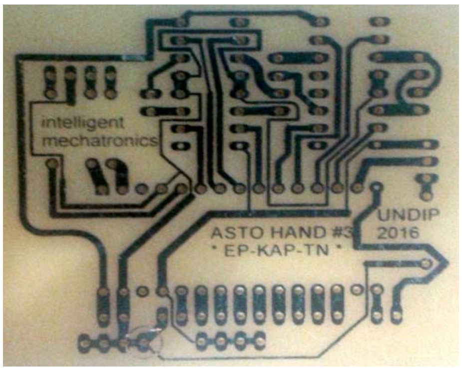


Fig. 4. Designed Printed Circuit Board (PCB) for wearble robot

For sensing the muscle activity of the remaining hand on study participant hand, Myo Armband electromyography (EMG) sensor from Thalmic Labs is chosen to measure the muscle activity of the user hand. This sensor has eight channels EMG which is arranged in a circle and Inertial Measurement Unit (IMU). At this stage of the research, Myo Armband is connected to a laptop for signal pattern recognition, and then the recognition results are transferred from laptop to microcontroller using serial communication. There is another option for signal acquisition, i.e direct communication using bluetooth between Myo Armband and another microcontroller with embedded signal recognition algorithm to the microcontroller, and then the result of pattern recognition is transferred by using serial communication to Arduino Nano V.3

III. Grasping Control Scheme

A. Grip patterns

For the grip pattern in the proposed wearable robot, we regulate a combination of maximum stroke position of each linear actuators and angular angles in servo motor to form movements that are useful for Activity of Daily Living (ADL).The suitable RGB LED will light on to indicate the current used working grip pattern. In this study, we proposed to develop five grip patterns as shown in Table I. The developed five grip patterns are power grasp, key grasping, pinching, tripod, and hook. The usage of the grip patterns are described in Table I. The widely used grip patterns in ADL are power grasp and hook.

TABLE I. THE DEVELOPED FIVE GRIP PATTERNS

Mode	Ilustration	Description
Power Grasp		All finger grasp, the end point is when thumb tip meet the middle and index tip.
Key Grasp		All finger position same as grasping mode except thumb. Thumb endpoint is above index.
Pinching		Only index and thumb that move. The endpoint is when both index and thumb tip meet.
Tripod		Only index, middle and thumb that move, the endpoint is same as grasping mode.
Hook		All fingers move except thumb, ending position of index, middle, little, and ring fingers are same as grasping mode

B. Grasping Control Strategy

In each grip patterns of the proposed wearable robot as mentioned in section III A, there is a maximum stroke length displacement value of each linear actuator in exoskeleton robotic fingers and angular angles of servo motors in extra robotic thumb. For controlling the movement of wearable robot, we used Myo Armband sensor as shown in Fig. 5 to measure the muscle activity of the hand. This sensor has pattern recognition software to recognize the hand gesture of user or wearer. There are six patterns that can be recognized by Myo Armband software i.e. rest, fist, wave in, wave out, finger spreads, and double tap. The illustration of the hand gesture results can be seen in Fig. 6.

In the proposed of wearable robot, three utilized types of signal pattern recognition result from Myo Armband software are 'wave in', 'wave out', and 'rest'. 'Wave in' is used for forward displacement strokes of the linear actuators and angular angles of servo motor to the endpoint of the executed mode. 'Wave out' is utilized for backward stroke of the linear actuator and angular angle of servo motor to the initial stroke. In the simple way, it can be said that 'Wave in' is used for flexion motion of wearable robot while 'Wave out' is utilized for extension motion of wearable robot. The 'rest' signal means that there is no contracting muscle on the hand. The 'rest' signal is employed to disable the motion of all actuators. The grasping control scheme of the wearable robot can be seen in Fig. 7.

Fig. 5. Myo Armband from Thalmic Labs

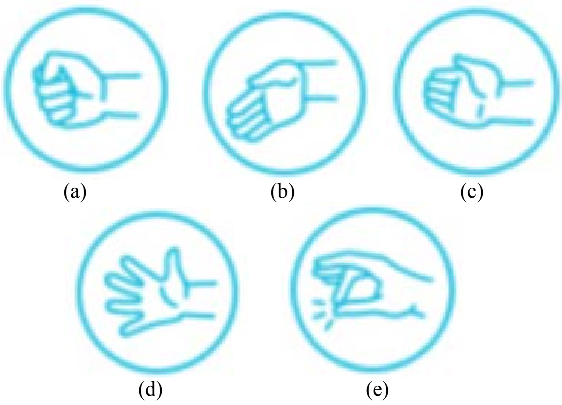


Fig. 6. Hand gestures pattern recognition in Myo Armband [12]; (a) Fist, (b) Wave in, (c) Wave out, (d) Finger spreads, (e) Double tap

TABLE II. GRASPING OBJECT WITHOUT HAND

Mode	Picture
Power Grasp	
Key Grasp	
Pinching	
Tripod	
Hook	

The input of hand gesture signal is read by Myo Armband, this signal is then recognized by Myo Armband software. The recognized signal is transmitted in to Arduino microcontroller using serial communication. The recognized and processed signal commands the linear actuator to move with the commanded linear displacement and commands the servo motor to rotate in to the commanded angular angle. The feedback control is employed in the four finger exoskeleton to control the commanded of linear displacement of linear actuator stroke.

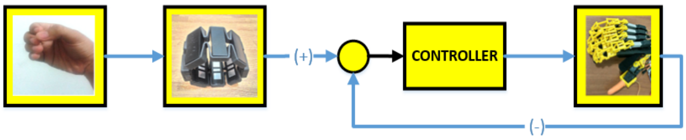


Fig. 7. Diagram block of the warable robot control

IV. Experimental Results

The experimental tests in this paper are divided into two parts. The first test is various object grasping tests without attaching the wearable robot on the human hand. The first test is conducted for evaluating the five developed grip patterns to perform grasping tasks in ADL. The second test is object grasping tasks with attaching the wearable robot on the right hand of healthy hand. The person with healthy hand will simulate the person with lost the ability to grasp object and his thumb fill be fixed in certain position. The Myo Armband is worn on another person with healthy hand or normal hand. Another person then moves the hand to give the input signal for wearable robot in order to perform the object grasping tests. The second test is conducted for evaluating the proposed of wearable robot can provide mechanical support to grasp various objects in different grip patterns. The objects that must be grasped vary in different weight, size, and shape.

The results in the first test for grip patterns test including the used grip pattern can be seen in Table II. In the power grasp mode, the wearable robot successfully grasps a water bottle. The second grasp test in key grasp, the robot can grasp and hold firmly the spoon. In pinching mode, the wearable robot successfully grasp a small coin by using index finger of exoskeleton and extra robotic thumb. The robot also grasps and holds firmly the marker without fall down to the ground by using grip pattern tripod. Finally, the robot can lift a bag using grip pattern hook. The results of grip patterns test show that the five grip patterns can successfully grasp five objects with different size and shape by using suitable grip patterns.

For the results of second test, it can be depicted in Fig 8. Results show that exoskeleton robotic fingers and extra robotic thumb can work together in order to perform various object grasping manipulations. The wearable robot also can grasp successfully various objects with different grip patterns. The objects that can be grasped firmly in the test are name card, solder, bag, marker, Blackboard eraser, CD discs, Ping-Pong ball, and spoon. The results also confirm that the proposed of four finger exoskeleton can provide mechanical support and external force on the human fingers to grasp the object. Extra robotic thumb can support the exoskeleton robotic fingers to grasp various objects in different shape and size. Based on the result tests, it can be concluded that the proposed of wearable robot can be employed for our previous study participant to assist and provide mechanical support for object grasping manipulation tasks in ADL.

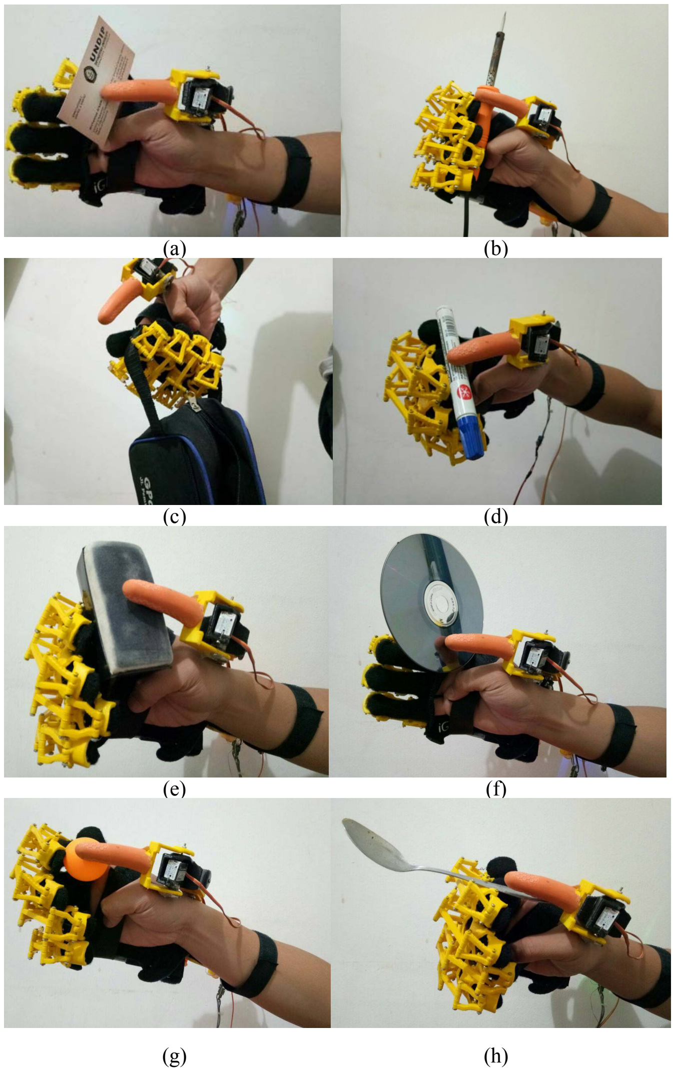


Fig. 8. Object graping test with different size and shape, (a) Name card, (b) Solder, (c) Bag, (d) Marker, (e) Balckboard eraser, (f) CD discs, (g) Ping-pong ball, (h) Spoon

V. Conclusion and Future Research

Based on the experimental test results, five developed grip patterns can successfully grasp five objects with different size and shape by using suitable grip patterns. The four finger exoskeleton and extra robotic thumb can work together in order to perform various object grasping manipulations. From the test results, exoskeleton robotic fingers can provide mechanical support and external force on the human fingers to grasp the object.

In the future research of exoskeleton robot hand for assisting human hand who lost the ability to grasp object, we will propose exoskeleton glove by using soft robotic technology. By exploring exoskeleton robot with soft robotic, this will enable the design of exoskeleton will be smaller, lighter, easier to align with the human fingers, and more comfortable to be worn than those of traditional hard robot.

REFERENCES

[1] P. Slade, A. Akhtar, M. Nguyen and T. Bretl, "Tact: Design and performance of an open-source, affordable, myoelectric prosthetic hand," 2015 IEEE International Conference on Robotics and Automation (ICRA), Seattle, WA, 2015, pp. 6451-6456.

[2] M. Yoshikawa, R. Sato, T. Higashihara, T. Ogasawara and N. Kawashima, "Rehand: Realistic electric prosthetic hand created with a 3D printer," 2015 37th Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC), Milan, 2015, pp. 2470-2473.

[3] M. Ariyanto, Munadi, G. D. Haryadi, R. Ismail, J. A. Pakpahan and K. A. Mustaqim, "A low cost anthropomorphic prosthetic hand using DC micro metal gear motor," 2016 3rd International Conference on Information Technology, Computer, and Electrical Engineering (ICITACEE), Semarang, Indonesia, 2016, pp. 42-46.

[4] R. Ismail, M. Ariyanto, W. Caesarendra and A. Nurmiranto, "Development of robotic hand integrated with SimMechanics 3D animation," 2016 International Seminar on Intelligent Technology and Its Applications (ISITIA), Lombok, 2016, pp. 629-634.

[5] S. K. Au, J. Weber and H. Herr, "Biomechanical Design of a Powered Ankle-Foot Prosthesis," 2007 IEEE 10th International Conference on Rehabilitation Robotics, Noordwijk, 2007, pp. 298-303.

[6] S. K. Au and H. M. Herr, "Powered ankle-foot prosthesis," in IEEE Robotics & Automation Magazine, vol. 15, no. 3, pp. 52-59, September 2008.

[7] N. S. K. Ho et al., "An EMG-driven exoskeleton hand robotic training device on chronic stroke subjects: Task training system for stroke rehabilitation," 2011 IEEE International Conference on Rehabilitation Robotics, Zurich, 2011, pp. 1-5.Exo

[8] S. W. Pu, J. Y. Chang, Y. C. Pei, C. C. Kuo and M. J. Wang, "Anthropometry-based structural design of a hand exoskeleton for rehabilitation," 2016 23rd International Conference on Mechatronics and Machine Vision in Practice (M2VIP), Nanjing, 2016, pp. 1-6.

[9] C. J. Gearhart, B. Varone, M. H. Stella and B. F. BuSha, "An effective 3-fingered augmenting exoskeleton for the human hand," 2016 38th Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC), Orlando, FL, 2016, pp. 590-593.

[10] ExoHand [Internet]. ExoHand | Festo Corporate. [cited 2017, Apr24]. Available from: https://www.festo.com/group/en/cms/10233.htm

[11] F. Y. Wu and H. H. Asada, "Implicit and Intuitive Grasp Posture Control for Wearable Robotic Fingers: A Data-Driven Method Using Partial Least Squares," in *IEEE Transactions on Robotics*, vol. 32, no. 1, pp. 176-186, Feb. 2016.

[12] D. L. Pan, K. Yang, Myo The Force be With You, Stanford University, 2016. Avalaible from:

http://stanford.edu/class/ee267/Spring2016/proposal_pan_yang.pdf