**Meeting Minutes**

**Performance Metrics and Benchmarks to Advance the State of Robotic Grasping**

**Held 9/23/2015**

Attendance:

1. John Amend - Empire Robotics, USA
2. Lionel Birglen - Polytechnique Montreal, Canada
3. Aaron Blasdel - Fetch Robotics, USA
4. Berk Calli - Yale University, USA
5. Mark Culleton - Trinity College Dublin, Ireland
6. Zoe Doulgeri - Aristotle University of Thessaloniki, Greece
7. Joe Falco - NIST, USA
8. Jeremy Fishel - SynTouch, USA
9. Stefan Gerstle - Schunk GmbH, Germany
10. Kaiyu Hang - KTH Royal Institute of Technology, Sweden
11. Dan Harburg - Soft Robotics Inc., USA
12. Kapil Katyal - Applied Physics Lab, USA
13. Miao Li - Swiss Federal Institute of Technology in Lausanne, Switzerland
14. Veronica Santos - UCLA, USA
15. Stefano Carpin - UC Merced, USA
16. Elena Messina - NIST, USA
17. Rick Norcross - NIST, USA
18. Maximo Roa - DLR Institute of Robotics and Mechatronics, Germany
19. Ravin de Souza - Swiss Federal Institute of Technology in Lausanne, Switzerland
20. Raul Suarez - Polytechnic University of Catalonia, Spain
21. Yu Sun, University of South Florida, USA
22. Karl Van Wyk - NIST, USA
23. Jeremy Wyatt – University of Birmingham, UK

Notes:

Meeting is organized around review of the following material:

1. <http://www.nist.gov/el/isd/grasp.cfm>
2. <http://www.eng.yale.edu/grablab/pubs/Calli_RAM2015.pdf>
3. NIST Presentation: Grasp\_Manipulate\_Benchmarking.ppt
4. NIST Draft Performance Metrics: Grasp\_Manipulate\_Draft\_Performance\_Metrics.xlsx

Bullets indicate a NIST response. Presentation is pseudo-chronological.

1. Introduction
   * Replicating and comparing results generated in the grasping community is difficult since there has yet to be a standardized set of test methods (protocols) and metrics. Emphasis should be placed on external measurement as to not rely on the intrinsic sensing capabilities of the hands.
   * Short term: benchmarks will provide developers insight in improving their designs, and help quantify advancement in the field
   * Long term: evaluations will help match capabilities of robotic hands to end-user needs as robotic hand technology becomes more commercial in the future
2. Berk Calli - Research groups around with world are conducting their own tests with their own objects, but the individual object properties matter a lot. Without having a common object set, it is very hard to come up with some conclusions about the system. We have compiled a set of objects, and created mesh models as well. The object set has been sent to other research groups (50 sets). Waiting list of another 50 groups. We are looking to propose some benchmarks and protocols that utilize these objects. Creating common website to share protocols and results. People have already started using their set for their own internal testing of software/hardware, but communication has been limited since web portal is not up yet. Regarding the question of having STLs of the objects for 3D printing: We indeed have STLs together with other model file types i.e. MTL, OBJ , PLY. Unfortunately, these models do not have the bottom parts of the objects, so may not be very suitable for 3D printing. However, one of the main goals of the YCB project is to deliver the physical objects to the research labs. Anyone can register to the set, and we will deliver it to them ASAP.

Here is our website for registration: <http://www.ycbbenchmarks.org/>

The models can be found here: <http://rll.eecs.berkeley.edu/ycb/>

We are also working on generating models that have the bottom parts.

1. Jeremy Wyatt - capabilities of hands vs capabilities of algorithms. Hardware vs software interactions. Shortcoming is that you need an actual hand to get metrics from tests. Availability of the objects is another hindrance. Nice thing about YCB is that the set consists of objects via STLs meaning that anyone can print the objects at any point in the future.
   * We have readily available, standard, homogenous materials. Ex: PVC pipe wrapped around 3D printed part to control surface characteristics. Surfaces of 3D printed parts have inherent variability depending on printer, material, and settings.
   * NIST is considering the idea of lending a robotic hand test stand with sensors, actuation, and software built-in to house the testing of a robotic hand across the packaged test methods. This would help validate the test methods, and generate data from a controlled implementation of the test methods. Robotic hand will not be included.
   * NIST also plans to upload current and future artifact designs so that they may be replicated (3D printed) by others
2. Dan Harburg – opening time is important in the calculation of cycle times for streamlining high-volume operations. Fatigue failure is necessary in the determination of work life (cycles to failure). Important for industrial applications. Would be used by hand developers (not customers) to report fatigue life from an industrial tools perspective.
   * NIST will add this metric to the list it is compiling
3. Kapil Katyal – in-hand manipulation, moving beyond grasping. Thoughts on tests/metrics?
   * A test method for in-hand manipulation is already in progress. The test method requires the use of a reference Motion Capture (MoCap) system to track the motion of the object in 6 DOF Cartesian space. Given an object of interest, the hand should be manipulating the object along a Cartesian trajectory. So far, test metrics include comparing the errors between the desired and actual object trajectory (using MoCap data), and errors between the desired trajectory and the hand’s estimate of the object’s trajectory. These metrics capture controller performance as well as touch-based object pose estimation performance.
4. Lionel Birglen – test methods seem to be biased towards sensor instead of robotic hand. Also, how do you define a robotic hand? How do you distinguish robotic gripper vs robotic hand?  A clear definition of what you consider a hand vs a gripper might be useful (although difficult since the field is constituted by a continuum of solutions in my opinion).
   * We don’t want to necessary limit the tests to robotic hands. Certainly, some of the test will apply to robotic grippers as well, including non-traditional designs like jam grippers. We should work as a group to formally define a robotic hand.
5. Yu Sun – you have a wide range of tests. Is it possible to group together the tests in different layers? Kinematics, higher-level control, etc. Have measures presented in this different levels.
   * Certainly, this is something that we will be working on.
6. Zoe Doulgeri – touch sensitivity seems to be applied to only the fingertip. What about different areas such as the back of the finger?
   * Sure, we would like for the tests to be generalizable to an extent. The test sensitivity test could be applied to other regions of the hand, but the results should specify which regions are being measured, and how you configured the hand to conduct the test.
7. Miao Li – Due to audio problems NIST discussed the following two videos showing tests from Miao’s Lab to measure what NIST refers to as ‘gasp efficiency’:

Video 1: adding weight to the object to see how much the grasp can withstand (IROS 2014).

<https://www.dropbox.com/s/h4w2q5gdfhx1pkd/Grasp_Adaptation_IROS2014.wmv?dl=0>

Video 2: shaking the object with acceleration until the object is dropped (TRO submission).

<https://www.dropbox.com/s/rug5tkywqjqw33j/TRO_submission.mp4?dl=0>

* + Grasp efficiency is a measure of the robotic hand to grasp with only the necessary amount of force necessary to hold onto the object. Humans typically apply a grip force only 10-40% more than the minimum amount to avoid slip. Such a trait would be useful in robotic hands to promote lower energy consumption and reduce wear-and-tear on either the hand or part.
  + An example test method and metric is having a robotic hand hold onto an object while the hand is subjected to acceleration via a robotic arm. The acceleration profiles are emitted in the horizontal and vertical directions, separately, while persistently increasing the magnitude of acceleration. The metric is the maximum acceleration the hand can sustain its grasp of the object before it slips out.
  + Another example is having the hand hold an object with controllable mass (e.g. filling a bottle with water)
  + Another example is having the object attached to a remote, cable-driven actuator that induces increasingly larger force. This is much like the existing “Slip Resistance” test we have already done. The difference is that it would be applied to more objects, and a parallel measurement of transmitted, internal grasp forces.

1. Jeremy Fishel - Recommendations for sensor specifications to include: sensor compliance with force-displacement curve to indicate stiffness, static force sensitivity, dynamic sensor noise while hand is in motion
2. Yu Son - These meetings are coming at a good time. IEEE RAS Technical Committee on Robotic Hand Grasping & Manipulation has submitted a workshop proposal for ICRA 2016.
3. Veronica Santos (via email) - How to separately assess the capabilities enabled by a hand's off-the-shelf hardware vs. the capabilities enabled by algorithms?  For example, will pre-specified finger gaits be used for in-hand manipulation and how would this work for hands with >3 digits and palmar flexion capabilities?

* The biggest drive of this effort is to help provide a uniform set of tools for measuring the performance of a hand such that we, as a community, can even stand a chance at comparing results. For manipulation, our current metrics label performance as the average error between where you want the grasped object to be, and its actual location (as measured by a reference Motion Capture system). The desired trajectories can be parameterized and the results will be reported along with them. As a developer, you would be free to use whatever approach you want to get the job done (the test method generic to the implementation). It is agreed that labeling what algorithm(s) and sensing/control modalities were used would be helpful in learning something from the performance results. We are currently brainstorming some ideas for creating a conduit for reporting results, conditions, and approach.

The feedback control algorithm described by Dr. Karl Van Wyk is a good first step, but the inverse kinematic solutions will become more difficult with higher DOF hands.  Upon watching the video clip on peg insertion, my first thought was, "How was the hand controlled and what sensory feedback modalities were used?"

* The algorithm designed and implemented by Karl does not actually use inverse kinematics. The algorithm is force based and works by issuing time-varying force profiles for each finger in contact with the object control the object to move to the commanded position. The use of kinematics are constrained to 1) using hand sensing to make estimation of the 6 DOF object pose, and 2) forward kinematics for each finger separately for use in their individual admittance force controllers. As for the peg-and-hole video, the force-based manipulation controller was used to control the states of the object. The following sensing modalities were used: 1) 3D contact force resultant, 2) 3D contact center of pressure, 3) 3D contact normal force directions, 4) hand joint position velocities and positions.