**Elliott and Connolly Benchmark**

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| Reference No / Version | 1.0 |
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| Adopted Protocol | Elliott and Connolly Benchmark Protocol |
| Scoring | This benchmark includes both qualitative and quantitative scoring metrics.The primary qualitative metric is *Success* or *Failure*, which is assessed for each manipulation pattern. In order to evaluate this metric, a list of criteria for each manipulation pattern has been provided. Additionally, experimenters can refer to videos of a human hand performing the corresponding pattern when determining whether a manipulation pattern has been performed successfully.In addition to this binary designation, failed manipulation patterns can also be labeled as *Incomplete*, and successful patterns can be labeled as *Non-anthropomorphic*. The only manipulation patterns which are eligible to be labeled as incomplete are Rotary Step and Interdigital Step. This is due to the fact that each of these patterns requires a certain amount of rotation (360 degrees, per the provided criteria) in order to be evaluated as successful, meaning it is possible to achieve partial completion by rotating the object less than 360 degrees. A successful manipulation pattern is labeled as *Non-anthrophorphic* if the object is rotated or translated along the correct axis, but in a manner that is dissimilar to human baseline examples.Quantitative scoring metrics for this benchmark are *Normalized Average Translation* and *Average Rotation*.*Normalized Average Translation* is defined as the distance an object is translated along a particular hand coordinate axis, normalized by the average finger length of the hand and averaged over *N* trials. Average finger length is defined as the average distance between the fingertips and the center of the hand. The center of the hand is defined as the point of intersection on the palm by lines extended from the fingertips. *Normalized Average Translation* can be calculated using the following equation:$T=\frac{\sum\_{i=1}^{N}d\_{i}}{N\*F}$,where *N* is the number of trials, $d\_{i}$ is the translation distance for an individual trial, and *F* is the average finger length of the hand. *Average Rotation* is defined as the degree to which an object is rotated about a particular hand coordinate axis, averaged over *N* trials. *Average Rotation* can be calculated using the following equation:$$R=\frac{\sum\_{i=1}^{N}ω\_{i}}{N},$$where N is the number of trials and $ω\_{i}$ is the degree of rotation for an individual trial.Additionally, we define performance scores, which are used to compare the performance of the robot hand to the performance of a human hand. The *Translation Performance Score* for a particular manipulation pattern *m* can be calculated as follows:$$P\_{m}^{T}=\frac{R\_{m}^{robot}}{R\_{m}^{human}}×100$$Likewise, *Rotation Performance Score* can be calculated as:$$P\_{m}^{R}=\frac{R\_{m}^{robot}}{R\_{m}^{human}}×100$$Thus, the performance score for a particular manipulation pattern indicates the percentage of translation or rotation achieved by the robot, as compared to the human baseline. |
| Details of Setup | * Robot hand used to perform benchmark
* Camera used, as well as camera setup and calibration procedures, in addition to any image postprocessing methods
* Information on technique used for control of robot hand
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| Results to Submit | * Quantitative scoring metrics, recorded in the included table
* Qualitative designations – Success or Failure (Incomplete or Non-anthropomorphic) for each manipulation pattern
* Video of robot performing all manipulation patterns (including failed patterns)
* Scores and video for human hand (optional)
* Provided detailed comments on
	+ What attributes of the hardware design contribute to its success?
	+ What attributes of the hardware design contribute to failures? (specifically address each failed manipulation pattern)
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