Guidelines for the workshop on "Impulsive systems: principles of rapid energy release and applications to unique robot behaviors"

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1 Introduction

This document outlines the scoring guidelines for analyzing the performance and rewarding various novel aspects of devices participating in demonstration events. The workshop consists of demonstration events that focus on different Latch-mediated spring actuation (LaMSA) behaviors (jumping, throwing, striking).

2 Event details

The workshop consists of four types of demonstration events and four different weight categories for each demonstration event. The weight categories are as follows:

- For <10g systems
- For 10-50g systems
- For 50-100g systems
- For 100-200g systems

Devices can be entered in any number of events as deemed appropriate by the participants. The types of demonstration events are as follows:

1. Jumping
   (a) High jump – maximum height
      - Vertical jump performance will be evaluated based on the metrics outlined in the next section.

   (b) High jump – jump accuracy
      - Device will jump as close as possible to the target height (e.g., 1m) and land as close as possible to the takeoff site.
      - Target distance will be provided before the event.

   (c) Long jump – maximum distance
      - Device performance will be evaluated based on the metrics outlined in the next section.

   (d) Long jump – jump accuracy
      - Device will jump as close as possible to the target distance (e.g., 1m).
      - Target distance will be provided before the event.

2. Shot put

- Device will throw the projectile (spherical steel ball bearings) as far as possible.
- Participants will be supplied with spherical steel ball bearings according to the weight class of the device. The following are the specifications of the steel ball bearings that shall be provided for shot put devices:
  - For <10g systems: 2.5mm diameter steel ball ($\sim$0.5g)
  - For 10-50g systems: 4.36mm diameter steel ball ($\sim$2.5g)
  - For 50-100g systems: 5.5mm diameter steel ball ($\sim$5g)
  - For 100-200g systems: 7mm diameter steel ball ($\sim$10g)
- Device performance will be evaluated based on the metrics outlined in the next section.

3. Archery
   - Device will shoot a projectile with the goal of hitting a small target (10cm diameter circle) at a fixed known distance, d (1m $< d <$ 5m), at a height of 1m.
   - Target distance will be provided during the event and participants can make changes to the device (swap out springs, etc.) to aim towards the target.
   - Each participant will have three trials and scoring will be evaluated based on the metrics outlined in the next section.
4. Striking
   - Device will strike a load cell.
   - Dimensions of the platform on which the device shall be mounted to strike at the load cell shall be provided before the event.
   - Device performance will be evaluated based on the metrics outlined in the next section.

3 Scoring

The scoring consists of different categories:

1. Performance metric: This is based on the actual score of the device (with dimensions: $l \times w \times h$, and mass m) in its respective event category. The performance scores of all participating devices pertaining to an event and corresponding weight category are normalized to the highest performing device in that category (see example).
   (a) Jumping
      i. Distance
         - High jump: Jump height/device height ($\alpha_p = h_{act}/h$)
         - Long jump: Jump distance/device characteristic dimension ($\alpha_p = d_{act}/max(l, w)$)
      ii. Control/Accuracy: Target jump distance or height will be provided before the event (e.g., 1m jump height or 2m jump length).
         - High jump:
           - Jump vertically as close as possible to the target height and land as close as possible to the take off site.
           - Given that accuracy is the main consideration here, a penalty score is first assigned as follows: $\left(\alpha_{penalty} = \left|h_{target} - h_{act}\right| / h_{target} + d_{act}/max(l, w)\right)$
           - Performance score is then assigned as follows: $\left(\alpha_p = 1 - \alpha_{penalty}/max(\alpha_{penalty})\right)$, where $max(\alpha_{penalty})$ is the $\alpha_{penalty}$ of the worst performing device.
         - Long jump:
           - Jump horizontally as close as possible to the target distance.

- Given that accuracy is the main consideration here, a penalty score is first assigned as follows: $\left(\alpha_{penalty} = \left|d_{target} - d_{act}\right| / d_{target}\right)$
- Performance score is then assigned as follows: $\left(\alpha_p = 1 - \alpha_{penalty} / max(\alpha_{penalty})\right)$, where $max(\alpha_{penalty})$ is the $\alpha_{penalty}$ of the worst performing device.

(b) Shot put
- Estimated projectile distance normalized by mass of the device ($\alpha_p = d_{proj}/m$).

(c) Archery
- For each trial i, the device gets a score of 1 if the target is hit and 0 otherwise. ($\alpha_p^i = 0$ or 1)
- Each device gets three trials. Overall score is the average score taken across three trials. $\left(\alpha_p = avg(\alpha_p^i)\right)$

(d) Striking
- Force output normalized by system weight ($\alpha_p = F_{punch}/W$).

2. Autonomy metrics:

(a) Power Autonomy (α_{pa}): is the energy source is on-board or not?
- 0: No on-board power source
- 1: On-board power source

(b) Operational Autonomy (α_{oa}): Autonomy with respect to following operational aspects under the LaMSA framework [1, 2]. The operational autonomy score is the average of the following components:

i. Loading: How is energy loaded into the elastic element?
- 0: Manual loading of elastic elements
- 1: Elastic elements loaded by an on-board actuator

ii. Energy release: Release of the stored elastic potential energy (i.e., latch removal).
- 0: Energy release is triggered manually
- 1: Energy release/latch removal is automatic through active (i.e., by an actuator) or passive means (force thresholds, etc.)

(c) Control Autonomy (α_{ca}): This score is an aggregate of the following aspects.

i. Resetting controller: Can the device reset automatically to repeat the behavior? For example, can the jumper right itself after landing to jump again without any manual intervention? Similarly, can a shotput device automatically reset itself for the next throw?
- 0: Device needs to be manually reset for the next operation (e.g., jumper needs to be manually positioned to jump again)
- 1: Device can automatically reset itself for next operation (e.g., jumper rights or stabilizes itself after landing and therefore is ready to initiate another jump)

ii. Performance controller: Can the device vary the energy output either by automatically changing the elastic element or the amount of energy stored in it, or using latch to mediate the release of stored elastic energy? For example, can the jumper jump a different height by either varying the amount of energy stored in the spring, or by using latch-mediation? Is the device able to do this without manual intervention (other than sending a command)?
- 0: If the device requires manual reset or change of components for different performance outputs
- 1: If the device can automatically change its performance through a controller

3. The total score (α_T) is the sum of relative performance score α_r (where performance score α_p is normalized for each device with respect to the performance α_p of the best-performing device in its respective category) and the net autonomy score. It is computed using the following equation:

$$\alpha_T = \alpha_r + \left(\alpha_{pa} + \alpha_{oa} + \alpha_{ca}\right)/3 \tag{1}$$

Where α_r for a device is given by $\alpha_r = \alpha_p / \alpha_p^{max}$. α_p^{max} is the α_p of best performing device in its respective weight category. See next section for an illustration of scoring guidelines outlined here.

4 Example

To illustrate the scoring guidelines outlined in the previous section, a few example devices and their performance characteristics are analyzed in this section. The devices used as examples consist of systems both from published literature and unpublished work. Two main events are considered in this example: jumping and shot put, with the former category further consisting of two further sub-categories: high jump and long jump evaluated for maximum height/distance. The devices across the event categories are scored based on both their performance as well as the degree of autonomy as defined in the previous section. For sake of simplicity, the example scoring process illustrated in this section does not specifically consider individual weight categories for calculating their relative performance score (α_r). Instead, all devices across different weight categories for a given event are considered. Figure 1 shows the scores of the devices. The following subsections explain the process and rationale behind the scores seen in Figure 1.

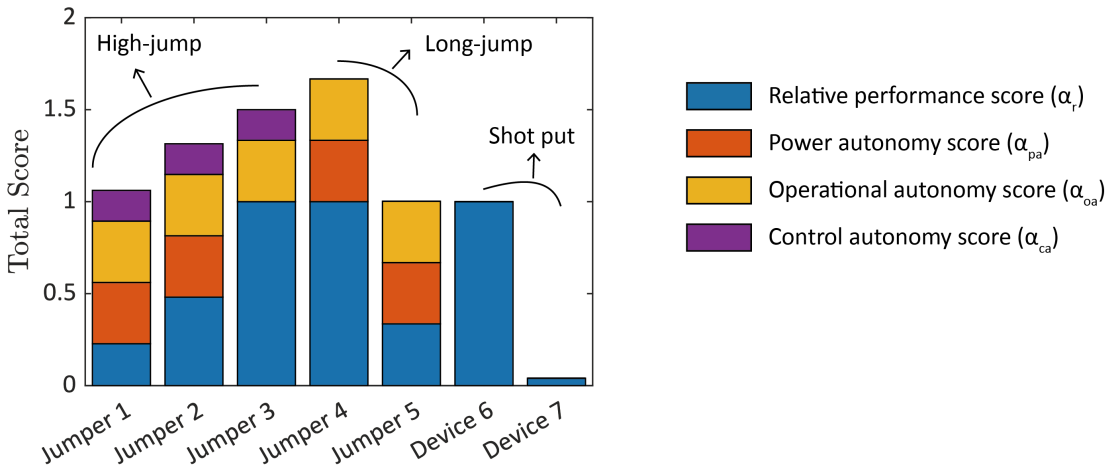

Figure 1: Score chart for example jumping and shot put devices used for illustrating the scoring metrics in section 3.

4.1 Jumping

4.1.1 High-jump

Table 1 illustrates scoring for a hypothetical high jump event (maximum height). The following series of steps illustrate the scoring process for a device participating in high-jump considering three example devices from literature (Jumper 1: EPFL jumper [3]; Jumper 2: MSU jumper [4]; and Jumper 3: Flea-inspired jumper [5]).

- Step 1: Compute the performance score (α_p) for each of the devices, which is the ratio of jump height h_{act} to that of device's body height h. It is seen that Jumper 3 has the highest performance score.
- Step 2: Compute relative performance score (α_r) for each of the devices. This done by normalizing the individual device scores with respect to the score of the best performing device. From Table 1, Jumper 3 has the highest α_p (27.826). Thus, the relative performance score (α_r) for all the devices are computed by normalizing their α_p with jumper 3's α_p. Therefore, Jumper 3 has an α_r of 1 (highest), and all the other device's α_r are scaled accordingly.

Table 1: Sample scoring for high-jump devices

Device		Jumper 1 [3]	Jumper 2 [4]	Jumper 3 [5]
Device mass m (g)		9.8	23.5	1.1
Body height h (m)		0.12	0.065	0.023
Jump height h_{act} (m)		0.76	0.87	0.64
Distance/mass (m/g)		0.0776	0.037	0.5818
Performance score α_p		6.333	13.385	27.826
Relative performance score α_r		0.228	0.481	1
Power Autonomy Score α_{pa}		1	1	0
Operational Autonomy Score	Loading	1	1	1
	Energy Release	1	1	1
	Net Score α_{oa}	1	1	1
Control Autonomy Score	Performance Controller	0	0	1
	Resetting Controller	1	1	0
	Net Score α_{ca}	0.5	0.5	0.5
Total Score α_T		1.061	1.314	1.5

- Step 3: Assign power autonomy scores (α_{pa}). The device receives a score of 1 if it is powered by an on-board battery (e.g., Jumpers 1 & 2). If not, it is scored 0 (e.g., Jumper 3).
- Step 4: Assign operational autonomy scores (α_{oa}).
  - Loading: All of the jumpers receive a score of 1 since they are all loaded automatically by an actuator.
  - Energy release: All of the jumpers receive a score of 1 since the energy release is triggered automatically (no manual intervention is required to remove the latch).
  - Operational autonomy score (α_{oa}): Average of the above two scores.
- Step 5: Assign control autonomy scores (α_{ca}).
  - Performance controller: Jumpers 1 & 2 receive a score of 0 since their components have to be changed to vary their jump performance (i.e., swap out springs, etc.). Jumper 3 receives a score of 1, since by varying the input current, the device can change the spring characteristics that allow it to vary jump performance.
  - Resetting controller: Jumpers 1 & 2 receive a score of 1 since their design automatically allows them to stabilize or reset themselves after landing to be able to jump again. However, jumper 3 needs to be manually reset and hence, gets a score of 0.
  - Control autonomy score (α_{ca}): Average of the above two scores. Each of the jumpers receives a score of 0.5.
- Step 6: Total score α_T
  - Add scores from steps 2-5 in the following way (from Eq(1)): $\alpha_T = \alpha_r + \left(\alpha_{pa} + \alpha_{oa} + \alpha_{ca}\right)/3$
  - The total score is a sum of the relative performance score and the average autonomy score.

4.1.2 Long jump

Table 2 illustrates the scoring for a hypothetical long jump event (maximum distance). The following series of steps illustrate the scoring process for a device participating in long jump, considering two example devices from literature (Jumper 4: TAUB jumper [6]; Jumper 5: Grillo III jumper [7]).

- Step 1: Compute the performance score (α_p) for each of the devices, which is the ratio of jump distance d_{act} to the device's characteristic dimension (length or width of the device, whichever is greater). It is seen that Jumper 4 has the highest performance score.
- Step 2: Compute the relative performance score (α_r) for each of the devices. This done by normalizing the individual device's score with respect to the score of the best performing device. From Table 2, Jumper 4 has the highest α_p (23.077). Thus, the relative performance score (α_r) for both the devices are computed by normalizing their α_p with jumper 4's α_p.
- Step 3: Assign power autonomy scores (α_{pa}). The device receives a score of 1 if it is powered by an on-board battery. If not, it is scored 0.
- Step 4: Assign operational autonomy scores (α_{oa}).
  - Loading: Each of the jumpers receive a score of 1 since they are all loaded automatically by an actuator.
  - Energy release: Each of the jumpers get a score of 1 since the energy release is triggered automatically (no manual intervention is required to remove the latch).
  - Operational autonomy score (α_{oa}): Average of the above two scores.
- Step 5: Assign control autonomy scores (α_{ca})
  - Performance controller: Both the jumpers receive a score of 0 since their components have to be changed to vary their jump performance (i.e., swap out springs, etc.).
  - Resetting controller: Both jumpers receive a score of 0 since they are manually reset after each jump.
  - Control autonomy score (α_{ca}): Average of the above two scores.
- Step 6: Total score α_T
  - Add scores from steps 2-5 in the same fashion as Eq(1).
  - The total score is a sum of the relative performance score and the average autonomy score.

4.2 Shot put

Table 3 illustrates scoring for a hypothetical shot put event. The following series of steps illustrate the scoring process for a device participating in shot put, considering two example devices (Device 6: 1g manually operated shot put device inspired by mantis shrimp mechanism, Device 7: 25g manually operated shot put device built based on principles similar to that of a trebuchet).

- Step 1: Compute performance score (α_p) for each of the devices, which is the ratio of estimated projectile throw distance d_{proj} to that of device mass m.
- Step 2: Compute relative performance score (α_r) for each of the devices. This done by normalizing the individual device's score with respect to the score of the best performing device. From Table 3, device 6 has the highest α_p ($14.19\,\mathrm{m\,g^{-1}}$). Thus, the relative performance score (α_r) for both devices are computed by normalizing their α_p with device 6's α_p.
- Step 3: Assign power autonomy scores (α_{pa}). The device receives a score of 1 if it is powered by an on-board battery. If not, it is scored 0 (both device 6 and 7).

Table 2: Sample scoring for long-jump devices

Device		Jumper 4 [6]	Jumper 5 [7]
Device mass m (g)		22.6	22
Body length l (m)		0.13	0.05
Jump distance d_{act} (m)		3.0	0.2
Distance/mass (m/g)		0.1372	0.0091
Performance score α_p		23.077	4
Relative performance score α_r		1	0.173
Power Autonomy Score α_{pa}		1	1
Operational Autonomy Score	Loading	1	1
	Energy Release	1	1
	Net Score α_{oa}	1	1
Control Autonomy Score	Performance Controller	0	0
	Resetting Controller	0	0
	Net Score α_{ca}	0	0
Total Score α_T		1.667	0.84

- Step 4: Assign operational autonomy scores (α_{oa}).
  - Loading: Both devices receive a score of 0 since they are manually loaded.
  - Energy release: Both devices receive a score of 0 since the latch is released manually.
  - Operational autonomy score (α_{oa}): Average of the above two scores.
- Step 5: Assign control autonomy scores (α_{ca})
  - Performance controller: Both devices receive a score of 0 since their components have to be changed to vary their jump performance (i.e., swap out springs, etc.).
  - Resetting controller: Both devices receive a score of 0 since they need to be manually reset after each operation.
  - Control autonomy score (α_{ca}): Average of the above two scores.
- Step 6: Total score α_T
  - Add scores from steps 2-5 in the same fashion as Eq(1).
  - The total score is a sum of the relative performance score and the average autonomy score.

Table 3: Sample scoring for shot put devices

Device		Device 6	Device 7
Device m mass (g)		1	25
Launch velocity (m/s)		11.8	12.6
Launch angle (degrees)		45.7	30.71
Estimated range d_{proj} (m)		14.19	14.21
Performance score α_p (m/g)		14.19	0.5684
Relative performance score α_r		1	0.04
Power Autonomy Score α_{pa}		0	0
Operational Autonomy Score	Loading	0	0
	Energy Release	0	0
	Net Score α_{oa}	0	0
Control Autonomy Score	Performance Controller	0	0
	Resetting Controller	0	0
	Net Score α_{ca}	0	0
Total Score α_T		1	0.04

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