

APPENDIX A

SIMULATOR DETAILS AND PARAMETERS

Our simulator uses Featherstone’s algorithm and the semi-implicit scheme of Guendelman et al. [1] ($1e^{-3}$ s). Ground contact uses an frictional ($\mu = 1$) inelastic impulse-based model. Height and weight for the correspond to a 50th percentile North American male. Skeletal dimensions/link masses are taken from Winter [2]. Link inertias are calculated using uniform density shapes scaled to match skeletal dimensions.

TABLE 1: Joint limits and PD gains. All limits are in radians. In all cases we use $\mathbf{k}_v = 0.1\mathbf{k}_p$. Special cases: neck limits are ± 0.4 for the head spin; lumbar limits are $\pm 0.1, \pm 0.1$ and ± 0.05 for walking and push-ups; hip limits are $\pm 0.2, \pm 0.2$ and ± 1.5 for walking; wrist limits are ± 0.2 for walking; knee limits $-0.5, 0$ for push-ups.

| DOF | x | y | z | \mathbf{k}_p |
|----------|------------|-----------|-------------|-------------------|
| neck | ± 0.1 | ± 0.1 | ± 0.1 | 1000 |
| lumbar | ± 0.8 | ± 0.8 | $-0.8, 2.8$ | 1000 |
| thorax | ± 0.1 | ± 0.1 | ± 0.1 | 1000 |
| shoulder | ± 3.14 | ± 0.8 | ± 3.14 | 200 |
| elbow | – | – | 0, 2.8 | 200 |
| wrist | ± 1 | – | ± 1 | 100 |
| hip | ± 0.6 | ± 0.8 | ± 1.5 | 700 |
| knee | – | – | $-2.8, 0$ | 700 |
| ankle | ± 0.6 | – | $-0.2, 1.2$ | 100/150 (x/z) |
| toe | – | – | 0, 0.3 | 10 |

TABLE 2: Objective weights used for all examples.

| Weight | Getting-Up | Walking | Handstand | Hand Walk | Head Spin | Hand Spin | Flips | Push-Ups | Crawling |
|------------------|------------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|
| w_{torque} | $1e^{-7}$ | $1e^{-8}$ | $1e^{-6}$ | $1e^{-6}$ | $1e^{-6}$ | $1e^{-6}$ | $1e^{-8}$ | $1e^{-6}$ | $1e^{-7}$ |
| w_{feet} | $5e^3$ | – | – | – | – | – | – | – | – |
| w_{ground} | $1e^2$ | – | – | – | – | – | – | – | $1e^3$ |
| $w_{restPose}$ | 1 | – | – | – | – | – | – | – | – |
| w_{COM} | – | 8 | – | – | – | – | – | – | – |
| w_{COMV} | – | – | 10 | 10 | 10 | 10 | – | – | – |
| w_{COMh} | – | – | – | – | – | – | $1e^5$ | 1 | – |
| $w_{COMHeight}$ | – | – | – | – | – | – | 1 | – | 1 |
| w_{hands} | – | – | $1e^3$ | $1e^3$ | $1e^3$ | $1e^4$ | – | $1e^2$ | – |
| $w_{heading}$ | – | 5 | – | $5e^4$ | – | – | – | – | – |
| $w_{headHeight}$ | – | – | 1 | 1 | 1 | – | 1 | – | 1 |
| w_{feetV} | – | – | 5 | 5 | 5 | – | – | – | – |
| $w_{stepDist}$ | – | 8 | – | $1e^4$ | – | – | – | – | $8e^3$ |
| w_{AM} | – | – | – | – | $1e^{-3}$ | $1e^{-2}$ | 1 | – | – |
| w_{horiz} | – | – | – | – | $1e^3$ | $1e^3$ | – | – | – |
| w_{toe} | – | – | – | – | – | – | – | 1 | – |
| $w_{stanceHand}$ | – | – | – | – | – | – | – | – | $1e^3$ |
| $w_{stanceKnee}$ | – | – | – | – | – | – | – | – | $1e^3$ |
| $w_{stanceToe}$ | – | 8 | – | – | – | – | – | – | $1e^3$ |
| $w_{swingHeel}$ | – | 8 | – | – | – | – | – | – | – |

REFERENCES

- [1] E. Guendelman, R. Bridson, and R. Fedkiw, “Nonconvex Rigid Bodies with Stacking,” *ACM Trans. Graphics*, vol. 22, no. 3, p. 871, 2003.
- [2] D. Winter, *Biomechanics and motor control of human movement*, 3rd ed. Wiley, 2004.