# Robot Fact sheet

Assignment III
Name: Jesus Arturo Sol Navarro
Group: ZMP Robots

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## Zero Moment Point Robots

A primary challenge for humanoid robots is locomotion, which is crucial for operating like humans in various environments (Mostafa 2023). Maintaining dynamic balance while standing, walking, or moving is a fundamental requirement. The Zero-Moment Point (ZMP) is a concept introduced 56 years ago that became the starting point for research in bipedal walking systems and initiated humanoid robotics development (Borovac, Nikolić, Raković, and Savić 2023). **ZMP is defined as that point on the ground at which the net moment of the inertial forces and the gravity forces has no component along the horizontal axes** (Vukobratovic and Borovac 2004). Alternatively, the ZMP is defined as the point on the support polygon (the region of contact with the ground, such as the foot sole) where the sum of the moments of the ground reaction forces equals zero (Mostafa 2023). A necessary condition for dynamic balance in a biped robot is that the ZMP must be located within the support polygon. If the ZMP reaches or exceeds the boundary of the support polygon, the robot becomes unstable and will tend to rotate around that edge. If the ZMP falls outside the support polygon, the robot cannot be dynamically stable and will fall (D. W. Kim, N.-H. Kim, and Park 2012).

In contrast to other strategies like ***Static Stability***, which requires the vertical projection of the CoM to be contained within the support polygon—a more restrictive criterion than ZMP that allows for more dynamic motions by considering inertial forces and moments, not just the static projection of mass. Moving on to ***Capture Point*** (CP), which represents the point on the ground onto which the robot must step to come to a complete rest; while both are point-based stability concepts often used with Linear Inverted Pendulum Model (LIPM), ZMP focuses on the point of zero horizontal moment during contact, whereas CP relates to the state required to stop. Compared to CP, the ZMP criterion is described as more conservative compared to biological walkers or methods like CP for more dynamic motions. Shifting focus to ***Hybrid Zero Dynamics*** (HZD), a framework using nonlinear feedback control to restrict the robot's full dynamics to a lower-dimensional, attractive, and invariant subset of its state space, while ZMP is a stability criterion and planning tool often used within control loops. HZD can also be applied to under-actuated systems, unlike traditional ZMP-based methods. In contrast, ***Spring-Loaded Inverted Pendulum (SLIP) models and Passive Dynamic Walking***, which model compliant legs and may include flight phases, focusing on stable cyclic locomotion or limit cycles rather than maintaining a specific point like ZMP during ground contact phases. ZMP relies on continuous ground contact forces and moments, applicable primarily during support phases. Finally, with respect to ***Optimal Control or Learning-Based Approaches***, these techniques generate motions or learn control policies rather than serve as fundamental stability criteria; they can incorporate ZMP, CP, or other concepts within their formulation or evaluation (Reher and Ames 2021). The **reasoning behind the ZMP** design and control can be understood as a single, measurable, and computationally tractable point on the ground that summarizes the complex whole-body dynamics relevant to tipping stability (Vukobratovic and Borovac 2004).

The ZMP control strategy offers key advantages like reliability by providing a clear balance criterion, continuously monitoring the Zero Moment Point to maintain stability (IMSystems 2024) and simplifying trajectory planning through models like the Linear Inverted Pendulum Model (LIPM) (Reher and Ames 2021). However, it demands significant computational resources for real-time adjustments, is sensitive to sudden disturbances and uneven terrain, and has dynamic limitations, making it less suitable for highly dynamic movements such as running or jumping (IMSystems 2024).

## HRP-4 Fact Sheet

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| **robot name** | HRP-4 |
| **institution/company** | Kawada Industries, Inc. and National Institute of Advanced Industrial Science and Technology (AIST). |
| **height [m]** | 1.514 (Kajita 2017a). |
| **weight [kg]** | 39 inc. batteries (Kajita 2017a). |
| **DOF** | Head: 2 + Arm: 2 × 7 + Hand: 2 × 2 + Waist: 2 + Leg: 2 × 6 = 34 DOF (Kajita 2017a). |
| **average/max. speed [m/s]** | 0.4375 (Kaneko 2011). |
| **walking cycle [steps/s]** | 1.25 (derived from step cycle is 0.8 sec/step.) (Kaneko 2011). |
| **step length [m]** | 0.35 (Kaneko 2011). |
| **payload [kg]** | Payload of each arm: 0.5 (National Institute of Advanced Industrial Science and Technology (AIST) 2010) |
| **battery life / operating time [min]** | Regarding its battery life, specific details about the HRP-4's operational duration are not available. However, it's worth noting that its predecessor, the HRP-4C, has a reported battery life of approximately 20 minutes (Kajita 2017b). |
| **# of motors, type of motors** | Low power motors operating at 80 W or lower for all joint shaft (Kaneko 2011). |
| **# and type of computers** | A PC/104 Pentium M computer with Wi-Fi and speakers. Software : Linux OS with RT-PreemptPatch and OpenRTM-aist middleware (Kaneko 2011). |

## References


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Kajita, S. (2017a). "HRP Robots (e.g. HRP-4)". In: *Humanoid Robotics: A Reference*. Ed. by Goswami, A. and Vadakkepat, P. DOI: 10.1007/978-94-007-7194-9_11-1.

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Kim, D. W., Kim, N.-H., and Park, G.-T. (2012). "ZMP based neural network inspired humanoid robot control". In: *Nonlinear Dynamics* 67.1, pp. 793–806. ISSN: 1573-269X. DOI: 10.1007/s11071-011-0027-1. URL: https://doi.org/10.1007/s11071-011-0027-1.

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Reher, J. and Ames, A. (May 2021). "Dynamic Walking: Toward Agile and Efficient Bipedal Robots". In: *Annual Review of Control, Robotics, and Autonomous Systems* 4. DOI: 10.1146/annurev-control-071020-045021.

Vukobratovic, M. and Borovac, B. (Mar. 2004). "Zero-Moment Point - Thirty Five Years of its Life." In: *I. J. Humanoid Robotics* 1, pp. 157–173. DOI: 10.1142/S0219843604000083.


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## AI usage declaration

### tools used

ChatGPT

### comments

This includes finding relevant peer-reviewed literature, improving the cohesion between paragraphs, and checking the grammar throughout the text.

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