The Control of Humanoid Robot: A Preliminary Literature Review

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Declaration

I declare that this assignment is my own work, unless otherwise referenced, as defined by the NTU policy on plagiarism. I have read the NTU Honour Code and Pledge.

Abstract

A humanoid robot provides a variety of professional and domestic/personal services to companies and persons across a wide range of application fields. Currently, the humanoid robot sector is expanding fast in tandem with the Fourth Industrial Revolution's technical breakthroughs.

Given the high interest and promise of humanoid robots, this study undertakes a thorough overview of previous and current research in the field. This report analyses the control of humanoid robot development efforts.

This paper examines the technological base that applies to the control of legged robot, specifically legged humanoid robot. Finally, this paper outlines understudied but potentially crucial possibilities and problems for future service robot research.

Keywords: dynamic motion; model predictive control (MPC), QCQP, angular momentum, quadratic program, ground reaction force, trajectory optimization, legged robot, velocity tracking, centroidal Inertia Isotropy metric, inertial measurement unit, proprioceptive actuation, whole-body control, bipedal locomotion, centre of mass, whole body impulse control, linear constraint, nonlinear programming, model hierarchy predictive control (MPHC)

I. Current Research

Humanoid robots have grown in popularity in recent years as an increasing demand for more adaptable and autonomous robots that can execute jobs in real-world contexts. Technological advances, such as computing power, sensors, and actuators, have fuelled the development of humanoid robots. These improvements have enabled the implementation of complicated controllers on robots to do tasks previously only conceivable for humans, such as very dynamic walking, running, and object manipulation.

It is challenging to achieve very dynamic movements in robots. In recent years, advances in mechanical design, enhanced algorithms, and more processing capacity have enabled new robots to implement natural gaits and dynamic maneuvers like backflips.

The 2015 DARPA Robotics Challenge (DRC) provided the foundation for the next generation of humanoid robots [1] [2] [3]. However, the mechanical designs of these robots and the algorithms used to control them have been primarily tailored at performing the minimal dynamic activities necessary for the DRC [4]. The MIT Cheetah robot's proprioceptive actuator design provided an effective solution to this trade-off [5]–[7], but has yet to be implemented on a humanoid robot. The research development of the general quadruplet robots are also giving impacts for the development of humanoid robot's research [5], [8]–[10].

I-A. Locomotion, Manipulation Control, Motion Planning

Motion planning systems based on centroidal dynamics are popular because of their unique blend of computational tractability and dynamic expressiveness. Without having to concern with the robot's multiple degrees of freedom by addressing the centroidal dynamics of the robot, these techniques capture the fundamental dynamics of the system [11]. Kino-dynamic planners [12], [13] optimize the robot's centroidal dynamics as well as joint-level kinematics at the same time, which has advantages in terms of generality.

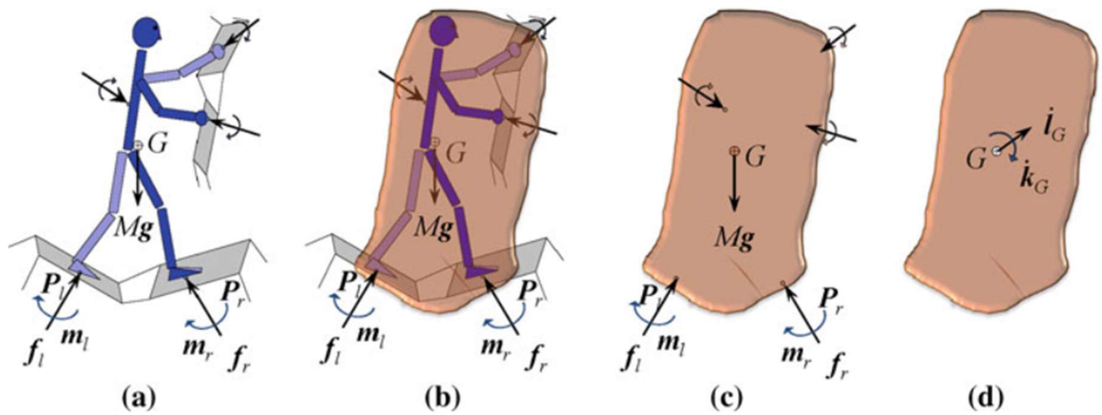

Figure 1. The Centroidal dynamics of humanoid robot.

Trajectory optimization-based techniques to motion planning based on full-body dynamics [14], [15] may leverage the robot's whole dynamic range, but they are prone to difficulties such as local minima and excessively lengthy solution times. These concerns can be avoided by utilizing a reduced-order model of the robot, such as a spring-mass model [16], [17], but these techniques are often limited in their applicability due to restrictive assumptions.

In contrast to the conventional Model Predictive Control (MPC) strategy for locomotion, which develops a hierarchical sequence of optimization problems, Model Hierarchy Predictive Control (MHPC) formulates a single optimization problem over a hierarchy of models [18]. A novel representation-free model predictive control (RF-MPC) framework for regulating different dynamic motions of a quadrupedal robot in three-dimensional (3-D) space is presented by [19]. Non-linear MPC (NMPC) presented by [20], [21] for dynamic motions.

An adaptive force-based control for legged robots [22] has demonstrated the effectiveness of adding adaptive control with quadratic programming (QP) force control. Because our method is based on force control, it preserves the benefits of the baseline framework, such as resilience to uneven terrain, adjustable friction restrictions, and mild impacts.

Two years have passed since the MIT Humanoid Robot published a paper of their humanoid robot completing a backflip [1]. In their realistic dynamic's simulation, they effectively exhibit dynamic behaviours like as back flips, front flips, and spinning jumps using carefully built hardware and control architecture.

The MIT Humanoid robot is a pioneering approach to adapt the MIT Cheetah robots' extremely successful design concepts [5], [5]–[7], [23], [24] to a humanoid robot. A unique kino-[19] planner that efficiently deals with the actuator restrictions of the robot is created in order to harness the full dynamic capabilities of the robot in impulsive motions. We use a hierarchical control system to achieve safe jump landings by efficiently merging model-predictive control with whole-body control.

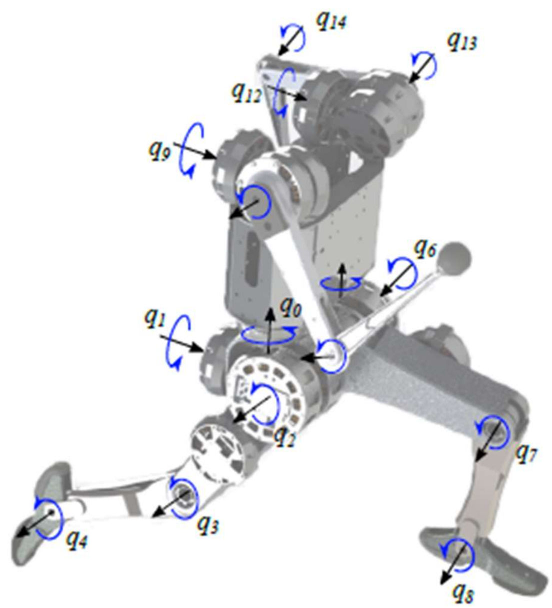

Figure 2. The Configuration of the MIT Humanoid Robot.

Recently, a kinodynamics-based pose optimization and loco-manipulation MPC framework on humanoid robots to tackle the problem of pushing heavy and large objects by leveraging humanoid whole-body poses and synchronized locomotion and manipulation control has been proposed [25]. It highlights the proposed approaches results in object-pushing tasks, including comparisons with previous systems, pushing large objects, external force disturbance rejection, and tracking a desired object trajectory in 3-D.

I-B. Stable Landing

To accomplish a stable landing, the robot must squander kinetic energy over an extended period of time while responding rapidly to a controller's expectation error resulting from unmodeled dynamics, modeling error, or external disturbance. This problem was addressed in one of the work [8] which introduced a hierarchical control framework integrating model predictive control (MPC) with a basic lumped-mass model for long-time horizon optimization and whole-body impulse control (WBIC) for instantaneous high bandwidth control.

WBIC and MPC shared the same position command in prior work. To fully exploit the best solution, WBIC uses the optimal motion discovered in MPC as the position reference, together with the response force commands. In addition, WBIC prioritizes a body orientation task over a centroidal momentum work to track desired centroidal angular momentum, so long as the body orientation command is obeyed.

I-C. Highly Dynamic Motion

The heuristic control implemented on Raibert's hoppers greatly influenced early research on highly dynamic motion in legged robots, such as leaping and sprinting. An unified model with inertia shaping [26] can approximately model the centroidal inertia and has improved the jumping performance on SLIDER, a knee-less bipedal robot. Stanford Doggo [27] merges the dexterity and inherent stability of quadruped robots with a vertical jumping agility greater than specialized monopods and matching that of the highest performing animal, the galago [20], [21].

In addition, the combination of MPC and joint PD controller has been propose by [28] to achieve smooth jumping transition and accurate jumping trajectories.

Other than that, online optimization has been presented by [9] incorporated with MPC, but it has limitation that their QP program the authors are using is a discretization of the continuous optimization, yielding numerical errors. Force-and-moment-based MPC has also been used by [29] to achieve highly dynamic locomotion on rough terrains for 10 DoF bipedal robots.

The Centroidal Inertia Isotropy metric has been used by Tello Leg [30] To quantify the effect of motor placement on the robot's dynamics, and the cooperation actuation for Hip, Knee, and ankle joints is utilized to generate large force in bipedal robots. However, the CA has increased mechanical complexity.

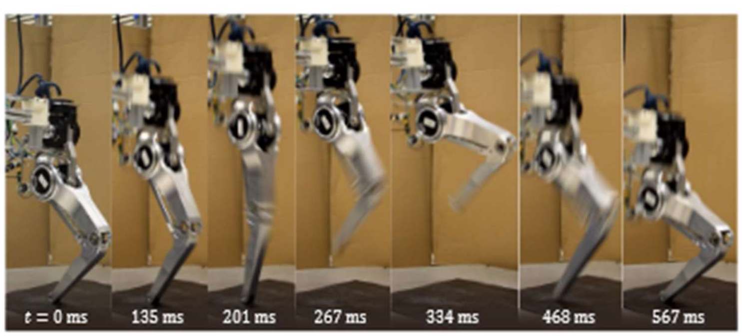

Figure 3. The Tello Leg was jumping in place.

For multi-tasks dynamic such as picking up and dropping off objects while turning and walking, this work [31] solves multiple contact modes via MPC framework.

I-D. Dynamic Balancing Tasks

For dynamic balancing tasks, adaptive-frequency MPC framework has been presented by [32] and the bipedal locomotion goes over terrain with uneven stepping stones. It is paired by WBC, CoM trajectory, and adaptive-frequency trajectory optimization. Other than that, this work [33] shows a formal connection between template and anchor models, so that the authors derived linear constraints which is CWC criterion that are sufficient conditions for maintaining ground contact. The work of [34] used proprioceptive actuation and Whole-body control (WBC) to enable bipedal robot has dynamic balance.

II. The Proposed Future Research

The best and the breakthrough method is presented by [35] which combines model-based controller with a data-driven technique that is commonly used in animation.

Figure 4. Using the control pipeline, animal-like motions can be reroduced by various robot models with different scales and actuation power.[28]

The used of simple data-driven approach to extract semantic information from animal motion data is the best idea from this research. A combination of MPC-WBC can track the reference trajectories effectively. As the semantic information is not constrained by morphology, our method can be generally applied to various quadrupedal robot models despite the discrepancy between the animal's and robots' morphology.

However, this finding was implemented in quadrupedal robots, and there is a high potential to implement the similar method in humanoid robot.

III. Challenges and Opportunities

Based on the comparison and analysis of current research and prictices in the field of humanoid robot control, the challenges and opportunities that are important for the development of humanoid robots are:

- Performing dynamic multiple degree of movements using online optimization
- Integrating the approach with vision, for example, to automatically detect and jump on obstacles.
- Optimizing the MPC formulation to enable faster and more aggressive motions.
- Handling inaccuracy of centroidal model to represent the behaviour of the bipedal robots due to substantial mass of their limbs.
- Improving the balance framework with a higher-level planner to handle larger disturbances.
- Considering joint and torque limits, self-collisions, and multi-contact scenarios.

- Jumping on steppingstones continuously

IV. Conclusions

Behind the advance of the development of humanoid robots, there is an interdisciplinary field of computer engineering, computer science, ergonomics, organizational behaviours, mechanical engineering, and artificial engineering. Deep learning methods such as convolutional neural networks have shown promising results for improving humanoid robots' capabilities such as object recognition, facial expression recognition and speech recognition.

Considering the need for a comprehensive view of humanoid robots that can guide the future research direction, this study attempted to provide a systematic literature review of technological developments and identify opportunities and challenges in service robots.

My prospective research topics was vision-based region control on robotics, and this review has increased my interest to study and research further in humanoid robotics.

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