A COMPARATIVE STUDY OF BIPED DYNAMIC WALKING

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Abstract

Biped legged robots have been motivated by its potential use in rough terrain, as well as for advancement in prosthesis manufacturing and testing. This paper will give comparative analysis of various walking schemes of biped humanoid robot and concentrates on issues related to its automatic control. The paper shows that there is scope for improvement in the present available biped robots and further enhancement can be done in order to augment controllability and speed of working with more accuracy. The deficit in the available technology has been addressed and the emphasis on which further research work must be done is highlighted.
Keywords: humanoid robot, dynamic walking robot, biped robot.

Introduction

Bipedal robots are inspired from human locomotion. Human locomotion is an interesting problem for different research domains, from biology to robotics, due to high complexity of interaction between the different kinds of mechanisms involved. In recent years there has been considerable research effort devoted to bipedal locomotion. The motivation of the research is the suitability of the biped structure for tasks in the human environment as substitutes of human. Walking robots are complicated machines with multidimensional movements. It is not possible to achieve the complete human skeleton system and muscular system due to its complexity but combination of modern control algorithms, robotics, and mechatronical systems can lead to a high-performance dynamic walking biped robot. Its realization requires the design of a state-space controller, various methods either utilize the zero moment point (ZMP) paradigm, or rely on the (passive) dynamic walking principle. Scheming effectual controllers for such robots can be a tough task, and sometimes mechanical equations usually itself is not enough for deriving its mathematical model. Still, work on passive dynamic walking robots proved so far that robotic walking pattern can be made very natural and efficient.

Literature Survey

Zonfrilli et al [1], Sardain et al [2] mentioned different biped mechanism to balance heavy mass over small foot, such as: passive, static, dynamic or purely dynamic walking. Passive walkers don't have controllers as shown in figure 1. They can only walk downhill by converting gravitational energy into kinetic energy.

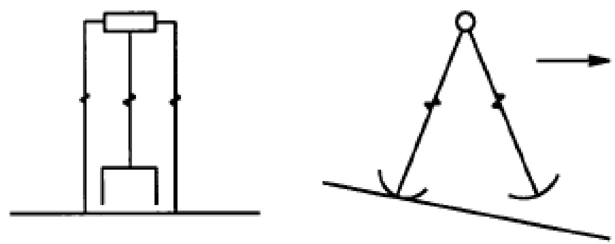

Figure 1: Passive walking

Mark Spong and Francesco Bullol [3] tried to reduce passive gaits sensitivity to slopes inclination but unable to eliminate it completely. While in static walking based on the basic principle of static equilibrium. Here projection of the Center of Mass is constantly made inside the polygon that restricted by the one or two soles in support. Although this method is simple but it is comparatively slow and required active feet. To overcome these drawbacks dynamic walking is suggested which achieve fast, natural motion via actuation of ankles to keep the Zero Moment Point or Center of Pressure or Center of Ground Reaction, which accounts for inertial forces as well as gravitational forces, within the support foot. It requires apart from active feet, many degrees of freedom as well as high-performance actuators and hardware. So it is complicating and thus requires substantial computing power of the controller to implement. Thus simpler way is to use inverted pendulum control mechanism. Such method is proposed by Kajita et al [4] by using linear inverted pendulum but results are impractical and are not natural So it moves few steps over flat surface before becoming unbalanced sideways by the oscillation of a rolling wave created by each heel-strike impact. Solution to this problem is provided by Jong H. Park and Kyoung D. Kim [5] by using gravity compensated inverted pendulum mode (GCIPM). This method assumes that the biped robot consists of two different masses, but results are in simulations only. Finally, purely dynamic walkers have passive or simply no feet, and achieve locomotion without equilibrium (neither static nor dynamic). As mentioned by Daan et al [6], pure dynamic implemented on open-loop strategy where a predefined time trajectory for the swing leg makes the swing leg move backwards just prior to foot impact. So, they have periodic walking pattern without requiring local controllability at all times. McGeer et al [7] has designed a “purely dynamic walking robot” by considering pair of pendulum will walk just as naturally as a wheel will roll. It is the most simple walking mechanism developed as it is free from any actuation control mechanism but more sensitive to shallow slope (about +-1o %). Apart from these conventional approaches, Aoustin et al [8] proposed novel simplified idea of Hybrid Zero Dynamics, where instead of tracking reference trajectory, it will try to converge through parameterize the walking motion with respect to a scalar valued function of the state of the robot. Through this approach robot can reconfigured to achieve different tasks, such as walking at different speeds, going up stairs, and running. Unexpected walking backward is observed during its practical analysis. Another advantage is that the model need not depend on old trial-and-error assumption of ZMP which would relieve designer from finding monotonic parameters priori. Although model retained its stability but there are uneven average velocity. So, more accurate impact model is needed to be developed. A potential disadvantage is that since the changes cause by impact surface must be determined from the model, it is unclear how sensitive the closed-loop system may be to model uncertainty. Apart from this some of the significant constraints like the inertia of the bars and cables are not considered. Other means of establishing the orientation of the torso need to be investigated.

Akihito Sano Junji Furusho [9] used angular momentum of the whole system for feedback-controlled walking. But model proposed suffers low processing speed because of common memory space for different processors, deviation from its desired value, also model fails for slope surfaces as body should be always kept upright in relation to the floor. Canudas et al [10] proposed dynamic model to compensate friction forces. But Sensitivity studies, parameter estimation and adaptation aren’t done. Also there model based on simulations, practical application of such model is questionable. Chevallereau & P. Sardain [11] aimed to generate walking and running gaits with large velocities. Author’s prototype has no feet so the contact point between the ground and the leg tip cannot move as in human walk. But construction of such robot is under progress only as potential conformity in the torque transmission path and links, effects of implementing the controller in discrete time and effects of impact condition is yet to be investigated. There is a possibility that robot may fall under uncertain obstacles, so special provision is required so that it experience minimum damage and may rise up on its own. Such provision is suggested by the Hirukawa et al [12] by using breaking bottleneck of specialized hardware or heavy lower part for the purpose shown in figure 2. But they are not considering any falling state, instead assuming that robot initially lying on the back or face. Also experiments are performed over flat surfaces only.

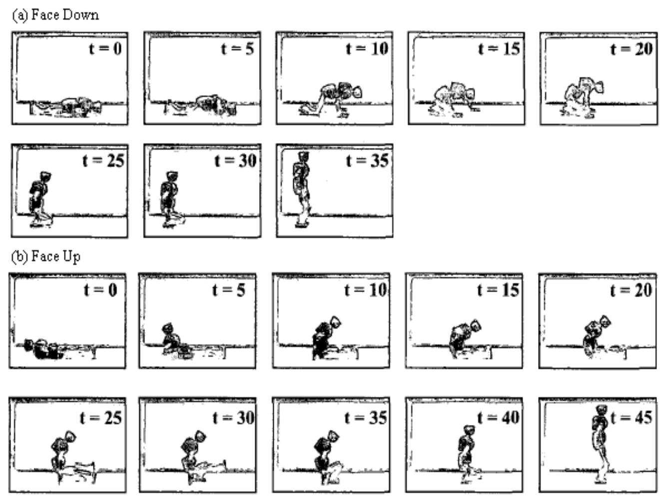

Figure 2: Getting up motion under different circumstances

Apart from obstruction, real human environment may also incline floor and stairs. Extra work is needed for such problems because flat surface mathematical modeling fails for inclined surface. Zheng et al [13] derived an algorithm for the biped robot control system to evaluate the inclination of the supporting foot and the unknown gradient, and a compliant motion scheme is then used to enable the robot to transfer from level walking to climbing the slope. But this proposed mechanism is based on static gait walking which is inferior to quasi-dynamic and dynamic gaits. As its slope reorganization time is shorter. Also this method fails for walking from a level to a negative slope because the feet hay stand on the edge formed by the two levels. The edge, however, does not provide a solid support to the robot. Alternative approach proposed by Fariz et al [14] by considering position and orientation into kinematics calculations so that walking pattern developed for flat surfaces can be used for inclined surfaces. Simulations show that this could be achieved by changing the orientation trajectory of pelvis and COM deviation prevented. But it isn’t promising as no real time practical is performed yet. Sakagami et al [15] mentioned the advanced features of the one of the best biped robot made so far, ASIMO. This robot is special because it process instructions from various types of raw sensory data such as orientation obtained by a gyro sensor, forces obtained by force sensors, image pixel data obtained by cameras and sound signals obtained by microphones. Then filter data consist of huge set of information such as velocity, acceleration, optical flow, edge sand color. Apart from this, there is provision for obstacle detection and map management system for navigation. It uses the sensory behavior space generated by reward and penalty based learning on a simulator to decide motion direction. There is also a database of face images of different people used to identify people. It can be used for robust navigation in uncertain environments to identification of humans and interaction with them using gestures and voice. But it is observed that its processing is quite slower due to manipulation of this huge database. Author also mentioned that its Vision processing is slower compared to control processing.

Such modeling is needed not just for human-like features, but because human body evolved to overcome obstruction like uneven surface balancing and motion under alien conditions where wheel robots fails. Javier et al [16] proposed fall avoidance mechanism through feedback control and fall management in which falling sequence can be triggered in order to reduce body- damage, or fast recovering. However, the overall fall avoidance rate is low. Improved method for floor and obstacles recognition through small stereo vision system developed by Yoo-Ki Cho et al [17]. But there is drawback in such system that is the terrain has to contain enough texture in order to obtain reliable data. Bipedal robots have scope in surveillance applications, hostile condition exploration, entertainment industry, exoskeletons for military and rescuers to transport heavy loads, development of more stable and comfortable prosthetic legs with self-balancing provision, etc as shown in figure 3. As biped robots can move in dubious environment, identify and interact with humans through gestures and voice, it can be used for domestic application.

Figure 3: Exoskeleton

Sugahara et al [18], mentioned such applications like to take care of elderly people. Due to versatility and adaptability in legged locomotion, it can be used for tough terrains. Artificial supporting structures or Exoskeleton is gaining attention. There is lot of scope and work going on. This application can be used by rescue workers and firefighters; Soldiers and Persons with walking disabilities. Zoss et al [19] shows that exoskeletons can be used for transporting heavy objects. But these structures have some limitations like sensitive to external forces and involuntary reflexes. Ekkelenkamp et al [20], design and implement a gait rehabilitation robot for treadmill training. The purpose is to reduce physical load on the recovering therapist patient and to offer assistance in leg movements in the forward direction and in keeping lateral balance. In order to avoid stiff control along predefined trajectory, author implemented the selective functional support that is user can choose between two modes that are Patient in charge mode and Robot in charge mode. But there is a problem in accuracy in the low force ranges caused by the imperfect open-loop torque control of the hip joint.

Conclusion

Enormous amount of work has been done for developing the biped robots but still more precision work can be done. Till now the main work was on the energy conserving properties of passive walkers, and designed their controllers to adjust the energy balance. Still the behavior of passive walkers remains difficult to understand, due to the highly nonlinear, coupled, and generally unstable dynamics, together with the hybrid aspects of switching between left and right foot. Controller design of passive dynamic walkers is based mainly on engineering intuition, biological inspiration, and physical tinkering with experimental robots. Such methods have always been the basis of new design, and the authors believe that they will always remain valuable in nonlinear control, mainly because the class of general nonlinear systems is so large and diverse, the optimal controller cannot just be computed from scratch. However, once a certain direction or type of solution has been determined by intuition or biological analogy, systematic and automated methods are valuable methods for specific quantitative design and fine-tuning.

Also it is observed that in the most of the model planar sagittal walking is consider which isn't practical because all three dimensions need to be considered, for example problem of the lateral balance around the edge of the foot. So, more work is required for 3D models.

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