International Journal of Image Processing and Vision Science

Volume 2 | Issue 2 Article 4

October 2013

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Recommended Citation

TALAPATRA, PRADIP KUMAR; DASH, SHAKTI PRASAD; and RAKESH, P. (2013) "VARIOUS APPROACHES OF DYNAMIC MODELLING OF BIPED ROBOTIC SYSTEM-A REVIEW," *International Journal of Image Processing and Vision Science*: Vol. 2 : Iss. 2 , Article 4.
DOI: 10.47893/IJIPVS.2013.1072
Available at: https://www.interscience.in/ijipvs/vol2/iss2/4

VARIOUS APPROACHES OF DYNAMIC MODELLING OF BIPED ROBOTIC SYSTEM-A REVIEW

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ABSTRACT:

Humans are the most advanced creatures of the nature. Accordingly it can be stated that humanoid robots are the most advanced creatures of human beings. Among the man-made systems such as automobile, hand-phones and multimedia devices, robots of future will hopefully be the most ideal assistants to human beings. During several decades of research, development projects aimed at building bipedal and humanoid robots has been increasing at a rapid rate. A brief review of current activities in the development of bipedal humanoid robotics is provided in this paper. The dynamic modelling of biped robotic system in the current trend is also described. The main objectives for using bipedal robots are introduced and bipedal locomotion as well as its dynamic behaviors in different fields are also considered. The use of dynamics of different kinds of mechanical systems in the field of humanoid robotics is also emphasized. Finally, a list of few projects in this field is provided.

KEYWORDS: *Biped humanoid robot, Degree of freedom (DOF), Servo motor, Stability of robot, Zero moment point*

1. INTRODUCTION:

With service robotics or medical applications, biped walking was studied for a long time, but the control laws proposed so far are not satisfactory in providing robust steady walks. The main specificity of the walking robots is the intermittent contact with the ground: it allows more versatility in their displacements, but it results in a structural instability. In order to move around, a walking robot is dependent on its interaction with the ground, and especially on the contact forces. But these forces are bounded, inducing some constraints on the dynamics and therefore on the stability of the robot.

The legged robot forms, which utilize discreet footholds rather than continuous support such as wheels or tracks, have been of particular interest. By taking advantage of the strategic footholds in the terrain, legs increase traction and decrease energy consumption.

In order to design a control law for biped walking, some proposed to monitor the contact forces while stabilizing a desired trajectory. The contact forces are monitored directly in or through the position of the center of pressure (also called Zero Moment Point). This way, small perturbations can be compensated without destabilizing the robot, but in case of strong perturbations, when the desired trajectory can't be followed anymore, no recovery option has been proposed so far. Some proposed a more global approach to the walking behavior, leading to some interesting stability results, but with no analytic proof.

Although a number of biped walking prototypes has been built over the years, several issues still hinder active use of biped robots in our everyday applications. The bipedal structure is inherently unstable and prone to falls. They have an instability problem even for level ground locomotion. Efficient and robust legged locomotion has always been an interesting but difficult problem to address, given the high degree of uncertainty and complex dynamics that arise in traversing unstructured

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terrain Attempts at building walking machines can be traced back at least to the 1960s. One of the first functioning bipedal robots was developed in the 1970s by Kato (Kato and Tsuiki, 1972). Today, there are many bipedal robot projects in the world, and the number of active projects is growing rapidly. Despite bipedal locomotion being a great challenge in autonomous and mobile robotics, Sony and Honda have made progress in these areas by developing Qrio and Asimo, respectively, Sony's Qrio robot is illustrated in Figure-1.

Figure-1 (**Sony's Qrio Robot**)

Some of the work in bipedal robotics are reviewed here with main focus on motor skills for walking robots. However, Also behaviors not related to locomotion are discussed.

2. BIPED LOCOMOTION OF ROBOT:

The concerning factor of bipedal robotic system is to provide stability to the body of robot while walking. Thus, most work on bipedal robots to date has been focused on locomotion. In general, the motion is divided into a single-support phase (with one foot on the ground) and a double-support phase. One of the simplest models of a walking robot is the 5-link biped introduced by Furusho and Masubuchi (1986) and subsequently used by several authors. This simulated robot, which is shown in [Figure-1], is constrained to move in the sagittal plane and has five degrees of freedom (DOF).

Figure-2 (KHR-2 Biped humanoid robot)

KHR-2 is one typical biped humanoid robot developed in 2003, shown in the Figure-2. It has been utilized as a test robot platform to develop a walking control algorithm for the authors' biped humanoid robots, KHR-3(HUBO) and Albert HUBO. The height, weight, and total number of degrees of freedom of KHR-2 are 56 kg, 120 cm, and 41 DOF (6 for each leg, 4 for each arm, 7 for each hand, 1 for torso, and 6 for head), respectively. All joint actuators are brushed DC motors with harmonic reduction gears or planetary gears. KHR-2 is remote-operated via a wireless LAN. Electrical circuit boards of joint motor

controllers and sensory devices were efficiently designed for minimum energy consumption. Aluminum was used as the body frame material. The thickness and size were also minimized so as to reduce the weight within an allowable range. For human-like appearance, the ratio of each body part corresponds with the human ratio. The degrees of freedom and dimensions are summarized in Table-1.
An anthropomorphic biped robot with a trunk is considered. Each leg consists of a thigh, a shin, and a foot and has six degrees of freedom (DOF): three DOF in the hip joint, one in the knee joint, and two in the ankle joint. Biped walking is a periodic phenomenon. A complete walking cycle is composed of two phases: a double-support phase and a single-support phase. During the double-support phase, both feet are in contact with the ground. This phase begins with the heel of the forward foot touching the ground, and ends with the toe of the rear foot leaving the ground. During the single-support phase, while one foot is stationary on the ground, the other foot swings from the rear to the front. The motion is not constrained to the sagittal plane, and the models most often include feet, arms, as well as additional DOF in the

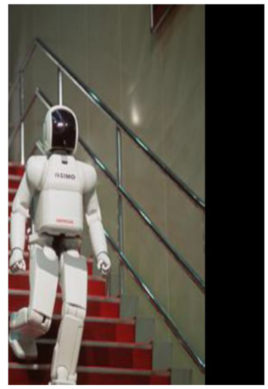

Figure-3 (Asimo robot by HONDA)

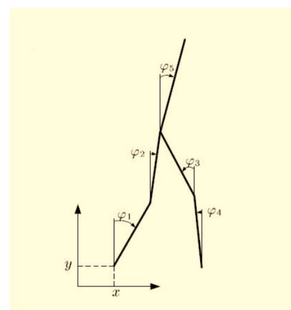

Figure-4 (five link robot structure)

Parts	Movement Of Parts		Degree Of Freedom	
Head	Eye (pan & tilt)		2 DOF x 2 = 4 DOF	
	Neck (pan & tilt)		2 DOF	
Arm	Shoulder (roll/pitch/yaw)		3 DOF x 2 = 6 DOF	
	Elbow (pitch)		1 DOF x 2 = 2 DOF	
Hand	Wrist (roll/pitch)		2 DOF x 2 = 4 DOF	
	Finger		1DOF x 5 x 2 = 10 DOF	
Torso	Waist (yaw)		1 DOF	
Leg	Hip (roll/pitch/yaw)		3 DOF x 2 = 6 DOF	
	Knee (pitch)		1 DOF x 2 = 2 DOF	
	Ankle (roll/pitch)		2 DOF x 2 = 4 DOF	
Total			41 DOF	
Dimensions	Height	1,200	Length of upper leg	290
	Width (Shoulder to shoulder)	420	Length of lower leg	280
(mm)	Depth (Chest to back)	213	Length between hip joints	142
	Length of upper arm	184	Width of sole	140
	Length of lower arm	185.5	Length of sole	233

Asimo robot is one of the product developed by Honda, is shown in the Figure-3. There exists many different formulations of the equations of motion for a bipedal robot, e.g. the Lagrangian formulation and the Newton-Euler formulation. The Lagrangian equations of motion for the simple five-link robot shown in Figure-4 are,

$M(z)\ddot{z} + C(z, \dot{z})\dot{z} + N(z) + A^T\lambda = \Gamma$

Where,

M = Inertia of matrix

C = Matrix of Coriolies and centrifugal force

N = Contains gravity terms

A = Constraint matrix

λ = Corresponding Lagrange's multiplier

Γ= Generalized forces

The Lagrangian equations of motion have the advantage that the internal forces of constraint need not be explicitly represented in order to determine the motion of the robot. However, in general, the Newton-Euler formulation is computationally the most efficient, with the computation time growing linearly with the number of degrees of freedom.

3. APPROACHES FOR DYNAMIC MODELLING OF ROBOTS:

The robot is completely controlled by a micro controller. To enable the movement of the robot seven servo motors have been used. For Right Ankle, Left Ankle, Right Knee, Left Knee, Right Top Joint, Left Top Joint and for Head. And now for the remote sensing purposes attached light sensor & temperature sensor. Distance sensors are used for the purpose of obstacle avoidance and X-Y-Z sensors for balancing purposes. The robot is mounted with a wireless camera for video surveillance purposes. The Figure-3 shows the microcontroller based embedded system in the

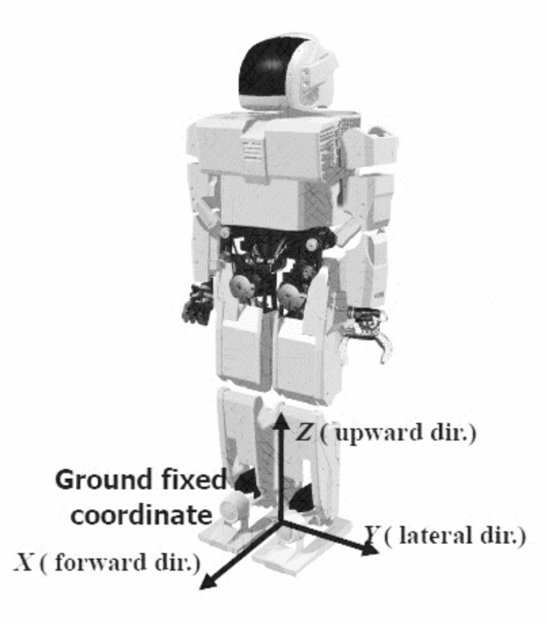

Figure-5 (3D coordinate system of biped robot)

Figure-5 shows a ground fixed coordinate frame for design of the joint trajectories of the walking pattern. Consequently, each joint trajectory is derived by solving the inverse kinematics and is then transferred to the joint motor controllers. Motion of the robot from one place to another is done in X-axis direction. Horizontal body motions occurs about the Z-axis and about Y-axis bending of different body parts according to the degree of freedom of specific part.

3.1 DYNAMICS OF WALKING PATTERN:

Figure-6 shows the overall structure of the generation of the walking pattern using reinforcement learning. The reinforcement learning system receives the current states, calculates the proper action, and the walking pattern generator generates the walking pattern based on this action. The reinforcement learning system learns the suitability of the action from its result and this process is repeated until the reinforcement learning system shows reasonable performance

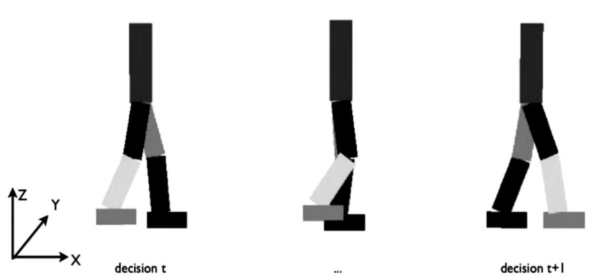

Figure-6 (Walking pattern of biped motion)

3.2 MOVEMENT CONTROL:

The embedded system software includes the interfacing of the sensors to the microcontroller, controlling the robotic movements and communicating with main system. The control station has a computer system interface which uses application software that communicates with the robot.

3.3 SERVO MOTOR:

Servos are controlled by sending them a pulse of variable width. The angle is determined by the duration of a pulse that is applied to the control wire. This is called Pulse width Modulation. The servo expects to see a pulse every 20 ms. The length of the pulse will determine how far the motor turns. For example, a 1.5 ms pulse will make the motor turn to the 90 degree position (neutral position). When a pulse is sent to a servo that is less than 1.5 ms the servo rotates to a position and holds its output shaft some number of degrees counter clockwise from the neutral point. When the pulse is wider than 1.5 ms the opposite occurs. The minimal width and the maximum width of pulse that will command the servo to turn to a valid position are functions of each servo.

The servo is controlled by three wires: ground (black), power (red), and command (typically white). Power is usually between 4v and 6v and should be separate from system power (as servos are electrically noisy).Even small servos can draw over an amp under heavy load so the power supply should be appropriately rated. Though not recommended, servos may be driven to higher voltages to improve torque and speed characteristics. Servos are commanded through "Pulse Width Modulation," or PWM, signals sent through the command wire. Once the servo has received the desired position the servo must attempt to match the desired and actual positions. It does this by turning a small, geared motor left or right. If, for example, the desired position is less than the actual position, the servo will turn to the left. On the other hand, if the desired position is greater than the actual position, the servo will turn to the right.

3.4 ADVANCED LOCOMOTION:

While the generation of stable bipedal gaits on flat ground has been at the focus of much of the research in bipedal robotics to date, some researchers have also begun to investigate more advanced types of locomotion, such as e.g. stair climbing. Honda’s latest humanoid, ASIMO, is able to negotiate stairs, as shown in Figure-3. Furuta et al. (2001) developed a small bipedal robot, ’morph’, capable of a large range of joint movements, allowing for more complex motions. Among other main behaviors, a somersault motion was implemented in this robot.

3.5 WALKING APPLICATIONS:

Bipedal Robots are the fundamental block of any advanced walking robots. By making the Bipedal robots fully autonomous, it can be used in environment where human cannot enter. Based on the analysis and study, the output of this type of robots can be used for developing artificial limbs for the physically challenged person.

4. FUTURE APPLICATION OF BIPED ROBOT:

Once fully functional, biped humanoid robots and other walking machines will be useful in many different applications. However, several possibilities of future applications are presented below:

(i) **Inspection of hazardous environments:** A robot controlled by remote operation, such as e.g. the Honda ASIMO robot, could find uses in, for instance, inspections of dangerous and hazardous environments.

(ii) **Prosthetics:** Walking machines can be used as walking aids for paraplegics or limb organs.

(iii) **Agricultural work**: A walking robot does less damage to the ground than a wheeled robot, and is also able to step over obstacles and move in complicated, non-smooth terrain.

Some more future application trends in the humanoid robots may include the moving robot system which monitors temperature, distance, light intensity etc. and sends the data to the master control station at regular intervals, thus updating the data. For sensing the temperature, light etc. respective sensors are also used. Data from the sensors are analyzed by the microcontroller and processed. Biped finds many important applications in fields like defense, industry and in space exploration. Further expansions can be made to improve its performance. By adding a robotic arm it can be used for implementing the pick and place feature. A digital camera can be added to capture images of the surroundings. This robot is sure to improve the way the humans live in near future.

The future advancement in biped humanoid robotic system can be carried out by going for Embedded Processor that can process and transmit the control signal faster to the actuators. Complex movements can be achieved by increasing the Degrees of Freedom. Vision system can help the robot to work autonomously. Remote control through wireless mode can also be considered.

Since the number of active humanoid robotics projects is growing rapidly with time, Bipedal humanoid robots with existing technologies are in a queue for future applications. A listing of some of the selected humanoid projects developed by various laboratories are shown in Table 2.

Table 2. A list of selected humanoid projects

NAME OF THE ROBOT	DEVELOPED BY	REFERENCE
Asimo	Honda	
Hermes	Bundeswehr University	Bischoff(1997)
SDR-3X	Sony	Kuroki et al.(2001)
Cog	MIT	Brooks et al.(1998)
PINO	Kitano symbiotic system project	Yamasaki et al.
HOAP-1	Fujitsu	
Elvis	Chalmers University of Technology	Nordin and Nordhal(1999)
BIP2000	INRIA, France	Espiau and Sardain (2000)
iSHA	Waseda University	Suzuki and Hashimoto(2001)

5. CONCLUSION:

The population of robots is growing rapidly. This growth is led by Japan that has almost twice as many robots as the USA. All estimates suggest that robots will play an ever-increasing role in modern society. They will continue to be used in tasks where danger, repetition, cost, and precision prevents humans from performing.

A walking robot needs to interact with its environment in order to control its global movements as seen in the article. Since this interaction is only performed through limited forces, this leads to a structural instability of the system. First attempts to control this instability led to monitor the contact forces. It appears then that the stability of the robot can be improved if more comprehensive description of the walking behavior can be managed. In order to complete the design of this control law, the generation of a set of walking trajectories that will allow to recover from any destabilization must be achieved. The walking patterns are required for continuous variations of the parameters. Moreover, the more comprehensive will be the set of trajectories, the more perturbations will be compensated. Passive mechanisms helped make control simple, efficient and natural looking. Actuators with negligible dynamics are important. The project Biped walking robot integrates the field of robotics with wireless communication. This article provides an insight into the structure, the walking mechanism and data communication in robots.

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