# Development of dynamic balance based algorithms for stable locomotion of Russian anthropomorphic robot AR-601M

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Anthropomorphic robots will gradually become a vital part of our daily life. To successfully perform various tasks these robots require reliable locomotion control algorithms, which could guarantee dynamic balance of the robot at every moment. Our study is focused on creating effective humanlike walking for a biped robot and a novel human-size Russian robot AR-601M is utilized for this research. In this paper we present AR-601M robot, overview existing approaches for locomotion control of a biped robot, and present current state of our study.

**Key Words:** anthropomorphic robot, biped robot locomotion, dynamic stability

## 1. Introduction

To date, one of the most critical tasks in field of legged robots is to create multi-terrain robots, which could perform different functions and operate in dangerous conditions, e.g. working in nuclear, chemically or biologically polluted environments, executing search and rescue operations, supporting humans in military and space missions. Such systems target to replace people in versatile operations, which may require the humanlike skills of locomotion inside buildings and ability to utilize technology and devices, which were originally built for a human user. Another essential task of modern robotics is to create a humanlike robotic assistant, which could work in a direct contact with a person and demonstrate an acceptable by a human social behavior. To perform social activities, which are not straightforwardly associated with a physical contact, such assistive robots are not necessarily required to have similar to a human size and weight. Small sized assistants could successfully provide reminder functions, share information with a human, and even teach a human to do fitness exercises. Yet for those robots – as well as for their human size analogies – the requirements for anthropomorphic dynamics of movements and high-energy efficiency come out on top.

The objectives of our research are to create a set of new approaches, algorithms and programming solutions for a humanlike biped robot's locomotion control system, which is based on static and dynamic balance control. Our target algorithms will collect and process data from various robot's sensors (gyroscopes, accelerometers, encoders, cameras, infrared and laser range finders, and pressure sensors), make sensor-based decisions and perform robot's locomotion control through motor driver system. In addition to ensuring sustainable maneuvering on a flat horizontal surface these algorithms should preserve robot balance when robot's center of mass location unintentionally changes due to external influence, for example, by applying limited force to robot's shoulder, hand, head or body.

The rest of this paper is organized as following. Section 2 describes characteristics of AR-601 robot, which is used in our research, and provides a comparison of AR-601 robot with analogies. Section 3 gives an overview of the main approaches and models for biped robot dynamic balance. Section 4 presents the next steps of our research and finally we conclude in Section 5.

## 2. System setup

The full-scale anthropomorphic robot AR-600 (fig. 1) is a humanoid robot created by a rather young Russian R&D company "Android Technics" ("Androidnaya Tehnika", [1]).

Figure 1. Anthropomorphic robot AR-600E, source http://npo- at.com/products/ar-600e/

AR-600 is based on a light alloy frame with elements of electric power. It has two anthropomorphic manipulators and two anthropomorphic legs, video observation system and audio system. With its 145 cm height and 65 kg weight AR-600 can reach up to 3.5 km/h speed. Depending on its particular configuration the robot may have up to 53 degrees of freedom (DoF) in general, while all models have a standard of six DoFs for each leg[1].

The robot uses its navigation and vision systems in order to manipulate with objects of everyday human usage. Tactile sensors on the fingertips can grasp objects with the specified torque. Speech synthesis and recognition systems allow a person to communicate with the AR-600 and give instructions to the robot orally. The robot can operate without recharging up to 2 hours. The robot has elementary artificial intelligence, basic navigation and communication functions. It can operate in a teleoperational mode

[1] "AR-600" is the name of the full-scale anthropomorphic robot series, while within the series there are various models (e.g., AR-600E, AR-601E, AR-603E, AR-601M) and each model has a different configuration and different number of DoF with regard to its particular application and cost.

and perform some elementary functions autonomously. Table 1 presents a comparison of some important characteristics of AR-600 model with Atlas (Google, not a commercially available model) and Reem C (Pal Robotics, a commercially available model) robots. Most of these characteristics are comparable, except that Atlas is hydraulically actuated, while both Reem C and AR-600 have electrical motors.

Table 1. Anthropomorphic robots technical characteristics comparison

| Robot Model/ Parameter | AR-600 | Atlas | PAL |
|---|---|---|---|
| Height | 1442 mm | 1880 mm | 1650 mm |
| Mass | 65 kg | 150 kg | 80 kg |
| Market Availability | Available | Not Available | Available |
| Degrees of freedom | From 37 to 53 | 28 | 44 |
| Body material | Plastic | Aluminum, steel, titanium | Plastic |
| Battery type | Li-FePo | No battery Cord, tether | Li-Ion |
| Network interfaces | Wi-fi, Ethernet | Optic network | Wi-fi, Ethernet, |
| Type of motor | Electrical | Hydraulic | Electrical |

The AR-600 series targets for various application areas, including military operations, space exploration, industrial work, emergency situations, personal assistance, health care services, security, and entertainment. Unfortunately, at the moment its locomotion algorithms are rather constrained and this is the main goal of our research – to improve the quality, speed and anthropomorphism of AR-600's series locomotion.

## 3. Existing methods overview

This section familiarizes a reader with several popular ways to model bipedal locomotion and methods of biped robot locomotion control.

### A. Modelling a robot for bipedal locomotion

Commonly used approaches to approximate a biped robot are a model of inverted pendulum and a model of an inverted pendulum with a spring.

**3D Inverted Pendulum or** 3D linear inverted pendulum model (3D-LIPM) approximates a biped robot in the following way. As the robot experiences a single supporting phase, its swinging leg is represented by an inverted pendulum whose massless rod connects the supporting foot to the center of mass of the robot [4]. For example, such model is further used in the following methods [14]: virtual height inverted pendulum mode, two masses inverted pendulum mode, multiple masses inverted pendulum mode, gravity compensated inverted pendulum mode, etc.

**Spring loaded inverted pendulum** (SLIP) models are generally known as one of the best and simplest abstractions describing the spring-like leg behavior which is found in human and animal running [6]. SLIP is described by a point mass that is attached to a massless prismatic spring with resting length and leg stiffness.

### B. Biped robot control methods

The important question is what approaches to the biped robot locomotion control should be applied in order to supply energy efficiency and acceptable locomotion speed while maintaining stability of the robot. Next, we briefly describe a number of methods, which are broadly applied for biped robot locomotion control by various research teams.

**Zero moment point (ZMP)** method defines a special point, called ZMP, where the sum of horizontal inertial and gravitational forces equals to zero [5]. In order to maintain biped robot balance its ZMP should lie within the boundaries of a predefined stability region. ZMP plays a role of a criterion in the stability analysis of biped robot locomotion and could be considered as a dynamic analogue of center of mass (CoM) or center of gravity (CoG) criterion for static stability analysis [9]. ZMP approach defines trajectory of a body and a foot without considering the load of each particular joint, which, unfortunately, causes poor energy efficiency of the locomotion.

A simplified model to compute ZMP is Cart-Table model [14]. Figure 2 shows a model of a biped robot, which includes a running cart on a mass-less table. The cart has mass $m$ and its position $(x, z)$ corresponds to the CoM of the biped robot. The table is expected to have exactly the same support polygon as the robot. As shown in the figure, the table is too small to let the cart stay on the edge, but if the cart has proper acceleration, the table can keep upright for a while. At this moment, the ZMP exists inside of the table foot.

**Passive walking method** relies on the body's momentum in order to provide the locomotion [10]. This method is sustained by the natural swing of the legs instead of placed at each joint motors. It is rather efficient for controlling robot locomotion because it creates movements in a similar to human motion way, but due to low stability for external disturbances, this approach is not broadly used.

**Artificial neural network controllers** apply heuristic algorithms to achieve optimization criterion of dynamic balance, for example achieving ZMP criterion requirements. Coupling physical and neural computations results in dynamically stable human-like gaits emergence without specific position or trajectory control [8]. Moreover, through its own dynamical properties the walking robot is capable to compensate for small disturbances. Major drawback of neural networks that makes them less practical for real-time control applications are the exponential growth of the number of parameters as a large-scale system becomes more complicated.

**Dimension reduction techniques** are applied in order to decrease energy consumption and make algorithm feasible. Those techniques reduce dimension of variables, which are used in the equations that describe control algorithms of a robot or reducing the number of such equations. Dimension reduction could be performed via SLIP, decoupling or zero dynamics [12].

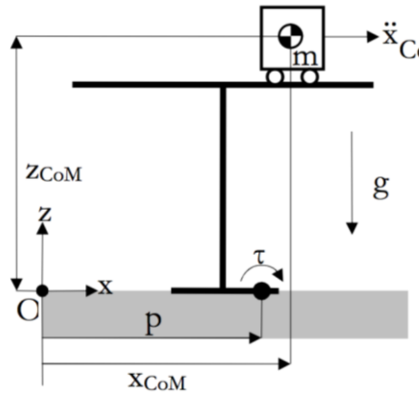


Figure 2. Cart-Table model, source http://embeddedprogrammer.blogspot.ru/2012/08/simulation-of-humanoid-robot.html

## 4. Future work

At the current stage of our research, we had completed the overview of the existing methods of balance based control algorithms for anthropomorphic biped robot locomotion and have started theoretical research in order to create a mathematical model of human gaits. These gaits will provide us with a humanlike locomotion for the robot and help to develop locomotion control algorithms. Through motion capture and analysis we will study human locomotion in order to identify its key features, collect statistically significant data about these features and create an adequate mathematical model of human locomotion based on obtained data.

At the next stage we plan to construct mathematical models for robots AR-601 and Aldebaran NAO and adapt the developed on the previous stage human locomotion model for these robots. This requires correlating model of a human locomotion with kinematic structure and features of given robotic platforms. Only important key features of a human locomotion model will be further integrated into robots' mathematical models.

Then we plan to develop the static and dynamic balance based controlling algorithms of sustainable robot locomotion. For further in-depth study dimension reduction techniques, optimal trajectory ZMP control and optimal feedback control approaches for locomotion control system were selected as the most promising ones. To apply these algorithms with a real robot it is also required to develop algorithms for sensory data collection and processing; in turn, these modules will provide input for decision-making and control actions computation algorithms. Finally, the algorithms responsible for robot actuators control will put the robot into motion.

Today the problems of low speed and high-energy consumption of bipedal locomotion are very significant. For example, probably the most reliable two-legged walking robots, PETMAN [2] and Atlas [3] from Boston Dynamics and electric Asimo from Honda, are directly affected by these issues. These robots consume ten or more times more energy than a person, when more or less scaling by weight and speed. For this reason, along with the main goal of ensuring dynamically stable locomotion, we plan to improve energy consumption and to provide a higher level of locomotion anthropomorphism with regard to the existing algorithms.

## 5. Conclusions

Our research is focused on creating effective human like locomotion for an anthropomorphic robot and a novel human-size Russian robot AR-601M is utilized for this research. In this paper, we presented AR-601M robot and overviewed current methodologies for biped robot locomotion control. We concluded that dimension reduction techniques, optimal trajectory ZMP control and optimal feedback control approaches are the most promising research directions in order to create successful locomotion control algorithms, which could improve dynamic stability of a biped robot locomotion, achieve human-like movements and decrease energy consumption.

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