Design of Low-Cost Android Robots

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Abstract. We have developed two low cost biped robots, using servos as actuators and an *EyeBot* as central controller. Sensors include acceleration sensors in two axes, infra-red sensors in each foot, and a digital color camera. The biped robots were designed as autonomous systems, which carry their own batteries and on-board computer systems, and do not require any umbilical cords or wireless connections. Each robot has nine degrees of freedom, with up to four degrees of freedom in each leg.

1 Introduction

Six-legged robots have the advantage of stability. In a typical walking pattern, three legs are on the ground at all times while three legs are moving. This gives static balance while walking, provided the robot's centre of mass is within the triangle formed by the three legs on the ground. Four-legged robots are considerably harder to balance, but are still fairly simple when compared to the dynamics of biped robots. Biped robots have one leg on the ground and one leg in the air during walking. Static balance can be achieved if a robot's feet are comparatively large and the left and right foot's ground contact areas are overlapping. However, this is not the case in human-like "android" robots, which require dynamic balance.

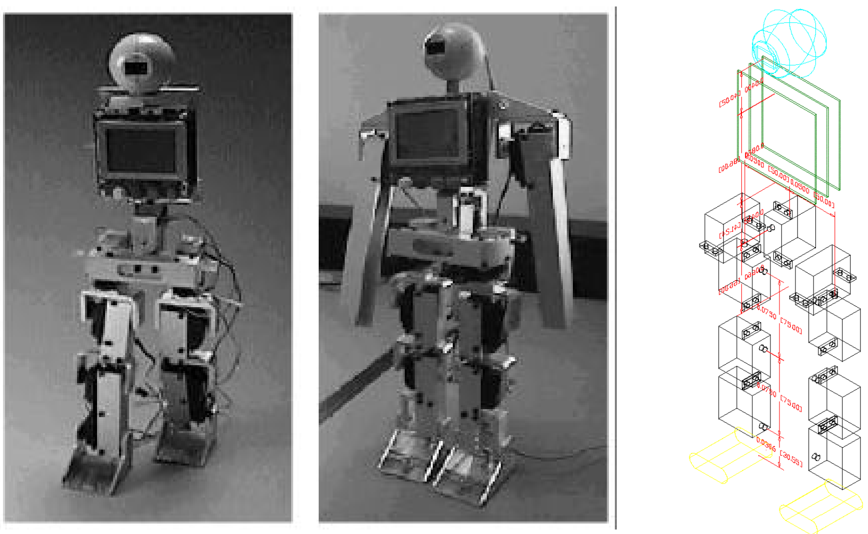

Fig. 1. Johnny and Jack with design of actuator placement

Our goal was to design and control an android robot with limited funds. We used servos as actuators with acceleration sensors and infra-red distance sensors, controlled by an *EyeBot* microcontroller system [2]. Programming of the android robot is done on a Linux workstation, the executable program is then being downloaded to the robot.

2 Biped Robot Design

The two robots developed by us so far have been named Johnny Walker and Jack Daniels, because of their struggle with balance during the early stages of the project. Both robots use an *EyeBot* controller as their on-board intelligence. They also carry rechargeable batteries and do not need any umbilical cords or wireless communication.

2.1 Mechanics Design

The robots use servos fixed in u-profiles for motion. Servos were the cheaper option as compared to DC motors or stepper motors and were also easier to interface. The major drawback of servos is that they do not provide an external feedback, so the controller never knows the exact position of a servo and therefore of a robot's limb.

We tried two different designs for the robot mechanics. Johnny has 3 degrees of freedom (dof) in each leg for bending the hip, knee and ankle, plus one 1 dof for turning each leg at the hip. Finally, 1 dof in the hip is required to bend the torso sideways to balance the lifted leg when walking. Jack is constructed similarly to Johnny, but uses passive ankles with springs instead of servos. He also has arms with 1 dof each in the shoulders. These arms, however, are currently not yet used for balancing or other useful tasks.

Fig. 2. Foot designs with active and passive ankle

Although in principle, it should be possible to generate walking patterns with passive ankles (like "walking on stilts"), we found it very difficult and now prefer the foot design with active ankles.

2.2 Sensor Design

Both robots use the same set of sensors:

- Digital camera
- Infrared sensors
- Acceleration sensors

The camera forms the robot’s head and can be used either for object detection or for motion detection of the robot’s own motion when walking, which is one of the problems we are currently investigating. Each foot uses two infrared sensors, one placed at the "toe" and one at the "heel". These are binary distance sensors, which are activated when the robot’s foot is no longer touching the ground. With two sensors per foot we can determine whether the robot tends to fall forward or backward, but we cannot distinguish sideway motion.

Acceleration sensors for two axes are the main sensors for balancing and walking. These sensors return values depending on the current acceleration in one of two axes, depending on the mounting angle. When a robot is moving only slowly, the sensor readings correspond to the robot’s relative attitude, i.e. leaning forward/backward or sideways. Sensor input from the infrared sensors and acceleration sensors are used as feedback for the control algorithm for balancing and walking.

3 Software Design

Our basic approach to walking is to have a pre-computed repetitive gait pattern with parameters, e.g. for step length, height of leg lift, speed, etc. This gait pattern can then be fine-tuned to fit the particular robot, but will still not be good enough for walking. We then use the current sensor readings as feedback and compare with desired sensor readings at that time point in the gait. Differences between current and desired sensor readings will result in immediate parameter adaptations to the gait pattern.

3.1 Gait Generation

We constructed a gait generation tool, which is being used to generate gait sequences off-line, which can be downloaded to the robot. This tool allows the independent setting of 9 dofs for each time step and graphically displays the robot’s attitude in three orthogonal views from the major axes.

The gait generation tool also allows the playback of an entered gait sequence. However, it does not perform any analysis of the mechanics for the viability of a gait.

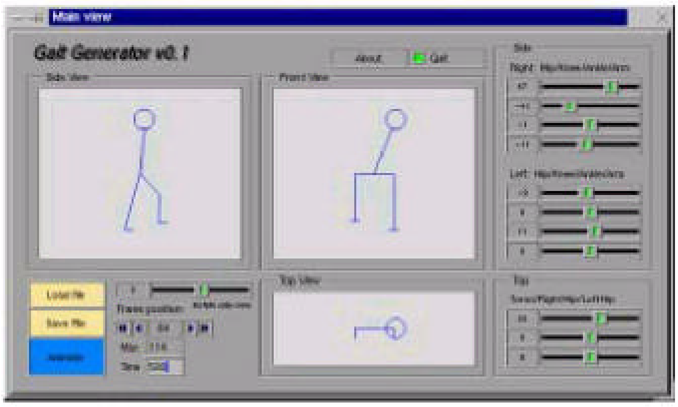

Fig. 3. Gait generation tool by Elliot Nicholls

3.2 Static Balancing

The first step towards walking is to achieve static balance. For this, we have the robot standing still, but use the acceleration sensors as a feedback with a software PI controller to the two hip joints. The robot is now actively standing straight. If pushed back, it will bend forward to counterbalance, and vice versa. Solving this isolated problem is similar to the inverted pendulum problem.

Fig. 4 shows typical sensor readings and actuator signals for a walking experiment.

- The top curve shows the accumulated foot switches for the right foot. First the foot is on the ground, then it is lifted up and down.
- The middle curves show acceleration data for forward/backward movement. (Raw data together with smoothed and adjusted curves). Clearly, the noise ratio is a problem with these sensors in this environment, which led to the integration of a hardware low-pass filter in later versions. This reduces sensor noise and noise generated by the servo actuators. The smoothed signal is quite useful for determining the robot's body attitude.
- The bottom curves show control signals for both hip joints.
(Right hip joint as solid curve, left hip joint as dashed curve).

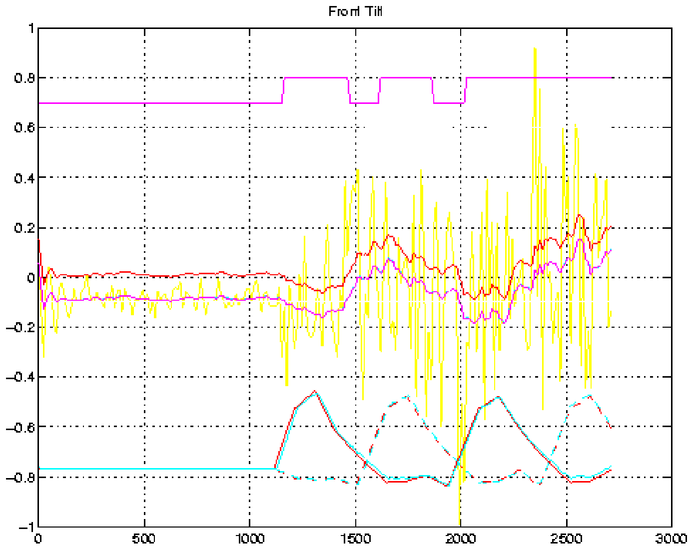

Fig. 4. Foot and acceleration sensor data with actuator signals

3.3 Dynamic Balancing and Walking

The main idea for dynamic balance during walking is to use a parameterized pre-computed gait pattern. The current parameters are step length, step speed, and height of leg lift. These parameters are adapted in real-time according to the difference in acceleration sensor readings to the predetermined desired values that are saved for every time point of a gait pattern.

Problems arise due to missing feedback and constant mechanical jitter from the servo actuators, due to a limited budget in robot construction. This could be overcome by using DC motors with encoders and end-switches instead, but would also require a more complex mechanical design. The current walking performance is still very unstable. Fig. 5 shows Johnny during a walk.

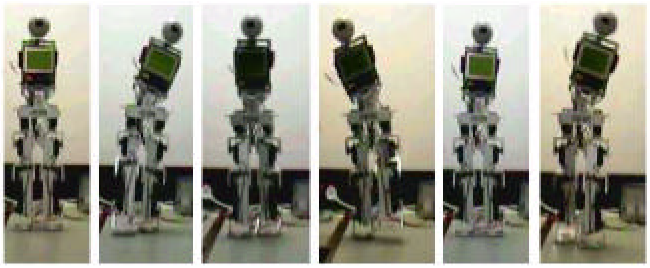

Fig. 5. Walking sequence

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Summary

We have presented a simple low-cost design for biped mobile robots, using DC servos, acceleration sensors, infrared proximity sensors, and an *EyeBot* controller. The robot is completely autonomous, carrying all its computer equipment and power supply onboard.

Our technique for balancing and walking is to use a pre-computed parameterized gait pattern, which is adapted according to real-time sensor readings and their difference from the desired values. Sensor data is used as feedback to the controller for balancing the robot. Problems arise due to missing actuator feedback and constant mechanical jitter from the servos, due to a limited budget in robot construction. This could be overcome by using DC motors with encoders and end-switches instead, but would also require a more complex mechanical design.

The robots' walking balance is still very unstable and lasts only for a few steps. In order to achieve a more robust dynamic walking balance, we are currently investigating using the zero-moment technique [4,5,6,9] and time-delay neural network approaches [1,3,7,8].

Additional information on the biped robots is available on the Internet:
`http://www.ee.uwa.edu.au/~braunl/eyebot/android`

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