Ballbot – A dynamically balanced single wheel robot

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A problem that has hindered robot development for many years is manoeuvrability; the functionality of current robots that interact with humans is limited due to their wide bases and low centre of gravity leading to cumbersome movement. Ballbot has been developed specifically to increase the functionality of robots around humans. It has a high centre of gravity, small base and balances dynamically on top of a spherical ball with only one point of contact with the floor. The omnidirectional movement allows it to move organically and fluidly through crowds and doors.

The aim of the summer research was to dynamically balance the Ballbot. The main focus was on the control theory and programming although some mechanical improvements were also made to the existing design.

Before experimental work began on the Ballbot, simulations and test programs had to be developed. These programs were developed in the Labview Graphical programming environment. Two models were built, both of varying complexity.

1. The first model was based on state feedback and relied on modern control theory. The Ballbot system was represented by a number of states: ball angle, body angle, ball velocity, body velocity and motor current. Driving these states to zero would balance the Ballbot. A Kalman filter was used to predict the current state, which was then multiplied by an LQR gain, optimising a cost function to produce a restoring motor voltage.

2. The second control method was a simpler PID control algorithm. This used the sensor readings to calculate the body tilt angle. The tilt angle was multiplied by PID gains to provide a corrective voltage to turn the motors. The simulation graphs that were generated in Labview are displayed in figure 1. The Ballbot has balanced entirely in 2 seconds in the state feedback model but in the PID model it has drifted slightly (the ball angle has increased).

Due to inaccuracies in the sensor model the state feedback control was unacceptable and the Kaman filter did not correctly predict the state of the system. Therefore it was decided to implement the PID control model. Figure 2b shows the Ballbot drifted from it’s starting position (blue ball angle line) which was due to a constant term being produced by the gyro integration. The integrated gyro rate (body tilt angle) was passed through a high pass filter to get rid of the low frequency drift. This gyro body tilt angle was then fused with the accelerometer body tilt angle (which had passed through a low pass filter to reduce noise) to be fed into the PID controller. The complementary filter allowed the two different tilt angles to be fused together to produce very accurate body tilt angles.

The PID control worked very well and allowed the Ballbot to balance and regain it’s balance if tipped. As there was no absolute position feedback control signal the control voltage that was applied to the Ballbot when it was balanced.

The Ballbot control theory was implemented successfully using national instruments hardware and software showing it can practically work. The next steps consist of making the Ballbot cheaper and available as a teaching aid for schools and universities. ARM microprocessors or Arduinos boards could be used as low cost alternatives to the compactRio. Other work includes making the Ballbot totally mobile. Currently it is connected to an external power supply and real-time computer controller. The Ballbot could be made as a standalone unit with the control programme running as an executable on start up and the battery on-board.

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