**Hands-on Lab**

**WhIP: Wheeled Inverted Pendulum**

WhIP is an NXT-based 2-wheeled inverted pendulum that is analogous to the Segway transporter. WhIP applies PID control to maintain balance. A HiTechnic NXT gyro is used to measure the body’s state (angular velocity and calculated angle). Wheel state (position and velocity) is then actuated to counter-act changes in the body angle. The next effect is that there are 2 degrees-of-freedom (body and wheel positions and velocities) which are controlled to maintain balance.

# **Preamble: Gyro Bias and Compensation**



**Figure:** WhIP coordinates and degrees-of-freedom

Gyros measure angular velocities. These velocities can be integrated to compute angles. Thus a gyro mounted on the body can serve to provide $θ$ (body angle) and $\dot{θ} $(body angular velocity). Computing an angle by integrating gyro data is notoriously subject to drift. Failure to compensate for drift will result in $θ$ growing over time.

**Step 1:** Calibration – computing gyro offset

Refer to program whipGyroCali1\_0.nxc. HiTechnic’s documentation says that their NXT gyro must be calibrated to compute an offset value. Computations are achieved by sampling the gyro and then calculating the average.

 sumOfAllRawOmegaReadings = 0.0; // zero because haven't added readings yet

 totalCounts = 0; // counts number of times gyro is read

 curTick = CurrentTick(); // start timer

 while (CurrentTick() < (3000 + curTick)) {

 rawOmega = SensorRaw(GYROPORT); // HiTechnic gyro returns long

 Wait(150);

 totalCounts = totalCounts + 1;

 sumOfAllRawOmegaReadings = sumOfAllRawOmegaReadings + rawOmega;

 PlayTone(TONE\_B7, 5); // 5 ms chirp

 }

 omegaBias = sumOfAllRawOmegaReadings / totalCounts;

**Step 2:** Lay WhIP flat (and hence motionless) and execute whipGyroCali1\_0.nxc

**Observation:** The WhIP is motionless (i.e. gyro is stationary) but running whipGyroCali1\_0.nxc shows that integration of the gyro’s angular velocity measurements yields $θ$ increasing (i.e. drift).

**Step 3:** Rename whipGyroCali1\_0.nxc to whipGyroLowPass1\_0.nxc and save. Implement a low-pass filter as follows:

#define LOWPASSFILTER 0.005 // constant for low-pass filter

// Value should be less than 1.0. Small values mean that previous value

// of omegaBias (i.e. gyro bias) is weighted more.

// adjust gyro bias due to drift

 omegaBias = rawOmega\*LOWPASSFILTER + (1.0-LOWPASSFILTER)\*omegaBias;

 bodyOmega = rawOmega-omegaBias; // [deg/s]

 intOmegaBias = omegaBias;

**Step 4:** Execute whipGyroLowPass1\_0.nxc and observe the resulting angle measurements

**Observation:** A low-pass filter blocks high frequencies. The expectation is that gyro values will not change radically during run-time. As such, the *compensated* signal is a weighted sum of old values (which should not change much) and the newly acquired incoming signal.

**Concept 1: WhIP PID control**

**Step 1:** Download whip112612.nxc, compile and execute it. In brief, the program does the following:



**Figure 1-1:** WhIP flowchart

**Exercises:** There are 4 gains: KGYROSPEED (body proportional gain), KGYROANGLE (body integration gain), KPOS (motor position gain), and KSPEED (motor derivative gain)

* 1. Set KGYROANGLE to 0 (keeping all other gains fixed at their default values). Note observations: does WhIP translate much? Does WhIP shake a lot? Increase KGYROANGLE and note observations.
	2. Set KGYROSPEED to 0 (keeping all other gains fixed at their default values). Note observations: does WhIP translate much? Does WhIP shake a lot? Increase KGYROSPEED and note observations.
	3. Set KPOS to 0 (keeping all other gains fixed at their default values). Note observations: does WhIP translate much? Does WhIP shake a lot? Increase KPOS and note observations.
	4. Set KSPEED to 0 (keeping all other gains fixed at their default values). Note observations: does WhIP translate much? Does WhIP shake a lot? Increase KSPEED and note observations.

**Concept 2: Multi-Threading**

Multi-threading allows multiple processes to execute simultaneously. In previous lab programs, there was a single process – it was called main(). NXC provides the ability to add processes, so that they run at the same time as main(). The function Follows() is used for this purpose.

Simultaneous execution of processes is often desired so that they don’t bog down each other. For example, one can create processes called whipBalance() and ultrasoundResponse(). The former keeps the WhIP balanced, while the latter polls the ultrasonic sensor.

**Step 1:** Mount an ultrasonic sensor on your WhIP. Connect to Port 4.

**Step 2:** Download whip102315.nxc, compile and execute it.

Note that main() has far fewer statements than whip112612.nxc. Much of the code, especially the PID components have been moved to a process called task whipBalance().

Also, a process called task ultrasoundResponse()has been added. This process polls the ultrasonic sensor and plays a tone if the sensor detects objects within a specific range.

Once main ends, then the processes whipBalance() and ultrasoundResponse() commence. The processes run endlessly until the WhIP falls down. After falling down, the NXC function StopAllTasks() is called to kill all running tasks, and thus shuts down the motors.

**Exercises:** Mount an ultrasonic sensor on your WhIP and

* 1. Examine task ultrasoundResponse(). Play different tones based on distance. For example, play TONE\_B3 for 0 <= usSensorValue <= 30; and TONE\_A3 for 31 < = usSensorValue <= 60.