NUGUS PROTO SPECIFICATION

GENERAL SPECIFICATIONS	
Height (cm)	90
Weight (kg)	7.5
Walking Speed (cm/s)	20

THE UNIVERSITY OF NEWCASTLE (AUSTRALIA)

NUgus Robot.

DEGREES OF FREEDOM	
Legs (each)	6
Arms (each)	3
Neck	2
Total	**20**

MOTORS AND SENSORS	
Dynamixel MX-106R Servo	x12
Dynamixel MX-64AR Servo	x6
FLIR BlackFly S BFS-U3-13Y3C-C	x2
3-axis Gyroscope	x1
3-axis Accelerometer	x1

1 Accelerometer & Gyroscope PROTO Implementation

The Webots program, provides users with a range of sensor nodes that can be modified to the needs of the user. Two of these sensors, the accelerometer and gyroscope, are used within the NUbots 'NUGUS' PROTO model. Both these simulated devices have been modeled to represent the 'lis331dlh' and 'L3G4200D' devices respectively, to a satisfactory level of accuracy [1][2].

1.0.1 Sensor Parameter Values

There are various modifiable parameters for both devices that have been adjusted accordingly by the team. The following listed values are those currently implemented:

1. Accelerometer Parameters
   - X-axis: TRUE
   - Y-axis: TRUE
   - Z-axis: TRUE
   - Resolution: 0.002
   - LUT: Defined in 1.3
2. Gyroscope Parameters
   - X-axis: TRUE
   - Y-axis: TRUE
   - Z-axis: TRUE
   - Resolution: 0.0175
   - LUT: Defined in 1.3

1.1 Process & Justification

The following sections will discuss the process, reasons and assumptions the team made thought development.

1.1.1 Gyroscope & Accelerometer Axis states

As within the physical robot, the NUgus uses 3-axis gyroscope and accelerometer sensors. Hence all three axis have been declared TRUE.

1.1.2 Gyroscope & Accelerometer Resolution Parameter

In-order to closely represent the physical device, the 'Resolution' value has been chosen according to the sensitivity value listed on their respective data sheets.

Accelerometer On page 9, Table 3 within the lis331dlh data sheet [1], information of sensitivity is given. The sensitivity value is measured to be 2e-3 g/digit at a measurement range of 4g, which is the range that will be measured. Hence for this reason a resolution value of 0.002 has been chosen.

Gyroscope On page 10, Table 4, within the L3G4200D data sheet [2], information of sensitivity is given. The sensitivity value is measured to be 17.5e-3 dps/digit at a measurement range of 500, which is the range that will be measured. Hence for this reason a resolution value of 0.0175 has been chosen.

1.1.3 Look Up Table for Accelerometer

As defined within the Webots documentation, A lookup table (LUT) indicates how the values measured by Webots must be mapped to Return values returned by the sensor. The noise on the return value is computed according to a Gaussian random number distribution whose range is calculated as a percent of the Return Value (RV).

Return Value Range Because the device outputs the RV as a 16-bit 2's complement, the RV range of the device should be -32768 to 32767. However, due to the Webots numerical limitation on LUT's [https://cyberbotics.com/doc/reference/distancesensor], the team has decided to apply a hypothetical 'DC gain' such that the output range will be from 0 to 65536. In addition to this, a range of 0 to 65536 allows for more sensible noise Values around RV = 0.

Sensor Input Range The team has decided that a sensing range of +/-4g will be satisfactory. For this reason the measured input values will range from -4 - Δ to 4 + Δ where Δ is the incremental measured value for each row within the LUT table. Δ is added such that Webots returns values no higher than 65536, or lower than 0, for acceleration readings outside +/-4g. In this case, Δ = 0.0625 g (512 RV Equivalent).

Noise Values LUT noise values are calculated proportionally to the respective RV such that a Constant RV Noise (CRVN) range is applied. The CRVN value is the noise of the sensor in terms of RV. This value is calculated in equation 3:

$$MeasuredGNoise@400Hz = 4.36E-3g \tag{1}$$

$$RVToGRatio = 8192RV/g \tag{2}$$

$$CRVN = (RVToGRatio) \cdot (MeasuredGNoise@400Hz) = 8192 \cdot 4.36E-3 = 35.71712RV \tag{3}$$

Because CRVN is assumed to be constant within the **Sensor Input Range**, a relationship between Noise, RV and CRVN needs to be derived. This relationship is calculated in equation 4:

$$\begin{aligned} CRVN &= RV \cdot Noise \\ Noise &= (CRVN/RV) : (0 < RV < 65536) \\ Noise &= 0 : (RV \leq 0, RV \geq 65536) \end{aligned} \tag{4}$$

1.1.4 Look Up Table for Gyroscope

Return Value Range Because the device outputs the RV as a 16-bit 2's complement, the RV range of the device should be -32768 to 32767. However, the team has decided to apply a hypothetical 'DC gain' such that the output range will be from 0 to 65536. Justifications for this decision is identical to the justifications within 1.1.3.

Sensor Input Range The team has decided that a sensing range of +/-500DpS will be satisfactory. For this reason the sensor input values will range from -500 - Δ to 500 + Δ. +/-500 DpS, where Δ = 7.813 DpS (512 RV Equivalent).

Noise Values The CRVN value for the gyroscope is calculated in equation 7:

$$MeasuredDpSNoise@400Hz = 0.6DpS \tag{5}$$

$$RVToDpSRatio = 65.54RV/DpS \tag{6}$$

$$CRVN = (RVToDpSRatio) * (MeasuredDpSNoise@400Hz) = 65.54 * 0.6 = 39.324RV \tag{7}$$

Applying equation 4 with the respective CRVN value gives us our respective Noise values for the gyroscope.

1.2 Modeling Assumptions

Various assumptions were made throughout the modelling process.

1. Assumed that both devices will sample at a frequency of 400Hz
2. Assumed that average noise is equal for all return values within 0 to 65536
3. Assumed that noise is zero for all return values outside of 0 to 65536

1.3 LUT & Plots

The following plots may help visualise the model. These plot examples are taken from the Gyroscope LUT. Figure 1 displays the Return Value (RV) vs the Measured Value (MV) relationship. As you can see the relationship is linear (RV = 65.54*(Measured Value) + 32768) for all values between 0 to 65536, RV = 0 for MV $\leq$ -500 and RV = 65536 for MV $\geq$ 500.

Figure 2 displays the relationship of Noise and CRVN to all RV's (Gyroscope). As you may note, as RV approaches 0, noise becomes larger infinitely. A limitation of this model is this asymptote and the sudden 'cut-of' with both noise and CRVN at RV = Δ = 512RV. This can be improved as Δ approaches 0, however in reality CRVN would never be constant and 'square'. Despite this, however, the team believes this satisfactory for its purpose.

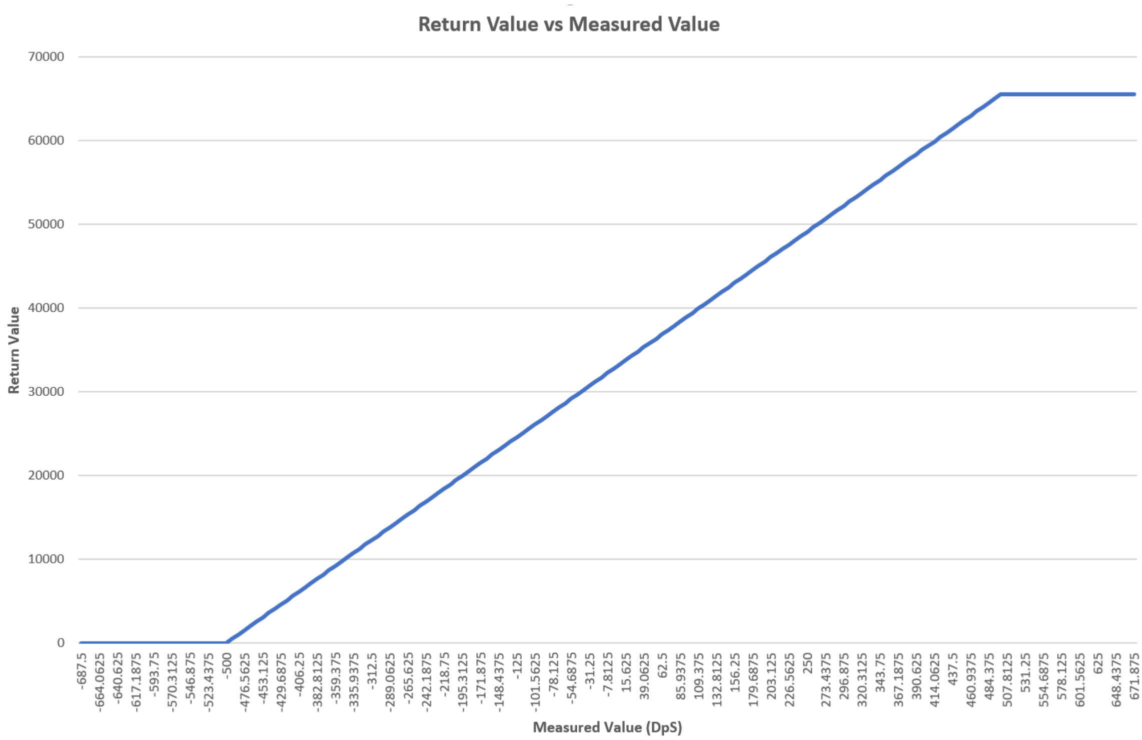

Figure 1: Plot of Return Value vs Measured Value

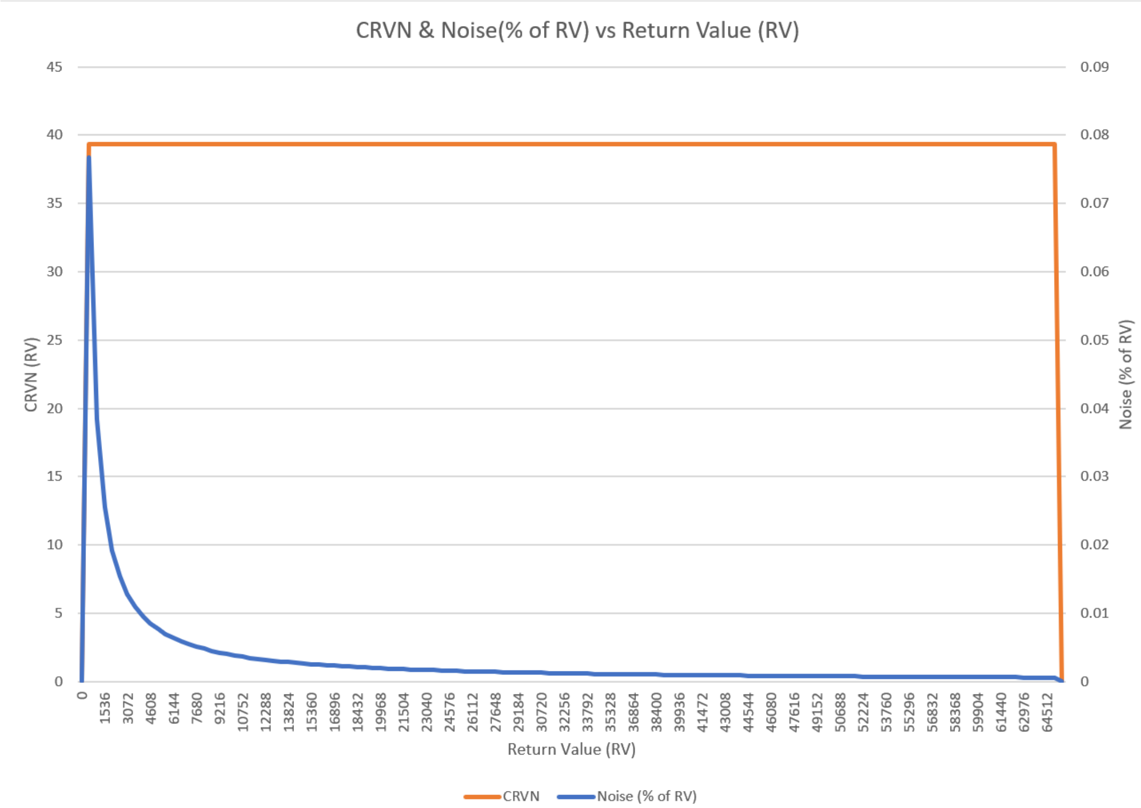

Figure 2: Plot of CRVN & NOISE vs Return Value

Table 1: Accelerometer LUT

Measured Value (g)	Return Value	Noise (%)
-4.0625	0	0
-4	0	0
-3.9375	512	0.06976
-3.875	1024	0.03488
...	...	...
3.875	64512	0.000553651
3.9375	65024	0.000549291
4	65536	0
4.0625	65536	0

Table 2: Gyroscope LUT

Measured Value (DpS)	Return Value	Noise (%)
-507.812	0	0
-500	0	0
-492.188	512	0.076804688
-484.375	1024	0.038402344
...	...	...
484.375	64512	0.000609561
492.188	65024	0.000604761
500	65536	0
507.812	65536	0

2 Motor Implementation

The arms and head of the NUgus robot use Dynamixel MX64AR servos, with two in each shoulder, one in each elbow, and two in the neck. The legs use Dynamixel MX106 servos, with two in each ankle, three in each hip, and one in each knee.

2.0.1 Actuators

All the active joints were implemented using the HingeJointWithBacklash.

2.0.2 Actuator & Joint Parameters

Parameters for the Dynamixel motors were provided in the model specifications document by the TC for voltages of 12v and 14.8v. The values for 14.8v were chosen as the NUgus robot operates at around 14v.

Motor Type	Parameter	Variable Name	Value
MX106	maxTorque	MX106-torque	10.00
MX106	maxVelocity	MX106-vel	5.76
MX106	dampingConstant	MX106-damping	1.23
MX106	staticFriction	MX106-friction	2.55
MX64	maxTorque	MX64-torque	7.30
MX64	maxVelocity	MX64-vel	8.17
MX64	dampingConstant	MX64-damping	0.65
MX64	staticFriction	MX64-friction	1.73

2.0.3 Motor Position Sensors

The Dynamixel motors use a 12 bit rotary encoder. For each motor a PositionSensor is used with a resolution of 0.0015 as specified in the model specifications document.

3 Camera Implementation

The camera was based on the FLIR BlackFly S BFS-U3-13Y3C-C camera [3] with the Lensation BF10M19828S118C lens [4]. Due to the lack of spherical lens support in Webots, we set the lens as close to the real lens while having a rectilinear projection. There are two cameras in each robot.

The **field of view** has been reduced to $\frac{\pi}{2}$ since the rectilinear lens cannot support a field of view of more than $\frac{2\pi}{3}$ and values between these had an undesirable zoom effect.

The **width** and **height** have been set to 640px and 480px respectively. This is lower than the physical camera specifications of 1280px and 1024px respectively because of bandwidth limitations.

Noise has been set to 1e-9 and motion blur to 10, as these seemed to be reasonable values for the camera due to its high frame rate.

Since we are using rectilinear projection due to the lack of true spherical projection, the **spherical** field and lens parameters and are set to their defaults.

The **focus** parameter was set using information from the lens datasheet. The focal length is set to 1.98mm, and the minimum focal distance set to the minimum object distance (MOD) value of 0.1m. The maximum focal distance is set to half the field.

4 Further Work

Known limitations of the current model, and potential changes before the competition, are

- More accurate camera parameters by physical testing with the cameras.
- Camera projection may be changed to spherical, if added to the simulator, or cylindrical.
- Adjust bounding boxes so that they do not self collide
- Determine correct backlash parameters

References

[1] STMicroElectronocs: MEMS digital output motion sensor ultra low-power high performance 3-axes "nano" accelerometer,
`https://www.st.com/resource/en/datasheet/cd00213470.pdf`

[2] STMicroElectronics: L3G4200D: three axis digital output gyroscope,
`https://www.elecrow.com/download/L3G4200_AN3393.pdf`

[3] FLIR: BlackFly S BFS-U3-13Y3C-C: Camera
`http://softwareservices.flir.com/BFS-U3-13Y3/latest/Model/spec.html`

[4] Lensation: Lensagon BF10M19828S118C: S-Mount lens
`https://www.lensation.de/pdf/BF10M19828S118C.pdf`