# Joint Laboratory Exercise Report
# The Dynamic Control of a Robot Car

EIE3123 Dynamic Electronic Systems / EIE3105 Integrated Project

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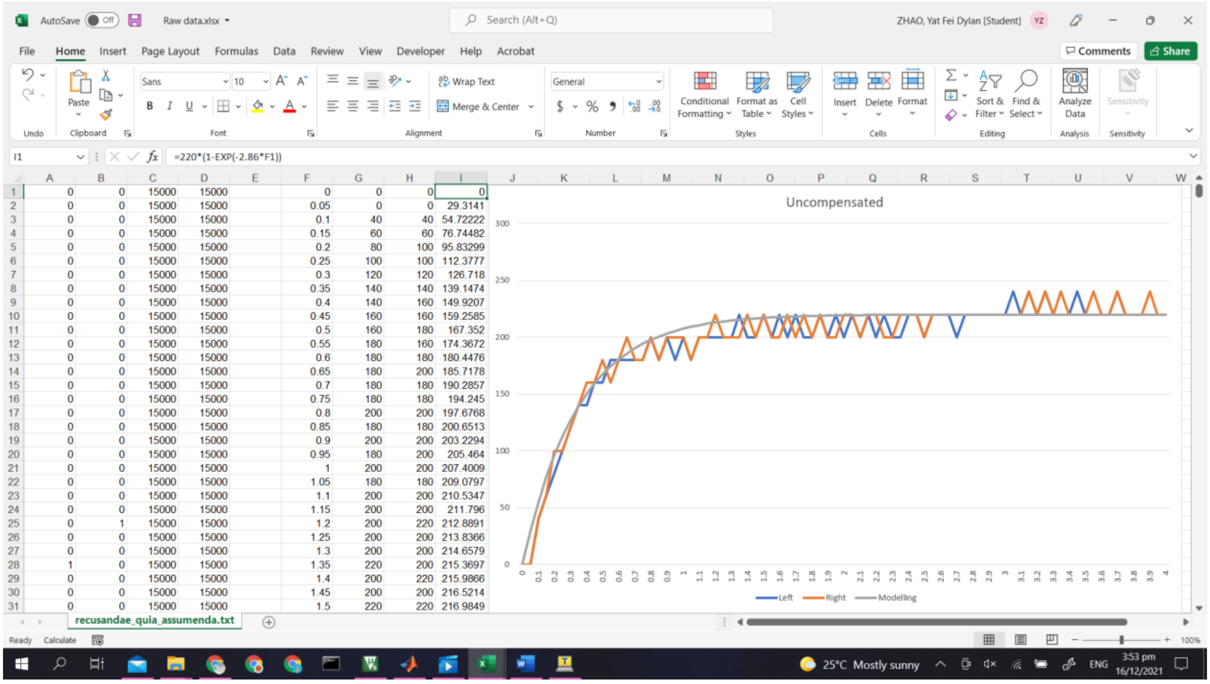
## 1 The Design of the Control System

I run the initial programme given by Dr Lawrence Cheung without any modification to get the initial speed values of the two wheels through Tera Term:




And as can be seen from the above graph, after testing, I find a function that best fits the graph:

$$g(t) = 220 \times (1 - \mathrm{e}^{-2.86\mathrm{t}})$$

The final speed is around 220.

The time used to reach its 63% speed (138.6) is about 0.35 seconds, so the time constant is:

$$a = \frac{1}{\tau} = 2.86\, rad/s$$

After performing Laplace transform, I get the open-loop transfer function:

$$G(s) = 220 \times \frac{2.86}{s + 2.86} \times \frac{1}{44999}$$

Now I proceed to design the PI controller for speed regulation. Recall the equation for PI controller:

$$G_c(s) = K_P + \frac{K_I}{s} = \frac{K_P(s + \frac{K_I}{K_P})}{s}$$

With the help of Matlab, I plot the bode diagram of the uncompensated open-loop $G_c(s)$ as on the next page. Choose the new 0-dB frequency at ω=13.6 rad/s. So the desired compensated gain is 60dB. Thus,

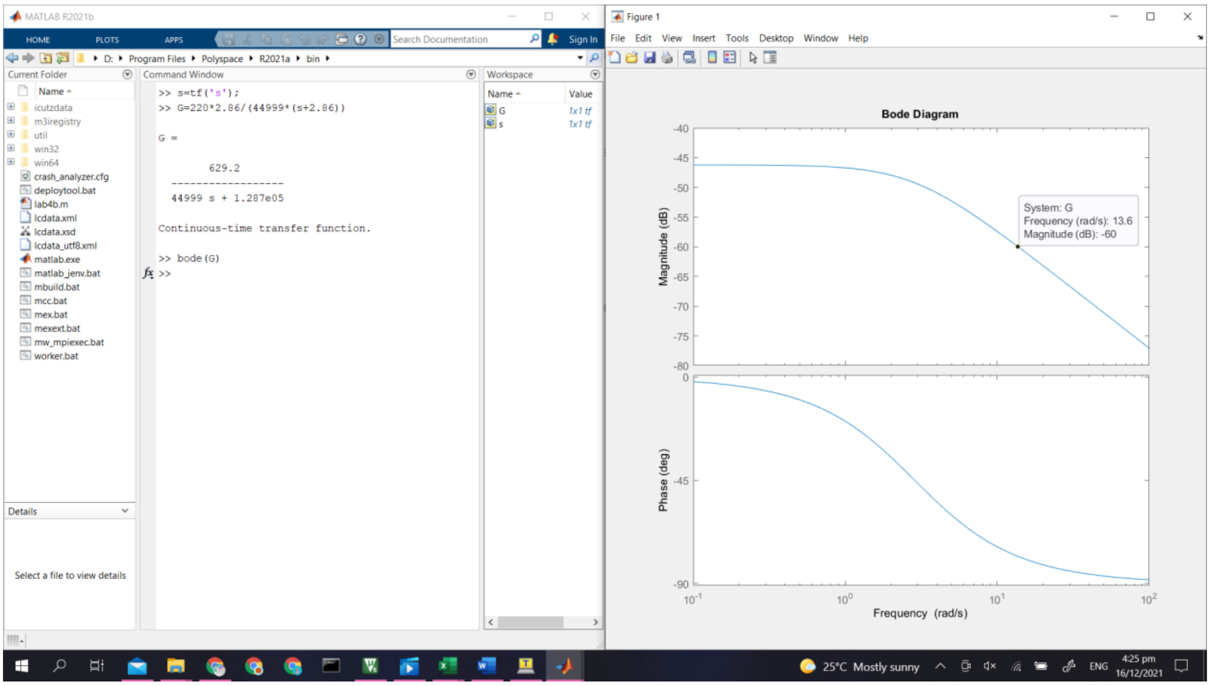
$$20 \times lgK_P = 60, K_P = 1000$$

And then,

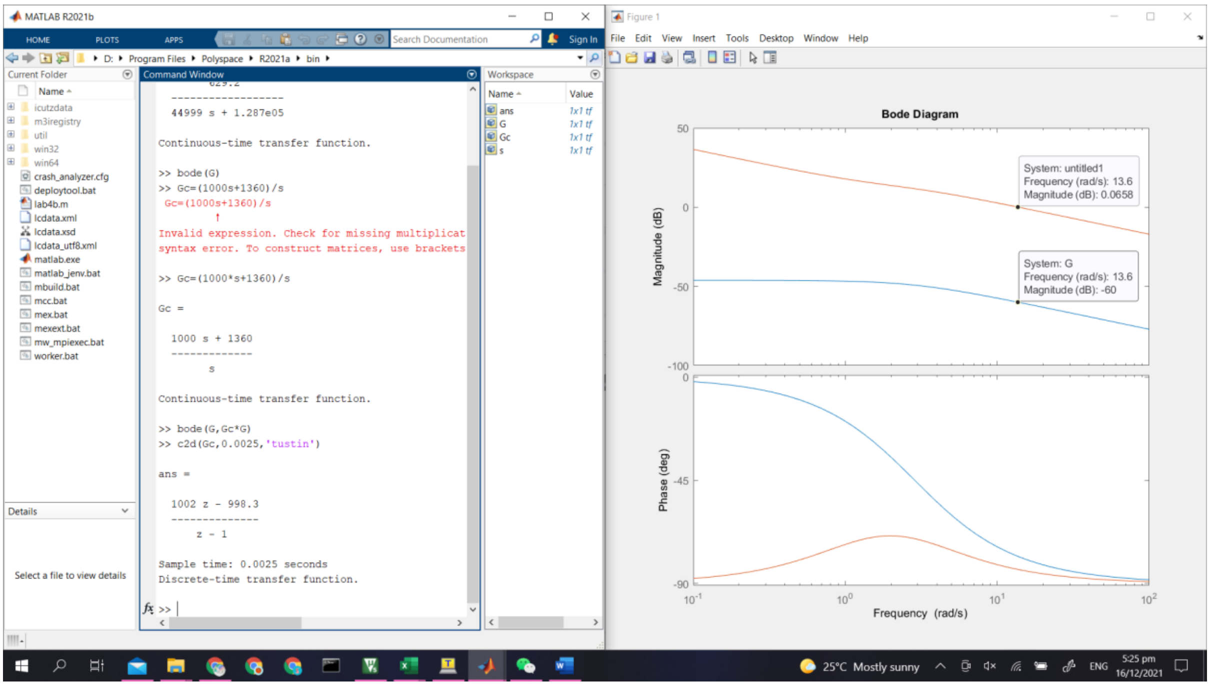
$$\frac{K_I}{K_P} = \frac{13.6}{10} = 1.36, K_I = 1360$$

As a result,

$$G_c(s)_{speed} = 1000 + \frac{1360}{s} = \frac{1000 \times (s + 1.36)}{s}$$




*bode diagram of the uncompensated open-loop G(s)*




*bode diagram of the compensated system $G_c(s)_{speed} \times G(s)$ and z-domain transfer function*

As can be seen from the above graph, the compensation criteria have been met.

Again with the help of Matlab, we get the transfer function in the z-domain:

$$G_c(z)_{speed} = \frac{1002z - 998.3}{z - 1}$$

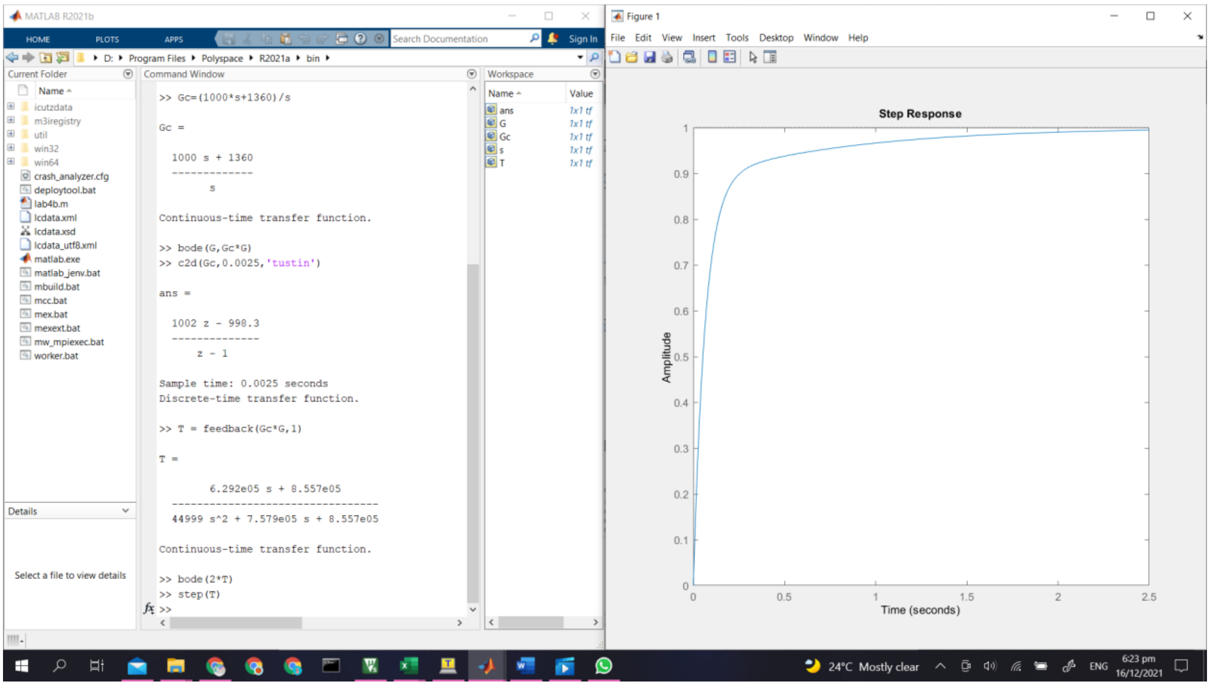
Thus, we get the difference equation:

$$D(z)_{speed} = D(z-1) + 1002E(z) - 998.3E(z-1)$$

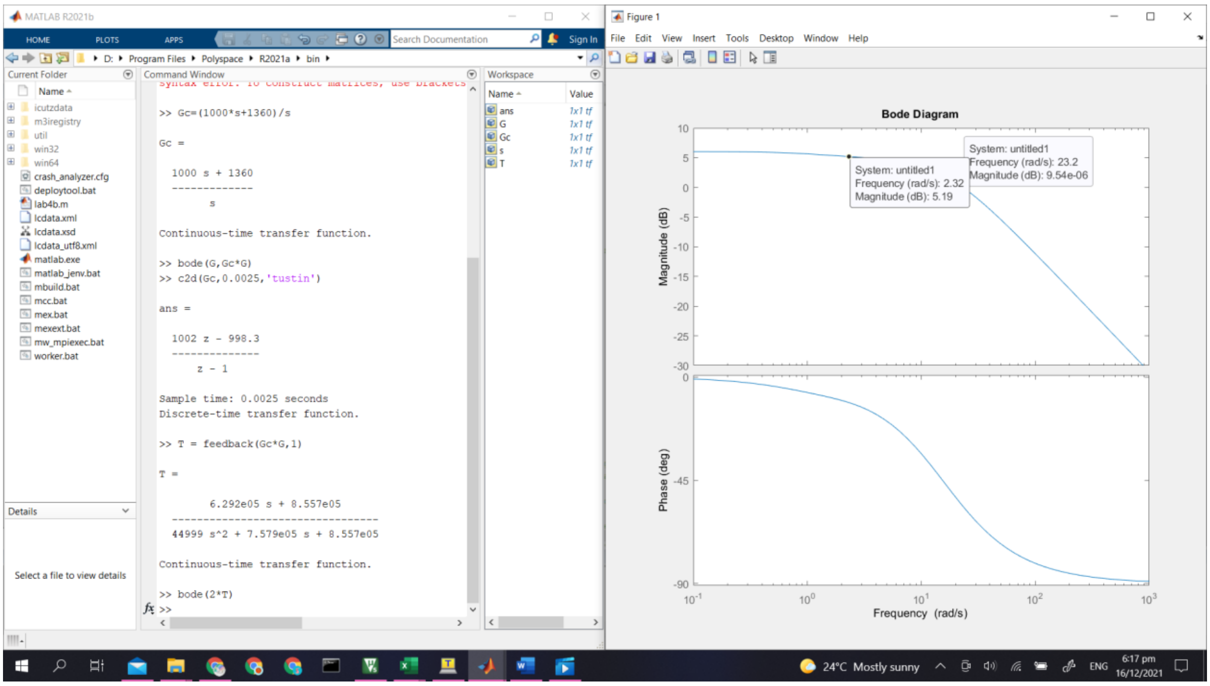
After dealing with speed regulation, I get the closed-loop transfer function:

$$T(s) = \frac{629200s + 855712}{44999s^2 + 757897.14s + 855712}$$

The step response after speed regulation:




Now I proceed to the line tracking part. Plotting the bode diagram of 2×T(s):



Choose ω=2.32 rad/s (1/10 of the 0-dB frequency) as the new 0-dB frequency, so the desired compensated gain is -5.19dB. Recall the equation for PI controller:

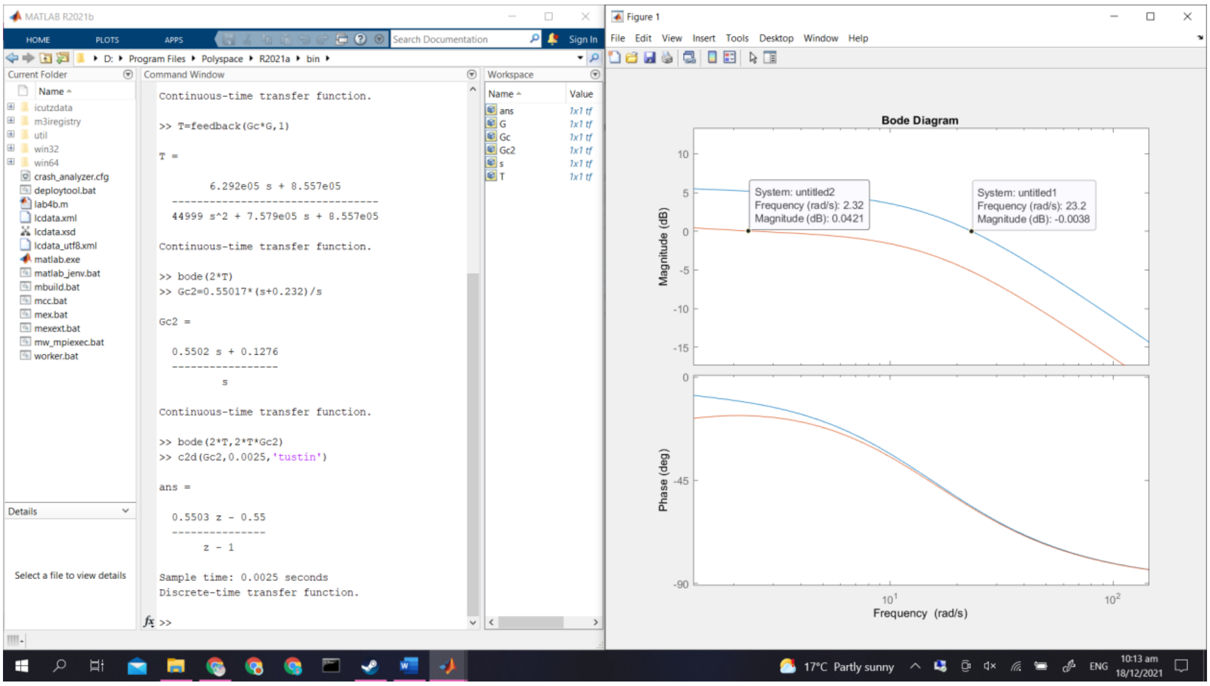
$$G_c(s) = K_P + \frac{K_I}{s} = \frac{K_P(s + \frac{K_I}{K_P})}{s}$$

Now,

$$20lgK_P = -5.19, K_P = 0.55017$$

The new zero of $G_c(s)$ is 1 decade below the 0-dB frequency, i.e., 0.232 rad/s, thus,

$$\frac{K_I}{K_P} = 0.232, K_I = 0.12764, G_c(s)_{line} = 0.55017 \times \frac{s + 0.232}{s}$$




*bode diagram of the compensated system $G_c(s)_{speed} \times G(s)$ and z-domain transfer function*

As can be seen from the above graph, the compensation criteria have been met.

Again with the help of Matlab, we get the transfer function in the z-domain:

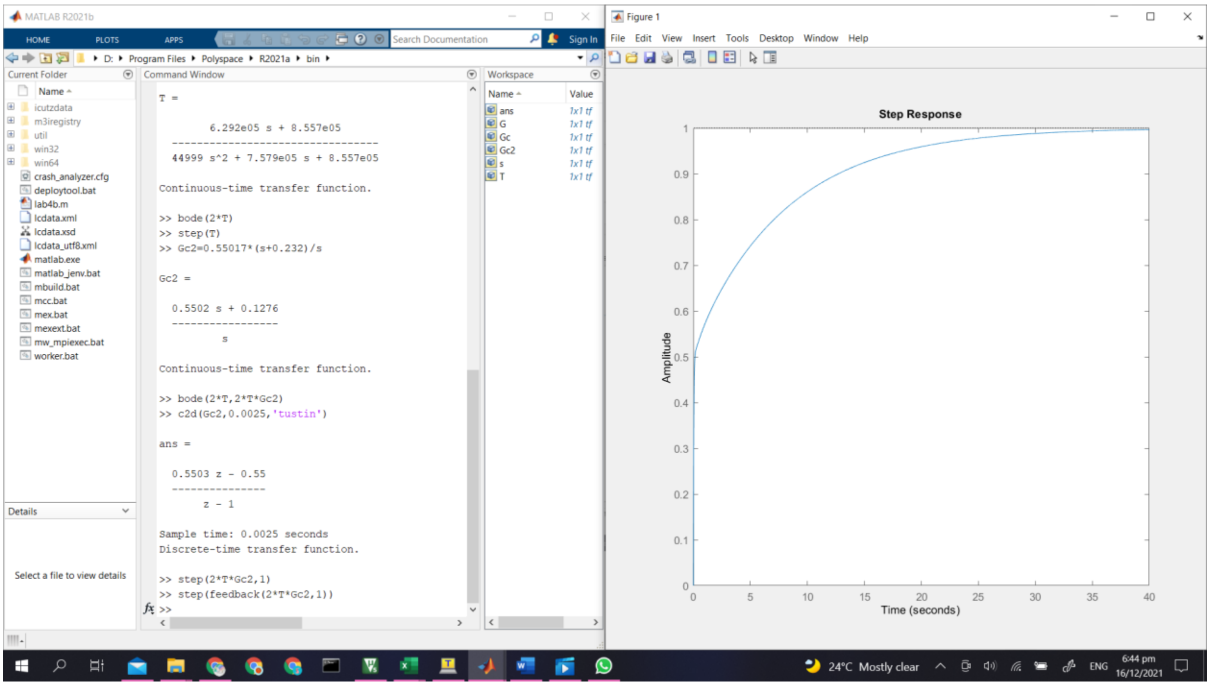
$$G_c(z)_{line} = \frac{0.5503z - 0.55}{z - 1}$$

Thus, we get the difference equation:

$$D(z)_{line} = D(z-1) + 0.5503E(z) - 0.55E(z-1)$$

The simulation of step response of the above complete PI controller design is to be shown in the next part.

## 2 The Simulation Result of the Control System



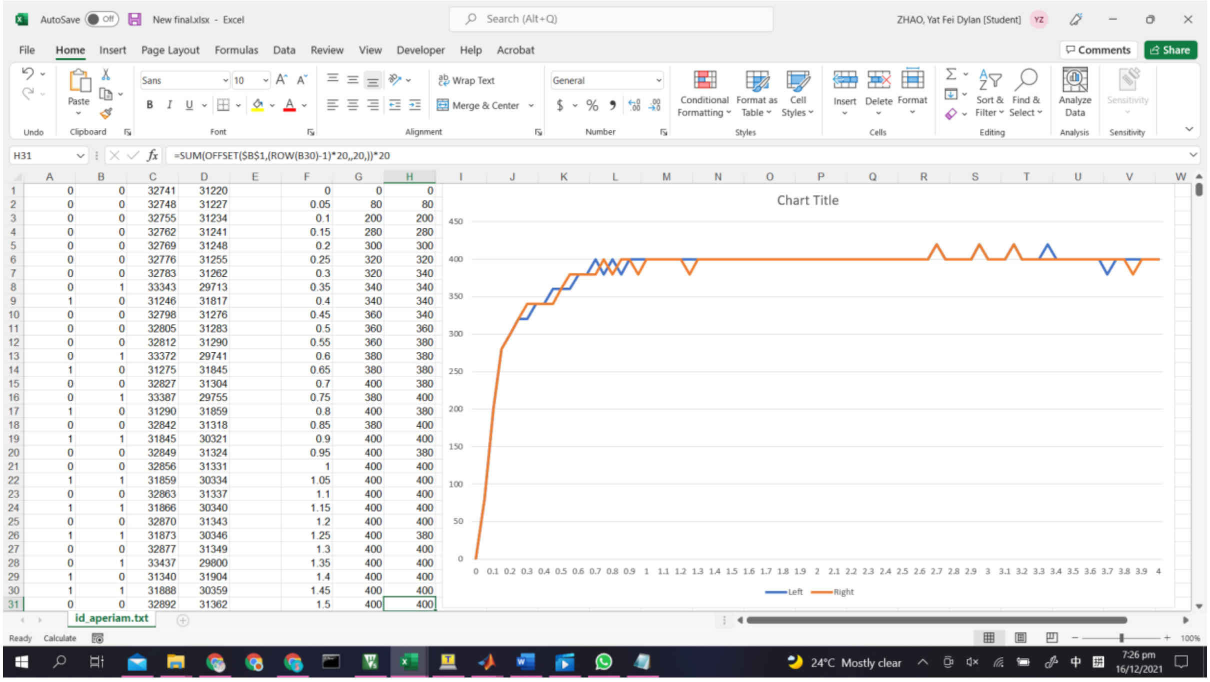

## 3 The implementation of the Control System

The detailed settings and implementation steps have been included in *control.cpp* (including the comments).

## 4 The Optimisation and the Performance Investigation of the Control System

As can be seen from the video accompanied by this report, the performance is satisfactory and has been orally recognised by Dr Cheung already. The system should have been optimised although sometimes the car can’t always move totally straight, which will be covered in the latter part of the report. Regarding the performance, I find that the robotic car moves even faster than before, which is what I did not expect before. I supposed the stability must be decreased when the speed increases. But at last, both the speed and the stability increase, which is quite surprising. The reading of the speed from the car will be shown later in the report.

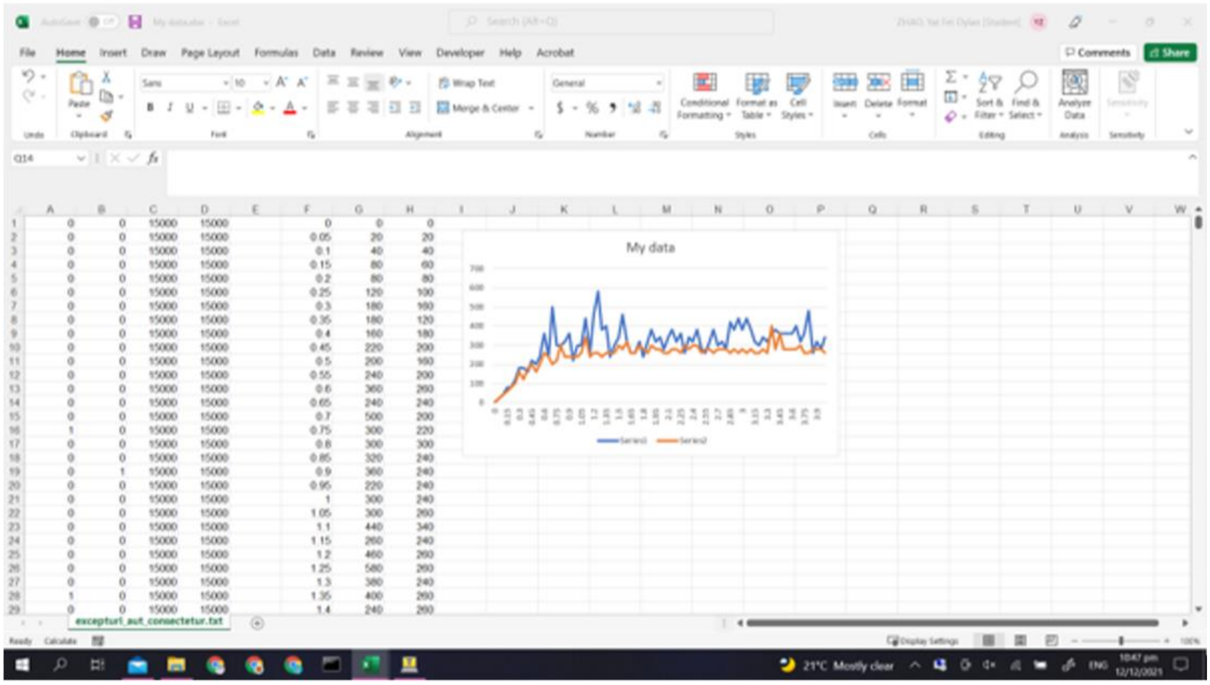
## 5 The Measurement of the Readings of the Counters of Two Wheels in my Last Run

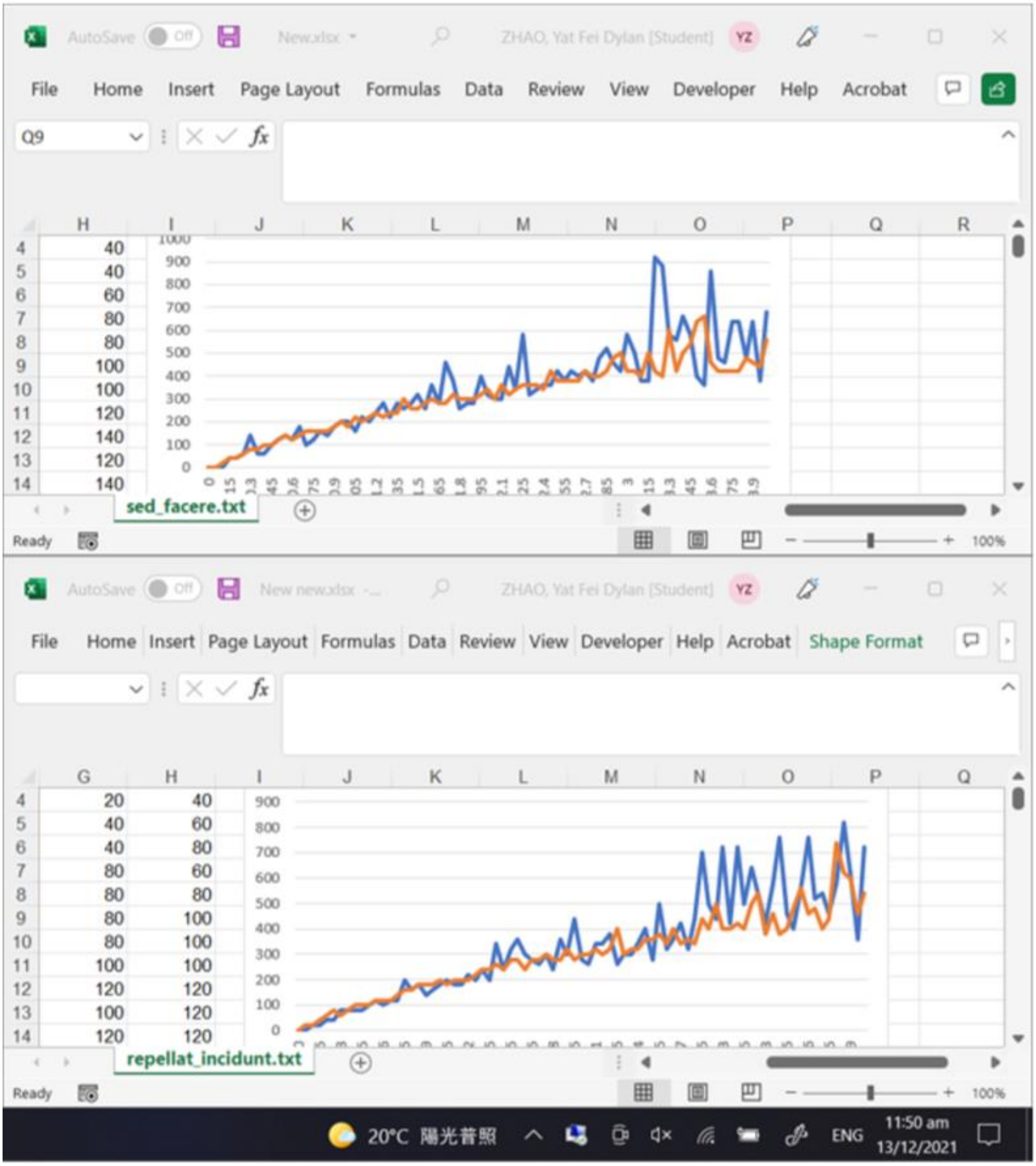



I'll submit the raw data of the readings both when the control system has and has not been implemented.

## 6 The Difficulties in the Implementation

The first and most serious difficulty is that the first robotic car assigned to me was very unstable. The speed diagram was extremely to model. I asked for new cars but the first few replacements did not work well either.






The second difficulty I encounter is that the car always has different performances in different tries when I run the car.

**7 How I Overcome the Difficulties**

For the problem regarding the lack of stability of the car, as I have mentioned in the previous part, I emailed Dr Cheung and Mr SY Lam for getting a new car to do the lab. I acted very kind and politely to Mr Lam when asking him for new cars. At last, we found out that the car with less power (running slower) might be much stabler. So the car I used, at last, was the slowest one when the control system has not been implemented among all the cars I had tried. That is also why “I supposed the stability must be decreased when the speed increases. But at last, both the speed and the stability increase, which is quite surprising", which I have mentioned in the previous part of this report.

For the problem regarding the difference among the performances in different runs, I get the very first data from the car when the control system has not been implemented (I used the worst data for data fitting and modelling). After the control system is complete and implemented, I let the car idle two to three times before I place it on the ground and begin testing. I found that the car somehow "has memory". It often does not work well at first, but after idling two to three times, it seems that it can learn from the previous experience and optimise itself in the next run. I think my way to overcome this problem is not the perfect solution, but it is the only way I can come up with after I accidentally find out. This problem should be related to the internal structure of the car.