SCHOOL OF ELECTRICAL, COMPUTER AND TELECOMMUNICATIONS ENGINEERING
ECTE451 PROJECT PROPOSAL FORM

1. Candidate Details	
Name: Kane Stoboi	Student No: 3897370
Supervisor: Zheng Li	
Title of Project: Closed Loop Stepper Motor Control With The TMC2100	

Brief Overview:

Current methods of driving stepper motors are primarily based upon a current controlled chopper principle. This method, though provides maximum torque, causes current ripple in motor windings resulting in magnetostriction of the rotor. This project will produce a stepper motor control system based around the TMC2100 stepper motor driver that will be designed to operate a bipolar stepper motor silently and accurately. A feedback system will be used to monitor the incoming step signals from an external controller as well as the actual movement of the stepper motor shaft to ensure no steps are lost during operation. The control board and feedback system will be able to attach easily to the stepper motor requiring little to no modification of a motor.

2. Project Description: (Expand to one page maximum)

Describe your project. Questions that you should answer are:
(a)   What problem is being addressed?

Stepper motors have become a common component used in positioning systems in many applications such as micro-surgical operations in the medical industry [1], the movements of fuel elements in nuclear engineering [2], as well as various other industrial applications. The decision to use stepper motors over traditional DC/AC motors are largely due to their accurate position, speed and motion control [1]. Stepper motors, being brushless motors, require a H-bridge circuit to achieve motion with digital signals controlling the switching of the MOSFETs to energise the stator coils. Although this current chopping is generally the most efficient way of driving stepper motors [3], it induces audio-frequency noise due to the constant energisation and de-energisation of the stator coils. This project will evaluate the options to reduce this audio noise.

Traditional stepper motor controllers use a current controlled chopper design [4] as it produces maximum velocity, torque and motor resonance dampening while minimising power loss and maintaining high performance for a wide range of velocities [5]. Small variations in coil currents cause eddy currents within the motor stator [6] causing increased power dissipation and high-frequency magnetostriction of the rotor magnetic material causing audio noise to be emitted by most stepper motors [7]. A voltage controlled chopper design significantly reduces the ripple current through the motor windings [4], in turn, reducing vibrations and mechanical noise while improving efficiency [7].

(b)   Why is this project important?

Although a voltage controlled chopper design is able to reduce the audio noise emitted from a stepper motor, the torque applied is reduced often causing slip [4]. The variation of torque, particularly at high speeds can also cause slippages [8]. Another common cause of slip in stepper motors is the if the excitation frequency of the motor coils is too high [9]. Once the excitation frequency reaches a critical point the motor stalls causing a permanent error in the controller's positioning [9]. By providing a feedback loop, stepper motors will be able to run at their maximum performance.

(c)   What are the objectives and planned outcomes of the project?

The objective of this project is to design and produce a stepper motor driver board using off the shelf parts to operate a stepper motor silently while not compromising on the speed or accuracy of positioning and utilise hardware that will remain within the $350 budget.

Objectives in the longer term will be to design a closed loop configuration to maximise the performance of stepper motors by being able to drive them to their maximum torque and speed capacity.

This project will take ECTE451 and ECTE458 to complete, therefore, the planned outcomes for ECTE451 have been developed with the objectives for ECTE458 to be re-visited upon analysis of the preliminary results.

For ECTE451, the initial literature will be analysed, and preliminary simulations/experiments will be run. This will include component research and selection, circuit topology investigations and comparison of results against existing control methods.

3. Project Plan: (Two pages maximum)

Trinamic's TMC2100 stepper motor driver contains both a voltage controlled chopper (stealthChop) and a current controlled chopper (spreadCycle) [10]. Additionally, the driver can be configured by seven configuration pins. This project intends to primarily use the voltage controlled chopper to drive the stepper motor and once slip is detected switch to the current controlled chopper to apply more torque. The controller of the system will use a closed-loop control system to maintain accurate positioning.

The project will require the design and manufacture of a custom circuit board using off the shelf components. The stepper motor controller will be based around the principles of a voltage controlled chopper to minimise power dissipation and audio noise emitted by the stepper motor. Additionally, an encoder will be used for the shaft position sensing to provide a closed loop control system. A stepper motor will be required to mount the controller board to and perform controller testing and data collection.

Oo et al show that a set of mathematical equations can be used to describe an open-loop stepper motor and controller [11]. By extending this approach, a closed loop model can be modelled in Simulink to test control algorithms before implementing the design on an MCU. An Arduino development board with the MATLAB support library for Arduino will be used to perform hardware-in-the-loop testing of the control system. The support library will allow real-time data from sensors over I2C and SPI to be collected and drive the stepper motors under test [12]. Once testing is complete the control system software will be implemented on an Arduino development board in C++ using the Arduino IDE.

The TMC2100 stepper motor driver has been chosen due to its silent stealthChop feature, high current capacity and ability to configure drive modes between a current controlled chopper to a voltage controlled chopper digitally enabling a controller to set as necessary [10].

The software will be written using MATLAB and the Arduino IDE which are available on SECTE computers, therefore, will not require additional software resources. Open-source software will be used for schematic and PCB layout requiring access to a computer.

The main experiment to be performed is the comparison of the developed control board with an existing driver such as the Pololu A4988.

Data will be collected on the accuracy, speed and audio noise of the motors being driven. The software algorithms will be validated in MATLAB before implementation on an Arduino development board in C++. The final hardware will be tested using correct probing techniques with an oscilloscope against competing algorithms.

After this proposal there are two remaining deliverables, the project report due Monday of week 12 and finally the project presentation in Monday of week 14. To track progress of the project and to ensure completion a set of milestones have been implemented.

Milestone 1 – Initial Paperwork
The initial paperwork will involve the completion of the WHS risk assessment and project form. A meeting with SECTE workshop staff will be set to discuss the hardware and tools required to complete this project. Lab access will also need to be gained as part of this milestone. This milestone should be completed by Friday week 4.

Milestone 2 – Selection/Order of Parts
All electronic components shall be selected and an order will be placed through the SECTE Stores Office by Friday week 6.

Milestone 3 – Order PCB for Magnetic Encoder
This milestone requires the completion of the circuit board to hold the magnetic encoder. Upon completion of the PCB the order for the manufacture can be made through the SECTE Stores Office. As the lead time for PCB manufacture is up to 14 business days it is critical that this milestone is reached before Friday week 6.

Milestone 4 – MATLAB Model
The MATLAB model is required to be completed by Friday Week 7. This entails the complete Simulink model of the stepper motor and driver. Additionally, the MATLAB Support Library should be implanted at this time to allow for hardware-in-the-loop testing of the control algorithms as they are developed.

Milestone 5 – Basic Control Algorithms
The algorithms to detect the positioning and velocity are required to be completed by Friday week 9 and will be implemented in Simulink. A software library will need to be developed to read real-time data from the encoder. The Simulink model will analyse the data and interact with the driver to respond to missed steps. As hardware construction will likely not be completed at this stage dummy data can be used for preliminary tests of the control algorithms.

Milestone 6 – Hardware Construction and Preliminary Tests
All parts and PCBs should be delivered by week 10 and hardware construction can begin. This involves the population of the circuit board with components connecting the driver board, Arduino and encoder together. Preliminary hardware tests will be conducted at this stage with all major software bugs to be removed by the end of week 10. This will allow the analysis of data over the midsession break.

The remaining three weeks will entail fine tuning of the control algorithms and developing libraries in C++ to allow porting of the control system to an MCU.

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4. Resources Required: (Expand to a half a page maximum)

This statement should identify any materials (software/hardware) or access to infrastructure required to complete the project.

MATLAB will be used along with the Arduino IDE for software development. A MATLAB licence is available through the university while the Arduino IDE is open-source software. Open-source software will also be used for schematic and PCB layout.

Being a hardware-based project, there will be the purchase of various components through the SECTE Stores Office. As the focus of the project is on a low-budget control system, it is envisaged that the budget will remain below $350 as required.

To test the hardware and software control system, access to a laboratory will be required to use equipment such as power supplies, oscilloscope, multimeters and function generators. To ensure that the developed system can be tested against comparable control systems used in research and the real-world, access to a laboratory will be sought out after completing the relevant WHS induction.

5. Literature Planner: (Expand to a two page maximum)
Attached as appendix B

6. Mind Map: (single A4 page)
Attached as Appendix A

Student Signature		
Declaration by the student: I have understood the feedback provided to me by the supervisor.		
	Signature	**Date**
Student Name:		

A marked assessment rubric will be appended once completed
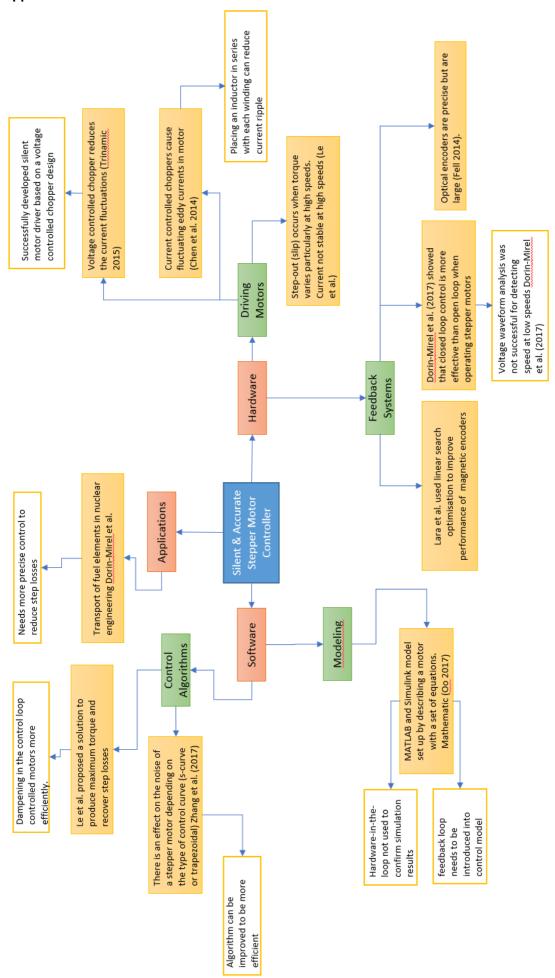
References

[1]   M. Raji, A. Shokanbi, and H. Monday, "Design of Ultra-low-end Controllers for Efficient Stepper Motor Control," *MATEC Web Conf.,* vol. 160, p. 02003, 2018.

[2]   S. Dorin-Mirel, I. Lita, and M. Oproescu, "Intelligent control system with application in nuclear equipment," ed: IEEE, 2017, p. 353.

[3]   M. Dababneh, W. Emar, and I. TTrad, "Chopper Control of a Bipolar Stepper Motor," *International Journal of Engineering,* vol. 7, no. 2, pp. 61-73, 2013.

[4]   T. M. Control, "Application Note 21," no. 1.01, 2015.

[5]   Trinamic, "Application note: Realizing a low noise PWM chopper " no. 0.1, 2012.

[6]   C. Chen and W. Youlong, "Analysis of the impact of current ripple on the eddy current loss of axial-flux permanent magnet motor," in *2014 IEEE Conference and Expo Transportation Electrification Asia-Pacific (ITEC Asia-Pacific)*, 2014, pp. 1-5.

[7]   T. M. Control, "Application Note 15," Application Note no. 1.01, 2015.

[8]   K. M. Le, H. V. Hoang, and J. W. Jeon, "An Advanced Closed-Loop Control to Improve the Performance of Hybrid Stepper Motors," *IEEE Transactions on Power Electronics,* vol. 32, no. 9, pp. 7244-7255, 2017.

[9]   S. Dorin-Mirel, I. Lita, and M. Oproescu, "Comparative analysis of stepper motors in open loop and closed loop used in nuclear engineering," in *2017 IEEE 23rd International Symposium for Design and Technology in Electronic Packaging (SIITME)*, 2017, pp. 357-360.

[10]   Trinamic, "TMC2100-LA Datasheet," no. 1.08, 2018.

[11]   H. L. Oo, "Modelling and control of an open-loop stepper motor in Matlab/Simulink," ed: IEEE, 2017, pp. 869-872.

[12]   T. M. Inc. (12 August 2018). *Arduino Support from MATLAB*. Available: https://au.mathworks.com/hardware-support/arduino-matlab.html

Appendix A

Central node: Silent & Accurate Stepper Motor Controller

Hardware
- **Driving Motors**
  - Successfully developed silent motor driver based on a voltage controlled chopper design
  - Voltage controlled chopper reduces the current fluctuations (Trinamic 2015)
  - Current controlled choppers cause fluctuating eddy currents in motor (Chen et al. 2014)
  - Placing an inductor in series with each winding can reduce current ripple
  - Step-out (slip) occurs when torque varies particularly at high speeds. Current not stable at high speeds (Le et al.)
- **Feedback Systems**
  - Optical encoders are precise but are large (Fell 2014).
  - Dorin-Mirel et al. (2017) showed that closed loop control is more effective than open loop when operating stepper motors
  - Voltage waveform analysis was not successful for detecting speed at low speeds Dorin-Mirel et al. (2017)
  - Lara et al. used linear search optimisation to improve performance of magnetic encoders

Applications
- Needs more precise control to reduce step losses
- Transport of fuel elements in nuclear engineering Dorin-Mirel et al.

Software
- **Control Algorithms**
  - Dampening in the control loop controlled motors more efficiently.
  - Le et al. proposed a solution to produce maximum torque and recover step losses
  - There is an effect on the noise of a stepper motor depending on the type of control curve (s-curve or trapezoidal) Zhang et al. (2017)
  - Algorithm can be improved to be more efficient
- **Modeling**
  - MATLAB and Simulink model set up by describing a motor with a set of equations. Mathematic (Oo 2017)
  - Hardware-in-the-loop not used to confirm simulation results
  - feedback loop needs to be introduced into control model

[1] This paper presents a simple and effective stepper motor controller that is capable of microstepping using an ATtiny45 as well as a driver circuit. More functionality of the driver circuit would be beneficial.

[2] This paper explored the control of stepper motors based on previous input commands.

[3] This paper explores two types of current limiters for limiting the current rise and fall through the motor windings and other inductive loads.

[4] This application notes document investigates the torque performance of a stepper motor being driven by a current controlled chopper and a voltage controlled chopper.

[5] This application note explains the voltage controlled chopper principle.

[6] This paper investigates the effect of current fluctuations on the eddy currents produced in the magnetic material of and induction motors stator. It found that the ripple can be improved by using an inductor in series with each motor winding.

[7] This application note compares the performance of a voltage controlled chopper and a current controlled chopper. It does not do any comparison on torque performance.

[8] This paper provides a position control method to increase the torque produced and retrieve any speed losses of stepper motors.

[9] This paper explored the effectiveness of open-loop and closed-loop control of stepper motors. It found that operating a stepper in a closed-loop configuration is more effective and reliable.

[10]   This datasheet provides the functional information for the TMC2100 stepper motor driver that is able to drive a stepper motor silently.

[11]   This paper presented an open-loop model of a stepper motor simulation designed in Simulink. This simulation was not implemented in hardware. A hardware-in-the-loop model could be used to verify the simulation.

[12]   This webpage provides information on the integration of an Arduino development board with the MATLAB environment.