CC2511 Assignment 2

Task Overview

You are to design and construct a control system for a computer numerical controlled (CNC) mill. Specifically, you will produce a printed circuit board to enable computer control of the mill's motors.

The mechanical design of the mill has already been done (see Fig. 1). There are several such mills in the electronics workshop for you to examine. You will work on the electronics and software to drive the milling machines.

Your design will be in the form of a "shield" that plugs into a FRDM development board.

You are responsible for the design of both hardware and software to implement the following features:

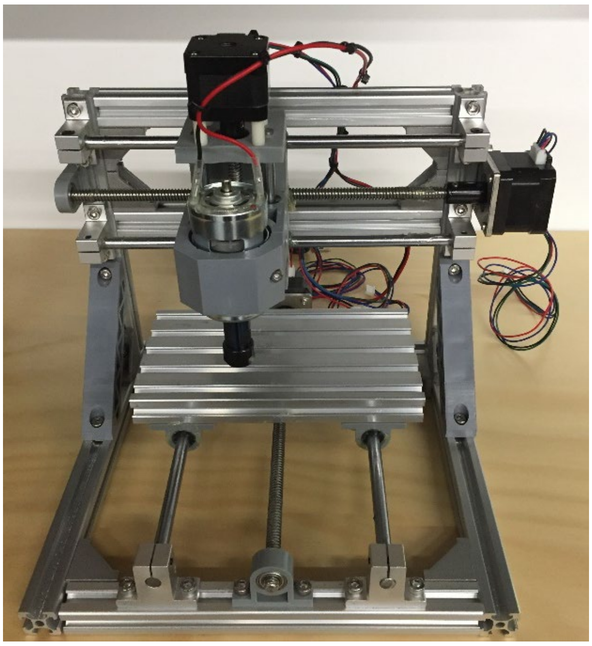

Figure 1: Design of the CNC mill.

- Operation of all components from a single power supply, which is a 12 – 24 V DC supply connected to your board via a barrel jack. This implies that you must power the FRDM board via the Vin pin so that it may operate without a computer connected via the USB cable.
- Control of the three stepper motors to enable arbitrary positioning of the cutting tool.
- Control over the spindle motor including varying the rotational speed of the cutting tool.
- Manual control using your choice of input methods to enable the user to directly command each of the motors. For example, you might provide a button that increments the X axis by a certain amount, and another button to decrement the X axis, and so on.
    - For clarity: it is not required that there be physical buttons on the circuit. A software interface (via a serial port) is perfectly acceptable.
- As an optional feature for a higher level of achievement, operation as an engraving machine. In this mode, the user will supply an image or a sequence of coordinates to be cut, and your program will autonomously control the mill in order to engrave the desired image.

You are to work in teams of 3 students. You are encouraged to organise your own team with classmates that have similar work/study schedules to facilitate easier collaboration. You must notify the subject coordinator by emailing a list of your proposed team members before the date indicated on LearnJCU. Any students who do not place themselves in a team will be randomly allocated.

Deadlines for PCB fabrication are inflexible

This assignment is organised into 4 parts with different due dates. The due dates must be strictly applied because your PCB design will be tiled alongside other groups' PCBs on large panels to be manufactured simultaneously. We are unable to hold up the entire class' manufacturing for a single group who might be late. If you believe that your group might be unable to meet the deadline, contact your lecturer as soon as possible to make an alternative arrangement.

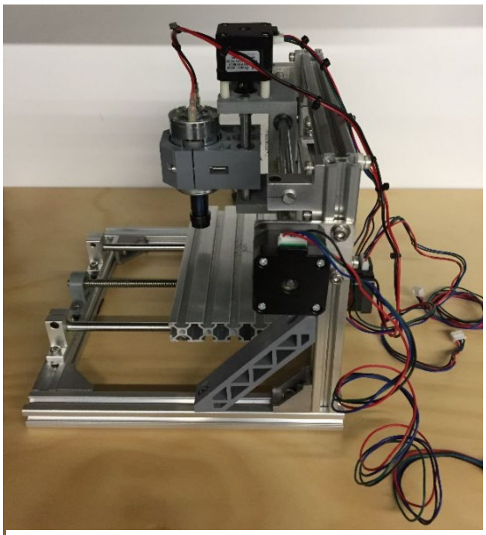

Figure 2: Side view of the CNC mill.

Specifications of the mill

Below are specifications of the milling machine and its motors. This information will be helpful in your design.

Stepper motors

Stepper motor	JLB 17HS1352-P4130
Wiring type	Bipolar (2 phases, 4 wires)
Step angle	1.8 degrees (200 steps/revolution)
Step accuracy	±5%
Phase resistance	2 Ω
Phase inductance	3.5 mH
Rated current	1.33 A
Drive voltage (DC)	2.66 V
Drive voltage (pulsed)	12 V – 24 V (with current limiting driver)
Stepper motor plug type	JST XH series, 2.5mm pitch, 4 contacts
Holding torque	1.26 Nm

Spindle motor

Rated voltage	12 – 24 V
No load current	0.3 A
Typical loaded current	1 – 2 A
Stall current	4.7 A
Winding inductance	0.7 mH
No load speed	Approx. 10000 rpm at 24V
Spindle chuck	ER11
Spindle motor plug type	JST VH series, 3.96 mm pitch

DC power

Input voltage	24 V nominal. Support 12 – 24 V input.
Connector type	Barrel jack
Pin diameter	2.1 mm
Plug diameter	5.5 mm
Polarity	Centre positive

Part 1: Schematic design and selection of components

Due date for this part: Friday, Week 7.

Design a circuit to control the CNC mill. You are required to submit your circuit schematic in Altium Designer format as well as a bill of materials (BOM) as a spreadsheet.

Your circuit is to be a “shield” that plugs into a FRDM development board. Your circuit must include:

- Headers to connect to the FRDM board.
- DC barrel jack for 12 – 24 V power input.
- Voltage regulation to generate lower voltage(s) for other components as needed.
- Appropriate bulk capacitance (≥ 100 µF) on every power rail that drives motors.
- A MOSFET-based switching circuit to control the spindle motor.
- Three stepper motor controllers.
- Headers to connect to the motors.
- Any additional features that you would like to implement.

Constraints: You are required to use the following components instead of any functionally similar alternatives:

- Texas Instruments DRV8825 stepper motor controller IC.
- Richtek RT7272A synchronous step-down converter.
- STMicroelectronics L7805CV linear regulator, 5V output.
- ON Semiconductor NTD6415ANL n-channel power MOSFET.

Apart from these constraints, you are free to choose any component that contributes to your design. Requests to purchase other components will be approved provided that the cost is reasonable and justified in the context of the task.

Compatible connectors

The following connectors are compatible with the existing hardware:

Connection	Connector type	Element14 order code
DC power input	Barrel jack 2.1x5.5mm	2524128
Stepper motor connector	JST B4B-XH-A (LF)(SN)	1516278
Spindle motor connector	JST B2P-VH(LF)(SN)	9492003

Design tips: general

- **You will find it helpful to start with a block diagram of the system.**
- There are several mills in the workshop. Look at them before you start work.
- An Altium library containing many of the required components is available on LearnJCU.
- Check the pins that you plan to use to ensure they are compatible with the functionality you require (e.g. FlexTimer for PWM).

Design tips: Power supply

- To allow your system to operate without a computer present, you must power the FRDM board from the same power supply as the rest of your circuit. You can do this by regulating the input voltage down to 5 – 9 V and connecting this supply into the FRDM board's V_{in} pin.

Design tips: Spindle motor circuit

- Ensure that you provide appropriate protection for your spindle motor control circuit, as discussed in lectures. A minimal implementation is a flyback diode across the motor and a pulldown resistor on the MOSFET gate.
- You might choose to breadboard the spindle motor control circuit. You will need to use an alternative MOSFET since the required part is surface mount. Your design is unlikely to be sensitive to the exact MOSFET performance so testing with an alternative MOSFET is fine. Through-hole (breadboardable) MOSFETs are available from the workshop. Check the datasheet for your chosen MOSFET to ensure that a 3.3 V logic signal is sufficient to turn it on.

Design tips: Stepper motor circuit

- It is highly recommended that you breadboard your stepper motor controller circuit to test its functionality. Breakout boards for the DRV8825 will be provided during the Week 6 laboratory.
- A current-sensing stepper motor driver such as these applies a fixed current, rather than a fixed voltage. Consequently, the stepper motor voltage is unimportant.
- The current sense resistors and voltage reference level determine the current applied to the motors, as per the equation in the DRV8825 datasheet. You will need to calculate appropriate values given the motor specifications listed earlier.
- You will need to implement three copies of your stepper motor control circuit. A convenient way to achieve this is with Altium's Sheet Symbols.
- The stepper motor controller contains a built-in voltage regulator that produces a 3.3 V output. Do not short these outputs together, because small differences in output voltage would the regulators to work against each other.

Design tips: contingency planning

- Plan ahead for fault finding and any repairs that you might need to make after your board has been manufactured. For example, it is recommended that you connect important signals to headers so that you can easily attach wires or bypass sections of your circuit.
- Some issues to consider:
    - What will you do if a voltage regulator fails? Can you bypass it with a header and a lab bench supply?
    - What will you do if a stepper motor controller fails? If you bring the step and direction pins out to a header, you can more easily connect a breadboarded replacement.

Requirements for the BOM

You must also submit a bill of materials (BOM) alongside your circuit layout. You can export the BOM from Altium and then adjust the formatting as needed.

Your BOM must include all components required for construction of your board. Note:

- All parts must be fully specified. For resistors and capacitors, include all details such as power/voltage rating, tolerance, etc.
- Passives found in the workshop storeroom do not require supplier links because we purchase these in bulk. These include:
    - Standard through-hole resistors and capacitors.
    - 1206 footprint SMD resistors and capacitors in standard sizes.
    - Single row, standard 2.54mm pitch headers.
- For all other components, you must find an order code and price from a supplier. We prefer element14 but will also accept other suppliers if element14 do not have the required part or their price is uncompetitive.
- Your BOM must include the unit price and total price for all items.
- An example of how to prepare a BOM was provided with the Assignment 1 reference design.

Part 2: PCB layout

Due date for this part: Monday, Week 9.

Design your PCB layout to implement the circuit. Your board will be commercially fabricated with fine component tolerances, through-hole plating, solder mask, and silkscreen.

The maximum board size is 100mm x 100mm, but you should aim for a smaller size board.

Design tips

- The Sheet Symbols in your schematic will carry across to Rooms on your PCB. You can duplicate the layout and routing of one room onto another. For example, you can lay out your stepper driver once and then copy it two more times.
- The stepper motor controller has specialised heatsinking requirements. Carefully read the datasheet.
- Be aware of the jumpers in the middle of the FRDM board, and make sure that your through-hole components will not collide with them.

Part 3: Construction and software

Due date for the software source code: Friday of Week 13.

You will be notified once your PCB arrives. You will need to solder the components and develop the software.

Some tips:

- **Use less solder paste than you first think.** Use the thinnest line of solder that you can make with the syringe. Anything more than the thinnest possible line is too much and risks bridging pins. Wipe it off with paper towel and try again.
- **Test your voltage regulation before connecting the FRDM board.** With your shield sitting on the bench, not touching the FRDM board, plug in the DC power jack and test that your Vin pin is actually 9 V or less.
- **Check clearances with the FRDM board before applying power.** Unplug all power sources, and carefully plug your shield into the FRDM board. Make sure any through-hole parts don't clash with the jumpers on the FRDM board.
- **Test each stepper motor control circuit separately before connecting an actual milling machine.** Use spare stepper motors with nothing attached so that you don't risk driving the milling machine to the end of its range of motion. Ensure that you have mastered the ability to move the motor in fine increments before connecting the actual mill.
- Make sure that long hair is tied back and that you wear safety glasses whenever you power up the spindle motor. You should implement a testing mode where you simply move stepper motors but leave the spindle unpowered.
- For an advanced level of achievement, consider implementing a mechanism to load milling instructions from a sequence of commands in a text file. A computer program, written in a high level language like Python or Matlab, could be used to stream the milling instructions over the serial port.

Part 4: Demonstration and report

You must demonstrate your product in the practical lab session in Week 13.

Your report is due on Friday of Week 13.

While the hardware and software designs are group work, each person must produce an individual report. There is a strict limit of 5 pages, but a good report is almost certainly shorter than that. Less is more. Be concise.

There is no prescribed format for the report, but at a minimum you must respond to the questions below. You may consider using these questions as headings to organise your document.

1. How does your system work? Describe both the hardware and software design as if you were explaining its operation to a fellow engineer.
2. Did you encounter any problems during the process? How did you overcome them?
3. With the benefit of hindsight, what would recommend be done differently? You must critically assess your design choices and make recommendations for a future engineer who might revise your work.
4. Were there any issues related to your group's teamwork? How did you overcome them?

Assessment Criteria

All components of the project are group work except for the report. Each student must produce an individual report.

Component (weighting)	High standard	Medium standard	Minimum standard	Fail
Circuit schematic (10%)	The circuit is very likely to perform as required. All components are correctly connected and are appropriated specified. The drawing is neat and professional.	The design is very likely to perform as required, once some minor errors are corrected. The majority of components are correctly specified, although not all components have correct footprints.	The design is likely to perform as required, once several minor errors are corrected. Most components are correctly specified. Several components have incorrect footprints. The drawing is difficult to follow, and does not have a professional appearance.	The design is not likely to perform as required. Major errors are present. Components are incorrect or missing.
PCB design (10%)	The design is elegant, and it is suitable for immediate fabrication. The positioning of components is efficient, the number of vias is minimised, and tracks are neatly routed following the shortest possible distances.	The design is suitable for immediate fabrication once minor errors are corrected. The positioning of components and the routing of tracks is acceptable but not optimal.	The design requires some revision before it can be manufactured. The positioning of components and the routing of tracks is inefficient.	The design must undergo major revision before it could be manufactured. Major electrical errors are present.

Component (weighting)	High standard	Medium standard	Minimum standard	Fail
Product (50%)	The overall system is highly functional and demonstrates additional features beyond those mandated on the task sheet. The software is responsive and pleasant to use.	The overall system satisfies the requirements listed on the task sheet. The software is functional and achieves its purpose. Some very minor "glitches" may occur but the system almost always operates correctly.	The overall system meets most of the requirements on the task sheet. Some transient "glitches" may occur but the system otherwise operates correctly most of the time.	The system is not functional or does not satisfy the requirements of the task.
Software code (10%)	The source code is neat, easy to read, and well commented. The software is modular and would be easy to extend.	The source code is mostly neat and easy to read, with good comments in most places. The software is modular and would be easy to extend.	The source code is legible but not always clear. Comments are sparse. Extending the software would not be easy.	The source code is difficult to understand and poorly commented.
Report (20%) **Not group work! Each student produces an individual report.** A strict limit of five A4 pages applies. Content appearing on sixth and subsequent pages will not be marked.	The hardware and software designs are clearly described and the design choices are well justified. The report responds well to all the questions asked on the task sheet. The document is professional in appearance, with correct Australian English grammar and spelling.	The hardware and software designs are well described and some justifications are given for the choices made. The report responds acceptably to the majority of questions asked on the task sheet. The document is mostly professional in appearance, with only minor errors in spelling or grammar.	The hardware and software designs are described with little or no justification of the choices made. The document requires some editing, but is mostly correct Australian English.	The report fails to describe or justify the design. The report has an unprofessional appearance and/or frequent errors in spelling and grammar.