UNIVERSITY OF CAMBRIDGE
DEPARTMENT OF ENGINEERING

1B Integrated Design Project

WEEK 1 Tasks and Exercises

TEAM COPY

TO BE RETURNED AT THE END OF THE PROJECT

Contents

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MECHANICAL

MT.1 Week 1 Tasks

It is important that the overall size and geometry of a product is defined as early as possible. To aid this requirement you should complete the following tasks during the first week.

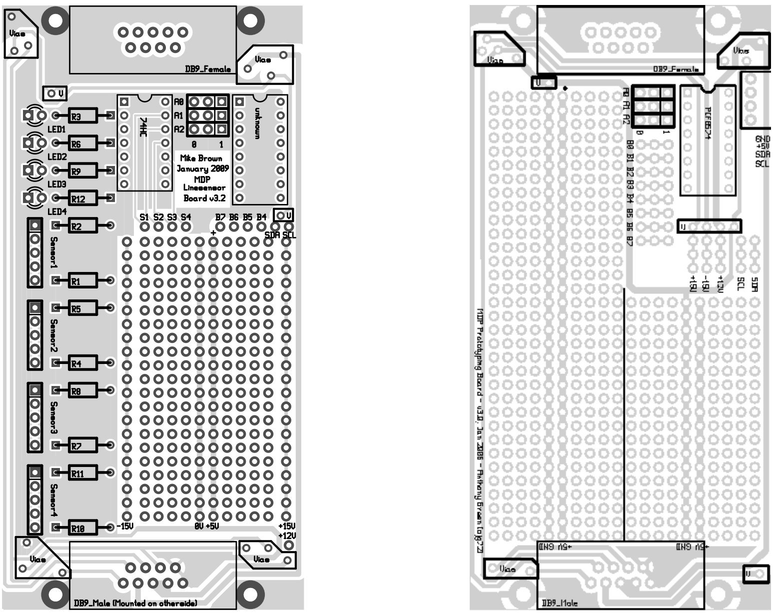
1. Investigate/document the materials available and possible structures with suitable strength/stiffness
2. Discuss, with the rest of the team, and document the max and minimum size of the overall robot and individual sub-systems
3. Demonstrate that the chosen size will enable all planned actions to be carried out.
4. Complete a dimensioned drawing/sketch, and possibly model, of the overall unit and critical sub-systems/mechanisms

ELECTRICAL

ET.1 Initial Inspection/Testing of Printed circuit boards (PCBs)

You are provided with two prototyping PCBs on which to construct your circuits as follows:

1. **PCB1** - Contains an area customised for the construction of 4 line following circuits, together with connectors for you to plug in the IR emitter/detector assemblies. There is also some area for the construction of other circuits. **You are strongly advised to design your line following circuits (see Figure 1) and to construct them on this area of PCB1**. You should aim to achieve this by the end of week 2 at the latest. This will facilitate a major part of the software and mechanical tasks, namely getting the AGV to navigate the playing area.
2. **PCB2** - Mainly prototyping area for the construction of the remainder of your circuits.
   Both PCBs incorporate customised areas for the PCF8574 chip and its addressing. This chip is used to interface between your circuits and the micro-controller. In addition, they have DB9 plugs (9 pin D-shaped plugs/sockets) which are used to physically stack the boards and to connect together common signals across the boards (ground, 5 V, 12 V, ± 15 V and the SDA/SCL [I2C data and clock] lines)



(a) Line following PCB(b) Prototyping PCB

Figure 1: Supplied PCBs

ET.1.1 Customised vs non-customised PCBs

Customised PCBs have copper tracks laid out so that when the various circuit components are soldered onto the PCB, they are automatically connected together as required by the circuit diagram. As such, customised PCBs require minimal construction work, and are therefore very reliable.

Non-customised PCBs (prototyping PCBs) are useful when attempting to design and validate a circuit. Typically they consist of rows of holes connected by copper tracks (in your case 4 holes) together with 0 V and 5 V tracks. Whilst this type of layout is highly flexible and customisable, and is therefore good for prototyping, you will generally need to make additional connections using plastic-coated copper wire. Hence the price paid for this flexibility is increased construction effort and potentially decreased reliability.

ET.1.2 PCB design and construction

Both PCBs are double sided, with tinned copper tracks on both sides, and with holes drilled so that you can insert and then solder components. Solder resist has been applied between the copper tracks to help prevent accidentally creating solder bridges between pairs of tracks. Some of the PCBs' tracks, as mentioned above, must be connected so that they are common to both boards, and for this to work such tracks require a means of being connected to each other despite existing on opposite sides of the board. Vias are used to achieve this. They are simply holes which have been soldered through so that the tracks on both sides of the board are then electrically connected by the via.

ET.2 Week 1 Exercise and Questions

By performing a few simple exercises with your PCBs, and answering the related questions you will gain the understanding needed to successfully design the layout for your circuits, and hence build them. A good working knowledge of your PCBs will also facilitate any circuit debugging you may need to carry out in the latter stages of the project.

- **Exercise 1**
  Identify the 0V, 5V, SDA and SCL pins of the D-type connectors on PCB1

  PCB Interconnections (D Plug)

1	SCL	6 SDA
2	5v	7 +15v
3	12v	8 -15v
4	12v	9 Gnd
5	Gnd	

  Using a digital multimeter check for electrical continuity of the respective pins ie that the pins have virtually no resistance between them on opposite sides of the board. Find the vias that enable this continuity for each of these signals, and label them on a photocopy of the track layout of PCB1.
- **Exercise 2**
  Stack PCB1 and PCB2 together by connecting male and female D-type connectors together. Now ensure that there is continuity between the 0V, 5V, SDA and SCL tracks on both boards. (You may (if you wish) solder the D-Type connectors in place to help facilitate this task however, you must not solder any other items onto the PCBs without first obtaining design acceptance for the relevant circuitry - See on-line video for help on soldering technique).
- **Exercise 3**
  On PCB1 there is an area of the board devoted to the 4 line following circuits. By looking at the circuit diagram for the line following circuits (Figure 2 and also the proposed circuit layout (Figure 1) identify and colour in on a photocopy of the track layout of PCB1 the 0V and 5V tracks on the underside of PCB1. Get hold of the data sheet on the Hex Schmitt inverter chip (look in the electrical pages of the IDP website), and by observing the tracks

on the underside of PCB1, identify and write down the input and output pin numbers of the Hex Schmitt inverter chip corresponding to each of the 4 line sensor circuits.

- **Exercise 4**
  This exercise concerns the PCF8574P chip, used to interface between your circuits and the micro-controller. First of all, obtain the data sheet for that chip, so that you know what each of the 16 pins is for.

  1. Which are the 0V, 5V, SDA and SCL pins ? Perform continuity checks between the tracks connected to these pins on the underside of PCB1 and the respective pins of the D-type connectors.
  2. To the left of the PCF8574P chip you will see a 3 by 3 grid of pins plus three jumpers which are used to connect pairs of those pins together. By observing the underside of PCB1, find out which pins of the PCF8574P chip are connected to the central column of the 3 by 3 grid of pins. The outside columns of the 3 by 3 grid of pins are connected to 0V and 5V tracks. By performing continuity checks or by observation find out which is which. Hence explain how the jumpers are used to set the address of the PCF8574P chip, and draw on your photocopy of the track layout of PCB1 the jumper positions to set an address of 101.
  3. By tracing the paths of the tracks on the underside of PCB1 connected to the output pins of the Hex Schmitt inverter chip to the input pins of the PCF8574P chip, write down the bit numbers corresponding to each of the 4 line following sensors.

  Complete the above exercises, and submit in your first report:-

  – Annotated circuit diagram of the line sensor PCB
  – Annotated diagram of the component layout on the line sensor PCB
  – Documentation (e.g. tables/drawings) for use within the team showing;
    * Connector usage and pin outs
    * Jumper settings
    * PCF8574 Port allocations

- **Exercise 5**
  Use the sensor test box to confirm you calculations about the current limiting and load resistors in the IR sensor circuit work for **All** your available sensors in the condition they plan to be deployed. The specification given on the datasheet is typical and does not take account of different lighting conditions or damage to the IR filters.

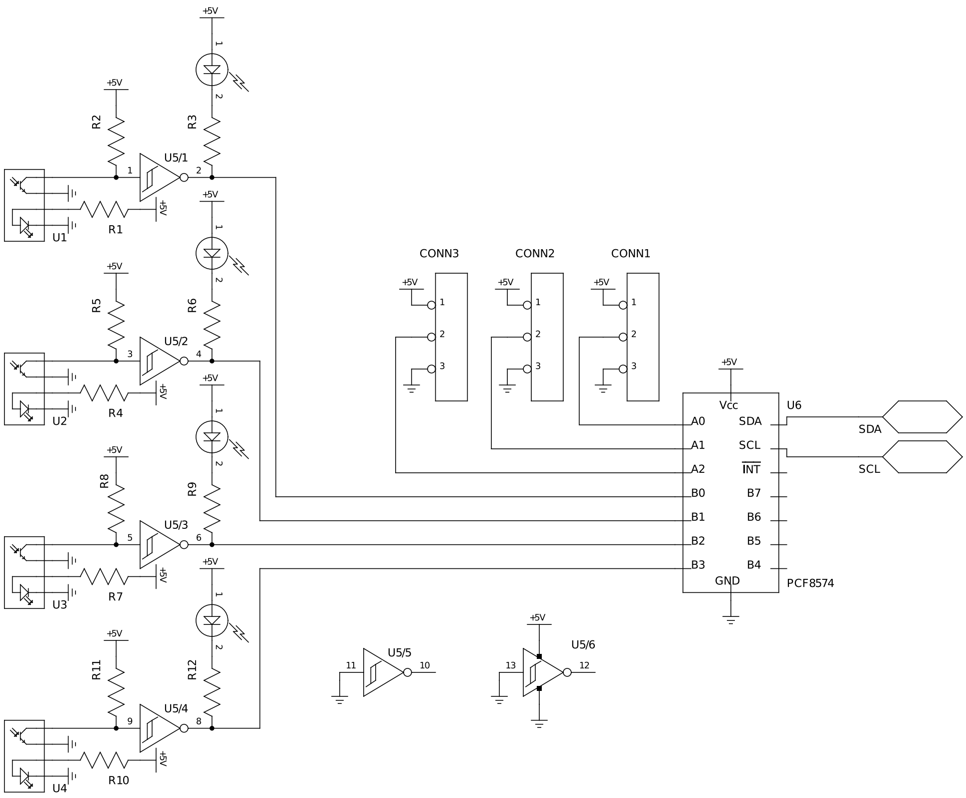


Figure 2: Line Following Circuit

SOFTWARE

ST.1 Week 1 Tasks and Experiments

ST.1.1 Formulating the Software Requirements

You should start to define the functionality of your software at an early stage both to ensure that the software you write can meet the evolving system specification and so that you can start to produce components of it (eg procedures and suitable datatypes) as soon as possible. Bear in mind when designing and writing your software that the design of other parts of the system may have to change due to unforeseen problems and that the software should be easily adaptable to these changes.

One aspect of the design which will need early thought is the line following algorithm since this will depend on such factors as response time and sensor placement.

ST.1.2 Initial Tasks and Experiments

The following tasks can be performed with the basic kit of parts and the test chassis before the mechanical team have produced the real chassis, i.e. starting as soon as the initial system design phase has been completed. Some of the electronics subsystem will be needed for the later tasks so it is important to discuss the scheduling of this with the electronics sub-team. The aim of these experiments is to provide useful design data, to provide a framework for gaining familiarity with the software task and to lead on to the production of software components for the final system. As well as conducting these experiments, it is essential to bear in mind that **most of the software must be written prior to integration with the completed mechanical and electronic subsystems**, i.e. you should aim to have all three sub-systems completed at roughly the same time.

1. Verify that the example test program given in the IDP Handbook will compile and run without

error on the workstation and that the "communications active" LED (see Technical Handbook) lights while the workstation is communicating with the robot. What happens if **i)** the robot is turned off and on while the program is running, or **ii)** the program is stopped and re-run without restarting the robot? Can you detect and recover from errors without restarting the program?

2. Determine the time taken for the complete operation of sending a test instruction from the workstation and receiving a response from the micro-controller. Hint: Use the facilities provided by the `stopwatch` class and, to minimise the effect of program startup time, use a largish number of repetitions of the robot test instruction.
3. Familiarise yourself with cross-compilation for the micro-controller, downloading programs and running these.
4. Familiarise yourself with the operation of the Sensor Simulator (see Technical Handbook). Verify that the simulator can correctly simulate the input and output of data at the addresses chosen for the PCF8574 chip(s) in the circuitry being developed by the electronics sub-team. Pay particular attention to the initialisation required to use **individual** bits (i.e. signals on the chip's input/output pins) as inputs and hence the possibility of using some pins as inputs and others as outputs. Discuss with the electronics sub-team the allocation of signals to the individual bits in these chips and hence develop the routines to read and write the chip(s).
5. Compare the speed of various operations, e.g. reading sensor and ADC values, using a program running on the workstation and one running on the micro-controller. Bear in mind that: the workstation processor is fast but the connection to the micro-controller is limited by bandwidth and traffic; whereas the micro-controller's ARM-based processor is much slower but commands and requests do not need to be transferred over the wireless network. What effect does output to the screen, e.g. for debugging, have on the speed in each case?
6. Calibrate the motor speed and acceleration against the values of the parameters to the motor and ramp commands for all the motors you intend to use (they will not necessarily be identical). This information will be of help to the mechanical designers in determining a suitable wheel size. You should discuss these results with them in light of the figures they have on the effect of load on motor speed.
7. Verify the operation and effect on the Status Register of the emergency stop commands `STOP_SELECT`, `STOP_IF_HIGH` and `STOP_IF_LOW`.
8. Consider, with the Mechanics team, the effect of controller gain and line-following sensor position on the damping ratio and motion of the vehicle. What constraints on sensor position are imposed by: **i)** control system stability; **ii)** cornering and reversing; and **iii)** the proposed construction? Controller equations for a simple system are given in the Systems Design section D.A. The test chassis may allow you test out some of these ideas and to start to develop line-following code.
9. Consider, with the rest of the team, the effects of motor dynamics and system inertia on stopping and starting the robot.
10. Develop prototype line following code, and hence test out your conclusions about sensor positioning, using the test chassis and interface circuitry produced by the electronics team for the sensors.