School of Electrical Engineering and Computing, pp. 1–14

ELEC3850
Project List

Semester 2 2018

1 Introduction

The projects listed below are all, to some extent, open-ended design problems. There are a number of extra features that can be added to each of these projects to enhance the final design and useability. Students have the freedom and should challenge themselves to embellish the projects beyond the listed specifications. There will be multiple groups taking the same project, so each group should try to differentiate their design from others. In evaluating the design project, the level of difficulty of the project will be taken into account. A straightforward project will attract lower marks than the successful implementation of a challenging one.

Where appropriate, the number of equipment sets available is listed in the project's title.

2 Budget and Equipment Sourcing

You may claim up to $200 for hardware purchased for completion of your project. If a claim is submitted the hardware becomes the property of the university and should be surrendered to tech staff at the conclusion of the course.

If you are not financially able to purchase equipment prior to reimbursement please discuss purchasing arrangements with the lecturer. This will not be an impediment to your successful completion of the course.

Electronic components are best sourced from RS (`http://au.rs-online.com/web/`) as they offer free shipping on all orders. eBay and Aliexpress are excellent sources for *some* parts (eg: microcontroller and FPGA development boards) but be aware that many semiconductors (especially op-amps and MOSFETs) will be low quality fakes and typically won't meet manufacturer's specifcations. Delivery times from China via "ePacket" shipping are around 14 days. Economy shipping can take up to a month and should not be used for this course.

Other recommended sources include:

- Element 14
- Mouser
- Digikey
- Jaycar (only if you *need* something *right now*)

Be aware that most companies will charge shipping below a certain cost threshold. It is recommended that you pool orders between groups to avoid shipping costs. Shipping is typically via courier and is overnight for parts stocked locally or around 1 week for parts sourced from overseas warehouses. **NB:** Somebody needs to be home to sign for courier deliveries. You may have parts delivered to the university (addressed to "Your Name, EE Building, University of Newcastle, etc) if you can't be home to receive a delivery.

If you choose to have a PCB manufactured I (Brenton) personally recommend PCBWay however there are many Chinese companies who offer cheap, and fast, PCB fabrication services. Again, try to pool orders between groups to reduce shipping costs.

NB: A final project costing is required for your final report.

3 User Interface Ideas

Many of these projects require (or recommend) the implementation of some kind of user interface. There are many technologies available for this, you are encouraged to consider:

- Variable resistors as knobs
- Rotary encoders as knobs
- Variable resistor sliders
- Buttons
- Graphics LCD
- Touch screen LCD
- Character LCD
- Bluetooth control from a phone/tablet
- USB or serial control from software running on a PC
- Use of accelerometers/gyroscopes (remember the Nintendo Wii?)
- Capacitive touch/slide modules.
- Gesture recognition (eg: via a Microsoft Kinect or similar)

4 Digital Audio Effects Processor

ELEC3400 (or equivalent) is recommeded knowledge for at least one group member when attempting this project.

4.1 Introduction

This project involves the creation of a device which can apply realtime (low-latency) digital effects to an audio signal. The project can be split into three broad components:

- Electronics: audio interface (signal input/output) and CPU
- Sotware: audio processing and hardware drivers
- User interface: Knobs, dials, buttons, LCD, touch screen, etc

The audio signal input/output may be any combination of analog or digital standards (3.5mm socket, balanced XLR, bluetooth audio, S/PDIF, etc) appropriate to an application of your choosing. Applications may include, but are not limited to:

- A component of a home theater system (eg: graphic equaliser)
- A mobile device optimised for portable, battery powered, operation for enhancement of headphone listening
- A musical effect (eg: guitar pedal)
- A recording studio device (compressor, reverb, etc)

4.2 Minimum Requirements

- Choose an audio CODEC or digital interface module
- Choose a CPU development board
- Implement a user-interface for volume control
- Get everything talking

At a minimum your device needs to make the incoming audio stream available as a variable within the software, implement a soft bypass (ie: re-create the incoming signal at an output port) and apply a user-variable gain (ie: volume) adjustment.

The use of pre-built modules (eg: audio CODEC or Bluetooth modules, microcontroller development boards, etc) is encouraged (if not necessary) for rapid prototyping.

The user interface must, at a minimum, allow the user to adjust the volume via a method of your choosing. ie: the volume adjustment can't simply be a hard-coded multiplication factor.

If processing analog audio your device must meet the following specifications:

- Sample at a "standard" audio sample rate (eg: 8, 11.025, 32, 44.1, 48, 96 kHz)
- Meet or exceed 80 dB total harmonic distortion plus noise (THD+N)

- Introduce a latency of no more than 50ms.

The above specification necessitates the use of an ADC/DAC with a bit depth of at least 14b. A purpose-designed audio CODEC (COder - DECoder) device is recommended.

4.3 Software Requirements

You are permitted to use any low-level libraries and configuration tools provided by the CPU manufacturer (eg: ST Standard Peripheral Library and CubeMX) but are not allowed to use any existing digital signal processing libraries (eg: a function which designs IIR filter coefficients). Use of low-level DSP functions which optimise use of the CPU resources (eg: SIMD or saturating arithmetic compiler intrinsics) is encouraged.

External libraries (eg: SD card or FAT filesystem drivers) are permitted if:

- Its use enhances the functionality of your project, and
- You justify why it was necessary (eg: beyond scope of course, obscenely difficult to write from scratch, etc), and
- You have discussed any potential marking issues with the lecturer.

4.4 Marking Criteria

Meeting the minimum requirements should be considered sufficient for achieving a passing grade. Higher marks will be awarded for:

- Custom PCB implementation of the audio interface and/or CPU
- Choice and design of power supply circuitry required for custom PCB implementations
- Design of custom PCB and user-interface to meet a chosen enclosure specification
- Research and implementation of digital audio effect algorithms
- Construction of a user interface which allows the user to adjust audio effect parameters
- Optimisation for power consumption (required if you are aiming to create a portable device)
- Choice of appropriate CPU given the chosen processing requirements
- Software design: Polled/Interrupt driven/RTOS? Processing latency/buffers?

Engineering challenges beyond the scope of this project include, but are not limited to:

- Implementation of a rechargeable battery system (including charging & protection circuitry)
- Design and construction of an enclosure

4.5 Supplied Hardware

Several STM32F407 based development kits are available for prototyping. The DE2 FPGA boards may also be used if you deem it necessary (impulse-response reverb algortihms, for example, may require up to several GFLOPS, which the DE2-70 development boards can provide. Consider this a HD-level implementation task).

You are encouraged to research available modules and make use of your allocated project budget. There are many suitable parts which can be cheaply sourced from China through eBay/Aliexpress/etc (eg: The UDA1380 audio codec module included with the Waveshare STM32 kit used in ELEC3730 is $15).

4.6 Effect Ideas

- Bass boost
- Bass/mid/treble tone controls
- Stereo enhancement
- Multi-channel Equilisation
- Time-delay effects (chorus, flanger, echo, slapback)
- Impulse response based auralization
- Distortion / overdrive / fuzz
- Compressor / limiter
- Multi-channel signal mixing eg: for a karaoke system

4.7 Research Topics

- Infinite impulse response (IIR) filters
- Finite impulse response (FIR) filters
- Audio system figures of merit: signal to noise radio (SNR), dynamic range, total harmonic distortion + noise (THD+N)
- Audio CODECs, their digital interfaces, and analog signal conditioning requirements
- Digital audio transmission standards (I2S (eye-squared-es) signaling, S/PDIF, Bluetooth audio)
- Impulse response models of acoustic systems (speakers, reverberant rooms, etc)
- Various topics in psychoacoustics (eg: equal loudness contours)
- Fixed Vs floating point arithmetic. Accuracy, dynamic range, and hardware cost compromises
- Methods for estimating the CPU requirements for a particular processing algorithm (Big-O notation, CPU cycle counting from assembly listings, etc)
- DSP specific CPU features such as SIMD (single instruction, multiple data), MAC (multiply-accumulate) instructions, and saturating arithmetic.
- (Advanced) FPGA implementation of various signal processing algorithms

5 Audio Spectrum Analyser

The objective of the project is to design and implement a system for displaying the time-varying frequency spectrum of an audio signal.

The project's core components are:

- Audio input (analog (op-amps and ADC) or digital (Bluetooth audio, S/PDIF, etc))
- A CPU which takes the audio data as an input and controls all other modules
- A software algorithm for computing the frequency spectrum
- A display device such as an LCD or LED matrix for displaying the spectrum

Optional extensions include, but are not limited to:

- A user interface for controlling how the spectrum is displayed (eg: update rate, frequency resolution, averaging etc).
- A method for storing or transferring the spectrum data to another device (eg: a PC, phone/tablet, SD card, UDP packet stream, etc).

The computation of the signal spectrum may be rather computationally expensive. You are expected to research possible algorithms for computing the frequency spectrum and estimate their computational overhead. From this estimate a suitable CPU or microcontroller can be chosen for your implementation. An FPGA implementation is also acceptable but should be considered a HD level solution.

NB: Libraries exist which can compute a frequency spectrum. If one is used you should expect a passing grade, but no higher. The primary difficulty in this project is that of optimisation and algorithm implementation. If a library is used marks may be compensated for in other areas (eg: via implementation of an Internet stream of the data or creation of an exceptional user interface).

The number of groups which can take this project is not strictly limited. Some equipment is available however you are expected, within reason, to purchase everything necessary with your allocated budget.

6 Microprocessor Controlled Synchronous Machine (2 groups max)

In this project, students are required to design and implement a microprocessor-based system for the control of a synchronous machine. The function of the controller will be to automatically connect the machine to the mains power supply and, once connected, provide power factor correction at a user specified level for a local load. This project will utilise the schools 41.5 Volt laboratory scale machines. Features to be considered in the design of the system include, but should not be limited to:

- Manual control of synchronisation to the mains power.
- Measurement of AC voltage, AC current and frequency.
- Automatic synchronisation to the mains power.
- Display of real and imaginary power delivered by the synchronous machine.
- Power factor correction.

Existing infrastructure for this project includes a DC motor, synchronous machine and various microprocessors/microcontrollers.

The system should include:

- A main CPU
- Basic user interface such as a 16x2 character LCD
- Sensors for the machines AC voltage and current
- Control of a contactor to connect the machine to mains (via a low-voltage variac output)

7 Exercise Bike with Heart Rate Control (2 groups max)

The idea of this project is to allow the rider of an exercise bike to be able to select a desired heart rate, for a particular cadence, to which the exercise system will seek to maintain through the application of an external load to the bike. A basic block diagram of the exercise system is shown in Figure 2. The idea of this project is implement a control system to maintain the riders heart rate at a user-specified level for a particular cadence by adjusting an external load. Features to be considered in the design of the exercise system include, but need not be limited to:

- Ability to enter
  - a desired heart rate and cadence into the system, or
  - a desired (constant) load, in watts, for the system to maintain.
- Smooth application and removal of load when controlling heart rate.
- The heart rate and cadence sensors are to connect to the main control unit using wireless communications to facilitate an easy connection and disconnection of the device from the bike. Sensors must be battery powered.
- Data storage and connection to a PC is to be implemented to allow the user to download previous exercise sessions.
- Speed and distance travelled are to be calculated, displayed and stored for the user.
- A facility to inform the user that their cadence rate is reducing.

The existing infrastructure for this project includes a mountain bike, exercise stand and a permanent magnet DC motor/generator. The mountain bike is clamped into the exercise stand such that the rear wheel is coupled through a roller, two sprockets and a chain to the DC generator. Loading of the system will consist of applying an electrical load to the generator.

8 Electrical Assist Bicycle (2 groups max)

The goal of this project is to create a system that allows the rider of a bicycle to select how much assistance is to be provided by an electric motor coupled to the rear wheel. The basic system, for example, may consist of four modes that can be selected by the rider:

- Mode 1: No assist.
- Mode 2: 50% assist (i.e. For every 1 watt of power provided by the rider 0.5 watts will be supplied by the electrical assist system)
- Mode 3: 100% assist
- Mode 4: 200% assist

Features to be considered in the design of the electrical assist system should include, but not limited to:

- Measurement (or real time estimate) of the riders power output.
- Smooth application and removal of the electrical assistance.
- Display of rider power output.
- Facility for a connection to a PC.
- Speed, distance travelled, total rider energy and energy supplied by the electrical assist system are to be calculated, displayed and stored for the user.

The existing infrastructure for this project includes a mountain bike, exercise stand and a permanent magnet DC motor. The mountain bike is clamped into the exercise stand such that the rear wheel is coupled through a roller, two sprockets and a chain to the DC motor. Load will be applied through the rear wheel of the bike.

9 Autonomous Intruder Detection Vehicle (5 groups max)

The goal of this project is to modify a remote control car to make it autonomous and able to detect an intruder. The vehicle should also avoid collision with walls or any other objects that may be present within its patrol area. An image of the intruder, when detected, should be captured and transmitted to a personal computer (PC) for display. Features to be considered in the design of the autonomous intruder detection vehicle include, but should not be limited to:

- Autonomous navigation without collision.
- Sensing of an intruder.
- Image capture of an intruder.
- Wireless transmission of an intruder alarm and image to a PC.

Further extensions could include:

- On-board camera streaming real time video to a display unit.
- Wireless communications for remote control of the vehicle.
- Developing a robot that is able to lock onto an intruder and follow them as they move.

Existing infrastructure for this project includes a remote control car, batteries and battery chargers. Several types of microcontrollers, wireless modules and cameras are available in the laboratories.

10 Search-and-Rescue Robots (3 groups max)

The goal of this project is to transform the Schools existing warehouse robots into search-and-rescue robots. Modifications will need to be performed to enable the existing robots to detect and pick up an object marked with an infrared LED and/or distinguished by pre-determined colours. The robots will also need to be capable of detecting steel ball bearings. It is required that the marked objects be collected with a robotic gripper whilst the steel ball bearings be collected with an electromagnet. The robot should also avoid collision with walls or any other objects. Features to be considered in the design of the search-and-rescue robots include, but should not be limited to:

- Sensing of infrared light.
- Sensing of colour (red, green and blue).
- Sensing of steel ball bearings.
- Construction of an electromagnet.
- Design/control of a robotic gripper.
- Autonomous navigation
- Anti-collision sensors.

Further extensions could include:

- On-board camera streaming real time video to a display unit
- Wireless communications for remote control of the robots. Ideally this project will use a Tablet PC for both the control of the robot and robot arm along with displaying the video stream.
- Developing a robot that is able to lock onto a target. The robot should be able to remain locked on the target as it moves.

This project may also serve as a competition between different teams to see whose robots can collect and deliver the most goods to the correct destinations, in a predetermined time. To obtain a coordinated fleet of robots (in this case 2 robots) it will be necessary to establish a wireless communication link between the robots. This will allow the robots to work together as a team and hence collect and deliver more goods. An example block diagram of the search-and-rescue robots is shown in Figure 5. Existing infrastructure for this project includes a robot and servo motors for the robotic gripper. A walled area of approximately 1.5 m^2 , will be used to test the operation of the warehouse robots. Goods will be placed at selected locations within the boundaries. The robots will be expected to retrieve and classify the goods then place them into pre-specified containers.

11 Autonomous City Vehicle (10 groups max)

The goal of this project is to design a prototype vehicle that can navigate around a predefined track marked by yellow divided lines (simulating a city). The vehicle must travel autonomously and avoid all obstacles and other vehicles. At the very basic level, students should be able to remotely/wirelessly control the vehicle (speed and steering) from a computer or phone/device. At the next level, the vehicle should be able to autonomously follow the track without any assistance. Additional challenges include stopping at intersections, parking in designated areas and yielding to emergency vehicles (which wirelessly broadcast an emergency signal). Note: Full marks are only obtainable by attempting these additional challenges. The vehicle comes with the following components:

- Microcontroller: STM32F407 Discovery Board
- Chassis: Shadow chassis; Wheel - 65mm rubber tire, pair; Hobby Gearmotor - 200 RPM (Pair)
- Wireless: Xbee 1mW wire Antenna - Series 1 802.15.4
- Camera: Pixy CMUcam5
- Battery

Basic components are available from EE lab store. Students have the freedom to design certain parts of the project by themselves (hardware, software, wireless communications), instead of simply assembling different provided components. For example, other methods for object recognition can be used in addition to the Pixy Cam. The road rules that the vehicle must obey include:

- Keeping to the Left Hand Side of the yellow dividing line and maintaining this position while crossing intersections. The vehicle is able to deviate from the lane only to park or avoid obstacles.
- Stopping for a minimum of 1 second at intersections (marked by a solid yellow line perpendicular to the lane) before proceeding.
- Stopping immediately when an emergency vehicle is detected unless they are in the middle of an intersection, in which case, they should clear the intersection before coming to a complete stop. An example road surface will be provided in the lab early in the semester for students to test their vehicles with.

12 Automatic Reverse Parking Vehicle (1 group only)

The goal of this project is to modify a remote control car to autonomously reverse park into a predetermined position. The system should work as follows:

- 3 beacons will placed to mark out the desired parking spot:
  - 2 at the front through which the trailer must pass through when reversing, and
  - 1 at the rear to indicate how far back into the site to park the trailer.
- The vehicle must reverse from its current position into the parking spot, or indicate if it is not possible from the current position.
- If it is not possible from the current position, the vehicle may move forward until it reaches a position it can safely park from (without aligning it for a simple straight line reverse).

Features to be considered in the design of the reversing system include, but should not be limited to:

- Detection and location of parking beacons.
- Sensing of trailer angle and relative position.
- Input of system parameters:
- Distances between wheels on vehicle and trailer.
- Distance of towball from the last set of wheels of the vehicle.
- Distance of the towball from the wheels of the trailer

This is a challenging control problem, a model and simulation of the parking system should be completed before it is implemented physically. Students aiming for a HD should consider the problem of reversing the vehicle with a trailer attached.