iDCC - Hardware, Software and Marketing of a Usable Digital Command Controller

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by

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Abstract

iDCC is the new implement of Digital Command Control (DCC) with a better user interface and a much better user experience compared to the existing DCC controllers on the market. The iDCC project was carried out firstly at 2009 and the proof-of-concept prototype was available at the beginning of this project. The goal of this project is to prepare this prototype for a commercialization through the real-world industry arrangement. This is also a new framework of a Master degree project. The author of this thesis has acted as a project manager and a hardware engineer to work with a 4-member software team and a 2-member marketing team whom all are the students of the University of Waikato. As hardware engineers, the duties were to test the previous prototype and develop a brand new hardware which has more functionality and stability. With the unique scanning technology developed in this project it eliminates the complexity of the model train operation and simplifies the technical format of DCC controllers. The enclosure case also has been designed by the author to meet the market need. The software team developed and tested the firmware to fulfil the concept of iDCC with the author. The market team prepared logos, product names, and advertising materials to achieve the market promotion requirement. The author also acts as the project manager to lead the teams together to achieve the goal. The final product is ready to be released to the market as an entry level DCC controller, and the result of this project also shows that this type of framework is sustainable so that it can be applied in any Master or even Phd level project.

Acknowledgements

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Chapter 1

Introduction

This work introduces "iDCC", a new implementation of the Digital Command Control (DCC) standard to control for model train. iDCC is the latest and easiest method to control multiple trains on the same rail. It eliminates the need for users to be seriously and technically literate. The purpose of this project is to commercialize iDCC product through the real-world industry arrangement.

The author of this thesis has acted as a hardware engineer and also a project manager to work with marketing and programming groups. The main concept centred is about developing an iDCC hardware to a manufacturable prototype along with the firmware development by programmers and the marketing materials preparation from our marketing team to complete the whole commercialization package.

The main duty of the author as a hardware engineer involves the development and redesign of the circuit from the prototype version of the iDCC hardware. The previous hardware successfully proved that the ideas of the iDCC were indeed practicable, but there are several potential technical issues arising when the tested iDCC hardware encounters the extreme circumstances such as a high current draw.

The new design of this hardware considers all terms of difficulties which could possibly come in contact in unusual cases resulting in the stability to the final product. The size of a program memory of the embedded microprocessor on the previous iDCC hardware required the greater amount due to the extra functions addition, therefore it has been upgraded from the PIC 16F series to the PIC 18F series. The original single-sided PCB layout design was also forced to be upgraded to the double-sided PCB layout so that it is able to meet with the necessary function increment. In addition, the enclosure case of iDCC has been improved to reach the market's need.

There is a team of 4-members from the Computer Science Department and the Software Engineering Department of the University of Waikato working on the C-language program for the embedded microprocessor with the author. The previous program from the last researcher was only enough to prove demonstrated the hardware functionally, but the most functions were considered to be incomplete. In order to understand the previous program through and through, a new program with multiple functions was created to fully support the tasks of the hardware. The several issues that were found in the previous program are solved in the new program. The stability of the controller is increased by this new program.

We believe that iDCC is a great technology creating customer choices, and this new choice will be able to alter the marketplace [1]. A good product marketing helps pitch a new product to the general public. At the early stage of this project, a class of about 130 students of the Marketing paper "Consumer Behaviour" was given the assignment for suggestions of the product name and ideas of the tag line. The name "Tereina" was selected from a total of 102 different product names to take the place of iDCC. Later on, two marketing students participated to help with the research of the marketing size, the logo design, the slogan and the filming of the advertisement in regard to this product.

This final product may be placed on the crowd-sourced venture-capital website called Kickstarter. Kickstarter is a crowd-funding web platform to raise funds for any kind of creative projects in the region of music, film, video, and technology etc. Kickstarter is our final goal to examine the idea and investigate the outcome of the real world.

1.1 Structure of this Thesis

In Chapter 2, the background information of this project is given. We start the introduction with the history of the model locomotive, and then explain how DCC works. The source of this project idea is also introduced.

In Chapter 3, the related work of the project is described. Before the author of the thesis started this project, there are some research works already done by two previous researchers. The functions of the controller were pre-defined based on the interviews conducted in 2009. We proceed to explain the related works that have been done by the author based on the previous hardware in details. As a project manager, the details of project management are also stated in this chapter.

In Chapter 4, we investigate and gain knowledge in relation to the previous hardware, where the issues that were discovered while testing the previous hardware are addressed. It is then followed by the descriptions of the development on the previous hardware in details. We also include the enclosure case design for the hardware in this chapter.

In Chapter 5, the existing embedded program, given at the beginning of the project, is described. We provide all details about the program, and the block diagram is presented for the purpose of understanding the logic of the program. We talk about the issues in the existing embedded program as well. The new embedded program is attached in the appendix, and is heavily commented.

In Chapter 6, we develop our own marketing strategy such as brand naming, tag-line and logo design for the project. The final price of these products is composed of labour cost and raw material cost, which is also listed in the chapter. At the end of this chapter, the crowd-sourced venture-capital website Kickstarter is introduced.

Chapter 2

History of the Technology

In the 1800s, Richard Trevithick invented the first steam engine tramway locomotive which can haul a load of 10 tons of iron and 70 men. Even since then, railroads had played a major role in transportation around the world. That gives subsequently the history of the model railways almost as old as the real railways. In fact, some early version models of the locomotive were made firstly as promotional tools for the genuine railways sales, even if they later on had become into playthings [2].

These ancient model locomotives were usually made of metal and they were often powered by clockwork mechanisms or live steam engines, just like the actual train. This makes the price of the model locomotive toy relatively high, thus only wealthy families could afford to buy one back in old days. However, model locomotives have become affordable nowadays and it has always been a Christmas delight to both young and old generations ever since the dramatic price dropped.

2.1 Conventional analogue control

Model locomotives have been improved over time, from being steam powered to by clockwork and finally to being electricity powered. In 1897, the first electric model locomotive was produced by the U.S. firm Carlisle & Finch. The speed and the direction of a model train were controlled by varying the voltage and altering the polarity of the rails. When the voltage is increasing, the model trains moves faster, in contrast, when the voltage is decreasing, the model trains slows down. For moving forwards, the right rail must be positively charged in respect to the left rail and vice versa. This is an analogue model railway as known as the conventional analogue control.

The advantage for an analogue model is cheap and simple to install. Over many years, many famous model train brands, from Triang to Bachmann, have been incorporated into, or bought by, the Hornby company. At the early stage of the development of the Hornby, the model trains set had three rails on the tracks due to the insulation problem of metal wheels (see in Figure 2.1). It can move a single train forward and backward with different speeds. If two model trains are on the powered section of the track, then both will move in the same direction.

Figure 2.1: First generation of O gauge Hornby electric model trains. [3]

The problem arose when the multiple trains needed to be controlled individually on the same track. The block control was then invented to overcome the unsolved obstacle of the transmitting of both power and control signal over the same pair of wires at the initial development stage of model trains. In fact, the same problem also happens to the household automation and the domestic power delivery.

The block control method also is called the cab control. This method has been used the complicated block wiring by dividing the model railway layout into several electrical blocks. Each block still only controls one model locomotive at one time, but several electrical blocks together can form a delicate railroad. By switching between blocks' connections, it is able to control multiple locomotives individually at the same time. With the block control method, the most of time will be spent on toggling switches to keep model train moving. This makes a controller of an analogue train system with a cab control rather complicated to operate and loses the delight of model train (see in Figure 2.2).

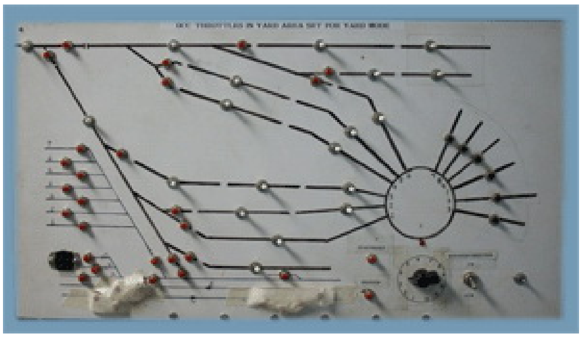

Figure 2.2: Traditional analogue controller with a block system. Switches route power to divided sections of track. [4]

2.2 Digital Command Control

DCC stands for Digital Command Control. It is the global standard for a train system to operate model railways digitally. DCC was developed by two German model railway manufacturers, Mrklin and Arnold [5]. It has been released into the marketplace in the mid-1990s. Later on, DCC has been accepted globally for the standardisation by the model trains society and published by National Model Railway Association (NMRA) in 1994. NMRA is an organization of model railroaders, which advances the worldwide scale of the model railroading community through education and standards as well as the advocacy and the fellowship [6].

DCC is a method to transmit fast switching DC signals from a train controller to form a modulated pulse waveform over the track for the remote control purpose while providing electric power. The length of time of waveform applied in each direction of the voltage provides a pathway for the encoding data. In order to represent a binary one, the time is short (normally 58μs for a half cycle); while a zero represents by a longer period (normally at least 100μs for a half cycle) [7].

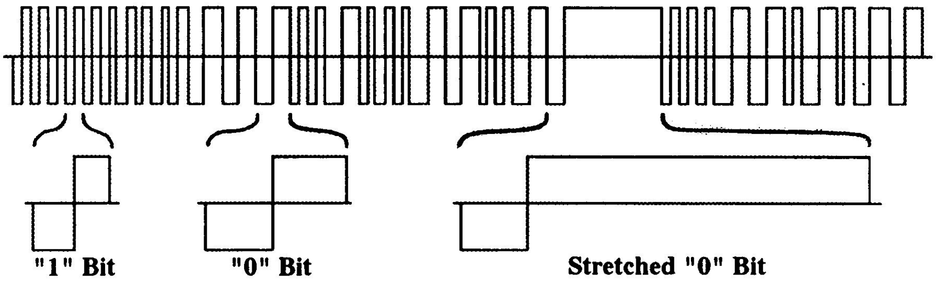

Figure 2.3: Example of a DCC signal and its encoded bit stream. [8]

When the encoding data is sent from the control station, a decoder that is attached to the model train will automatically read and de-code the message. The decoder will then decide the amount and the direction of the current that will go through the motor of the locomotive to control its speed and direction.

DCC were invented and designed to achieve controlling multiple locomotives individually at the same time on the same rails. The greatest thing of DCC compared to the traditional analogue train is that 2 wires that wired from a DCC controller can usually control up to 128 different trains and/or devices. The disadvantage of DCC controls compared to analogue controls is more expensive. Not only DCC controller itself, but also each model train to be used with DCC costs more with extra requirement to be equipped with a decoder.

DCC technology can also be extended for small infrastructure networks (such as home automation systems). For example, DCC allows users to install a small modulated voltage circuit on the power board and a decoder circuit on

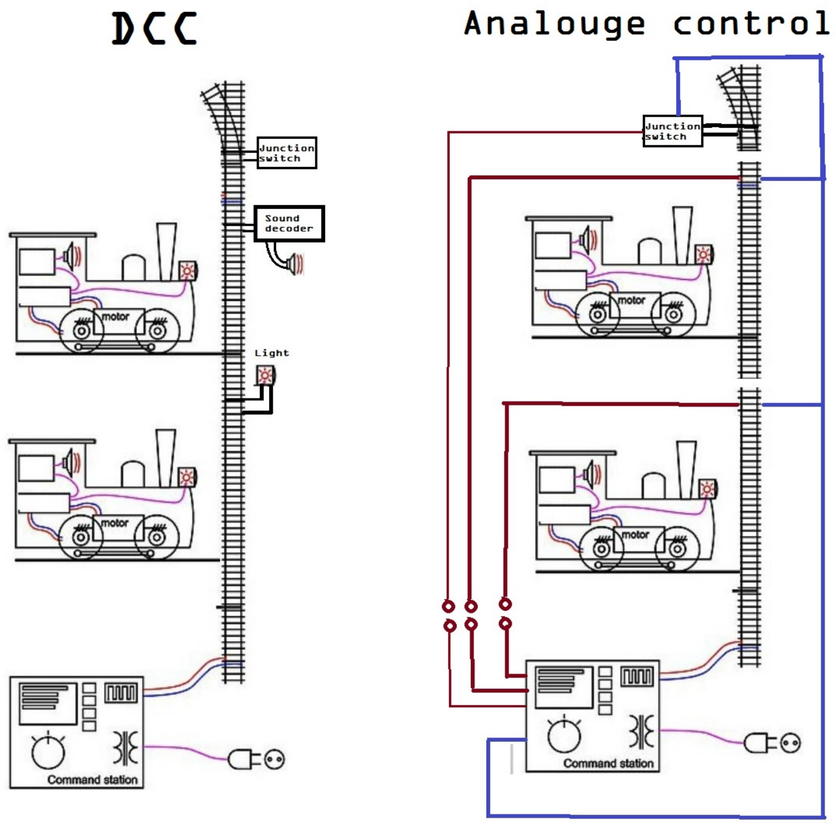

Figure 2.4: Difference between analogue train and DCC train system as suggested by DCC manufacturer

any electronic device to achieve home automation.

2.3 Background

DCC has been introduced to the model trains market for more than twenty years. Professor Jonathan Scott, the author's supervisor, is a model railway hobbyist. He owns a great number of different types of model trains which ranges from the steam engine powered system to the latest DCC controlled system. In his leisure time, he also designed an analogue Pulse Width-Modulation (PWM) train controller with all scales; one block detector and many other improved train controllers were based on the previous version of his own designs.

In his own opinion, he sees the current DCC products as a defective design and he always think that he could improve the system. This is similar as to how Steve Jobs viewed that mobile phones were the awful invention before.

Figure 2.5: Current DCC controllers in the market.

Figure 2.5 provides the examples of the current DCC train controllers in the market, in which complicacy, un-user friendly and technical format of DCC train controllers are a major problem that caused impeding of the acceptance of DCC in the marketplace. [9] The difficulty of operating the controller without reading user manual is high.

In terms of "commercial awareness", there might be a market for the better product. A better product should be always easier to manage even it is the same core hardware. Consumers always want to buy a product that could bestow a better user experience.

As a professor, he would like to see a "better design" that can be collected into the literature; so that even if we do not manage to produce a superior product ourselves, there is a need for the world to realise that there is always a possibility to do better.

In fact, there are several brand giants such as Hornby and Digitrax in the model locomotive industry. Especial for Hornby which almost dominates the whole market of model locomotives it has not offered user-friendly DCC controllers in the past decade. The most popular DCC controller in Hornby is "The Hornby Elite". Hornby made the advertisement for the Elite shown in

Figure 2.6. It depicts a complex- looking piece of equipment that at glance could be mistaken as any instrument from an engineering lab, rather than a consumer toy. [9]

Figure 2.6: Advertisement for The Hornby Elite.

Hornby stated the slogan "If you can use a TV remote than you can use the Elite" in the advertisement. It tried to persuade the potential buyers that the controller is easy to operate, but in reality, the product itself would give them some frustrating, technical experiences. This makes us to believe that there is a gap in the market for the DCC controller to fill.

Chapter 3

History of the Project

This project was begun by a student as an honours undergraduate project named "iDCC" in 2010. The previous version of iDCC hardware, schematic and code of the program was supplied to the author at the beginning of this project. There is no support documentation coming with the hardware.

As what is mentioned in the Chapter 1, this project was commenced with the hardware, the software and the marketing developments all at one time. For the marketing development part, the mock-up case is requested for the presentation to meet with the branding group at start of this project. The design of the controller panel aimed to allow that users can easily understand and operate the controller without any support documentations. The look of the control panel equipped with the prototype version of iDCC hardware was designed and produced by the author shown in the Figure 3.1.

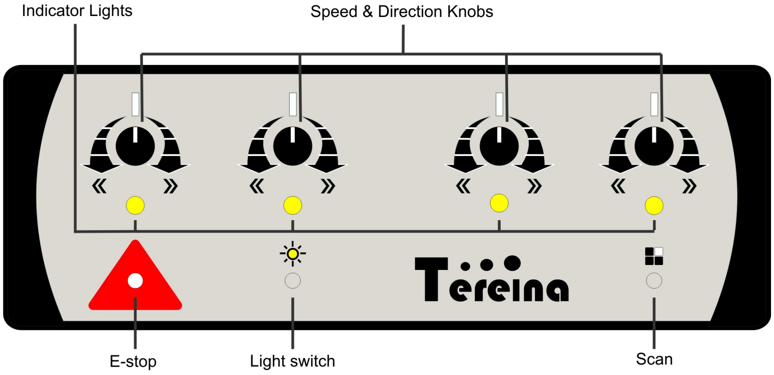

Figure 3.1: Panel design for iDCC controller.

The enclosure case design was from Professor Jonathan Scott. The case is made from 100mm*100mm*300mm aluminiumsquare tube with two wooden end-plates. The end-plates are arranged to present the panel slightly tilted forward. It allows users to gain a better control experience.(see Figure 3.2)

Figure 3.2: Mock-up of the enclosure for presentation to branding and software groups.

3.1 Function requirement

The primary key functions of this product were pre-defined and determined to remove the difficulty level of operation for the model train use. According to the interviews which were conducted by Professor Jonathan and a student researcher in 2009, in a model train club where DCC was widely deployed, only a small fraction of the club members understood the DCC technology [9]. The reason is because of the overly complex and technical format of controllers, therefore all key functions of iDCC are created to make DCC technology easier to utilize. This section will cover four main functions of iDCC in details.

1. Multiple control function

   The four adjustable knobs setting on the control panel makes it easy to control multiple model locomotives. When the user adjusts knobs, the model locomotives will move forward or backward depending on the an-

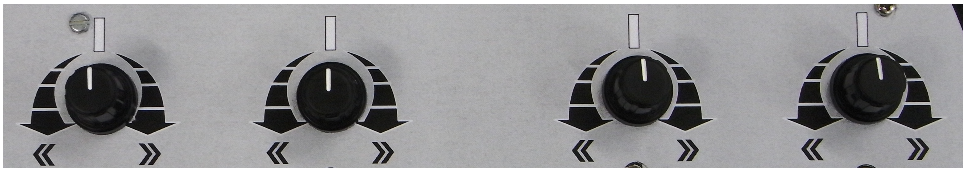

Figure 3.3: Speed and direction control knob on the panel.

gle and the direction of the knob turning.

To stop a locomotive, you will need to point the knob straight up to the center white stripe. To increase the speed of the locomotives, you can adjust knobs clockwise or anti-clockwise away from the center white stripe.

Table 3.1: Illustration for the control knob

Direction of adjusting	Direction of Locomotive
White stripe to clockwise	Moving forward
White stripe to anti-clockwise	Moving backward

Each knob can be matched with one single locomotive; a single iDCC controller has the ability to manage up to four locomotives at the same time.

2. Scan function

The scan function is one of main selling points while comparing with other existing DCC product on the market. These existing DCC controllers do not have the scan ability to discover the number of trains on the track; as a result, they can only manually write down the address of the train and input this to the DCC controller to achieve the multiple locomotives controlling.

In the past two years, previous researchers have created the scanning technology and solved the technical problems such as assigning and remembering addresses of the trains. Scan function will enable the finding and the setting of addresses for new added trains and hence this results in the train controller's abilities to identify the numbers of trains in the presence and control them.

A push button on the control panel was assigned for the scan function. The controller will not automatically detect the new locomotive if the locomotive is added only after the controller has been switched on. The scan function has to be re-applied. Restarting the controller or flipping the controller right way up will automatically apply the scan function to correctly gain the address of new locomotive.

3. Emergency stop function

Emergency stop (E-stop) button provides the ability of a break without delay for all model locomotives under urgent circumstances. When the E-stop button is pressed, all model locomotives that are on track will stop immediately and all indicate lights on the iDCC controller will flash rapidly.

When E-stop is applied, the control knobs and other buttons will not function. To cancel the E-stop function, you can press the E-stop button again, and the iDCC controller will resume to its previous working status.

E-stop button has to be pressed in order to control the model locomotive after scanning function; this is because the E-stop function will automatically be applied after the scanning function finishes.

4. Programming function

The old DCC system required to electrically isolate a length of track from the main track layout when programming. In order to program a new locomotive, all other locomotives are necessary to remove from the track first and also that all point decoders are disconnected from the layout. Users need to manually input an address number into the controller and follow particular steps by pressing the keypad to complete the programming function. This procedure can become rather frustrated at times.

iDCC provides a rapid programming procedure for users. To address a new locomotive, they can simply invert the entire iDCC controller box, exposing a short section of track connected to the underside, and then place the locomotive on an attached programming track on the back of iDCC. All other locomotives and point decoders can remain the same on the main layout. No keypad entering is required for iDCC.

iDCC recognizes that the iDCC controller has been inverted and automatically switches to Service Mode to be ready for addressing. Users can simply put the new model locomotive on the addressing track on the back of the iDCC which is shown in Figure 3.4. It will automatically search any available unique address for the new locomotive and re-program its decoder. While it is re-programming the decoder, the service light beside the addressing track will flash rapidly. Once the service light stops flashing and stays on, the addressing procedure in iDCC for the new locomotive is completed. The user can then replace the new locomotive back on to the main track layout and switch iDCC to Control Mode by pointing iDCC to an upright direction.

3.2 User manual

For the better illustration to marketing and programming groups, the "Tereina" user manual is written by the author at the early stage of this project. "Tereina" was a formally original given name provided from the marketing paper "Consumer Behaviour" for this product. The detail of product naming

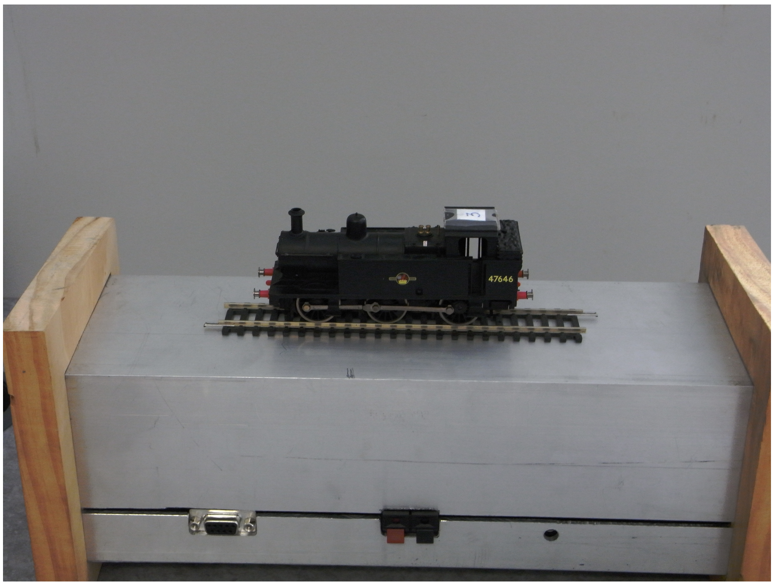

Figure 3.4: The automatic programming track activated by inversion of the enclosure.

will cover in Chapter 4.

"Tereina" user manual provides users with a comprehensive guide for understanding and operating iDCC. The manual covered an overview for the front panel, the technical electronic data and RS-232 commands. It was also used to explain and describe the functions of iDCC in details.

Later on, the programming group took it as specification for the firmware design. (See Appendix A for the full version of user manual)

3.3 Project management

The success of a project depends on clearly defined functions and appropriate managements. iDCC project is a year time-limited project due to the time frame of Master of the Engineering program in the University of Waikato. In a year's time, the author acts as a project manager to keep track of the status of individual tasks within a project. The aim is to get the hardware, the software and the marketing material ready for the commercialization. To precisely manage the timeline of this project, a Gantt chart is used for project planning. (See Appendix B for detail)

In the project, we take full advantage of using all sources that the university can provide, such as papers MKET215 ”Consumer Behavior” and COMP314 ”Software Engineering Project”. However, it also means that the part of first half timeline and the most of second half timeline has to be coordinated with the schedule of these papers.

In the first half of the project, we plan to cooperate with the marketing paper to come out with the product name and the tagline. The procedure of product naming includes an assignment design, a presentation and a name selection. The product naming procedure expects to be completed in the end of April.

Gaining knowledge of the previous hardware and software expects to take four weeks for the development for both marketing and programming groups. At same time, the author is preparing the user manual and the mock-up case for the programming group in the second half of this project. One week is spend on the stability test of the previous iDCC hardware. The hardware development happens right after the user manual completion.

The paper ”Software Engineering Project” starts in the mid of June at B semester, but the actual programming team members for iDCC project are selected and announced in the end of July. The programming team has around 14 weeks available for working on the project. In this time period, the author has to assist the programming team to understand iDCC hardware and embedding a language as they haven’t come across it before. The firmware expects to work full tasks as the user manual stated. The due date for the programming team participation is on 19th of October.

Later, marketing materials for Kickstarter such as the product description, pictures and the video advertisement are prepared for releasing for the rest of time. According to our plan, this product should be released on Kickstarter website in the mid of January 2013.

Chapter 4

Hardware

Author received a circuit diagram and a iDCC hardware which had been used to prove the scan and invert-to-program functions worked by previous researcher at beginning of this project. The hardware had been tested by the author, all the functions worked in half way but it is enough to proof the design of hardware was good. The problem of half working functionality is from software side.

4.1 Understand of the previous hardware

A typical DCC command controller is in combination with its power module. It supplies an estimation of 15V to the track according to the RPs standards provided from NRMA [6]. A pulse width modulation (PWM) module modulates the 12V to 15V DC voltage on the track to encode the control message while providing power.

The DCC standards from NRMA make the technical specification depending on the length of the time for voltage pulse, the magnitude of voltage that supply the track and the format of encoding message in the DC pulse. Accordingly, a power module, a microprocessor, some connectors and the PWM module are the only components required to form a basic DCC command station.

Here we break the previous hardware into small section and explain in detail.

1. Power module

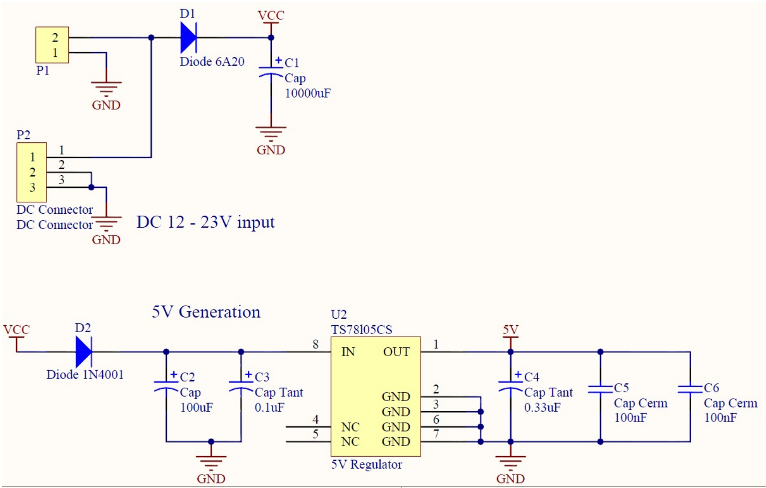

Figure 4.1: Power input circuit and 5V power module are for first prototype iDCC.

In first prototype iDCC, a 7805Bt 5V voltage regulator is used to supply 5V power source to PIC 16F960. The external power input voltage range is restricted between DC 12V to 23V. 23V is the maximum voltage that is allowed to use for transmitting power through the tracks according to the NMRA standard.

A 10000μF capacitor is used to smooth the pulsating power input, so nearly constant DC voltage is supplied to the track and the 5V regulator.

2. Microprocessor

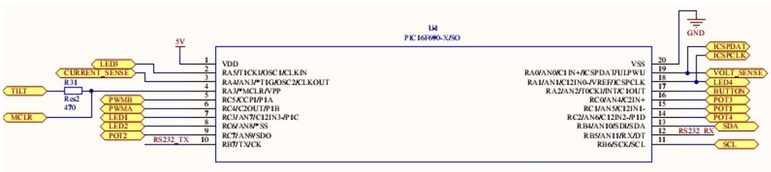

Figure 4.2: PIC 16F690 is used in iDCC.

The embedded microprocessor for this iDCC is PIC 16F960 which has only 4096 words program memory; while 88% of its program memory is consumed by the existing program. Increasing the size of the program memory is crucial in the future if additional functions are required.

There are total twenty pins for PIC 16F960. Except for VDD and GND pin, the rest of pins are occupied and assigned for particular functions.

3. PWM module

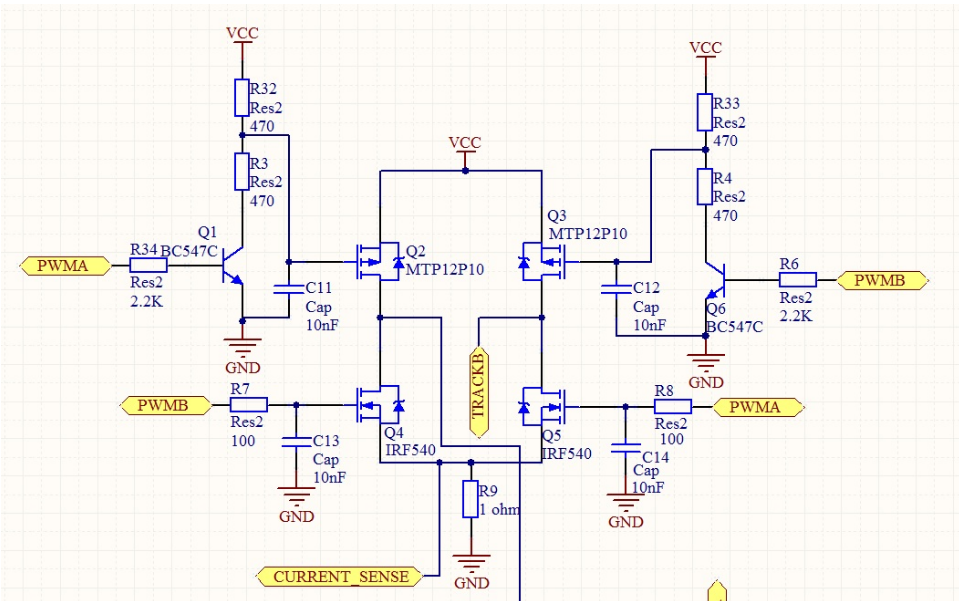

Figure 4.3: H-bridge design of first prototype iDCC.

Half H-bridge design is used in iDCC. Figure 4.3 shows that PWM module of iDCC consists of 2 P-Channel MOSFET (Q2, Q3) and 2 N-Channel MOSFET (Q4,Q5) to form a H-bridge for creating rectangular voltage waveform. PWMA and PWMB pins from the microprocessor (μP) control the timing of open and/or close gate of H-bridge. There are two pairs of a voltage divider: resistor R32 and R3, and R33 and R4. These voltage dividers are used for dropping the voltage level on the P-Channel MOSFET to half of Vcc when the P-channel MOSFET opens.

When PWMA is logic 1 (5V) and PWMB is logic 0 (0V), Q2 and Q5 are turning on, Q3 and Q4 are off. Current goes from Q2 to the track and back to Q5 then to the grounds to form a positive rectangular waveform. When PWMA is 0 and PWMB is 1, it will go opposite and hence form a negative rectangular waveform.

Capacitors C11 to C14 are filtering the possible spike that is created from PIC. Resistor R9 works as the current sensor for the scanning function which is covered in Chapter 3.

4. RS-232 pc communication module

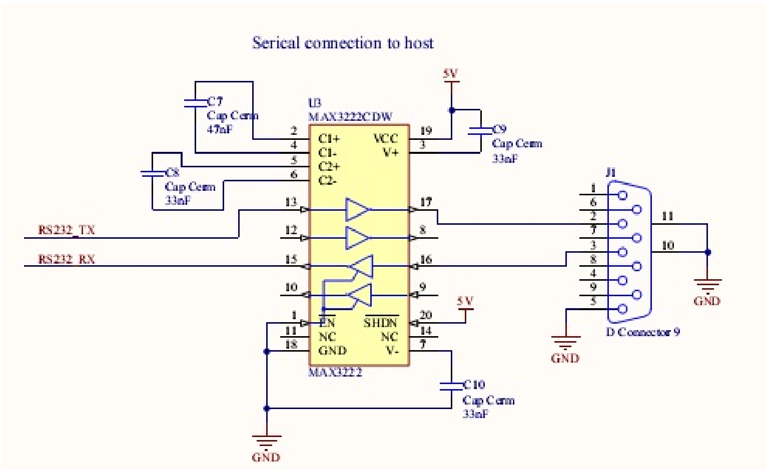

Figure 4.4: MAX3222C transceivers is used to support RS-232 function.

The different voltage levels run at a μP and a computer. To enable a true RS-232 computer serial port to communicate from the μP, the most common MAX3222 transceiver is selected. By having the transceiver, 0V micro-controller signal will change to -15 computer voltage; In contrast, 5V μP signal will change to +15V computer voltage. In fact, the voltage will only get closer to +/- 9V. MAX3222C transceivers has low-dropout transmitter feature and requires four small charge pump capacitors to work in full function.

5. Tilt sensor

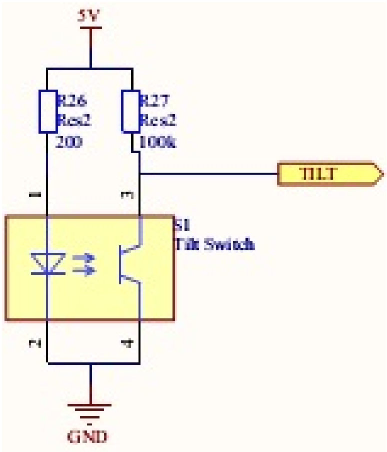

Figure 4.5: Tilt sensor module is for detecting position of iDCC.

A tilt switch S1 works as a tilt sensor to detect the controller position. When the controller is facing upright, "Tilt" pin of the μP will receive positive 5V as logic 1. Logic 0 will be received when the controller is flipping to an opposite direction. This is for detecting iDCC as in control mode (upright direction) or service mode (inversion).

6. Buttons module circuit

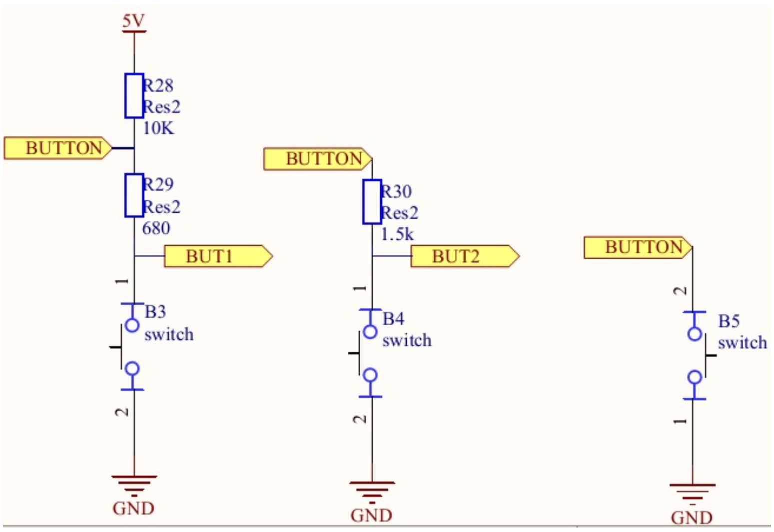

Figure 4.6: Buttons module uses voltage divider technique.

Three push-buttons are used individually for three basic functions: emergency stop functions, Light/ horn switching function and scanning function covered in Chapter 3.

These three push-buttons share the same pins due to the limit of the number of pin on PIC16F690. The simple voltage divider technique is applied to recognize each button. BUTTON pin of the μPr is set to analogue input and read the voltage variation when one of buttons is applied.

R28 is the top resistor of the voltage divider. When B3 button is pressed, voltage that runs across the BUTTON pin of the μP will be:

$$5V * (680/(10K + 680)) = 0.32V$$

However, when B4 button is pressed, BUTTON pin becomes:

$$5V * (1.5K/(10K + 1.5K)) = 0.65V$$

BUTTON pin of the μP will received full 5V when B5 buttons is pressed.

4.2 Issues from previous hardware

There were few issues that are needed to be expressed while the previous hardware has been tested.

- Supply current for the track is limited by 1A diode.
- H-bridge heats up when attempting to draw 4A current from the track.
- The footprint connection of buttons are wrong.
- Three push-buttons shared an analog due to pin limitation of microprocessor.
- A bigger program memory is needed.

Replacing 1A diode with 6A diode could solve the problem of the limit supply current.

Our primary aim is to design a controller that is able to use all scales of model locomotives. The current required from the locomotive varies on the different scale of locomotives, therefore the power supply of the controller for all scales is needed to handle all current levels from tiny Z scale locomotives to 5A, the largest G scale locomotives.

PWM module such as H-bridge plays a major role of encoding control message and supplies the power to the track. The common problem of H-bridge is overheating when it draws a high current. The P-channel MOSFET (P-mos) of H-bridge is the likely cause of the overheated problem and this is due to its high Drain source ON resistance (Rds on). The following testing circuit layout was set up to test how much current it can draw while H-bridge module is set in the safe temperature range.(see Figure 4.7)

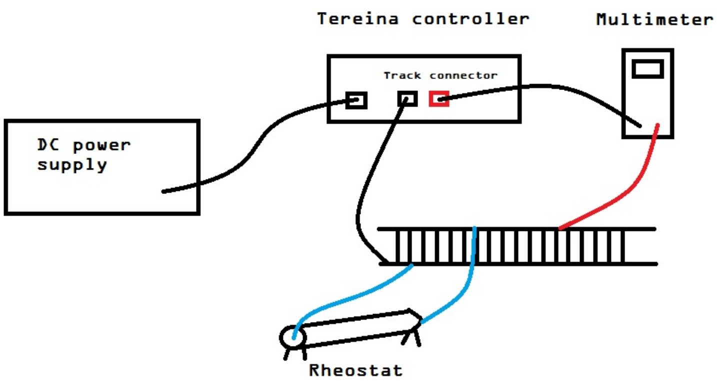

Figure 4.7: The testing circuit of safe current draw for train controller.

The infra-red thermometer Lutron TM-2000 is used to measure the changing of H-bridge while the draw current is increasing. This experiment engaged under a normal room temperature of 24 °C in the electronic laboratory. The following data was recorded and repeated twice.

According to the datasheet, the maximum operating and storage temperature range of the Pmos is from 65°C to 150 °C. From the result, the temperature of 120 °C was measured at 1.1A, but the aim of our controller should achieve up

Table 4.1: Relationship of Current and Temperature of high driver side P-mos

Current(A)	Temp(°C)	
	1st time	2nd time
0	24	24
0.12	24	24
0.34	25	26
0.5	26	26
0.6	37	37
0.7	42	43
0.8	66	67
0.9	90	92
1	94	97
1.1	118	120

to 4A. This issue can be fixed by changing the H-bridge design to four N-mos instead of two P-mos and two N-mos.

The current microprocessor on the iDCC is PIC 16F690 from Microchip Inc. Further referring to Section 4.1, it should be upgraded as the program memory was insufficient to support extra functions of the program. The following features were taken into consideration while selecting upgraded microprocessor:

- ECCP+ feature for the PWM
- 2 Timers
- more than 8 10 bits Analog-To-Digital Converters
- much bigger than 4096 words program memory
- extra pins for extra function
- similar price range (low cost)

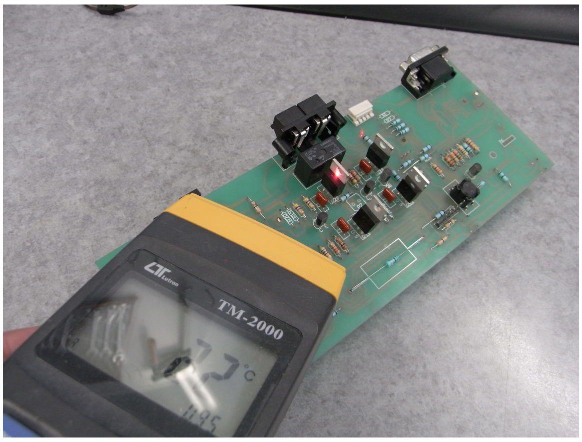

Figure 4.8: The source of the heat is confirmed and located at high side drive P-channel MOSFET of H-bridge.

Microchip has over hundred types of PIC microprocessor. There is a web function called "Microchip Advanced Part Selector" from Microchip which was used to search the desired microprocessor that is achieving all the replace to after requirements [10]. From our observation and specification, PIC 18F26K22 is the most suitable choice. It has a 32768 words program memory which is eight times bigger than a 16F690's program memory and eight more pins on the PIC were added for the additional function. The cost of 16F690 is NZD$4.22 while comparing to the price of 18F26K22 which is NZD$5.63. There is not much difference in terms of cost and consequently, PIC 18F26K22 is selected to replace 16F690.

The potential problem of using PIC 18F26K22 was that the current development programmer software MPLAB did not support 18F PIC. Furthermore the development programmer PICKIT2 only partly supports it. The new PICKIT 3 views it as the full functions to support to 18F PIC, but it costs US $50. If we are to consider it from the market perspective, this is a cost that should be avoided.

In the end of 2011, Microchip released the new firmware for PICKIT2 to provide programming support for additional devices that MPLAB IDE does not support. [11] By updating firmware file to the latest version, PICKIT2 can now load the C code into 18F with limitation through the In Circuit Serial Programming (ICSP) method.

4.3 Development and redesign hardware

In the new hardware, these problems that were identified in Section 4.2 were taken into consideration and fixed to increase its stability. There were also a redesign and an improvement on the power supply system. An extra Programming indicator LED have been added to the new hardware. There was also a change for the current sensor to prevent the damage on the resistor when a high current was drawn from the track.

Nowadays, smart phone can be seen everywhere. People are heavily depending and addictive to the phone applications. Using a smart phone as a remote control has been done before with toy helicopters and remote cars. The impressive sale number with those types of toys and phone applications proves that this idea will add an outstanding value to our final product. Therefore we decided to add a Bluetooth function into our controller, so users are able to operate the model train via the controller itself, computers or smart phones.

In this section, the improved design on each part will be explained in detail.

1. Power supplies

   The new hardware which is called "Tereina" has multiple voltage 5V and 3.3V supplies on the PCB. Extra 3.3V supply required due to the new added 3.3V Bluetooth module, but these supplies shared the same input power source of DC 12V.

   The potential problem is if two or more supplies are cascaded, the overall efficiency is affected. Say if two supplies each of which is 80% efficient, and they are joined together. Power drawn from the second power supply incurs losses in both, so it only actually get 64% efficiency overall.

In our case, Tereina draws the most power from the main power input 12V, therefore the circuit would not have efficiency problem.

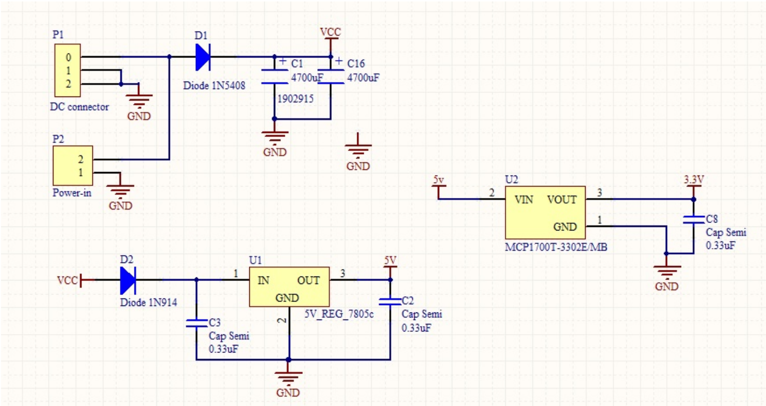

Figure 4.9: Multi-voltage power supplies are for different module in Tereina.

The primary power source and the 5V supply module still use the same design as before.The size of 10000μF capacitor was over the height we expected, therefore the two 4700μF capacitors were connected in parallel instead of the one 10000μF capacitor. A MCP1700 voltage regulator was used to supply 3.3V to the Bluetooth module RN-42

2. Bluetooth module

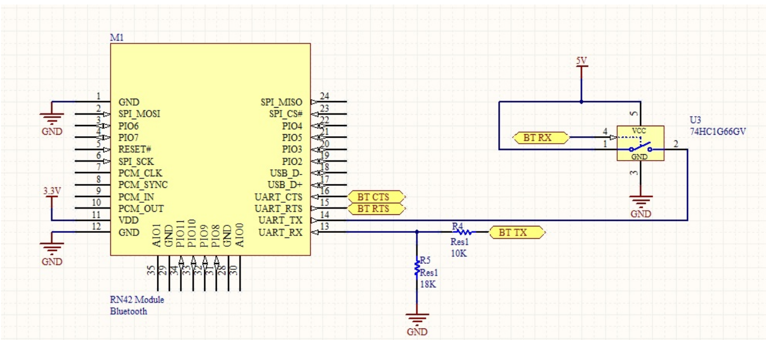

Figure 4.10: Bluetooth RN-42 module with application.

RN-42 Bluetooth is the most common use, a small form factor, low power, class 2 Bluetooth radio for designer's who want to add wireless capability to their products. It used 3.3V power which is different from the 5V primary supply and rest of circuit.

Potential problem were cause when RX and TX are trying to communicate the signals between Bluetooth and microprocessor. To illustrate, when microprocessor try to send the logic 1 signal (5V) through the Bluetooth module, the 5V signal that exceeded its maximum input logic high level voltage (3.7V) of RN-42 will cause damage to the Bluetooth module according to datasheet.

The simplest way to solve problem was to add a simple voltage divider as shown in Figure 4.10. The resistor R4 and R5 will then dropped the TX signal of microprocessor from 5V to 3.2V.

$5V * (18k/(18k + 10k)) = 3.21V$

As found in page 441 in the PIC18F26K22 datasheet, the minimum input high voltage with TTL buffer on I/O input is 2.0V, consequently 3.3V is the detectable voltage level for logic high. When a logic high signal 3.3V was received by the Bluetooth and transferred tomicroprocessor; the microprocessor is able to detect 3.3v as the logic high signal easily. While on the other matter in relation to the commercial product, any possible uncertainty factor should be prevented. A level shifter U3 was used to shift a 3.3V signal to 5V signal and guarantee that a 5V signal was always transmitted to the microprocessor when the logic is high.

3. PWM module

As shown in Figure 4.11, Q1 and Q2 were replaced by the two N-Channel MOSFETs. The reason of change was that P-Channel MOSFET almost had six times higher Drain - source ON resistance 0.3 than N-channel MOSFET 0.055 Rds(on). When dealing high current drawn, resistance hugely effects power dissipation according to formula $P = I^2R$. This

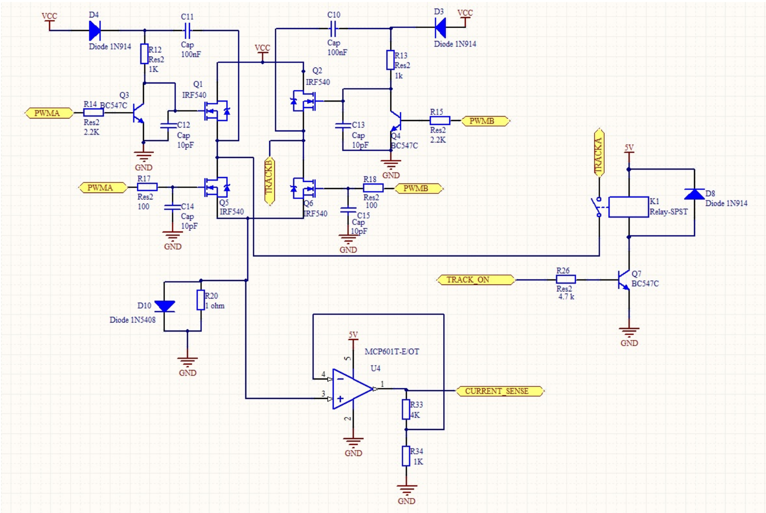

Figure 4.11: Four Nmos H-bridge.

power usually converted to heat and then conducted or radiated away from the device. When the highest current 4A has been drawn from the track, power dissipation of high side P-Channel MOSFET will be:

$P = 4^2 * 0.3 = 4.8W$

Power dissipation of replaced N-Channel MOSFET will be:

$P = 4^2 * 0.055 = 0.88W$

From the above calculation, power dissipation of N-Channel MOSFET was much less than P-Channel MOSFET which means heat from PWM module reduced. We also dissembled and investigated H-bridge combination of the current DCC product, four N-Channel MOSFET H-bridge are used in Hornby controller. This makes us believe that four N-Channel MOSFET H-bridge is the right decision.

There is another important problem that we have to consider for using 4 n-channel MOSFET H-bridge. When driving high side MOSFETS of H-bridge, a N-channel MOSFETS required a positive voltage at the gate with respect to its source. PIC 18F26K22 was used to control switching timing for the H-bridge; therefore 5V was supplied from PIC to the logic gates. Since the main 12V supplied to the track which was connected to the source of the high side MOSFETS, when one of the high side MOS-

FETS was turning on, the voltage at the source of the MOSFET raised to a little less than 12V. The logic can only drive 5V. This makes the Vgs negative with respect to the voltage on the track, thus the MOSFET is closed when it should be opened.

The ”charge pump” method was used to approach this problem. Capacitor C10 and C11 worked as the bootstrap capacitor. When Q3 was on, the bootstrap capacitor C11 was charged up, when Q3 was off, the C11 pumped back the energy that stored before into the high side MOSFET. This will pump the voltage on the gate of MOSFET to near double of VCC. In our case, 24V was supplied to the gate of top MOSFET; the Vgs will become 12V which makes the high side MOSFET fully on.

4. Current sensor

The current sensor at the bottom of H-bridge is the required part of the scanning function. The old current sensor was used a single 1Ω resistor, it worked perfectly when there was only about an average 450mA drawn of from the track. When a total 4A current has been drawn from the track, a 16W power dissipation on the 1 resistor exceeded its limit and this would burn the resistor.

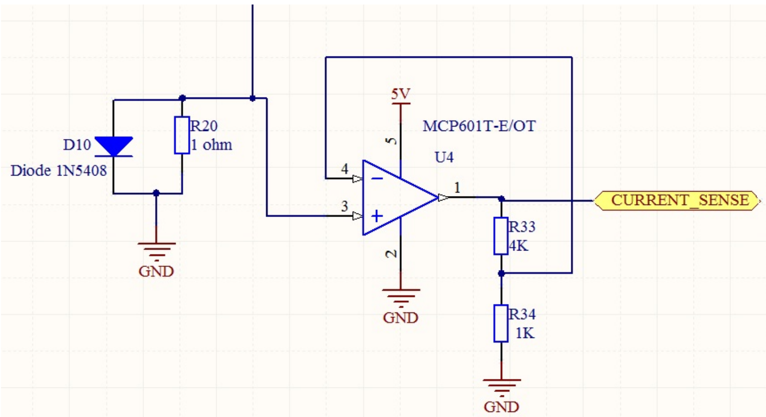

Figure 4.12: New current sensor circuit.

The new current sensor also used the 1Ω resistor R20, but it paralleled with a diode. When the current is over 0.6A which makes voltage across the D10 diode and the R20 resistor over 0.6V, then the D10 diode starts to conduct and control the current. When a 1A current is passing through a diode, theoretically the 0.8 forward voltages will be detected and pass through the U4 operational amplifier (op-amp) shown in Figure 4.12. When dealing with the maximum 4A current, an estimated 0.88 V forward voltage will be detected according to characteristics graph of D10 diode.

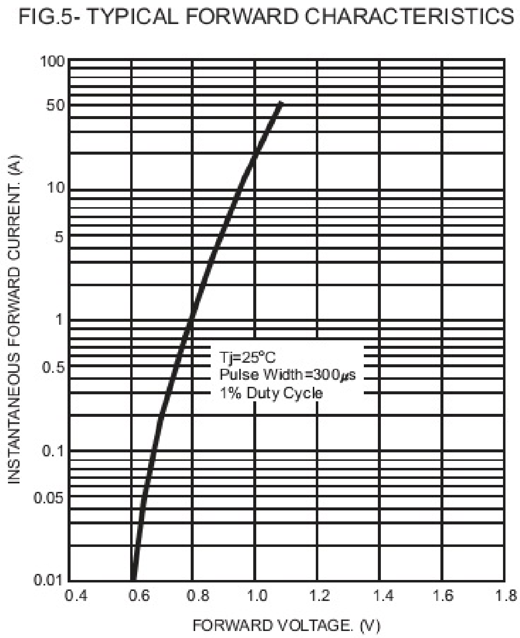

Figure 4.13: Typical forward characteristics of the D10 diode.

The voltage change between varying currents was small due to the D10 diode; therefore the U4 operational amplifier (op-amp) was needed to amplify the difference of the voltage change. A negative feedback of the op-amp circuit was designed and applied to this current sensor. The overall gain from the feedback op-amp circuit was determined mostly by the voltage divider R33 and R34. The Vout of the op-amp is just sufficient to reach around and pull the inverting input to the same voltage level as V positive.

In our case, the voltage gain of the current sensor is determined by $1 + (R33/R34)$. The overall voltage gain of our circuit is 5 times.

If a normal 400mA current is drawn from the track, the voltage across the 1 resistor will be

$$V = I * R = 0.4A * 1 = 0.4V$$

It is not exceed 0.6V, the D10 diode will not conduct. Vin will remain at 0.4V,Vout will be at 2V.

$$Vout = Vin * (1 + (R33/R34)) = 0.4V * 5 = 2V$$

If a 1A current is drawn from the track, the D10 diode starts to conduct and drop the voltage level approximately to 0.8V at Vin of op-amp. Vout will become 4V.

$$Vout = Vin * (1 + (R33/R34)) = 0.8V * 5 = 4V$$

The maximum supplied current for Tereina controller was designed to be 4A. When a 4A current is passing through the track, the maximum 0.88V voltage will across the 1 resistor which will not damage the resistor and also reduce the power dissipation.

5. Programming LED

   A single LED was added to indicate the progress of programming a new address of decoder on the locomotive.

The full version schematic of Tereina is in Appendix C.

4.4 PCB layout

The PCB layout of the previous version of hardware was given. It was a single side PCB design and the most of passive components were in the top layer. The potentiometers, LEDs, pushbuttons, the microprocessor and the entire route were on the bottom layers. 17 jumpers were used in the layout.

The new PCB layout was designed on the base of the full version of schematic in Appendix C. The First version of the new PCB layout followed the previous design rules, such as a single side route. It was too difficult to complete all route in one single side because extra 8 more pins of a microprocessor and modules were added. More than 25 jumpers were used in the single side design. The routes on the single side were too crowded, this might cause shorted between the tracks easily.(see Figure 4.14)

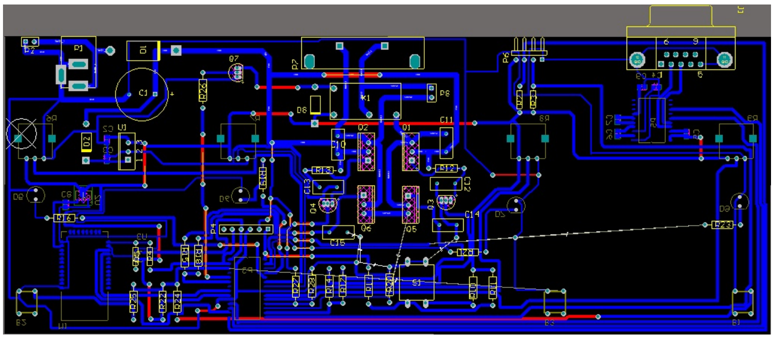

Figure 4.14: Crowed route around microprocessor on first version PCB layout of Terina. Red wired is where the jumper used.

The solution to avoid those crowded routing was that redesign into a double sides PCB layout. The cost of the double sides PCB production was the only factor worth considering regarding to the commercialization process. Reducing raw material costs results in the profit increasing without any burdens on the final setting price. It enables the capacity having a competitive price while comparing to another similar product as well. Couple of PCB manufacturers based in NZ have been contacted for the quote of the PCB. The cost of a single side PCB was normally 8 to 10 dollars cheaper than a double side PCB. The price difference was minimal and acceptable.

A new double sides PCB layout hardware version 1.0 was created. Most electronic components were still remained at the bottom layer, but the route of the PCB layout now was much clear and less crowded. Only 12 vias were used in the design. After adjusting position of potentiometer, rearranging components and customizing screw holes were made, the final hardware version 1.8 of the PCB layout with screw holes was now completed.

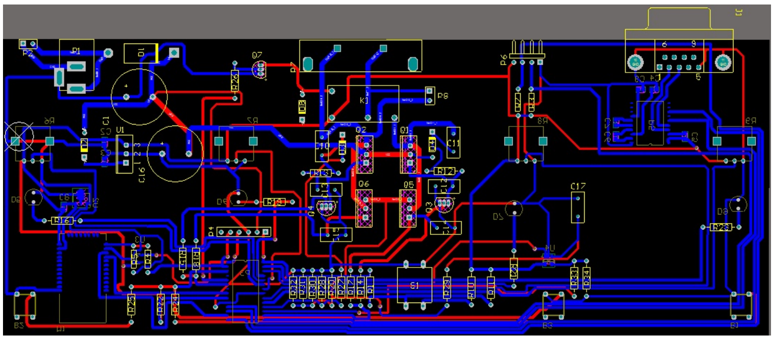

Figure 4.15: Completed double side Tereina PCB design.

Here is what a first hand-made prototype board based on the hardware version 1.8 shown in Figure 4.16. The detail of component layout and PCB layout are in Appendix D.

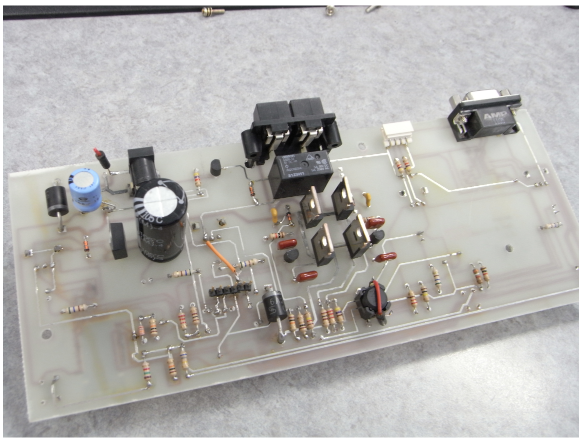

Figure 4.16: First prototype based on hardware version 1.8.

Figure 4.17: Original enclosure case of iDCC.

4.5 Enclosure case design

The first enclosure case was made by Professor Jonathan Scott shown in Figure 4.17. The rectangular box is made of aluminum and the end-plates are two pieces of wooden boards that was designed purposely to hold the enclosure. The two wooden boards were arranged to allow the control panel to slightly tilted forward.

The aluminum case was cut straight from a 10 meters long building material. Aluminum is a type of metal to easy work with. It also has a rust-resistant feature. The case dimensions are 300mm*100mm*100mm. The holes on the panel were designed for the speed control knobs, LEDs and push-buttons.

The iDCC board could not be able to fit into the enclosure at the beginning, because the size of PCB board with the track connector and RS-232 connectors exceeded the fitting length for the aluminum case. To solve this problem, the cutting of rear plate to the aluminum case had been done as shown in Figure 4.18. The cutting machine in the workshop of the University of Waikato could not hold the rectangular case on the edge and execute the cut; as a result, the simple hand saw was used to cut the rear side of the case.

The cutting process took around 30 minutes. Nevertheless, with that the case needs to manufacture in the quantity of 10 or more in mind, this was not be

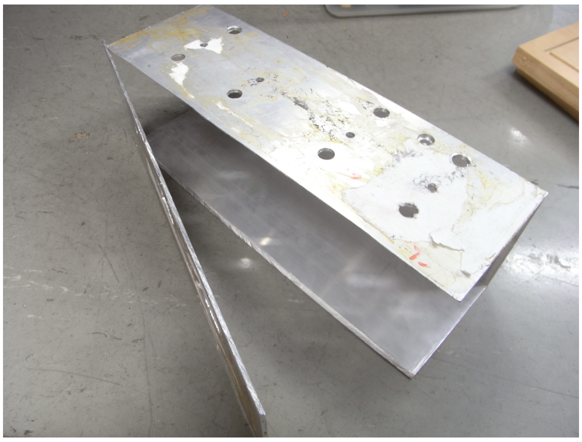

Figure 4.18: Separated rear plate of case.

the ideal and efficient method used to produce the case.

The second case design was based on the same material and specification to the first case. This case was required for the demonstration purpose to the software and marketing group. The second design was aiming mainly to arrange elements, as well as the best way to accomplish the purpose of manufacturing. The primary purpose of the second case design was to improve the accessibility of assembly and manufacture. As shown in Figure 4.19, the change of the design was made by separating the aluminum case by 26mm from the top in horizontal direction. In this design, the cutting machine in LSL can easily hold up the case in an upright position and cut through the case. The time of the cutting process would then be reduced dramatically from 30 minutes to 1 minute.

The hardware circuit board was secured and screwed on the top plate of the case as shown as in Figure 4.20. By doing this, the circuit board holds firmly on the top panel which also ensure that the buttons and the adjusting knobs will fit into each desired hole. It also prevent any physical damage to the circuit board from any point of view.

The first two case designs were made at the early stage of the project. The change of the case design was only suggested by the marketing team of this

Figure 4.19: Second case design.

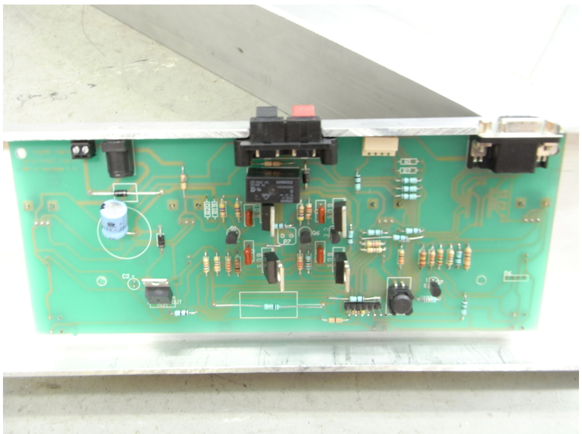

Figure 4.20: Circuit board attached to the top panel.

project after the research and the investigation of project on the Kickstarter website have been carried out.

The enclosure case design is another important attractive point for the users who are interested in the purchase of this product. Take the example of the Apple Company; Jonathan Ive is the English designer who leads the design team at Apple. His team has mainly focused on designing major Apple products including the most popular product - iPhone. The external appearance of iPhone was unique and fashionable. The most of young customers nowadays choose to buy iPhone because of not only its functions; but also its appearance. In the end of 2012, Apple especially obtaining the Intellectual Property right of the external appearance design of iPhone 1 also makes this aspect loud and clear.

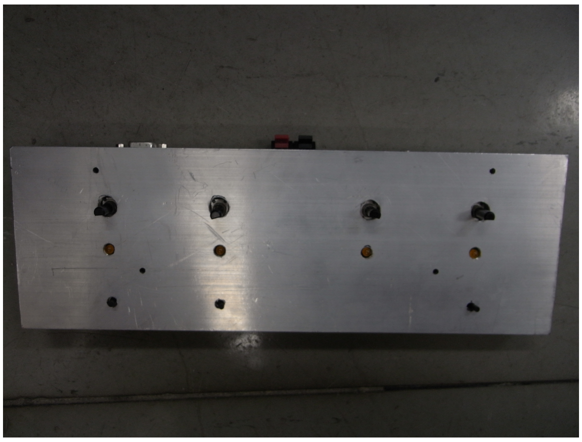

Figure 4.21: Pushbuttons, LEDs and adjusting knobs were fitted in firmly.

The third case design idea initiated from the controller of an old video game console shown in Figure 4.22. The simulation 3D view of the case design was created by the software "Solidwork 2013". The material of this case consists of two aluminum plates, five 50mm and four 25mm spacers. The purpose of this design was to reduce the material use on the case and drop the manufacture cost. The process of assembling the case was relatively easy due to the design.

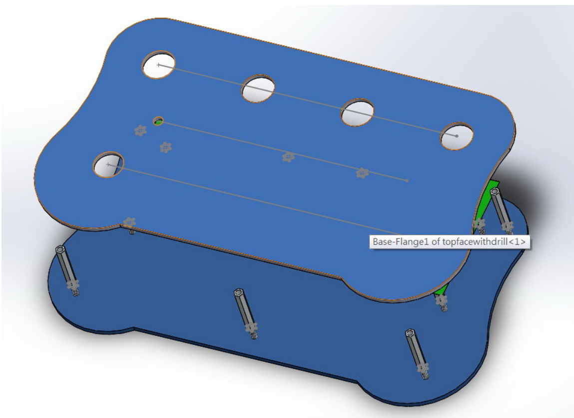

Figure 4.22: 3D case view of third case design.

The idea of leaving the electronic components exposed was not recommended by the author's supervisor. Yet, the completed product design will certainly have to be fully covered and protected in the box if it serves the purpose for commercial sales. The reason of sealing the product in the box is to prevent the electronic components damaged by inevitably daily manual operation such as touching. It also gives a reasonable amount of protection from dirt and moisture etc.

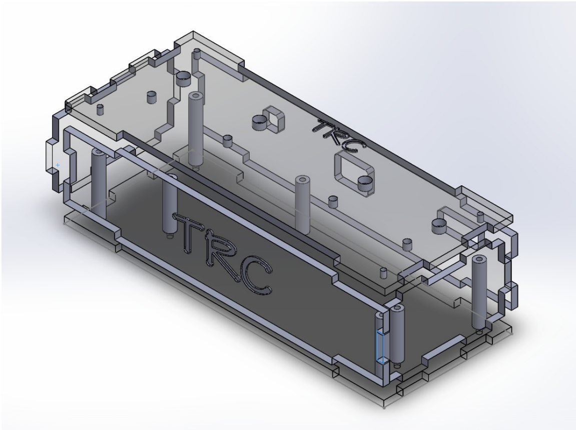

Figure 4.23: 3D case view of final case design.

The fourth and final versions of the case design were created and made of acrylic material. The feature of the see through box is popular. By allowing electronic components being seen creates a "modern" feeling and an excitement to the consumers. The final case required the process of water jet cutting and laser printing.

Common 4mm thickness Acrylic panel was selected for the case material. Four 50mm spacers were mounted on the base of the case to support and secure the top cover. There were also three 40mm spacers mounted at the bottom of the case in order to support the circuit board.(See the Appendix E for details about the dimension of the final design)

Chapter 5

Software

The original code of the embedded microcontroller was written by the previous researchers. In 2011, an undergraduate engineering student undertook a summer scholarship of this project to modify and improve the code. The modified program was given to the author at the beginning of this project. The code is incomplete but it is enough to indicate that the concept of hardware was feasible.

In this project, the author worked with a 4-member team of programmers supervised by Dr. David Streader from the School of Computer and Mathematical Sciences of the University of Waikato to create the firmware to implement the human interface vision. The software team worked total around 14 weeks on the project.

5.1 Understanding of the previous Code

The existing code was written in C programming language via the software MPLAB IDE v8.70. The modified code consists of two main sections, the header files and the main C source code. There are two different header files, initialize.h and $train_control.h$ in the program. The initialize.h file focuses on initialization macros used in the train controller. The $train_contol.h$ file defines specific text term and variables used in C source code.

The *trainControllertest.c* file contained the C execute code for the iDCC. This is the major file that is able to convert all of our ideas into practical functions.

1. *Initialize.h* - header file

   There were 14 macros to be defined to initialize, including the PWM procedure, the internal oscillator configuration and so on. In this file, the Pin map of PIC16F690 had been classified. Last line of the code was an initialize combination of all 14 macros, therefore only 1 line of the code was needed to initialize all 14 macros in the main loop of C file.

2. *traincontrol.h* - header file

   Definitions for declaring variables defined listed in this file. For example, MAXTRAINS is the integer variables that determine how many times of the scanning routine have been done before it finished scanning. Currently MAXTRAINS set to 3, because iDCC controller was designed to control the maximum of four trains (address 0, 1, 2 and 3) at the same time. When the major variable required adjusting, and the $train_control.h$ file was only the file to edit. There is no longer needed to edit any other source code to reduce the chance of bug occurring in the program.

3. *trainControllertest.c* - C source file

   All the main functions of the iDCC controller were contained in this file. Every function was created individually. Some functions, such as the scanning function and the sending encoding signal function, were split into more minor functions for easier testing purposes.

The block diagram (Figure 5.1) explained the process of software affecting hardware in the controller. And the detail of each function will be explained individually.

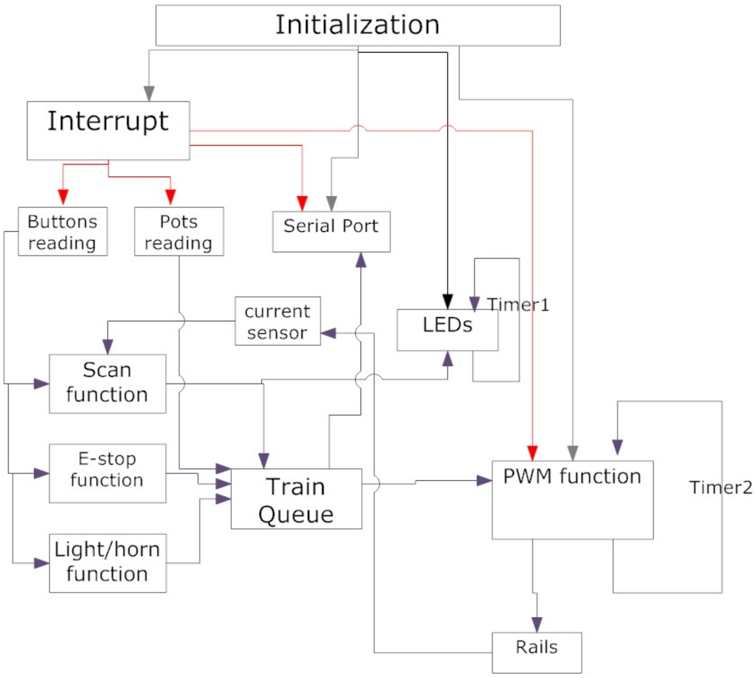

Figure 5.1: The block diagram of iDCC program logic.

All registers of the microcontroller needed to be set to correct values before it starts to function,therefore the initialize.h file recalled in the main loop for this initialization purpose. Two timers Timer1 and Timer2, also were set in the initialization and used for the PWM function, the LED flash purpose and the interrupt routine.

Train Queue

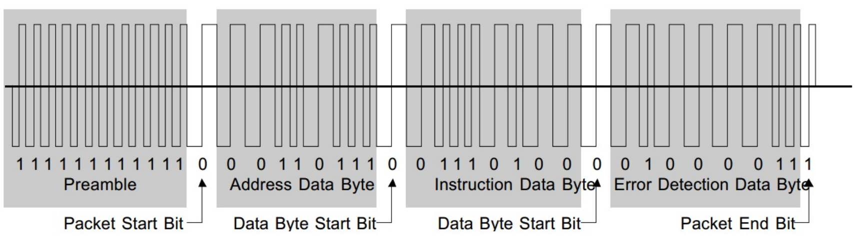

Figure 5.2: An example of an acceptable command control packet that uses three data bytes. [8]

Train Queue is the most important function that generates the full packet of the encoding command and save it into array buffer and be ready to sent to the train.It is a route that actually communicate to the train. A full valid transmitted packet used three data bytes: one address data byte, one instruction data byte and one error detection data byte (see Figure 5.2). There is a preamble packet required for proper reception before the transmitted packet. The preamble packet consists of a sequence of "1" bits. A digital decoder must not accept as a valid, any preamble that has less than 10 complete one bits. [8] The instruction data byte determined the speed and direction of the model locomotive and varied depend on the reading from potentiometers, E-stop function and serial port control. The address data byte determined which model locomotive was controlled and varied depending on the result of scanning function and serial port control.

Interrupt

The interrupt contained four individual interrupts on change action; potentiometers value reading for speed and direction control, buttons value reading for three main functions (covered in Section 3.2), serial port receiving and transmitting, and operation or service mode detection.

Buttons interrupt

When a change of buttons occurred, the interrupt of buttons reading will be triggered. For example, when the scanning button was pressed, it will stimulate the interrupt of buttons reading. The voltage across the button pin for each buttons will be different due to the voltage divider method used on the hardware. Microcontroller detected third button was pressed via analogue-digital converter (ADC) function on the buttons pin then executed the scanning function.

Pots reading interrupt

the interrupt of potentiometer reading is triggering constantly. The reading from each potentiometer will be used in the instruction data byte of train queue for steering the model locomotive.

Scanning function

In order to discover the model locomotive on track, the microcontroller generating the full packet started from the train address byte from 0 to 10 sequentially with the full speed command sending it to railways via the PWM function, and then detected the current from the current sensor to achieve the scanning purpose. If there is a current drawn from the track it means that the microcontroller finds the model locomotives with a certain address.

For example, if the train with the address number 2 was placed on the track when activated scanning function, the microcontroller will send out the train queue starting with address 0 with full speed command to the track then detect any current drawn once packet sent. If no current was detected means that there was no train with address 0 on the track. An approximately 400mA will be detected once the full packet with address 2 sent out from the microcontroller.

E-stop function

When Emergency stop function is initialled, the 00001 instruction data byte will insert into the train queue for all model locomotive. 00001 is the standard E-stop command according to RPs from NMRA. [8] The digital decoders on the locomotive shall immediately stop delivering power to the motor.

Light/horn function

In a normal standard DCC train system, only four bits (S1, S2, S3 and S) of instruction data byte were used to transmit speed information (See Figure 5.2). C bit by default shall contain one additional speed bit, but it usually worked for the extra feature such as the headlight of a locomotive or horn control. When light/horn function is initialled, the bit four of instruction data byte (C) will toggle deepens on previous status. If it is one, then zero will apply to C bit.

Serial port

Serial port was used to communication with computer to display system information such as reading of address of locomotive and volatile. It also can interfere the train queue directly. For example, executing service mode packet from computer is one of functions of the serial port.

The full version of detail commented code of the previous program is in Appendix F.

5.2 Issue from previous software

The purpose of the previous program is to test the function of the hardware and the concept of the idea, and it proved that the hardware works for the most of function such as the speed and direction control for the locomotive, the emergency stop function and others. While testing the functions that were defined in the user manual, several problems occurred:

- The scanning function was incomplete. It detected the "ghost" locomotive occasionally while scanning.
- The programming function was only set to erase all volatile memory on the Digital Decoder on the locomotive and return to its normal power-up state. The default factory address was the address 3.
- The train controller had a chance to restart automatically.

Invalid train detection

While testing the functions with the code, the controller detected the invalid trains seven out of ten times. For example, two trains with address 2 and 3 were placed on the track for testing the scanning function. When initializing the scanning function for the first time, iDCC can detect two trains with address 2 and 3 time accurately. When the scanning function reapplied again, sometimes an extra locomotive with random address would be detected.

One possible cause for this is that the remaining current from the motor of the last locomotive was detected while scanning for next locomotive. To testing if our theory was right, the gap period between scanning each locomotive was increased. The original process of scanning was that after discovering one locomotive, the controller would then move on to the next address and search for the next locomotive immediately. In fact, it gave whatever the current still left on the track no chance to vanish completely. By prolonging the gap time to the next scanning, it confers a better possibility for the total current removal. This solution ameliorates the accuracy of scanning, but there is still a small chance to detect invalid locomotive addresses while testing. The rate of scanning any invalid locomotive, however, was much lower than that of without increased time between each scanning, therefore we know that we were on the correct direction towards the ultimate solution.

Since a small chance of detecting invalid locomotives still remained, we decided to fully disconnect the track from the controller between times for each address scanning. The relay in the circuit was also switched off each time between address scanning. It ensured that the rail was completely disconnected each time, so that no remaining current stayed on the track. This new solution gave 100% accuracy of the scanning function, which means no more invalid trains were detected after this method has been applied.

5.3 New firmware

In the previous version of the program, all functions of train controllers were put into one single C- source file. There were total 861 lines of code which contain over 20 individual function calls. Even through the previous researcher already detailed commented in the code, it is still difficult to understand the logic of the program from such a long program code.

In the new firmware, the main C code is split into five different C source files: $buffer.c$, $interrupt.c$, $packet.c$, $serialbuffer.c$ and the main $traincontroller.c$. Each source file contains its own related function calls. For example, $buffer.c$ file contains all the function calls for the buffer function and it has its own header file to define all variables used for the buffer. This is the method the computer programmer always applies to their code for a clear layout.

- $buffer.c$ - The code creates the function calls that can add bits and a packet into a train queue. There was the $Buffer_freespace$ function which can calculate the size of free space in a train queue. The $buffer.c$ file collected all function calls about modifying a train queue.
- $interrupt.c$- It was all about interrupt functions such as button interrupt, timer interrupt and others.
- packet.c file In this file, the certain format of a packet according to NRMA PRs was set. When a function is called by the users, it searches through the code and find the particular packet to send out.

  111111111111 0 00000000 0 01000001 0 01000001 1
  Preamble Byte One Byte Two Byte Three

  For example, when emergency stop function was called, PIC searched through the file and created a three byte packet like above and sent to the rail.

- serialbuffer.c file All communication functions to computer locate in this file. It includes add or read byte from serial buffer and recognize the customize format code in order to do specific function.

5.3.1 New program workflow

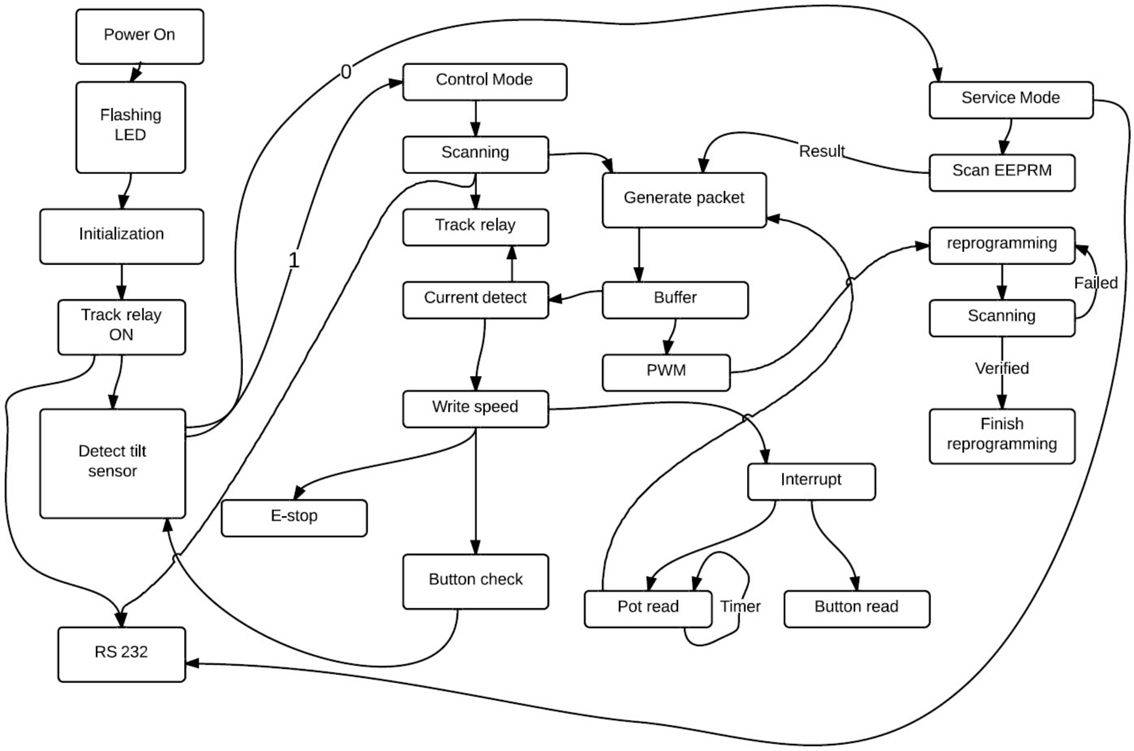

Figure 5.3: Flow chart for the new software

When Tereina is powered, the microprocessor (μP) will first flash the indicator lights to show the power is on and then run the initialization for some μP operations. The initialization includes

- Setup for PWM operation
- Internal oscillator configuration
- Interrupts Enabled
- General Registers
- Setup I/O pins
- Setup ADC parameters

- Timer configurations
- Setup for EUSART(RS232) different font from others
- Setup for I2C port different font from others

After the initialization is completed, then μP processes to turn on the track relay to secure the connection for scanning. The operation mode will be detected by measuring the high or low logic input via a tilt sensor. By this method, it is able detect Tereinas orientation and recognize whether Tereina is in the operation mode or the service mode. Afterward the analogue to digital converter (ADC) is set to be ready to read the potentiometer regardless of the types of operating mode.

At the same time, μP also sent out a message to a computer through RS232 to reveal the starting order. "Tereina, iDCC Train Controller"

5.3.1.1 Tereina into operation mode

If Tereina is in an upright position, it will execute the scanning function first. While activating the scanning, buttons and potentiometer interrupts are disabled to prevent any interference to the scanning function. At the beginning of a scanning function, μP creates an array to store any temporary packet. The current sensor is set to ready for reading the current from the track. To preventing any current left on the motor of locomotives, Tereina will disconnect the track for about 65ms and turn it on again right after. In order to ensure a clean scanning result every time, Tereina will also clear the array of known trains from last scanning if there is any.

Now, μP proceeds to stop any currently running trains and generate a full speed ahead packet for the train with address 1. μP tells the particular train address to go full speed via this order. Depending on if there is a change of current on the track or not, the presence of a train on the track using the address 1 can be determined. The current threshold is set to be around 400mA to block any noise that may affect the scanning accuracy. Tereina can detect the current from a motor within 4 instructions and stop, then move to next train. The train appears to not be moving during the scanning function because of fast pick the current and stop, but the sound from the motor indicates the current passing. If it discovers the train with address 1, μP will send a message presenting "Train found at address: 1" to computer.

We know there always can be a chance to miss the reading somehow, so we wait for another 15μs to give the same train a second chance to be read repeatedly. After this, we disconnect the track for 65μs by switch off the relay to keep from false detection and repeat the above process with address number increase until the maximum of four trains is found or stop at address 10 by default (it can increase to 127 which will take longer.)

It is worth to mention that there is a 255 byte buffer which is dealing with the packet overload to PWM function, because a full packet being sent out completely through PWM function requires at least 2ms. The full packet is collected in a array buffer which stores address bits, instruction bits and the checksum. When the buffer is free, the buffer will grab this packet and form into a baseline packet in the buffer, and then the packet is ready for the PWM to send it out. A timer is used to control the timing of PWM function. If the "1" signal is ready to be sent out, the timer will set to 116μs to allow full cycle of bit 1 to be sent (58μs is half cycle). When the timer is overflow, it will trigger the μP to grab the next bit that queue in the buffer and send it out by reset the timer depends on the 1 or 0 signal. By the default setting it is to send a sequence of "1"s if there is no baseline packet been created.

After the train found, μP re-enable buttons and potentiometer interrupts which will send the message to the computer expressing "Scanning complete!". The emergency stop is automatically applied after the scanning function, therefore it requires to the cancel emergency stop to gain the control of train.

After the scanning is completed, the following is writing a speed packet to the train that we know it exists. It involves reading potentiometers value. A timer is used to trigger a potentiometers reading or a button reading interrupt about every 128ms. For potentiometers, this interrupt waits until the ADC is free, and then triggers a reading of the next potentiometer and stores it into the array. By this means, each potentiometer is polled more than twice per second. The speed control is depending on the reading of each potentiometers. μP will check whether the emergency stop has been applied or not. μP will not write a speed packet if the system is stopped through the emergency stop function. The direction of a train will be resolved on the position of the potentiometer being adjusted: clockwise or anticlockwise. The above procedure will be repeated for every train from the scanning result.

Processing with any buttons that have been pressed is what will happen next. This concerns the interrupt of the change function on μP. When a button is pressed, μP detectes the change and triggers the interrupt to read the button. We begin with setting a button pin of μP to the analogue input, and then we change the ADC mode bit indicate the button read happening. With it all being settled down, the ADC reading of button values can be functioned correctly. The process is similar to the potentiometers reading, but this time the interrupt records the button value and inform the mainline with the outcome. μP will re-set the same pin back up as the digital input, and enable Interrupt on Change (IOCA) for that pin. μP will execute different functions such as scan, E-stop and light switching function depending on the button value reading.

5.3.1.2 Tereina into service mode

If Tereina is placed upside down, it reprograms the train on the track to a new address. Firstly it sends out the message to a computer ordering "Reprogramming train!, and then it scans EEPROM for least used address. Each time when scanning train, the number of used times of each address will be saved into EEPROM while the power is continuously on. μP gets the train decoder to reset by default and move to attempt to program the train. While at the beginning of reprogramming, the controller direction is the first thing to be detected. If the controller becomes upright, the programming will be terminated. Then it sends the service preamble to enter the service mode for the decoder on the programming train. The train with the address that is at least used from EEPROM is programmed and μP will verify if a train is assigned to this address. If it is failed to programming the same address, μP will be back to search the EEPROM stage and repeat the procedure from then.

The full version of heavily commented code is in Appendix G in CD format. The comments in the code allow anyone can read through the code and understand the logic of the program.

Chapter 6

Marketing

A good marketing strategy is a key success factor for commercial products. Marketing strategy includes all activities in the field of marketing that can lead to increasing sales and achieving a good brand image. Product naming, slogan, retail price decision and advertising material are all important factors for the product commercialization.

6.1 Brand naming

A strong branding is invaluable because it usually results in higher sales. In most cases, product naming is the first marketing strategy involved when a completed prototype is ready for the market. It is considered as a critical part of the product. A good product name always can catch the attention of consumers which elicits the willing of consumer to understand the product.

When the hardware and the software were given to the author at the beginning of this project, the technology embodied in the hardware was referred to as "iDCC". "iDCC" idea was from iMac and iPhone which invoked the "imaginative" aspect of the user interface design. As a commercial product, the brand name is treated seriously as a trademark for protection. For that reason, iDCC is not suitable to represent the product, because the product name started with "i" word always reminds customers of Apple Incorporated deeply. This will be no benefit and in a way of deceiving since the product is not from Apple Incorporated.

The product naming process can take months or even years to complete. It involves the application of creative and knowledge of marketing. The University of Waikato offers a course entitled "Consumer Behaviour", MKTG255. This paper examines how and why consumers acquire, use, and dispose of goods, services, and ideas, with special attention to marketing, advertising, and public policy applications. The assignment was set to give out to the MKTG255 students every two weeks and there were ten parts in total during this course.

We discussed with the course coordinator Dr.Valentyne Melnyk planning to take advantage of this source fully. The assignment written by Professor Jonathan Scott and the author based on the initial iDCC controller were designed to suggest a name and a tag line. The name of "iDCC" was not mentioned in the assignments, because it would restrict the boundaries of their creativity according to Dr.Valentyna Melnyk. The detail information about "iDCC" elementary characterisation, e.g price, functions, and reliability which are relative to competition was provided to students. These attributes helped the marketing students come up with the brand naming. An associative network of consumer's perceptions for iDCC was also created to help the marketing students gather all the information they required quickly. The full version of assignment was in the Appendix H.

Before handing out the assignment, we gave the market student a small presentation. The speech about our product was given to 130 students in the lecture of Consumer Behaviour, with the aim of illustrating the functions and the advantages of iDCC to students. In the end of this assignment, total 102 brand names and slogans were submitted. (See Appendix I)

From the point of view of marketing, a brand name has to be short and easy to memorise. It also requires representing the spirit of product. Most importantly, it needs to be able to catch the consumer's attention right away. There were few brand names that have been nominated before the final selection was confirmed.

- The Fat Controller

  This name came from an UK cartoon series "Thomas and Friends". Sir Topham Hatt, who also known as The Fat Controller, is one of characters in the cartoon and acts as the head of the railway.

  It is a great name for our product for those who know Thomas and Friends, but not so eye-catching for other consumers who have a different culture background. The model train industry is a lucrative niche market worldwide [9], therefore the factor of reaching to different culture backgrounds needs to be taken into consideration heavily. For example, for people grew up in Asia countries, Thomas and friends has an alternative name due to the translation. Each character is given a distinct name as well. The Fat Controller means nothing for these people, only the image of a big heavy controller.

  The reason of this recommend name to be mentioned especially is that, out of the 102 different brand names, there were five students unexpectedly choosing the same name "The Fat Controller" to be the brand name for the product.

- EasyCon

  Easycon stands for easy controller. Simplification and a user-friendly interface were our aim and "Easycon" gives the consumer the feeling of easiness to control.

- DigiLOck

The name was chosen because of its tag line ”Simplistic, digital locomotive engineering technology”. When the brand name and the tag line are combined together, they provide a sense of the professional and high technology feeling.

- Tereina

  Tereina means the train in the New Zealand native language of Maori. This gives the product a distinct New Zealand feel which is absolutely appropriate because the product actually is made in New Zealand.

  With New Zealand alone, the market is estimated to consist of approximate 9000 consumers based on the exhibition attendance [9]. The size of the market in New Zealand is large compared to another country with their population proportionally. The name may gain the chance of support from local model locomotive hobbyists.

  New Zealand is also the favourable country around worldwide, where products made are normally assumed to be high-quality, and this is another advantage for selecting Tereina to be the product name.

  All in all, the brand name Teriena was selected to represent the product.

6.2 Tag line

Tag line is a slogan that sums up the product. The idea behind a slogan is to capture the attention of people. Great slogans are short, yet very effective The most successful example was ”Connecting People” from Nokia Cooperation from 1967 to 2006. The slogan ”Connecting People” was well-known back in time, and it appeared everywhere including in TV advertisements, in magazines or on billboards.(see Figure 6.1) Two simple words give an impression of technology connecting people together, which also truly display the core idea of Nokia human technology.

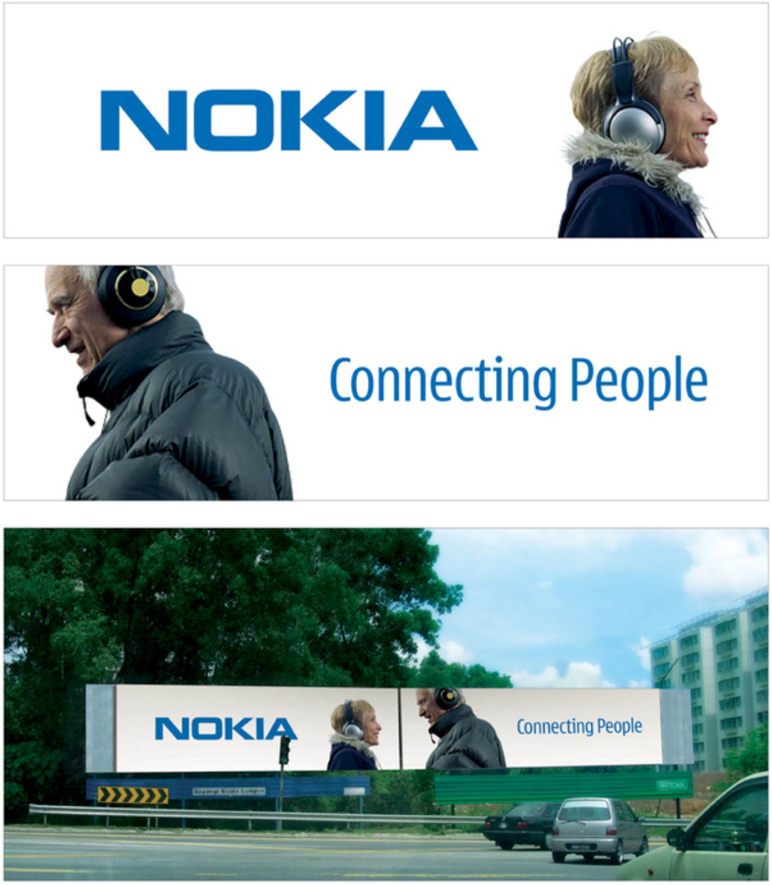

Figure 6.1: Two separate billboards worked as 1 canvas. Billboards were installed closely together to bring the image of "Connecting People" into life.

From the result of the marketing assignment, a great range of tag lines was suggested along with a brand name. Some combinations with a brand name and a slogan were left a deeper impression than others, such as

- EasyCon - Because fun should be simple
- Coach man - Trains without the Training
- Digi Command - Maximum control. Minimal complexities. The future of DCC, full steam ahead.
- DigiLOck - Simplistic, digital locomotive engineering technology

The meaning of a tag line must link to the brand name, and also reflect on the main concept of the product. A well-constructed tag line can last on the minds of consumers for years. From the marketing aspect, a good tag line should be short and not more than three words. It has to be pointing out the main features or concepts of the product. The tag line of "Optimal control. Zero difficulty. No keypad. Because fun should be simple." was selected. It was edited and combined from three different tag lines we collected. Although the tag line is longer than what is usually desired, but it states out all main features of our product. The following is the final decision on the brand name and the tag line from the marketing class.

Tereina - "Optimal control. Zero difficulty. No keypad. Because fun should be simple."

6.3 Logo design

A brand name alone normally cannot express their definition completely and utterly so we aimed to incorporate images of trains into the logo and the advertisement. When the mock up case was made for the purpose of presentation at the beginning of this project, the brand name JBRL suggesting by Professor Jonathan Scott and the author was discussed. JBRL was a combination of initial of three researchers and our supervisors (Professor Jonathan Scott) who have been involved in this project. The logo shown in Figure 6.2 was designed by the author for the name JBRL. The idea was to combine the image of a train into the logo since it is about a train controller. The J character in the logo can be deemed as the head of a locomotive with the steam coming from the pipe of a train.

Later, when the brand name was decided to change to Tereina from the result of the Consumer Behaiver assignment, the same idea was applied to the second logo.(see Figure 6.3)

Figure 6.2: First logo design base on name JBRL for the mock-up case.

Figure 6.3: Second logo design base on name Tereina for the mock-up case.

6.4 Market size

The marketing size for the DCC model train equipment is really hard to be estimated. There are two main reasons: the first one is that DCC technology has open source standards and recommended practices from The National Model Railroad Association. Every manufacturer of the DCC train equipment follows these criteria; therefore the train equipments from one manufacturer can be compatible with those from another manufacturer. The train equipments were usually shared and mixed up between the manufacturers in the consumer's end.

Secondly, most of the model hobbyists with electronic background usually D.I.Y their own model train equipments from the railroad to the locomotive by buying parts from various manufacturers and then putting it together by themselves. There are over 30 non-commercial (or semi-commercial) webpages which can provide model railway components and/or all the electronic project information.

These two reasons contribute to the complexity of the estimation on the market size of DCC model train equipment.

Figure 6.4: Model railway exhibitions held in New Zealand.

The only data connected to the market size were found from model railway exhibitions which are held around the world each year. In United Kingdom, there are 12 major model railway exhibitions held in different counties each year. Each exhibition attracted over 2000 people last year. The market in UK is estimated to consist of approximately at least 20,000 consumers, based on the exhibition attendance. Japan, UK, Europe, Australia and many other countries are also into the model railroad. The market for the model railroad is across the whole world, hence we know the size of the market is enough to make profit. In addition, Tereina controller has the functions that current DCC controllers on the market do not have, which makes Tereina controller stand out of all other controllers.

6.5 Retail price

A commercial technology product mainly costs from three areas: material, marketing and labour. In the real world, engineers are expected to take a project with a limit budge, therefore engineers also play the role of controlling costs within desired levels for the product. In the "Silicon Valley" model, engineers are also stockholders and may be even involved with whole marketing strategy for the product.

The retail price decision is another critical factor which affects the willingness of consumers to purchase a product. The decision of market selling price for a product needs to considered several factors including:

- Cost of raw material
- Cost of labour
- Percentage of profit
- Average selling price
- Uniqueness of product

6.5.1 Cost of raw material

The cost of raw material of our product included electronic components and the PCB board for hardware, and the material cost for the enclosure case.

The components selection becomes really important for reducing the cost of raw material while an engineer is developing a manufacturable prototype. The price of electronic components is varying between different suppliers. The price difference can be huge due to the amount of each component as well. The author has been searching the best price through internet, several emails and negotiations were made to minimise the cost of raw material as much as possible. The price quotes were mainly from two major electronic suppliers: RS and Element 14, both are based in NZ. The total cost of electronic components was around NZ $50. (see Appendix J for detail)

The size of the final version of a double sided PCB is $219.87mm * 86.13mm$. The price difference between customize PCB manufactures in New Zealand and in China is enormous. The price quotation from a manufacturer based in New Zealand was NZ $647.78 including GST for 6 boards. Lead time is 4 days. The PCB factory in China quoted the price for 8 bare PCBs including the shipping fee to NZ was US $148.87 , NZ $178.54 as in currency conversion. Lead time is 6 days.

PCB manufacture Cost of each PCB

PCB manufacture	Cost of each PCB(NZD)
New Zealand	$108
China	$22.3

By choosing the PCB manufacturer base in China can effectively reduce the cost of production to almost one-fifth.

The enclosure case consists of 6 pieces of different size acrylic panels. They were cut from one sheet of 1.2 m * 2.1 m which costs NZ $160. The total surface area of acrylic panels was

$2*250mm*100mm(topandbutton)+2*100mm*60mm(endplates)+2*250mm*60mm(frontandback) = 0.092m^2$

Cost of material of each enclosure case will be around NZ $6.

$Costofmaterial = (0.092m^2/(1.2m*2.1m))*\$160 = \$5.84$

The total raw material cost of TRC including electronic components and the enclosure case will be estimated at around NZ $70.

6.5.2 Cost of labour

The total time the author spent on fitting components, soldering and testing wire shorted possibility until circuit competition was two hours and 36 minutes. A student working in part-time gets paid as minimum salary NZ $13.5 in New Zealand. We were planning to hire the electronic students whom study in the University of Waikato to assemble the Tereina circuit if the number of order was exceeding our expectation. The labour cost on the assembly for each Tereina controller was estimated at around NZ $41.

The total cost of production for each Tereina controller is around NZ $110.

6.5.3 Average selling price

Basic DCC controllers from Hornby are sold for around US$150 - $400. Digitrax, one of major competitors of Hornby, has a price range for starter set product from US $220- $450.(see Figure 6.6)

Figure 6.5: Current Digitrax DCC controllers retail price.

As a basic DCC controller, fundamental control functions such as the direction control and the speed control were included. The entire basic controller from different manufacturers (price range at $150-$200) only offer the single train control at one time. The multiple train control at the same time can only be found on the premium level of controllers. The advance PC communication function only exists in the top line product.

There is a new DCC controller Z21 been released on July of 2012. The main feature of Z21 is that Z21 can control a model locomotive through tablets and smart phones. The communication between the controller and any PC was opened to users who use multi-protocol central module for DCC and Motorola format. It is the latest and also the top line product for the DCC controller, and the retail price of Z21 is US $558.20.

While the prototype was getting to completion, we noticed that the DCC controller offered a magnificent benefit to consumers because it is usable by all rather than a selected few, which is entirely different from the competitors' offerings. Regards to the functionalities, this Tereina controller should be listed in the top line product. From the market view, the lower selling prices, the better sales. But we planned to use the skimming price strategy, which means that the selling price of Tereina controller will not decrease for the competition in term of price advantage. The retail price expects to be at US $400. The prices allows for recouping of the production cost and reflecting the high quality of this product as well.

6.6 Kickstarter

In April 2009, a website called "Kickstarter" (www.kickstarter.com) founded by Perry Chen, Yancey Strickler, and Charles Adler has been released to the market [12]. Kickstarter is an American-based company that provides a web platform to raise funds for any kind of creative projects including music, film, video, technology and etc. The fund is collected through the crowed funding method. People on Kickstarter cannot "invest" in Kickstarter projects to make money. They can only "back" projects in exchange for a tangible reward or one-of-a-kind experience, like a personal note of thanks, custom T-shirts, dinner with an author, or an initial production run of a new product. [13]

As of October 10, 2012, there were 73,620 launched projects (3,426 in progress), with a success rate of 43.85%. The total number of dollars pledged was $381 million. [14] There are many successful funding cases for the high-technology start-ups across worldwide.

For example, The Genie!, a device for motion control and image capture for Time Lapse Photography was created by Chris Thomson and Ben Ryan in

Queenstown, New Zealand in April 2012. They were seeking US $150,000 for the manufacture of their device. They offered the pledger different options to pledge their funding, such as "Early bird adapter of product", "Print name on the inside of the box as a contributor on the first production run" and others. After two month pledge time, they successfully had 978 backers and pledged total US $636,766 which is 425% over their pledge goal. (See Figure 6.7)

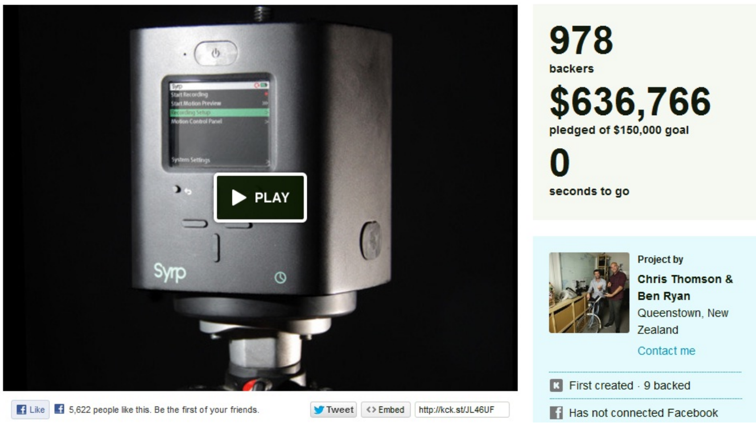

Figure 6.6: Successful example of the Kickstarter project.

The path of The Genie! is what we wish to duplicate. By studying several Kickstarter projects, a decent advertisement video, an eye-catching photo and a very detailed product description are essential. We had been trying to create the professional commercial image for the Tereina.

The full version of the Tereina product description is in Appendix K.

6.6.1 Advertisement Video

The plan was to have two advertisement videos for the Tereina. One video is the commercial advertisement and the other video is about the introduction of the Tereina for Kickstarter. However because of time limitation, only the introduction video has been made.

- Commercial ads

During the early stage of the project, Professor Jonathan provided the screen play script for iDCC. The idea of the screen play came from the early Apple Macintosh advertisement "Nightmare Before Christmas". It described a couple tries to figure out the computer they bought for the kids on Christmas Eve. It did not go well, and there were 27 callers ahead of them on the help line. In the end, the couple said "May be we got the wrong computer".

The Tereina controller has a similar situation compared to other DCC controllers as in Apple Macintosh to other personal computers. The main characters in the screen play script changed to a father and a son. The concept is that a father gives a DCC train set as Christmas gift to his son. They both are so excited about this DCC train set. The train set is assembled fast. However, seconds later, they find out the controller is way too complex to operate. The son's Christmas is ruined just because of it.

Next, we duplicated the scene. The new actors play another family which is similar to the last scene. This time the father of this family gives a Tereina controller as Christmas gift to his son instead. They do not have any problems and they know how to operate instantly. Happy Christmas is there for all the family.

- Introduction video

  Introduction video is practically for the Kickstart. Projects on the Kickstarter are usually on-going status. The introduction video allows people on the Kickstarter to understand the background of the project.

  In the video, the author introduces the Tereina and explains how it forms from a simple idea. Next, the video of Tereina shows the viewer the Tereina in action for the purpose of reinforcing the great product image. In the end, the author summarizes the product and emphasizes why pledges are important. The full version of video is in CD format in Appendix L.

Chapter 7

Conclusion

Through the role of being a hardware engineer in this project, we have gained a broad scale of the DCC knowledge from the previous hardware and the existing Hornby DCC controller. While testing the previous hardware, several issues were found and then solved. The development and the redesign of the iDCC were completed. These improvements have applied into the Tereina controller to make it more competitive and stable.

The original plan was to give a new hardware to the programming team in the mid of second half of the project, but debugging and testing on the new hardware took longer time than what the author thought. This delay obstructed the development of the Bluetooth function. The programming team could not commence to set up with Bluetooth for testing properly since the new hardware was not available. Fortunately, the program memory problem did not affect the procedure of the firmware development. In the end of the programming team participation, there was still over 20% of program memory available in an old processor through using the code optimization function.

We did a great job on the budget controlling. We have carefully selected the common electronic components and avoid using expensive items. We listed all the components and send the list out to different suppliers for the quote. After comparing between various suppliers, we discovered that the price difference could be up 50% as the largest margin and this is something we did not expect.

As being the project manager, I would have to say this project can have been improved on many aspects if more time is permitted. At the beginning of this project, we aimed to develop this iDCC product to the final commercialize package stage in the end of January 2013, but we did not manage to do so.

There were many unavoidable factors to hinder this project development. As what is detailed in Chapter 1, all the team members involved in this project are students of the University of Waikato. Just like every student, they have other commitments no matter whether they are academic or private beside this project. Each person in our teams made as much effort as they can in their best attempt though. For example, the programming team worked really hard on the firmware with the author, and we had regular meetings to keep things on track every Wednesday and Friday. The plan for the programming team is that each team member worked on individual tasks and we could construct the code together in the end. However because of it, if one of team members had a test or was being sick leading to an absence in the meeting, we would have to reschedule it the next day. It may not seem to be a huge delay, but given they only had around 14 weeks to work, this is something could really be an impact to the project. Also during the semester, the team as being students had a two weeks term break. This is something that that author cannot control. In additional, the time-line that the author set for them to complete each task had had not been met because they never came cross the embedding C language prior. These elements are something I did not notice when I drew the plan for them.

Overall, all the functions in the firmware that are covered in the user manual were completed, except for the RS232 communication command and the Bluetooth application from the programming team participation. The author himself took over the remained job to complete the most of RS-232 command later on. The new firmware provides the stability and makes Tereina an outstanding DCC controller.

For the marketing part, the product naming and the tagline processing was really successful in the first half of this project. Later, two voluntary marketing student interns joined and helped with marketing material. We have done estimating the marketing size of the train models, and successfully designing the logo for our product. The video advertisements also were finished and ready for the Kickstarter. There is one thing worth to mention. As being volunteer interns, the marketing work of this project for them is an extra work which they had devoted themselves to in their leisure time. Hence it is understandable that they spent a bit longer than how long they actually needed. Nevertheless we achieved all the requirements of the whole commercial package for the Kickstarter.

In conclusion, the current Tereina controller is ready to be released into the market as an entry level DCC controller. Yet, there are always some more works which can make this Tereina even more competitive with other DCC controllers on the market.

Apart from the product, this project is a new framework experiment for a Master degree project. The typical master project usually allows a student to work on his/her own to carry out the research and gain the help from their supervisor. However, this project is to work with several teams from different professional areas, which is like a down-sized version of the real industry environment. From the outcome that we have presented in this thesis, we believe that this type of framework is sustainable so that it can be applied in any Master or even higher level project at any institutions.

7.1 Future work

In this project, we focused on the three main areas for this product: the marketing, the software and the hardware. We suggest following these three main directions for any future works.

We finished all the material for the marketing. Even though there are always rooms to have superiorly creative ideas for the video and also the better post-production work for the visual part. It will help leave deeper impression to the consumers.

The future work could pay attention on reducing the cost of raw materials. Currently, all the price quotes except for PCB are from NZ based companies. If we can have find all the parts in Chinese companies, I expect that the cost will lessen 10% to 20% more.

We completed the hardware with the Bluetooth function, but the currently firmware does not support it. The future work could focus on the region where the development of a firmware supporting the Bluetooth application. Such auto-communications between two controllers via Bluetooth will enable the controller to control up to eight model trains. The development of the smart phone application for the iDCC to control model trains through the firmware and Andriod/iOS application is another area worth exploring. Furthermore, the RS-232 communication in the current firmware needs to be completed to meet the requirements for the general DCC software, such as JMRI computer control which based on EasyDCC operation command [15].

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Appendix A

Tereina user manual

Tereina
User Manual

Optimal control. Zero difficulty. No keypad. Because fun should be simple.

Jonathan Scott & Benson Chang

March 26, 2013

Quick Start

Tereina is a new form of controller that simply eliminates the complexity. You no longer need to be a geek to control a digital train. Simply connect Tereina to your model railroad track and turn it on. Figure 0.1 shows how to connect Tereina to your layout.

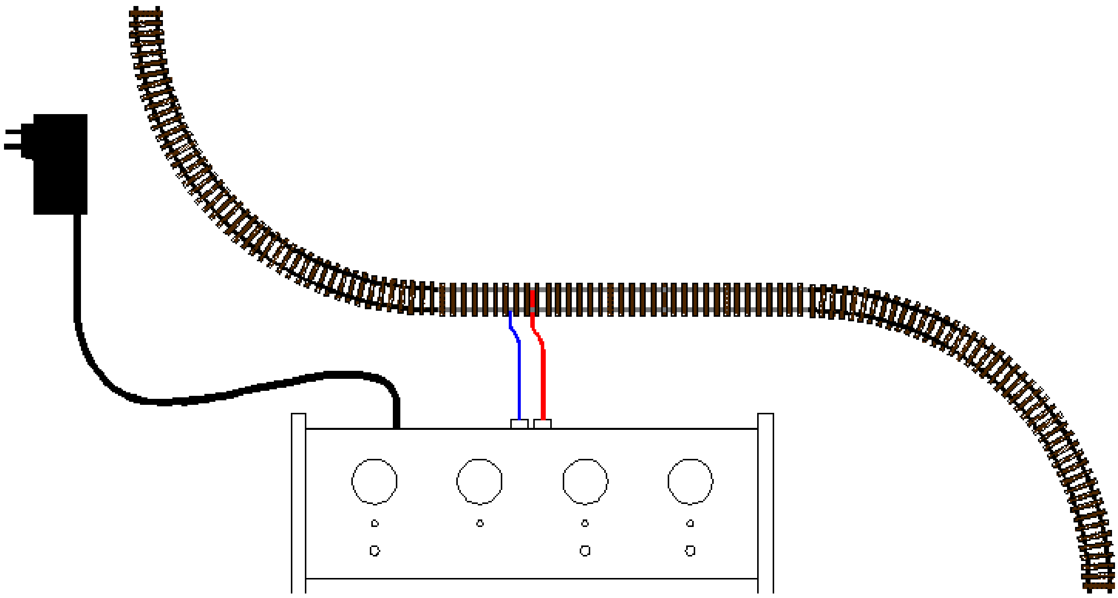

Figure 0.1: Example of connecting Tereina

Place the locomotives on the track, and switch on the power. After a few seconds, a light next to one of the knobs will light up for each locomotive. Now you can drive the train. Turn the knob clockwise and the locomotive will go forward, turn it to the left and the locomotive will go backwards.

What if two or more locomotives get “connected” to one knob, so they all move when you turn one knob? Simply do this: Turn the controller upside-down. You will see a short length of “programming” track on the bottom of the controller. Remove the locomotive that you want to move to another knob, and place it on the programming track. The indicator light will flash. Wait until the light stops flashing and stays on constantly, a few seconds. Replace the locomotive on the track, and flip to controller right way up again. The controller will rescan, and each locomotive will have its own knob.

If you add any trains after the power has been switched on, press the scan button on the controller. This makes the controller look for new trains, just like turning on the power or flipping the controller right-way up.

There is a whole lot more that Tereina can do: talk to your computer, switch train lights on and off, expand from 4 to 8 locomotives, freeze trains to avoid collisions, and so forth. Please read the rest of the manual when you are ready to learn all about these things.

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1 Introduction

Tereina is a new model railway controller that adheres to the NMRA DCC standard but offers an imaginative, user-friendly, analog-style, interface that we call "iDCC". The advantages of DCC, the simplicity of analog.

2 Front Control Panel

Read this chapter to learn about Tereina features, function of buttons and knobs.

Control Panel of Tereina Overview

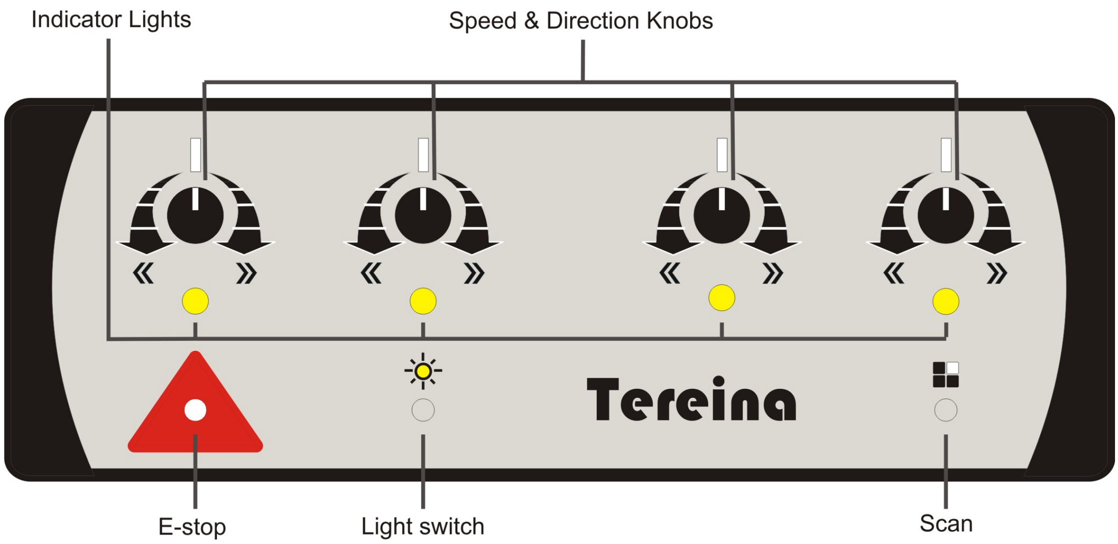


Figure 2.1: Front Control Panel

Speed & Direction Knobs

A few adjustable knobs make it easy to control multiple locomotives. To stop a locomotive, point the knob straight up, at the centre white stripe. To increase speed of locomotives, you can adjust knobs clockwise or anti-clockwise from centre white stripe to increase speed of locomotive.

Direction of adjusting	Direction of locomotive
White stripe to clockwise	Moving forward
White stripe to anti-clockwise	Moving backward

Each knob can be matched with one single locomotive, a single Tereina has ability to control up to four locomotives at same time.

Indicator Lights

Indicator lights show which knob is set and ready to drive locomotives. There are four indicator lights on control panel. Each indicator light is matched in line with one of the knobs that is next to the light. When a light below to one of the knobs lights up, then you can turn the knob to control the locomotive.

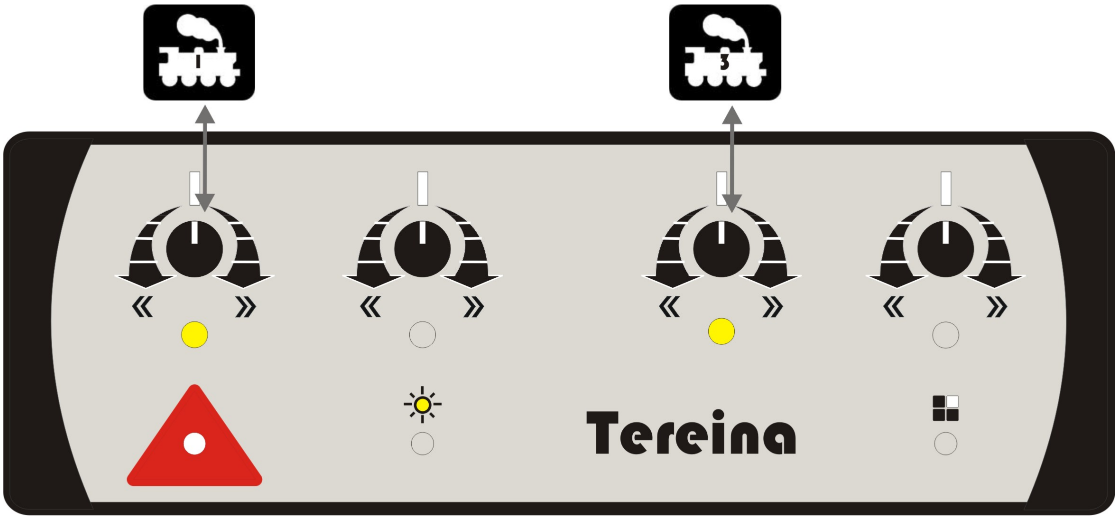


Figure 2.2: Example of controlling locomotives by 1st and 3rd knobs

When indicator light is flashing, it means that knob controls the last moved locomotive. When you apply light of locomotive on/off function (see Light switch section), it only affects to last moved locomotive.

Emergency stop

Emergency stop (E-stop) button provides the ability of emergency break for all model locomotives

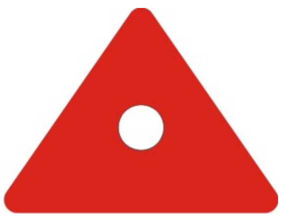


Figure 2.3: Emergency Stop button

When the E-stop button is pressed, all model locomotives that are on railroad track will stop immediately and all indicate lights will flash rapidly. When E-stop is applied, the control knob and other buttons won't function. To cancel E-stop function, you can press E-stop button again, then Tereina will back to previous working status.

Light Switch

In some model locomotives, there is a small light that installed in front of locomotive. In this case, Tereina also has Light switch button that provides ability of turning on/off lights of a last moved model train.

Figure 2.4: Light switch symbol

When lights button is pressed, the light of locomotive will turn on or off depending on previous light state of last moved train.

Scan button

Scan button provides ability of finding and setting addresses to control knob for new add trains, therefore Tereina is able to identify the numbers of trains are presence and control them. While scanning locomotives, the indicator lights will flash. When scanning is completed, Tereina will automatically jump into E-stop status. In order to control locomotives, E-stop button has to be reapplied to cancel E-stop function.

Figure 2.5: Scan button symbol

If adding any locomotives after the power has been switched on, Tereina would not automatically detect new locomotive. You will need to press Scan button, this maks Tereina detects for new locomotives and point specfic knob to control new locomotives. Restarting controller or flipping Tereina right way up will achieve same function.

3 Underneath Tereina

Bottom of Tereina Overview

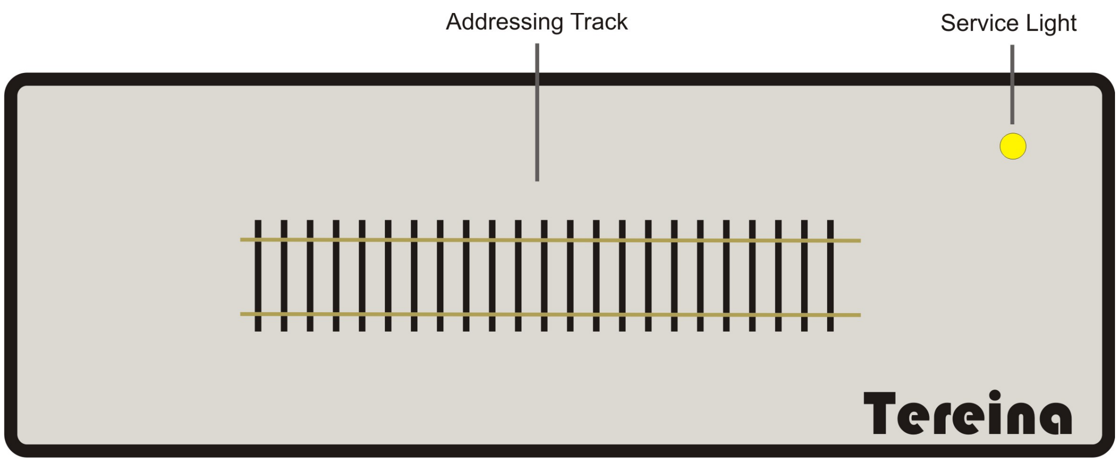


Figure 3.1: Back of Tereina

Each locomotive has an address so that each train knows when the Tereina is sending insruction to it. When a new model locomotive wants to be added into rail, user can simply place Tereina in an inverted direction and Back Addressing Panel (Figure 3.1)will appear and Tereina will turn into service mode automatically for re-programing locomotive.

Service Light

Service light shows that Tereina is in Service Mode or not. When Tereina is placed inverted, Terina detects Back Address Panel is now faced to you and switches to Service Mode then Service light turns on. When Service light is on, it means Tereina is ready to re-program decoder of locomotive.

Addressing Track

To addressing a new locomotive, you can simply place the new model locomotive on the Addressing Track. Tereina will automatically search available unoccupied addresses for the new locomotive and re-program its decoder. While it is re-programing decoder, the service light will flash rapidly. Once the service light stops flashing and stays on, addressing in Tereina for the locomotive is now completed. You can place the locomotive back on to the rail and switch Tereina to control mode by placing it in an upright direction.

How does addressing work?

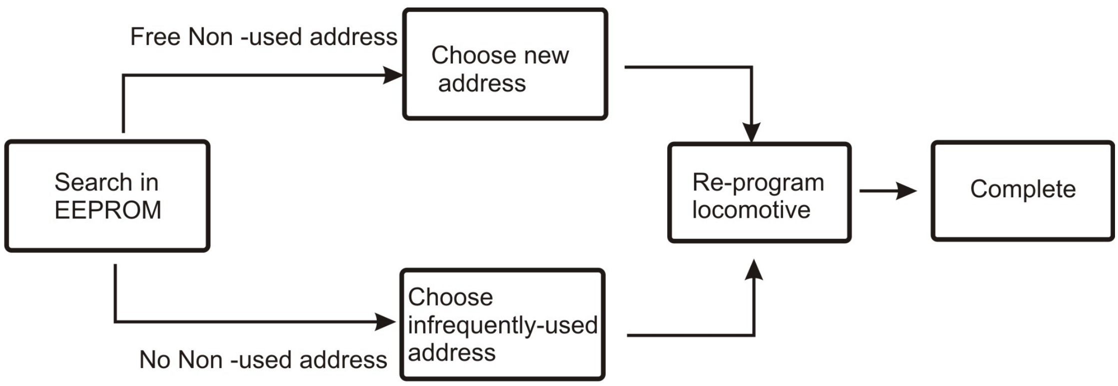


Figure 3.2: Addressing procedure

When a locomotive is placed on Addressing Track, Tereina search through EEP-ROM where Tereina stores addresses that used before. If there are address that haven't been used before, Tereina will take that address and re-program locomotive. Tereina also memorize how many times of each address that have been used. If all the address in Tereina has been used, Tereina will cycle through all the addresses, choose the most infrequently-used address and re-program locomotive.

4 Side of Tereina

Side of Tereina Overview

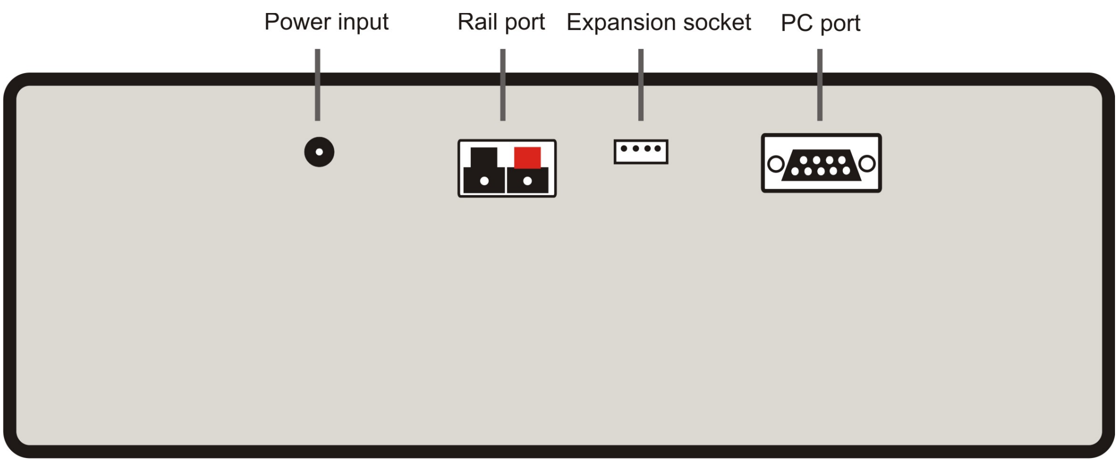


Figure 4.1: Side of Tereina

Rail port

Rail port is used to connect Tereina to railroad track and send signal through rail port that tell locomotives what to do. Command signal packet format follows National Model Railroad Association (NMRA) DCC standard.

Power input

Acceptable DC input range is between 12 to 23V. Typical suggested input is 12V. Tereina can supply current to model railroad up to 4A at current hardware default. It will probably provide enough power to allow four locomotives depend on scale to be running at a time. Common model railroad system required current is under 1A, some special big model railroad might be required current is up to 4 A. If under special circumstances even more power is requrested, you may always use a higher “AMP” rated power supply. Terina will have ability to supply upto 36A within safe range. The D1 diode will need to replace by larger value diode.

P.S. If the current rating is exceeded safe operation range, Tereina will automatically cut off the connection between the layout to protect the controller.

PC port

PC port is pathway to connecting your computer to Tereina. It should be noted that connecting a computer to a DCC layout is not required for setup or the running of your layout, but it will provide many benefits. User will be able to monitor all information that send from Tereina to each locomotive, programming of locomotives and get total control of your railroad layout.

Hardware

PC port uses RS-232 standard and support by MAX232 pic. A MAX232 dual RS-232 transmitter/receiver (U5) converts the output of the UART to the proper signal levels. This device produces its own +/- 10 volt source from the +5 volt supply. All you need to do is connect Tereina with normal 9 pin D-SUB male connector cable to PC serial port socket.

RS-232 commands

All RS-232 commands must use the ASCII character set (upper case) and each command order has to be terminated by a Carriage Return (Enter). The command sequences must use the following format to be executed. If the command executes correctly, various responses will be transmitted and are described at each command description. If the command received was invalid or, for whatever reason, could not be decoded, a response of ?<CR> will be transmitted. This response also indicates that the system is now ready for another command.

CONTROL COMMANDS

Rescan

Format:

RS	No data required. Causes all the addresses of decoder (train) on track to be scanned and new address will to be recorded into EEPROM .

Successful completion of this command will be indicated by transmitting O<CR> to indicate Tereina is ready for next command. O is indicating ready for next Operation Command.

List

Format:

L	No data required. Causes the addresses of all decoders (trains) that were found on the track during the last scan to be sent to the PC.

Example:

L 12 0F 23	There are three trains on the track. The addresses of locos are #18 (12h), #16 (0Fh) and #35(23h).

After transmitting the requested information, <CR> will be transmitted at end to indicate the system is ready for the next command.

Knob assignment

Format:

KB y xx	Assign loco address with a hex value of xx (cannot exceed decimal value 127 or 7Fh) to the y which is knob number 1~4 from left to right on panel or 5~8 on the expansion Tereina.

Example:

KB 2 55	Assign loco #85 to the 2nd knob, allowed user is able to physical control loco.

Successful completion of this command will be indicated by transmitting O<CR> to indicate Tereina is ready for next command.

Validate memory

Format:

VM	No data required. Causes the number of non-used memory that were found in the EEPROM to be sent to the PC. The information transmitted is in hex value (xx) between 0~127 beginnings with the character 'VM'. Hex value represents how many unused address are left in memory.

Example:

VM 05	There are 5 addresses in memory haven't been assigned or programed to loco.

There are 5 addresses in memory haven't been assigned or programed to loco.

Current Monitor

This command can monitor the current which has drawn from railroad layout.

Format:

CM	No data required. Causes the reading value of current sensor to be sent to the PC

Successful completion of this command will be indicated by transmitting O<CR> to indicate Tereina is ready for next command.

Queue and Dequeue packet

Tereina also can queue packet and dequeue packet as EasyDCC.

Queue Packet

Format:

Q xx xx ... xx	Where xx is the hex value of each byte of the packet to be placed in the main command queue (up to 6 bytes may be specified, and must include the checksum byte). Once in the main command queue, the packet will be sent each cycle until it is removed by a Dequeue command or replaced by another packet to the same decoder number.

Each cycle will consist of sending to the main track each packet that resulted from information polled from a physical throttle (local and handheld), then sending each packet that has been placed in the main command queue, then sending each packet that has been placed in the temporary command queue (see description of temporary command queue at Send Packet command description).

When a decoder number is the same in a packet being received and in a packet already in the queue, the newest packet will replace the existing one. Two packets addressing the same decoder cannot be in the main command queue. Packets may contain decoder numbers up to 10239 (hex 27FF). The maximum number of packets that may be placed in either queue is 32. (Operational note: If 32 3-byte packets are placed in a queue, that represents a time delay of approximately 1/4 second that is added between packets to any one decoder on the main track.)

Example:

Q 17 67 70	Put a command for loco address 23 for speed 6, forward direction, in the main queue.
Q C6 0C 67 AD	Put a command for loco address 1548 (hex 60C) for speed 6, forward direction, in the main queue.

Successful completion of placing the packet in the queue will be indicated by transmitting O<CR> to indicate the system is ready for the next command. If the packet will cause the queue limit to be exceeded the packet will not be placed in the queue. This will be indicated by transmitting R<CR> . ("R" indicating the command was decoded but Refused). The system will then be ready for another command.

See the section on DATA FORMATS for a description of the basic packet formats.

Dequeue Packet

Format:

D xx xx	Where xx xx is the hex address of the loco (decoder) whose packet is to be removed from the main command queue. The first byte of the address must be 00 to indicate 'short' address. The two msb's of the first byte must be 1's to indicate 'long' address. See Example.

Example:

D C6 0C	Remove command for loco #1548 (60Ch) from main queue.
D 00 17	Remove command for loco #23 (17h), short address, from main queue.
D C0 17	Remove command for loco #23 (17h), long address, from main queue.

Successful completion of removing the packet from the queue will be indicated by transmitting O<CR> to indicate the system is ready for the next command. If the decoder number specified is in the queue more than one time, all entries will be removed. If the decoder number cannot be found in the queue, no action will be taken but the system will not reject the command and will

Figure 4.2: Queue and Dequeue section from EasyDCC

SERVICE COMMANDS

Service Mode

Format:

M	No data required. Causes computer to over-write gravity switch on circuit and main track to be halted and prevents any further command packet activity on the track. Tereina switches from operation mode to programming mode. No knobs or pushbutton on the Tereina will be acknowledged. These conditions will remain until leaving the Service mode

Successful completion of this command will be indicated by transmitting S<CR> to indicate Tereina is ready for next command where “S” stands for Programming commands. It will only accepted Service commands while it is in Service mode.

Exit Service Mode

Format:

X	No data required. Causes the Tereina to resume normal operation mode. The knobs and pushbuttons will be enabled.

Successful completion of this command will be indicated by transmitting O<CR> to indicate Tereina is ready for next Operation command where “O” stands for Service commands.

Extend address decoder

According to NRMA standard, a normal decoder has bits 0-6 contain an address with a value between 1 and 127. Bit seven must have a value of "0". Total 127 addresses can be recorded into EEPROM. If there are more than 127 addresses, a long address is required and only multi-function decoder can be set in CVs and supported. A long address can support up to 9999 addresses. Consult the decoder manual to determine if it supports long addresses.

Program Address

Format:

P xxx	Program decoder with enter value where xxx is a hex value address.

Example:

P 002 Program the decoder with a address of 002.

Interface to a computer

“going to edit”

“JMRI is free building tools that Tereina is using for model railroad computer control. It intended as a jumping-off point for hobbyists who want to control their layouts from a computer without having to create an entire system from scratch. Please visit `http://jmri.org/` for more information.**”**

Expansion socket

When you want to control more than 4 locomotives at a time, you can get another Tereina and simply connect two Tereina together via Expansion socket as shown in Figure 4.3. Now you can control maximum up to 8 locomotives at same time at same model railroad track, it is time to share fun with your family and friends.

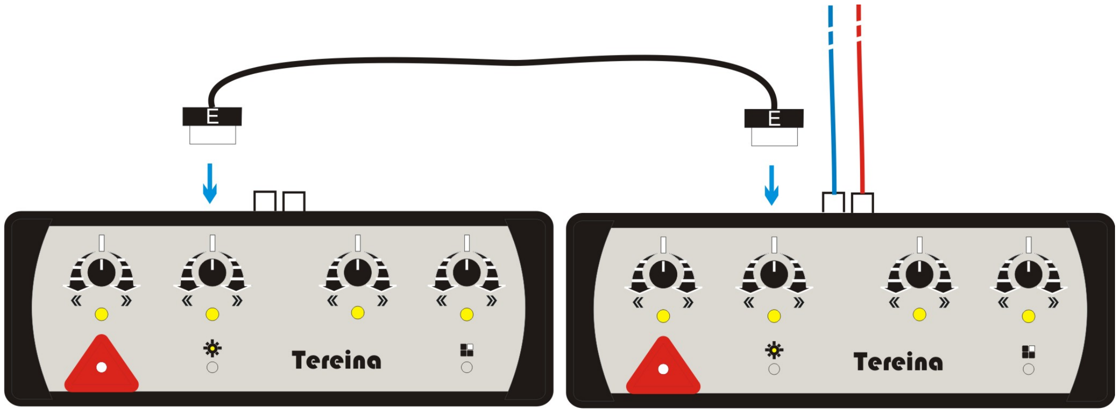


Figure 4.3: Example of connect two Tereina

Please note only the main (master) Tereina controller receives the external power, and the second (slave) Tereina draws power from main Terina via Expansion socket. The second (slave) Tereina only works as four expand knobs.

5 Tereina Circuit

Tereina circuit diagram

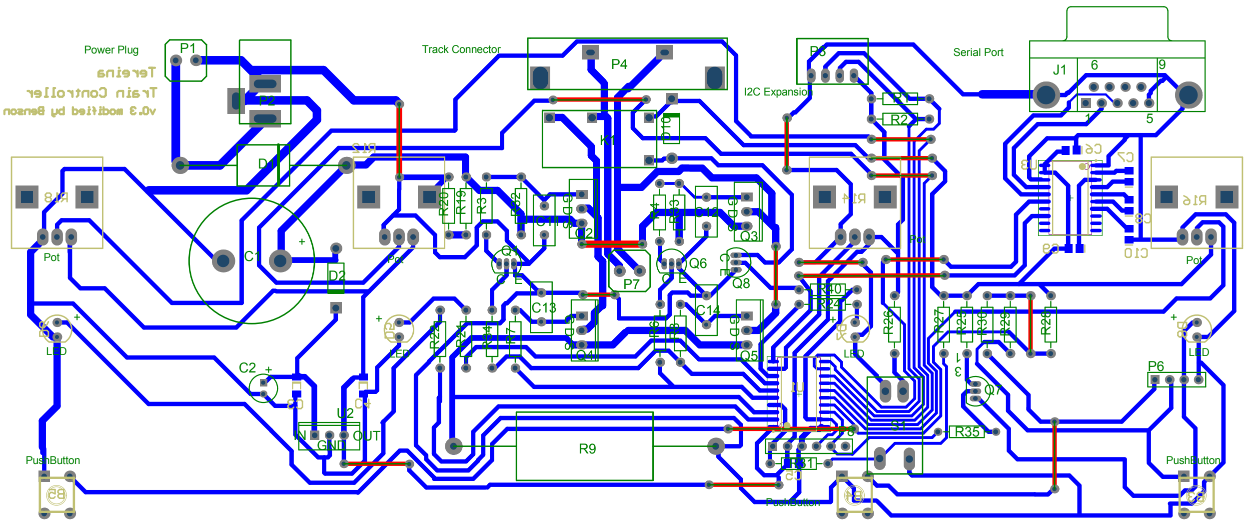


Figure 5.1: Tereina PCB layout

Parts List On 16/02/2011 at 1:10:18 p.m.			
Comment	Pattern	Q	Components
5MM LED	LED_5mm_RAD-0.1	4	
7805 Voltage regulator	TO-220-AB	1	Tawian Semiconductors 5V Linear Voltage Regulator
BC547C	29-04	4	Amplifier Transistor NPN Silicon
Cap Cerm	C0805	6	Capacitor (Semiconductor SIM Model)
Cap Tant	3261	2	Polarized Capacitor (Radial)
Cap	B	1	Polarized Capacitor (Radial)
Cap	FILTER_CAP	1	Polarized Capacitor (Radial)
Cap	RAD-0.2	4	Capacitor
D Connector 9	DSUB1.385-2H9	1	Receptacle Assembly, 9 Position, Right Angle
DC Connector	DC CONNECTOR	1	Socket, Low voltage, 2.1mm
Diode 1N4001	DO-41	2	1 Amp General Purpose Rectifier
Diode 6A20	PROTECTION DIODE	1	Taiwan Semiconductor 6A20 Diode
Expansion Socket	EXPANSION CONNECTOR	1	Header, Right angle, 2.5mm, 4way
Header 4	HDR1X4	1	Header, 4-Pin
Header 6	HDR1X6	1	Header, 6-Pin
IRF540	TO-220AB	2	HEXFET N-Channel Power MOSFET
MAX3222	DW020_L	1	RS232 Driver/Receiver
MTP12P10	221A-06	2	Power Field Effect Transistor
PIC16F690-X/SO	DW020_L	1	PIC16F690-X/SO
POT	POT	4	POT 100KD, vertical PCB mount
Relay-SPST	relay	1	Single-Pole Single-Throw Relay
RES	CURRENT_RES	1	1ohm, 5W, 5% tolerance
Res2	AXIAL-0.4	24	Resistor
switch	Switch_Tactile 6 x 6 mm OMRON B3F-1070	3	Switch, Tactile, PCB, 1.57N
Terminal Block 2-way	Terminal Block-2way	2	Header, 2-Pin
Tilt Switch	TILT_SWITCH	1	Photo sense tilt switch, lead free
Track Connector	TRACK_CONNECTOR	1	Terminal Block, Speaker, 2P

Dimension

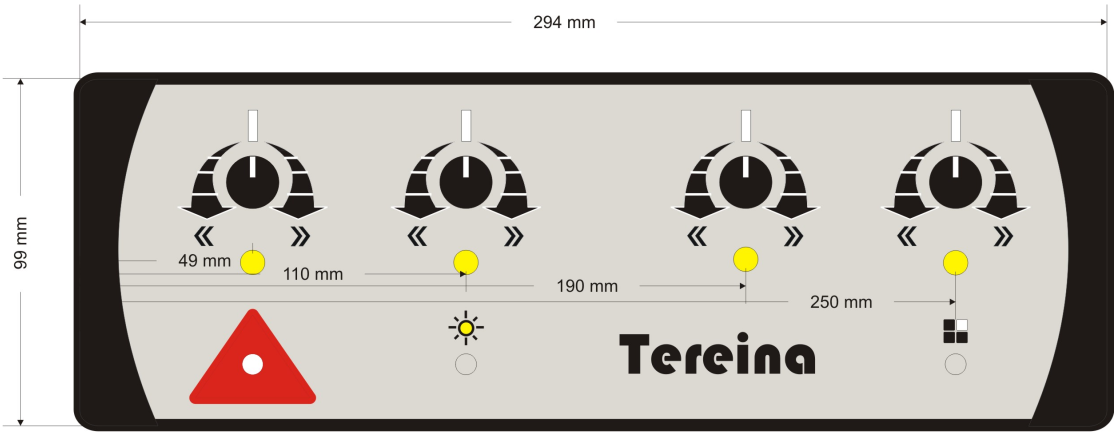


Figure 5.2: Dimension of Control panel

Appendix B

Gantt chart

iDCC project

The Uni ersit o aikato

To a s Date 3 15 2012 Thurs a

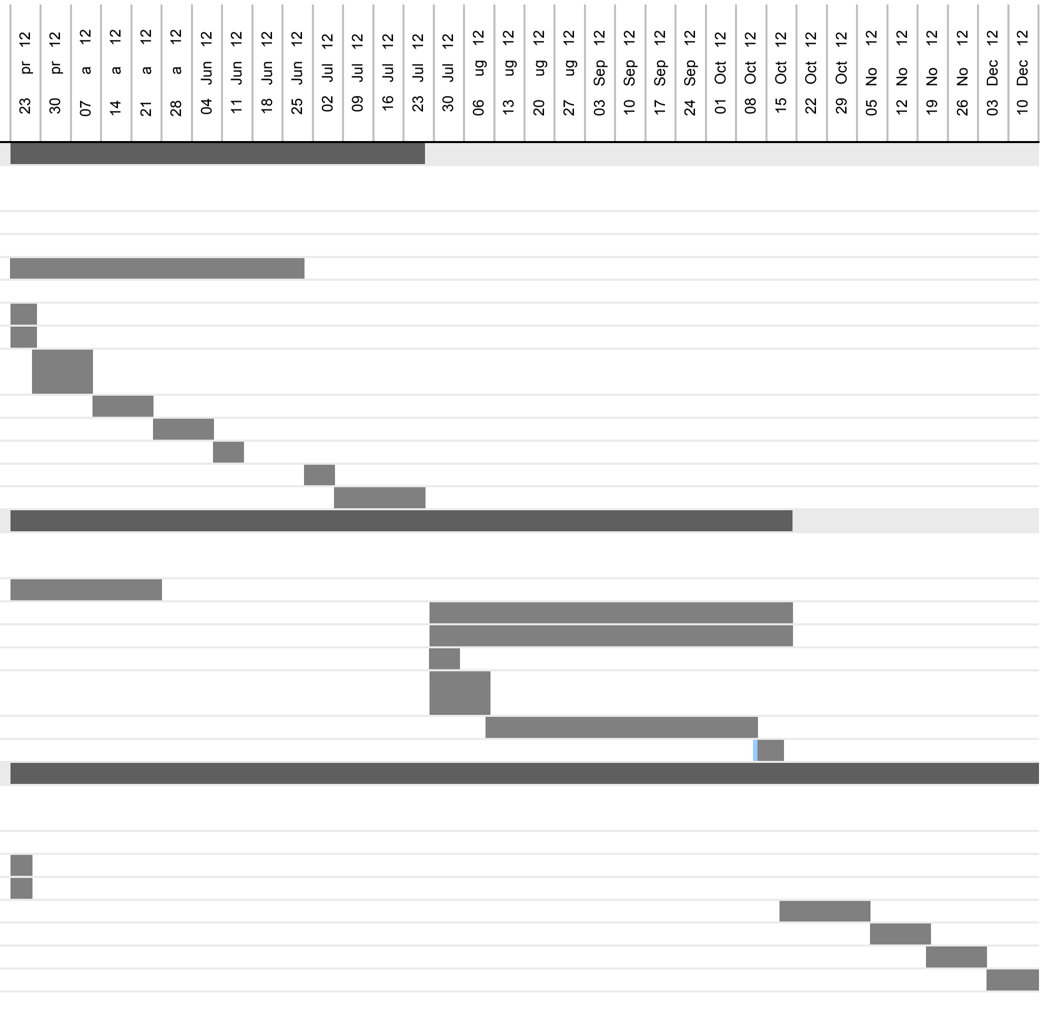
ertical re line

Pro ect Lea Benson Chang

Start Date 2 27 2012 on a

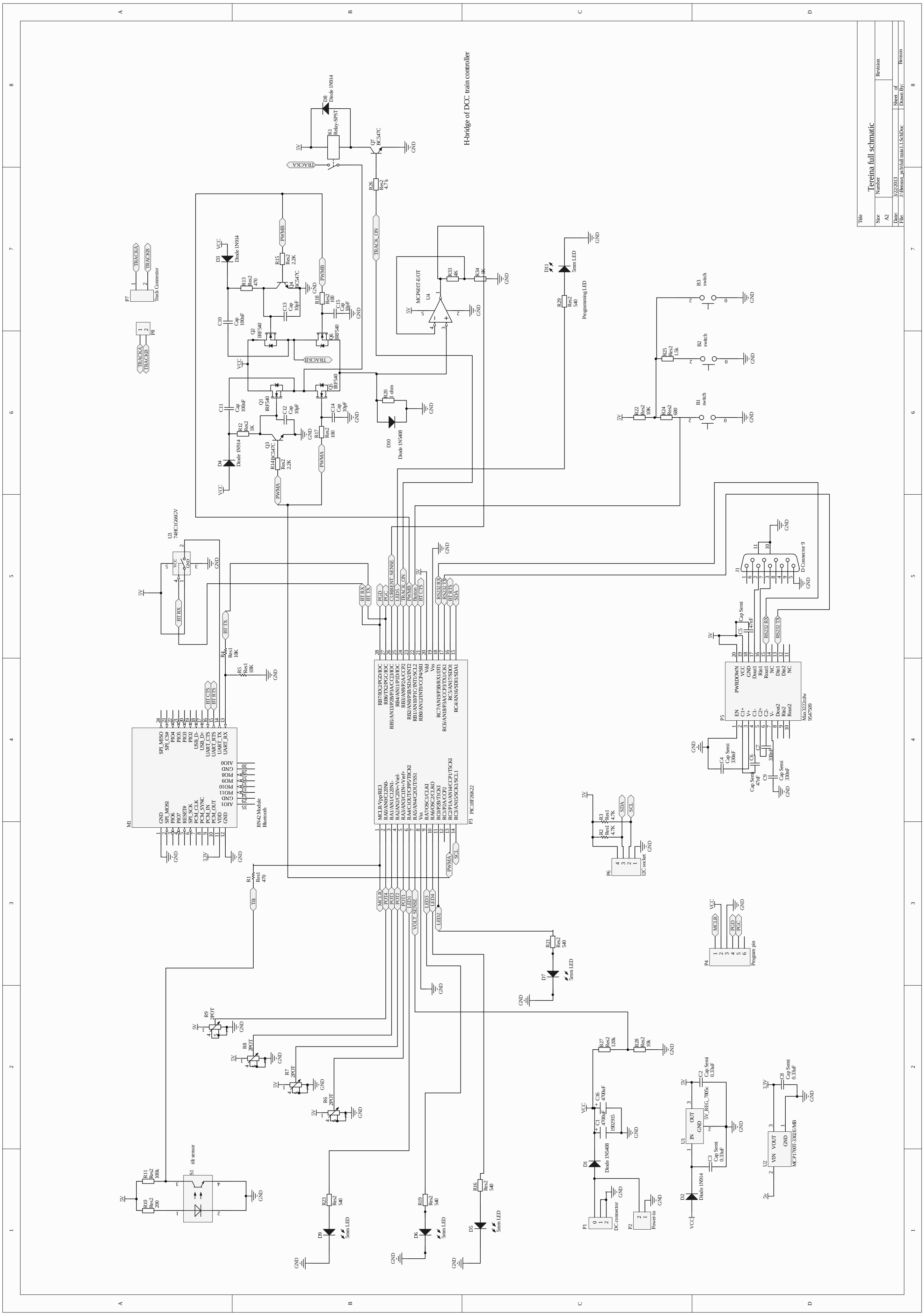
First Day of Week (Mon=2): 2

WBS	Tasks	Task Lead	Start	End	Duration Da s	Co plete	orking Da s	Da s Co plete	Da s Re aining
1	**Hardware**	Benson	2 27 12	7 27 12	152	4	110	6	146
1 1	Understanding previous hardware		2 27 12	3 18 12	21	50	15	10	11
1 2	User manual		3 18 12	3 31 12	14	0	10	0	14
1 3	Test and discover issue		3 31 12	4 6 12	7	0	5	0	7
1 4	Development		4 7 12	6 29 12	84	0	60	0	84
1 4 1	issue fixed		4 8 12	4 14 12	7	0	5	0	7
1 4 2	new functions added		4 8 12	4 28 12	21	0	15	0	21
1 4 3	Circuit design		4 8 12	4 28 12	21	0	15	0	21
1 4 4	Test new design and debug		4 28 12	5 11 12	14	0	10	0	14
1 4 5	Part selection		5 12 12	5 25 12	14	0	10	0	14
1 4 6	PCB layout		5 26 12	6 8 12	14	0	10	0	14
1 4 7	Price quote		6 9 12	6 15 12	7	0	5	0	7
1 5	Prototype		6 30 12	7 6 12	7	0	5	0	7
1 6	Enclosure design		7 7 12	7 27 12	21	0	15	0	21
2	**Software**	Benson	2 27 12	10 20 12	237	4	170	8	229
2 1	Uderstanding previous firmware		2 27 12	3 18 12	21	50	15	10	11
2 2	Test and discover issue		3 19 12	5 27 12	70	0	50	0	70
2 3	Programing team start		7 29 12	10 20 12	84	0	60	0	84
2 4	Development		7 29 12	10 20 12	84	0	60	0	84
2 4 1	Set up		7 29 12	8 4 12	7	0	5	0	7
2 4 2	understanding embeded language		7 29 12	8 11 12	14	0	10	0	14
2 4 3	function development		8 11 12	10 12 12	63	0	45	0	63
2 5	Debug and completion		10 12 12	10 18 12	7	25	5	1	6
3	**Marketing**	Benson	3 5 12	12 18 12	289	6	207	16	273
3 1	Contact and organize for brand naming		3 5 12	3 18 12	14	50	10	7	7
3 2	Assignment		3 18 12	3 31 12	14	0	10	0	14
3 3	Brand naming		3 31 12	4 27 12	28	0	20	0	28
3 3 1	name selection		4 21 12	4 27 12	7	0	5	0	7
3 4	research size of train market		10 18 12	11 7 12	21	0	15	0	21
3 5	logo design		11 8 12	11 21 12	14	0	10	0	14
3 6	product description		11 21 12	12 4 12	14	0	10	0	14
3 7	video ads script		12 5 12	12 18 12	14	0	10	0	14
3 8	filming video ads		12 19 12	1 8 13	21	0	15	0	21



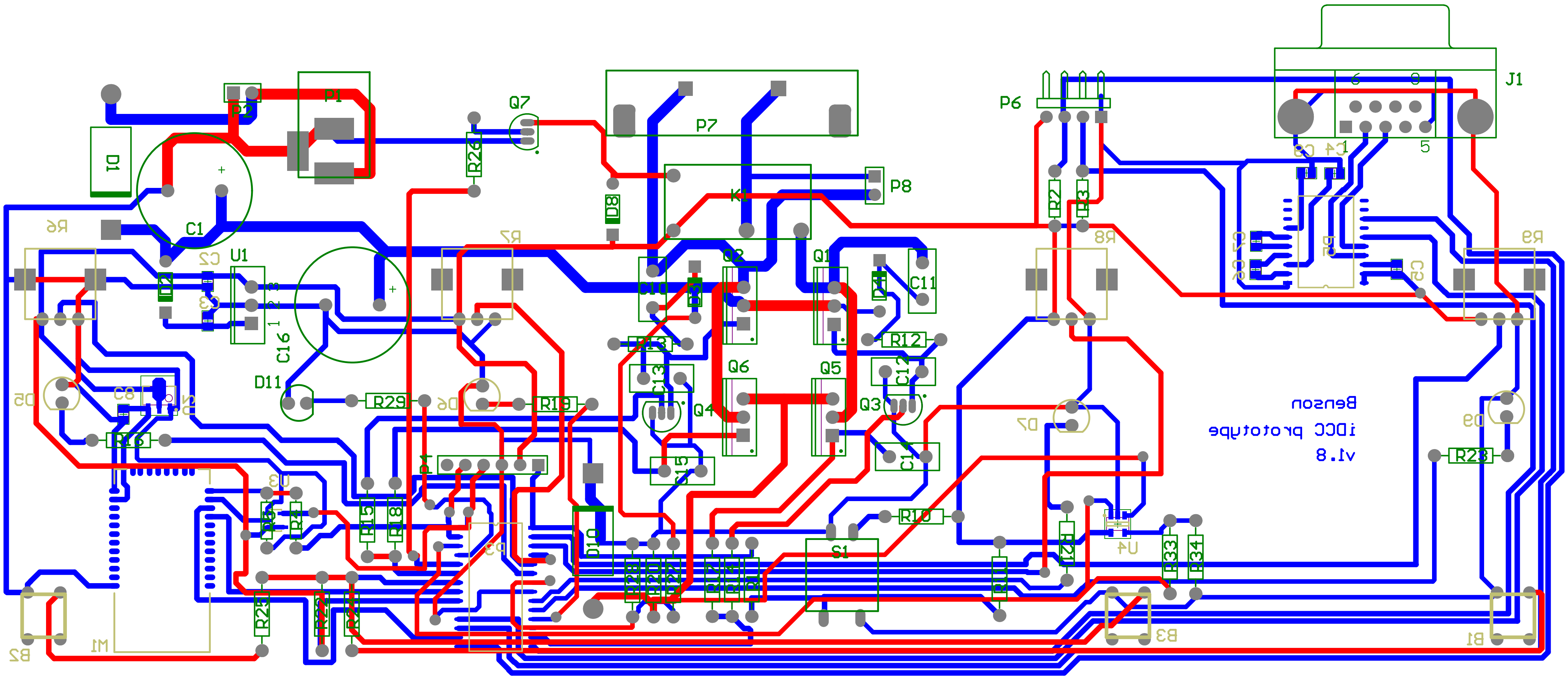
Appendix C

Tereina schematic


H-bridge of DCC train controller
Tereina full schmatic

Appendix D

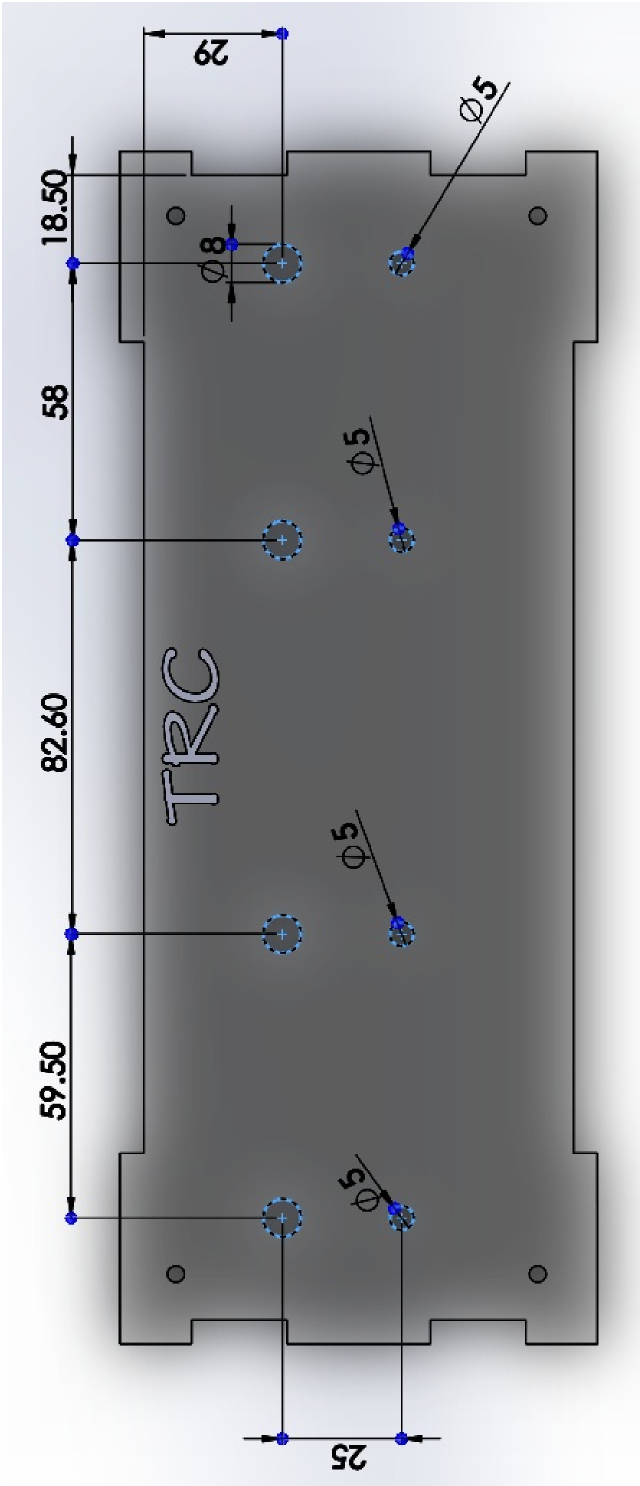
PCB layout of Tereina

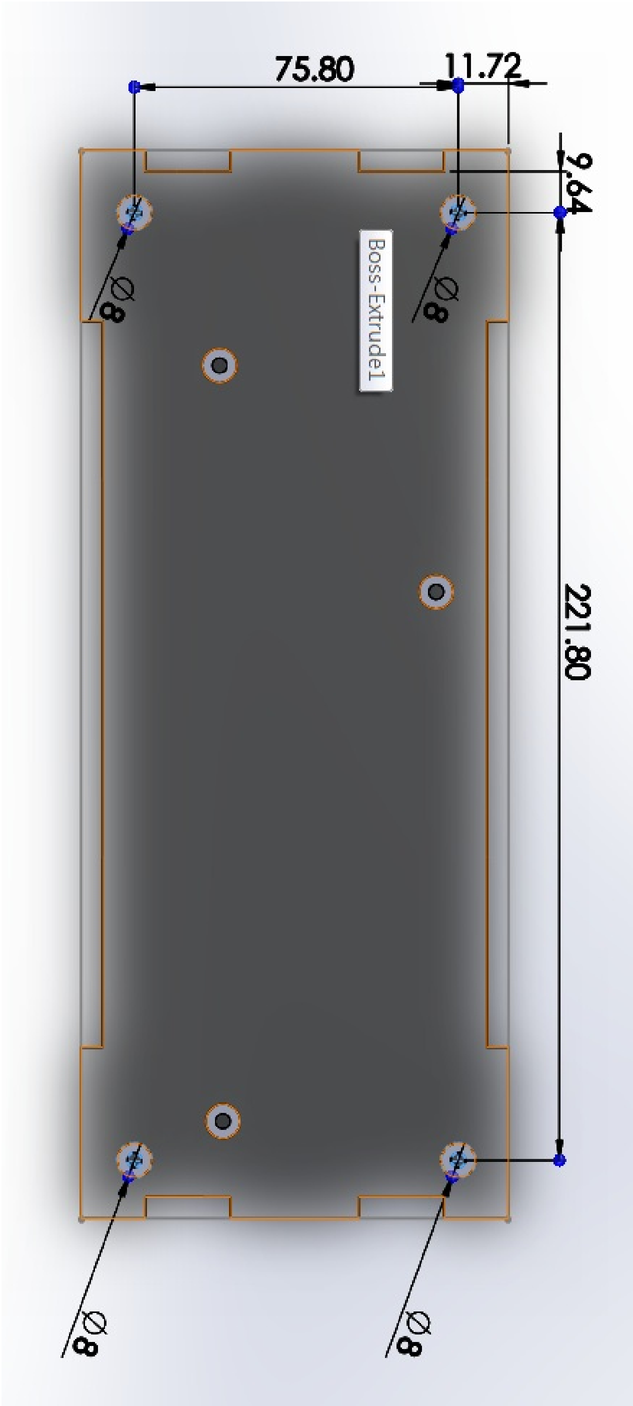

Benson
iDCC prototype
v1.8
J1
P6
P7
P8
P1
P2
K1
Q1
Q2
Q3
Q4
Q5
Q6
Q7
U1
U3
U4
S1
C1
C10
C11
C12
C13
C14
C15
C16
D1
D2
D3
D4
D8
D10
D11
R10
R12
R13
R19
R23
R26
R29
R33
R34
B1
B2
B3
M1

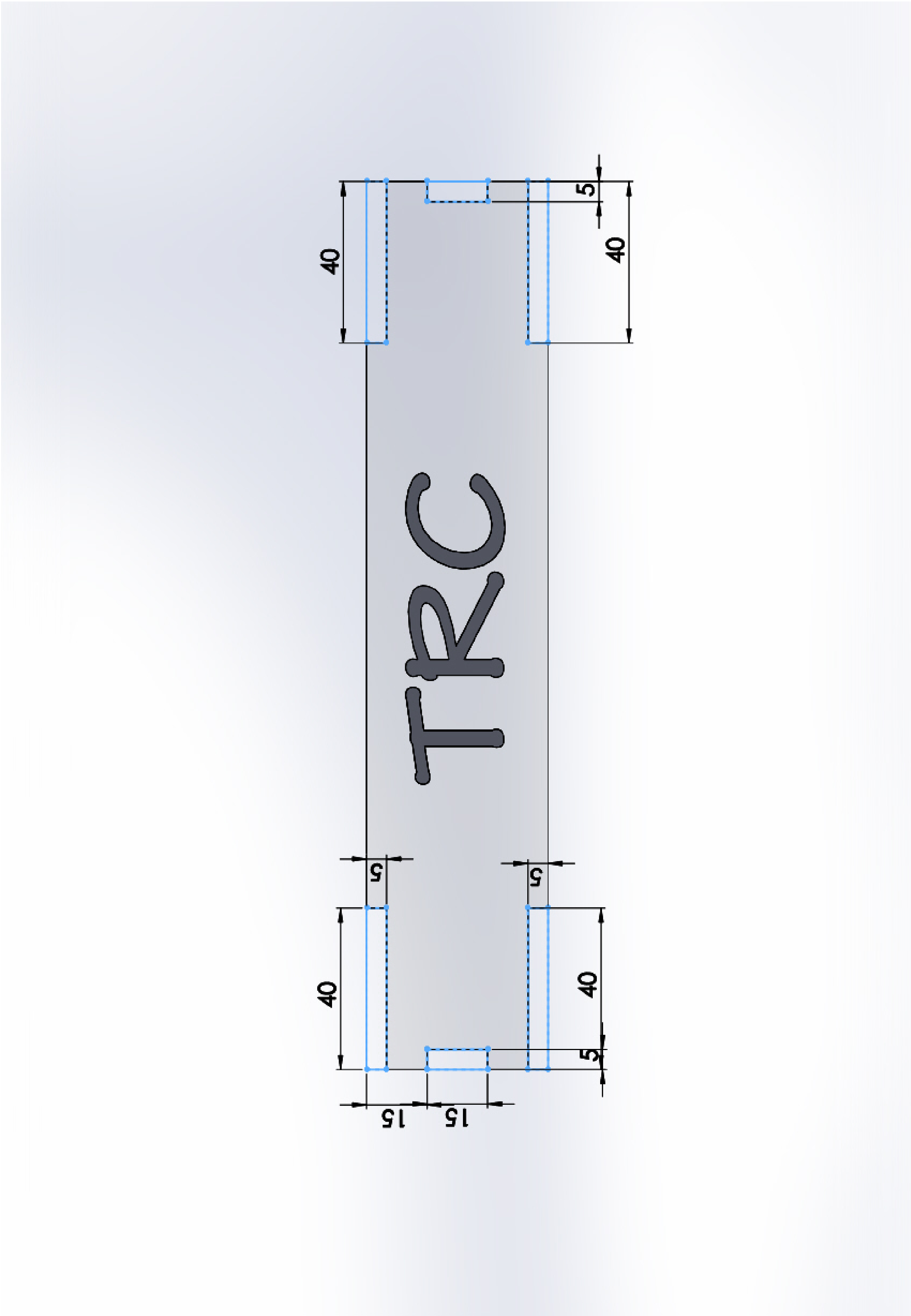
Appendix E

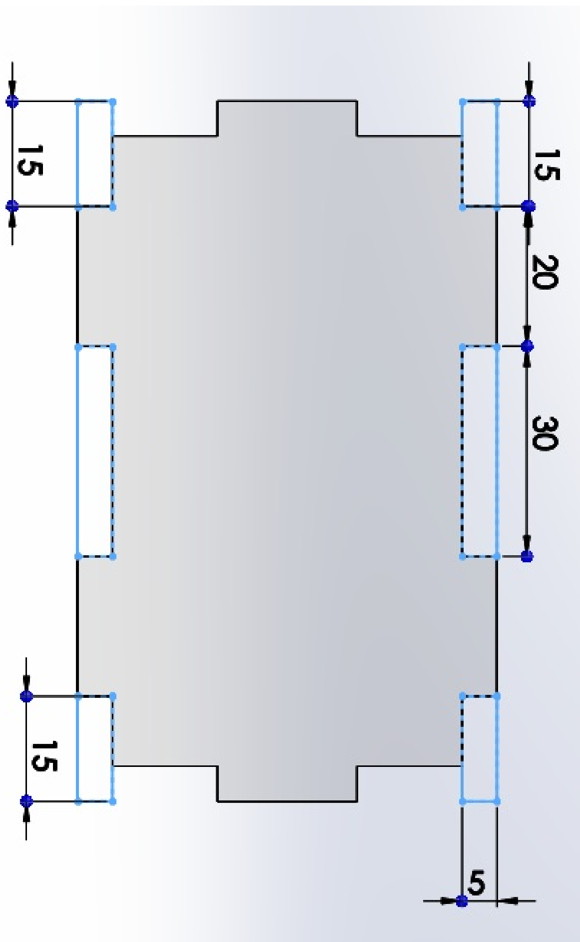
Dimension of final case

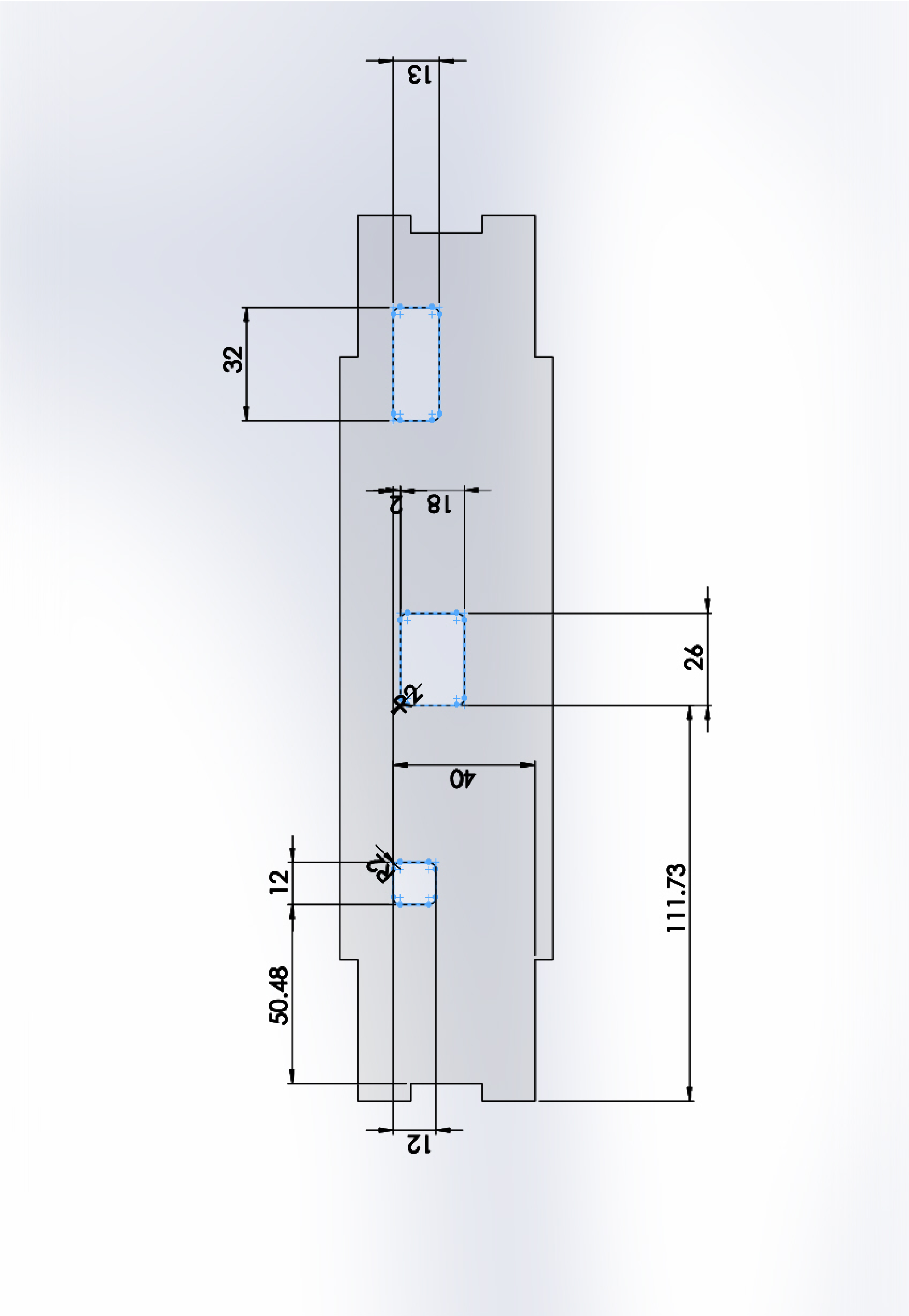
The full version of solidwork case design files are under the folder named "final-case-design"


29
Ø5
18.50
Ø8
58
Ø5
82.60
TRC
Ø5
59.50
Ø5
25


75.80
11.72
9.64
221.80
Ø8
Ø8
Ø8
Ø8
Boss-Extrude1


TRC
40
40
5
40
40
5
5
5
15
15


15
15
20
30
15
5


13
32
2
18
26
R2
40
R2
12
111.73
50.48
12

Appendix F

The previous program code listing

The files are under the folder named ”previous-software” in the attached CD.

Appendix G

The new firmware

The files are under the folder named "new-firmware" in the attached CD.

Appendix H

The marketing assignment

MKTG355/455 CONSUMER BEHAVIOUR

ASSIGNMENT 2, 2012

You are approached by a startup company. They have a new design for a high-technology, up-market, niche enthusiast product. It needs a name and a tag line. This sheet and the accompanying demonstration/slides will introduce you to the target audience, the history of the market, the competition's products, and the new technology.

History: Toy trains have been manufactured for almost as long as real trains have been running, a couple of centuries. Around 120 years ago clockwork models were replaced with electric ones. Advanced manufacturing techniques continue to make models more realistic. Wikipedia provides a concise summary and links into a deluge of enthusiast information on the web. Dozens of large and hundreds of small manufacturers support the market. Customer interface is via the web, paper magazines, and numerous enthusiast clubs and meetings. In the 1980s a digital system was developed to run model trains. This system offers advantages such as greatly simplified wiring and the ability to run several trains independently, but has not been adopted by many users in spite of a high level of global. This is because it requires considerable technical skill and computer awareness. Where the digital system (called "DCC") has been adopted, such as large clubs, our research shows that it is supported by relatively few of the members on behalf of the others. The toy train sets that you will find in stores downtown in most cities remain stubbornly analog.

The Product: The new product removes the user's need to have any great technical skill. Every competition products requires the user to understand addressing, to be able to program addresses into trains, and to remember the address associated with each train. This new product handles all this automatically, and so does not require a keyboard or LCD display at all. Competitors' products sell for anything between NZ$100 and NZ$1000. This product would be pitched at the mid- to high-end customer, approximately $400. This product will be suitable for both the novice and serious users. It handles only 4 trains for each unit purchased, other products can address up to 99 trains all by themselves, but note that most layouts have 3 to 10 trains at most.

Size: The size is not fixed by the technology but purely by choice. In other words, they can be as big or small as you want. When you see ours demonstrated, you will see why it is the size it is, it allows a great trick that will totally differentiate it from others: To program a train with controllers made by ALL other companies you have to remove all the other trains from the track and then do a sequence of presses on the keypad. Ours turns upside-down, and you put the train on a small piece of track that you find on the bottom, and all is taken care of automatically (without you having to press anything, and without you even having to know that there is such a thing as an address). Thus ours is the same size as a locomotive.

Batteries: Ours, like the competition ones, consumes hardly any power apart from that sent to the model train. Some have "wireless remote controls" that are obviously battery operated, in addition to the base unit that plugs into the mains, but these do not seem very popular, because they do not do much for anyone whose train set is smaller than a house. I believe that very few customers want battery operation. We do NOT have a wireless remote control option.

Computer connectivity: Some models have a connection so that they can be plugged into a computer, and a program runs the trains. Ours does. Many do not.

Expansion: Other units have one or sometimes 2 knobs, and you must key in the address of each train to make a knob control that train. Our controller provides 4 knobs, one per train. If 4 is not enough, you can plug in a second controller, and ours then immediately provides 8 knobs, and can control 8 trains.

Consists: It is possible to have two locomotives pulling the one train. This is called a "consist". Most controllers permit two trains to be programmed so that they act as one, but it requires a complicated sequence of keystrokes, or you can cheat by programming two locomotives to the same address and swapping the forward direction on one if it is to be connected back-to-back instead of back-to-front with the first loco. Ours can do this, but only using the computer interface... it's easier to turn two knobs, as steam train drivers had to, when two pulled one train!

Construction: Most of these units are small plastic boxes. Ours is constructed in a metal-and-wood case. This makes it feel and look classier and more expensive (and does make it a bit more expensive). The Hornby Live Steam controllers (which cost a bundle and are not digital) use the same approach, heavy metal boxes and chunky brass knobs and levers. We would be one of the "chunkier" designs, but not the most chunky of all. The lack of a keyboard is far more able to make the design robust. You can sit on ours and it does not get hurt. It is tough, "solidly made".

You are asked to:

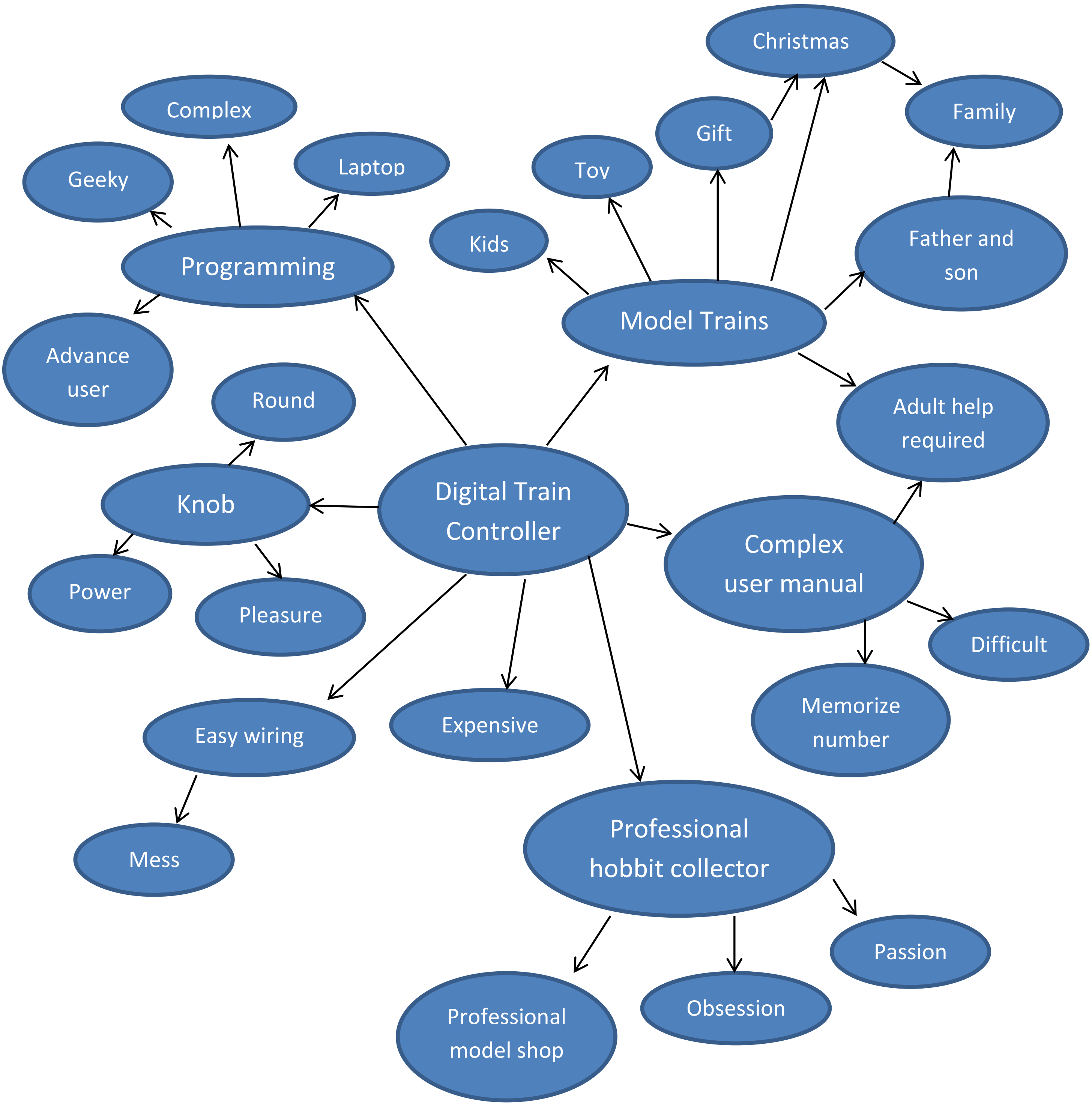
1. Propose a brand name for the new product to differentiate it from the competition and identify the new line of products;
2. Invent a tag line or slogan for the product line that would convince potential customers that this really is a “better way to go”.

Your contact for technical enquiries about the product is Benson Chang <nzbenson.chang@gmail.com>

Please restrict your assignment to 500 words excluding references and headings. Remember, a good assignment in the Consumer Behavior paper ALWAYS has academic references (i.e., a reference to one or more of the following journals: Journal of Consumer research, Journal of Marketing, Journal of Marketing Research, Marketing Science, Management Science, Journal of the Academy of Marketing Science, International Journal of Research in Marketing, Journal of Consumer Psychology, Psychology and Marketing, Journal of Advertising). Use APA style for referencing.

Attribute	Existing products	The new product
Programming	Require user to choose, remember and program locomotive addresses	Automatic, no need to remember anything
Capability	All offer “consist” and firmware functions (per minimum NMRA standard)	Consist and firmware functions possible only via interface to a PC
User Interface	Requires use of keypad and small LCD, select trains one by one or two by two	No keypad, one knob per train
Expansion	A unit typically allows for control of 99 to 127 trains	Each unit controls only 4 trains (buy second unit to expand to 8)
Cordless operation	Some offer wireless remote control	Not supported
Connectivity	Some offer PC interface	PC interface, plus proprietary expansion interface
Construction	Mostly plastic, expensive models have chunky metal controls	Sturdy metal-and-wood construction
Price	Range from NZ$100 to NZ$1000, typically NZ$200-250	Target price will be NZ$400

Associative network of consumer's perceptions of digital train controller (DCC)



Appendix I

Collection of brand name and tagline from the assignment

Whole Class List MKTG355-12A (HAM) Consumer Behaviour

Surname	Preferred Nar	Brand Name	Slogan
ngell	Bronte	Trigger Tracks	getting our trains going not our in
therton	Isa elle	Train Brain	Pla now think later
Bal win	Nicole	T INC3000	Loco oti e ease at our ingertips
Barr	Katherine	Choo Eas	The user rie l igital train control
Bowie	Brent	New Orient Trans ission Control	The right wa to go
Brown	Sio ahn	Strong steerer s	Trains are ri en to last
Chan	Nick	Ballast	B LL ST DCC Controller Si pl the est oun ation o an o el
Chang	Connie	Turn2Go	ou ll lo e the wa Turn2Go controls
Chen	Ke han	Si tastic	ho nee s Progra ing Si tastic E powering pure en o ent o Dri ing
Chisnall	Leanne	The at Controller	ast uto atic Trou le ree progra ing or o el trains eans ore ti e or un
Chong	ong Cheng	uto ate Co ing Controller CC	Let our inger e the station aster
Christe	Briana	Rail aster	Si pl the aster o o el rails
Clarke	a	STTR CK 4 0	Keeping ou on track
Consta le	Tro	Loco uick	Loco uick aking un uick an eas
Coxhea	Luke	Track aster	The ke to eco ing aster o our own railwa
Cullen	elissa	S art Train	ast Track our uture
Dicke	Leana	JBRJ Digital	Don t go o the Rails CONTROL oursel
Diprose	Cerelia	uto otion	Go Digital Like Clockwork
Dow	Luana	Loco ate	Transport oursel
Drea on	Dallas	Ele ental	No training re uire
Elkington	Pania	E Ben er	Take Control It s Eas
ole	Nicola	utoRail	Let the ourne egin
Gil ert	arguerite	Train Troll	Experience Digitall Controlling ll our Trains The Si ple a The Train Toll a
ansen	Ja e	train	here the technical is a e practical
ar	shle	Si pl loco	No ke pa no thinking ust go
awtin	Dane	NE GE TR INS	Trains that on t re uire a con uctor
ol es	Blair	The uto atic resser rail	No ke pa No progra ing No hassle
ornse	Jessica	Si pTrain	Si plicit at its est
u el	oni ue	DigiChoo	Eas pla without ela
Keane	nnelise	Eas Con uctor	No co es No ke pa No stress Digital control a e eas
Kee	Ellie	Si ple TR INing	Si ple train our TR IN without all that progra ing uss
Ki ell	Stephanie	S arTracks	Take a reath o resh air with S art Tracks uilt or the tracks ahea
Kont e	Ti an	Rail Gui ance RG	twist o the han the un egins

Lal	Krishan	The JBRL uto Progra er	so e things are etter kept si ple
Leach	Sa uel	Iron Steer	The e olution in igital controlling
Lissington	Bra en	The at Controller	e a not e a le to anage his weight ut he sure can anage our trains
ac ie	Care	Powertrain	Train ithout Sweat
akheri	a ur	oti us	uninhi ite technolog
anssen	E a	Loco Ease	Is progra ing our loco oti e with a DCC aking ou Loco Choo Choo se Loco Ease
c rthur	an a	Benson	aking it Eas
cCartne	To	ol heel	re olution in controller experience
cColla	Sarah	JB Rail s Cle er Con uctor	Classig esign o ern intelligence
cLeo	Brigi	TrackCO	Trou le ree Train Tracking
iers Jones	Josh	The at Controller	Opti al control ero i icult
Orr	Renae	astTrack	ro no ices to train pro essionals ast Track our wa to success
Pan	Shuhao	Dr E O	e o not onl ale the controller we also ale the change
Powell	Ro	Controrail	ore training ore un
Rea	Greg	The ar aster	rein enting our railwa
Rei	Dana	Train e	the eas wa to train
Scott	lana		
Shashikant Pa	Upesh	Tereina	Unco plicate let the goo ti es chg along
Sin en	Rachel	The Con uctor	The iser rie l control panel
Singh	ineet	JBRL GenN a ance auto atic Dig	So Si pl l It s e en eas or a an who co es with anual
Stokes	annah	Enginuit	Si ple esign
er onk	leur	Choo Tuner	lwa s on the rails
ake iel	Rachel	ision Train	Pla with our train track on t train it
illia s	Stephanie	icro Tracks	Re o es the pain ro anaging trains
ilson	Jor an	Train aster	Train to pla Not an ore
ilson	Kell	Railwa Con uctor	S ooth Railing hea
ong	i Sian	iController	Gain instant grati ication with iController
oo	Sarah	Track ate	So a ance et so si ple
hang	pril	TNT	TNT controller or Pro essionals

Whole Class List MKTG255-12A (HAM) Consumer Behaviour

Surname	**Preferred Nar**	Bran Na e	Slogan
llen	Larissa		
n erson	Cloe	Si pl Controllers	Qualit teste ri er appro e

Burgess	Ben	Kings Cross Trains	e take all the work out or the procustion an allow ou to take o the con uction
Clear	R	uto ation Station	No co plicate a resses No co plicate progra ing Just trains
Cu ing	Danica	SS	Keeping our trains on track
a ish	nna	Digi oti e	I enti the new line o pro ucts
erguson	Courtne	Digi Loco oti e	NO KE P D NO PROGR ING NO NU L
inla	nnie	Si plistic Direction	The e or less controller to get our places
oster	Shaun	Eas con	Because un shoul e si ple
raser	Nikita	The at Controller	Start our engines all our o the
u	Jun	Ease Pro essional Loco otion Contro	No ore ke s ut a whole lot ore Ease
Gar iner	Dannii Jo	Digi Co an	axi u control ini al co plexities The uture o DCC ull stea ahea
Gi s	Brigita	The utoconnector	Si plicit at our ingertips
Glentworth	atthew	GBRL EnterTrain ent	Little To s or Big Bo s
Gru ner	Daniel	Coach an	Trains without the Training
all erg	Karina	Toot Toot	Trains hga e ne er een this si ple
a l	Ken l	uto Rail ate	Si ple is intelligent uto ation is ree o uto rail ate is the light at th ene o teh tunnel
a l	K	uto Track	So e people use their intelligence ut ore intelligent people on t The use auto track
annah	Renee	Locomotive ‘King’	igh Per or ance with ease
ol ap el	Da i	Brain Box	The uture o o el train controllers
opkins	Re ecca	Train our train	Trains will ne er e teh sa e
Jennings	ont	Strea line Co an er	Stop eing the at Controller Co an our trains with ease
Karaitiana	Claire	Digi oti e	ake it eas eco e Digi oti e
Lake	Becki	LocoEa e	The control is in our han s
Lee	Iris	Digitoot	
Li a	ishnah	ULTI TR IN	no ore hassle we got it all
artin	Josh	The at Controller	Training to e in control can e tough Controlling our trains oesn t ha e to e
artin	To	DigiLOck	Si plistic igital loco oti e engineering technolog
astro uono	shle	aster Tech	Use the aster o e er thing aster
cCollu	Dane	Train o atic	Co plicate l eas to use
cl or	Sophie	Loco Go Ga get	The worl s ost a ance loco oti e
ills	Sean	S art Train	Tire progra ing the rest Pick the est
Na lor	ie	Si plex	Si pl Controlling
Oli er	Lisa	Train Control	or the real an whos in control
Orr	Nate	Unparallele	Breaking own the arriers in a see ingl straight orwar worl
Paltri ge	Jaco	Control Pro	Controlling oursel has ne er een easier
Phillips	oll	Tech Train	ance loco otion at its si plest

Quach	Can	The Jon Benson	Eas to use an one o a kin
Shea	atthew	Eas Track	Si ple solutions or co plete control
Si iona	Oll	E S R IL E ICLE	C TC T E RE L R ILS
Spaans	Dianne	Train Control	our a iction si pl controlle
Stea	elle	Track aster	Control our trains without getting pu e
Stewart	Bre	ccelertrain	Eas as 1 2 choo choo
Stockle	Loren	E Rail	Controlling our Ca oose
Store	K le	Qua ro Con uctor	Just lip it an go
Sun	Oli er	ition	here legen egins
Tho as	Natasha	Train Brain	Take it Eas
Toia	Ja e	ECO ooster	Together we will o e orwar on the track that lies ahea
Tressler	lex	Tech Ease DCC Controllers	ero a ressing Si pli ie train o e ent or our en o ent
T nan	Laura	I Train Controls	Just plug it in an go
ang	Qian	histle	Pla with attitu e
ar	Ste ie		
ikstro	Linus	Si pl Go	Chil ishl Si ple
ilson	Ellen	utoChoo	ar work is one ore ti e or un
n ar	George	ccessi le llie	One ox to acilitate all our progra ing nee s
n ar	Kate	Strea line Si ekick	Tracking the Re olution

Whole Class List MKTG255-12A (TGA) Consumer Behaviour

Surname	**Preferred Nar**	Bran Na e	Slogan
Berr	Ethan	Digi Con uctor	Being the Con uctor has ne er een easier
Prince	Clinton	Prolocotrol	or the a ateur wanting expert results

Whole Class List MKTG355-12A (TGA) Consumer Behaviour

Surname	**Preferred Nar**	Bran Na e	Slogan
o s	Daniel	Eagle E e	ini al progra ing axi u un

Appendix J

Price quote for a Tereina

Co ent	Description	Designator	ootprint	Quantit	URL	ro	Or er Quantit 10	price ro ele ent14	10	Or er Quantit 100	rice ro ele ent14
DC connector	dc plug	P1	Dc connector	1	http://nz.element1	Element14	10	0.6595	6.595	100	0.6595
Power-in	Terminal block, 2-Pin	P2	HDR1X2	1	http://nz.element1	Element14	10	0.1698	1.698	100	0.1698
switch	SW-SPST TACTILE OM	B1, B2, B3	SW-SPST tactile	3	http://nz.element1	Element14	30	0.0989	2.967	300	0.0989
Capacitor		C1, C16	Cap_4700uf	2	http://nz.element1	Element14	20	0.4963	9.926	200	0.4963
		C2, C3, C4, C7, C8, C9	0.33uF	6	http://nz.element1	Element14	60	0.0099	0.594	600	0.0099
		C5, C6	47nF	2	http://nz.element1	Element14	20	0.0102	0.204	200	0.0102
Capacitor	Capacitor	C12, C13, C14, C15	RAD-0.2	4	http://nz.element1	Element14	40	0.0194	0.776	400	0.0194
	Capacitor	C10,C11		2	http://nz.element1	Element14	20	0.006	0.12	200	0.006
Diode 1N5408	3 Amp Medium Power Si	D1, D10	DO-201AD	2	http://nz.element1	Element14	20	0.1483	2.966	200	0.1483
Diode 1N914	High Conductance Fast D	D2, D3, D4, D8	DO-35	4	http://nz.element1	Element14	40	0.0152	0.608	400	0.0152
5mm LED	5mm LED	D5, D6, D7, D9	5mm_LED	4	http://nz.element1	Element14	40	0.1352	5.408	400	0.1352
D Connector 9	Receptacle Assembly, 9 P	J1	DSUB1.385-2H9	1	http://nz.element1	Element14	10	1.287	12.87	100	1.287
Relay-SPST	Single-Pole Single-Throw	K1	Relay-SPDT	1	http://nz.element1	Element14	10	1.661	16.61	100	1.661
Program pin	Header, 6-Pin	P4	HDR1X6	6	http://nz.element1	Element14	60	0.0272	1.632	600	0.0272
Max3222cdw	rs-232 transevier	P5	Max3222cdw-20	1	http://nz.element1	Element14	10	2.5349	25.349	100	2.5349
I2C socket	Header, 4-Pin	P6	HDR1X4H	1	http://nz.element1	Element14	10	0.1058	1.058	100	0.1058
Terminal Block 2-	Program track header	P8	HDR1X2	1	http://nz.element1	Element14	10	0.0444	0.444	100	0.0444
	Program track connector			1	http://nz.element1	Element14	10	0.0125	0.125	100	0.0125
IRF540	HEXFET N-Channel Pow	Q1, Q2, Q5, Q6	TO-220AB	4	http://nz.element1	Element14	40	1.8216	72.864	400	1.8216
BC549C	Amplifier Transistor NPN	Q3, Q4, Q7	TO-226-AA	3	http://nz.element1	Element14	30	0.0353	1.059	300	0.0353
POT	POT 50KD, vertical PCB	R6, R7, R8, R9	POT	4	http://newzealand	RS	40	0.94	37.6	400	0.94
Tilt Switch	Photo sense tilt switch, lea	S1	Tilt_switch_footp	1	http://nz.element1	Element14	10	4.6512	46.512	100	4.6512
5V_REG_7805c	Positive-Voltage Regulato	U1	kc03	1	http://nz.element1	Element14	10	0.4008	4.008	100	0.4008
MCP1700T-3302I	Low Quiescent Current LI	U2	SOT-89-MB3_N	1	http://nz.element1	Element14	10	0.5038	5.038	100	0.5038
74HC1G66GV	5V Single Bilateral Switch	U3	SOT753	1	http://nz.element1	Element14	10	0.0541	0.541	100	0.0541
OP-AMP		U4	MCP601T-E/OT	1	http://nz.element1	Element14	10	0.6	6	100	0.4
Rn-42 bluetooth	bluetooth	M1	MODULE BLUE	1	http://www.digike	Digikey	10	17.29	172.9	100	16.055
PIC18F26K22	PIC18F26K22	P3	DIP18	1	http://www.digike	Digikey	10	2.66	26.6	100	2.21
Resistor	470	R1		1		Element14	10			100	
	4 7k	R2 R3 R26		3		Element14	30			300	
	10k	R4 R22 R28		3		Element14	30			300	
	18k	R5		1		Element14	10			100	

	220	R10		1		Element14	10			100	
	100k	R11		1		Element14	10			100	
	1k	R12 R13 R34		3		Element14	30			300	
	2.2k	R14 R15		2		Element14	20			200	
	560	R16 R19 R21 R23 R29		5		Element14	50			500	
	100	R17 R18		2		Element14	20			200	
	1	R20		1		Element14	10			100	
	680	R24		1		Element14	10			100	
	1.5k	R25		1		Element14	10			100	
	120k	R27		1		Element14	10			100	
	3.9k	R33		1		Element14	10			100	
						all resistors costs appr		2	20		2
							single unit price for 10		48.3072	for 100	36.5133

Appendix K

Kickstarter Tereina description

Kickstarter draft

Tereina *is a ready to use DCC model train controller that anyone – beginner or veteran model train enthusiast – can use.*

Background information

What is DCC?

DCC, standing for Digital Command Control, is simply the technology standard for a system to operate model railways digitally. Light, sound and track switching can all be controlled in this way. Signals are sent from the controller, through the track, and into the locomotive where it is then interpreted by a small digital chip (known as a decoder.) The decoder powers the motor accordingly, turning on the lights or even sounding the horn.

What is Tereina?

Tereina is the easiest to use model train controller within the DCC system, on the market today. Quite simply, the Tereina controller takes away the complicated instructions that are prevalent in all of the other controllers available on the market.

- Unique scanning function – you will no longer need to remember all the address of your model locomotive and label each train. In order to control, you will have to manually input to throttle in order to control. Simply press scan button, Tereina will automatically recognize the model locomotives that has been placed on the railroad and assign it to one of adjusting knobs for controlling purpose.

- Easier programing procedure – when you want addressing new model locomotive with different address part from existing one. Only thing you have to do is flipping Tereina controller upside down and place model locomotive on the track. Tereina controller will automatically run through EEPROM to search suitable address and program model locomotive with it.

- Control up to four locomotives – Most of topline DCC controllers has ability to control only two model locomotives at the same time. Tereina provide you control up to four locomotives at the same time. It is fun to share with you and your three friends.

Easy to set-up and use, handmade in New Zealand with an optional Bluetooth function, meaning you can control your trains through your phone or computer, and with the possibility of up to 4 trains per controller, the Tereina is a revolution in model locomotive control.

Tereina is the graduated project for electronic engineering at The University of Waikato in New Zealand.

The Team

The team consists of myself, Benson Chang, my mentor, Professor Jonathan Scott, a software development team of five computer science students from The University of Waikato, and a marketing team of two communications students from the UoW too.

We need your help!
Funds raised through this project will be entirely used to manufacture Tereina controllers. Large-scale production will help reduce costs enormously, e.g. the price of making 100 would only be 1/3 of the price of making 10. We would also like to gage the size of the market/how many people are interested in this product and possibly others like it so even if you decide not to pledge, please leave us a message with any feedback you might have!

Appendix L

Full version of Tereina video ads

The video file is under the folder named "advertisement" in the attached CD.