School of Engineering Science
Simon Fraser University
Burnaby, BC V5A 1S6
nomadpen@techstyles.ca

February 25, 2009

Prof. Patrick Leung
School of Engineering Science
Simon Fraser University
Burnaby, British Columbia
V5A 1S6

Re: ENSC 440/305 Design Specifications for the Nomad Digital Pen

Dear Prof. Leung:

Please find the Design Specifications document from TechStyles Incorporation, attached to this letter. This document provides a set of technical guidelines and specifications for the design and development of the Nomad Digital Pen. The Nomad Pen is a stand-alone paperless digital pen that will sense the movements of the user's hand drawings capture the digital data and store it in the built-in memory.

The design specifications described in this document apply to the proof-of-concept model only. Design improvements for future iterations of the Nomad Digital Pen are discussed later in the document, but will not be implemented in this stage of development.

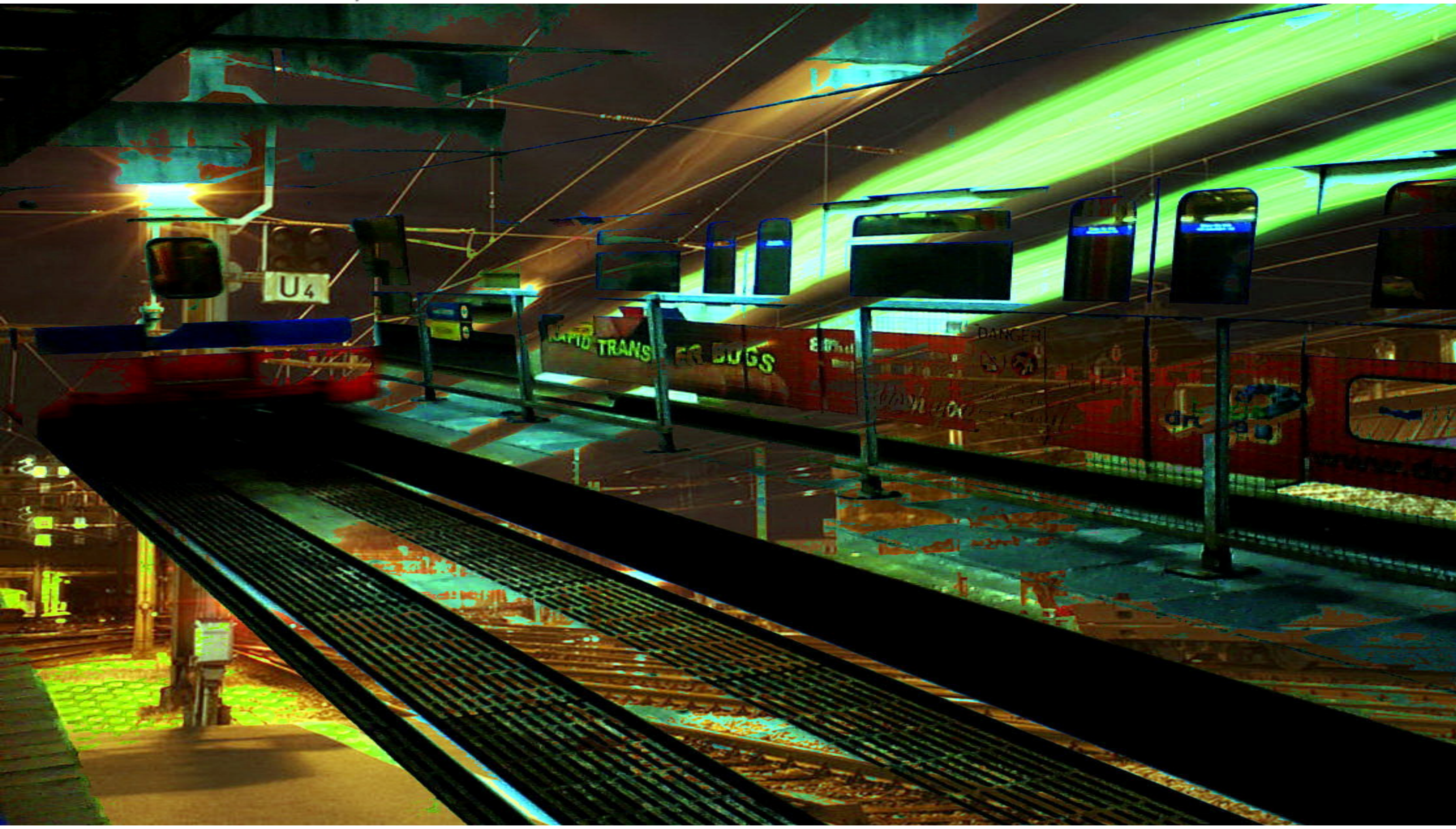
Should you have any questions or comments, please feel free to contact us by email at *nomadpen@techstyles.ca* or by phone at (604) 518-9152.

Sincerely,

Behzad Jazizadeh
Chief Executive Officer
TechStyles Incorporation

Enclosure: Design Specifications for the Nomad Digital Pen

TechStyles
Incorporated



DESIGN SPECIFICATIONS FOR THE NOMAD DIGITAL PEN

Project Team: *Zhen Gang Xiao*
Simran Sarai
Unnati Sapre
Behzad Jazizadeh

Contact Person: *Behzad Jazizadeh*
nomadpen@techstyles.ca

Submitted to: *Prof. Patrick Leung – ENSC 440*
Steve Whitmore – ENSC 305
School of Engineering Science
Simon Fraser University

Issued date: *February 25, 2009*
Revision: *1.0*

0. Executive Summary

The forgoing design specifications for the Nomad Digital Pen provide detailed descriptions in different categories and classifications for the design and development in the proof-of-concept stage. The design specifications in the document are exclusively discussed for the proof-of-concept model. As a result, and in order to be compatible with CSA marking scheme and the functional specifications document prior to this, only design considerations belonging to the functional requirements marked with I or II, are to be discussed and described in accordance with the document *Functional Specification for the Nomad Digital Pen* [1].

In this document the design details and development outlines for the Nomad Pen are provided. Further, justifications for the design choices are discussed. Possible design improvements for future stages of development of the Nomad Pen are also included. The input information/data to the pen is provided by the user, in one hand, to control the functionality of the device and by the motion sensors, on the other hand, to provide raw data to the processor and later to the memory according to the movements. Sensors located near the tip of the pen will detect linear acceleration in three X, Y and Z axes and angular velocity about the three X, Y and Z axes.

The processor interfaces the sensors, performs the control algorithm and provides the information to the memory and the UART module. The UART module then transfer data to the computer where the graphical user interface will come into play and gives real-time visual feedback to the user about the drawings. The power supplied by the programmer is considered to be sufficient to provide a maximum of 5 V DC power to the entire system for the proof of concept.

Detailed description regarding the requirements and criteria for selection of suitable microcontroller, sensors, memory and other circuitry will be provided. Graphical User Interface, the flow chart and a detailed description and process flow is also included. Also a detailed description of the test cases and verification outlines for the system-level and component-level testing is provided. User-level testing is also covered as the final stage in testing procedure which is normally done after proof of concept and/or prototype stage and before field testing.

During the course of the project the team realized that the four-month development cycle planned and targeted in the *Functional Specifications for the Nomad Digital Pen* [1] would be sufficient to complete the design implementation and calibration of the proof-of-concept. Therefore, the completion date for the proof-of-concept phase of design and development of the Nomad Pen is going to be April 30, 2009.

Table of Contents

List of Figures

List of Tables

Glossary

CSA	Canadian Standards Association
ISO	International Organization for Standards
UART	Universal Asynchronous Receiver/Transmitter
LED	Light Emitting Diode
GUI	Graphical User Interface
DC	Direct Current
USB	Universal Serial Bus
RoHS	Restriction of Hazardous Substances
IEC	International Electrotechnical Committee
LCD	Liquid Crystal Display
MCU	Micro Controller Unit
PDIP	Plastic Dual In-line Package
SOIC	Small-Outline Integrated Circuit
SD	Secure Digital
COM	COMmunication port
QA	Quality Assurance
API	Application Peripheral Interface
USART	Universal Synchronous Asynchronous Receiver Transmitter
EUSART	Enhanced USART
SDM	Surface Detection Mechanism
PIC	Peripheral Interface Controller
PCB	Printed Circuit Board
EMI	Electro-Magnetic Interference
SPI	Serial Peripheral Interface
I^2C	Inter-Integrated Circuit
EIA	Electronics Industries Association

1. Introduction

The Nomad Digital Pen is a paper-less stand alone solution for capturing data while writing and/or drawing that will have the capability of working on any surface with any slope. The comfort and ease of use that this pen brings to its users would be distinct aspects of this pen which are not found in any other alternatives in the market. Data capturing is done by sensing the position of the tip of the pen as its moves, and then translating the raw data into useful information for the graphical application use. This smart pen also provides a built-in storage for data such that the user can reliably keep the captured data for later upload. The specifications for design, implementation and calibration of the Nomad Digital Pen, as proposed by TechStyles Inc., are described and discussed in details in this document for design specifications. The main goal for this design is to create a one-piece device that will not only be able to write on any surface but also will take away the frustration of having multiple accessories and peripherals.

1.1. Scope

The current document specifies the design of the Nomad Digital Pen and explains how the design specifications are to be met according to functional requirements as was described in *Functional Specifications for the Nomad Digital Pen* [1]. The design specifications include the requirements for the proof-of-concept development stage and a discussion regarding the set of requirements and specifications for the prototype model. The same set of specifications will be traceable in future design documents and possible upgrades later. As the main focus is going to be on the proof-of-concept, only design considerations related to the functional requirements marked with I and II will be of interest to discuss explicitly and in details.

1.2. Intended Audience

The design specifications document is intended for use by all members of TechStyles Inc. through out the course of the project. The operations officer and their team shall refer to the design considerations as a concrete measure of progress throughout the different phases of design, implementation and development. Hardware designers as well as software developers shall refer to the requirements as an overall design reference to be continuously remembered from product design through the implementation. Validation engineers shall use this document to assist them in verifying the similarities of functional aspects of final proof of concept in the actual system with the design specification document. Finally, Ergonomists shall be able to use the design specifications document to verify the usability of the product and to design user test outlines.

2. System Specifications

The Nomad Digital Pen is going to be designed to sense the acceleration for translational movements and the velocity for rotations. It then stores the digital data onto the built-in memory for later use. The process of extracting the position data from the accelerometer and gyro-meter is entirely done in the software development section. Detailed design requirements applicable to the Nomad Digital Pen in the proof of concept stage are presented in this section. Also general design features related to the prototype stage are included.

3. Overall System Design

This section provides a high-level overview of the system design. The detailed design aspects common to all components and units of the Nomad Digital Pen are discussed in the upcoming sections. Further, detailed design features related to specific individual parts of the Nomad Pen are to be found in their corresponding subsections as follows.

3.1. Mechanical Design

As can be seen in the next page, Figure-1 provides an overview of the proposed mechanical design for the Nomad Digital Pen in the prototype stage. Note that the diagram to the left of the figure has been made as a cross-sectional view to show the underlying mechanisms, parts and components. The length of the pen is 14 cm (= 140 mm) which is from the top of the cap to the bottom of the tip. The diameter of the pen at its maximum cross section is to be 1.2 cm (=12 mm). In the process of mechanical design for the prototype, the design team considered the following sections for different components and units to be installed inside the pen:

- Ink Chamber
- Sensors
    - Accelerometer
    - Gyro-Meter
- Micro-Controller Unit (MCU)
- Flash Memory Unit
- Batteries
- LED
- Power On/Off Button
- Data Transfer Module

Other mechanical design considerations include the cap. Also it was decided to have the prototype designed so that it can be separable into three parts, for batteries, for flash memory and for ink cartridge. This provides a modular feature to the entire design while maintaining structural integrity of the Nomad Digital Pen and having the product as a stand-alone solution. The first line of product will be a molded solid design which maintains the modularity of the pen supporting the above mentioned structure. The three modular parts are to be designed in such a way that they would be screwed into each other, hence maintain the attachment.

It is worthwhile mentioning that considerations provided in the prototype with regards to the part dimensions and components sizes are, to a great extent, maintained throughout the stage of proof-of-concept model. The dimensions for each section consisting its corresponding part/component is also found in the figure below.

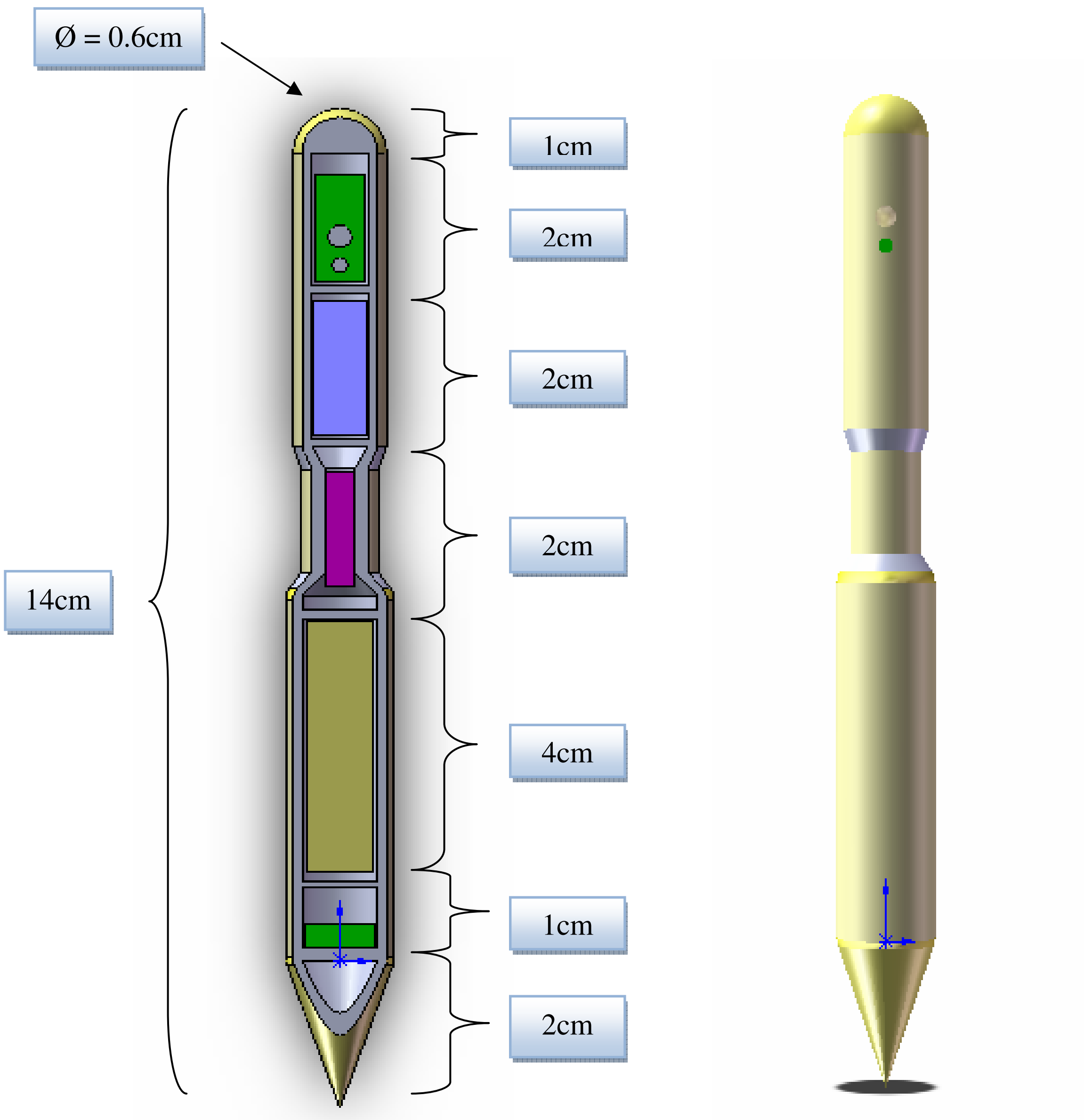


Figure-1, proposed mechanical design for the prototype of Nomad Digital Pen

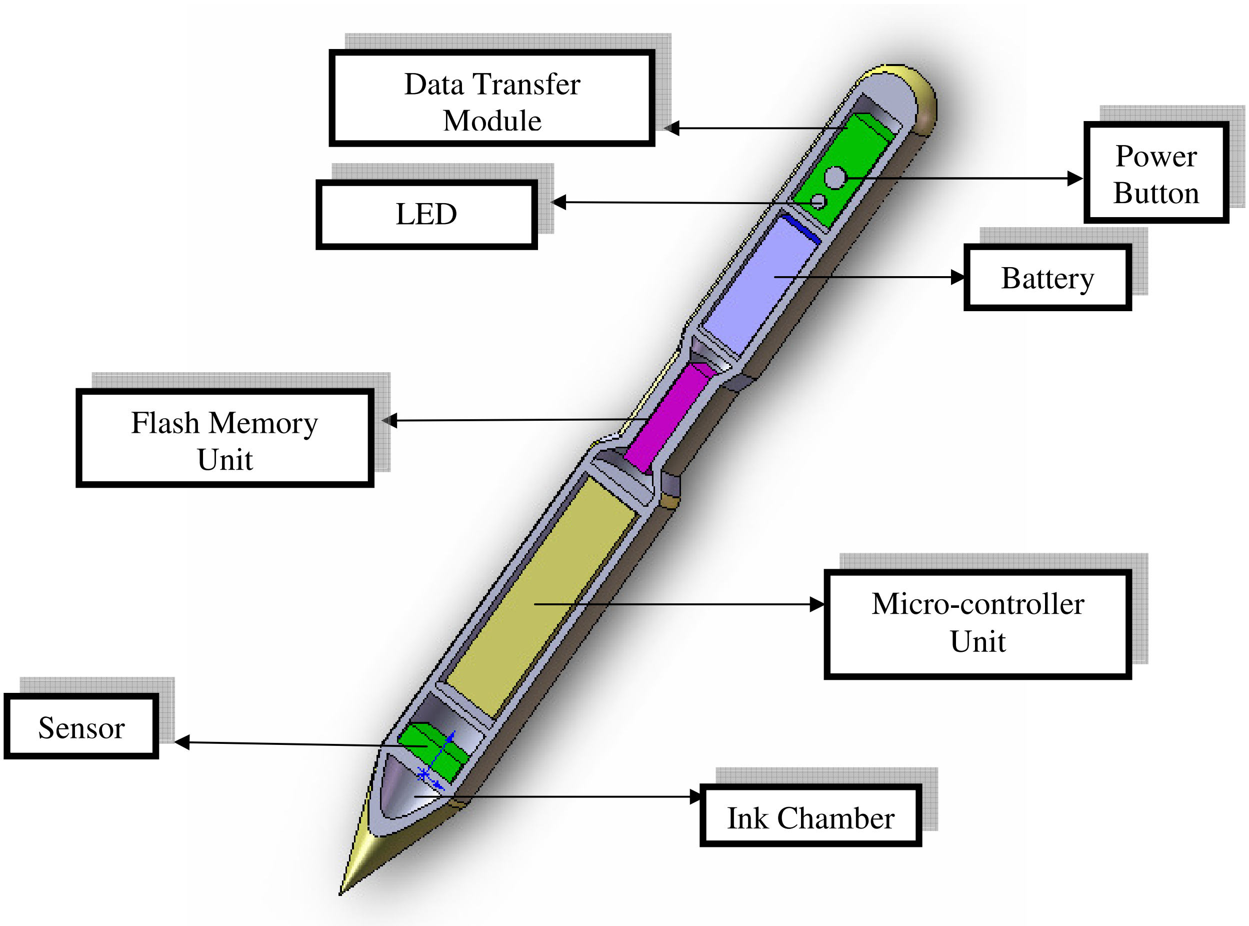


Figure-2, different parts and sections considered for them in the design

3.2. High-level System Design

This section provides a high-level system overview of the entire integration for the prototype and also the implemented system for the proof of concept and describes the placement of components on the chair. Figure-3 illustrates a block diagram showing the system inputs and outputs along with the relationships between modules and logical transitions between them. Figure-4 then illustrates a subset of the prototype which is to be implemented in the proof of concept development stage.

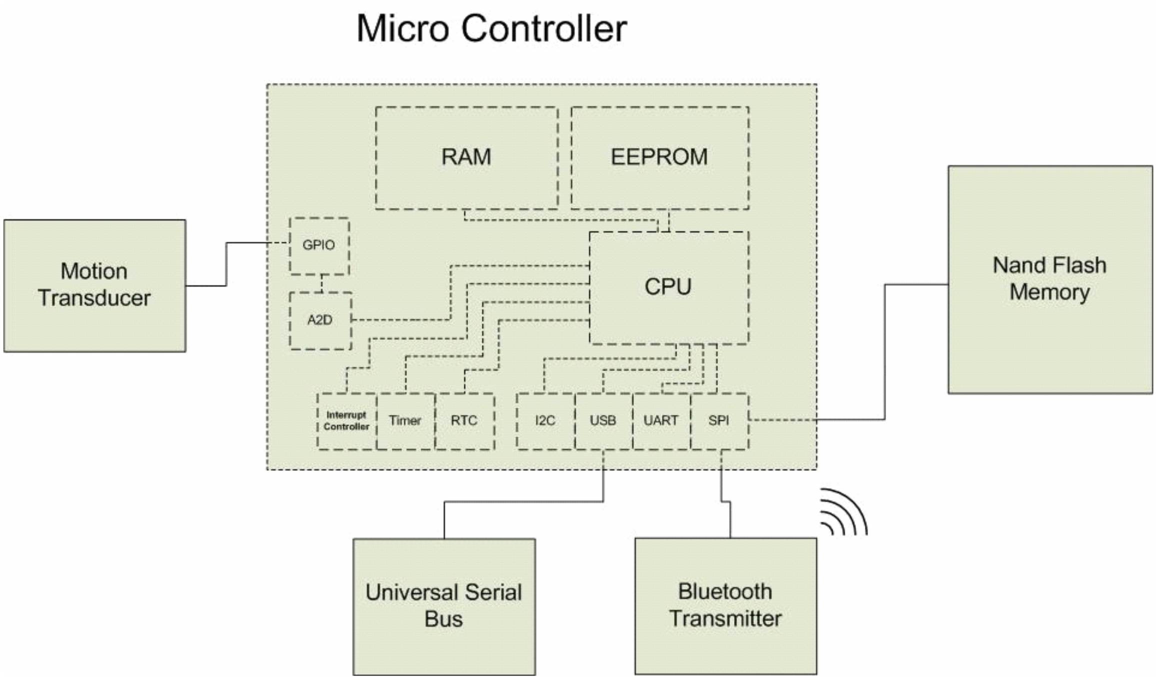


Figure-3, Detailed System Block Diagram for the prototype [2]

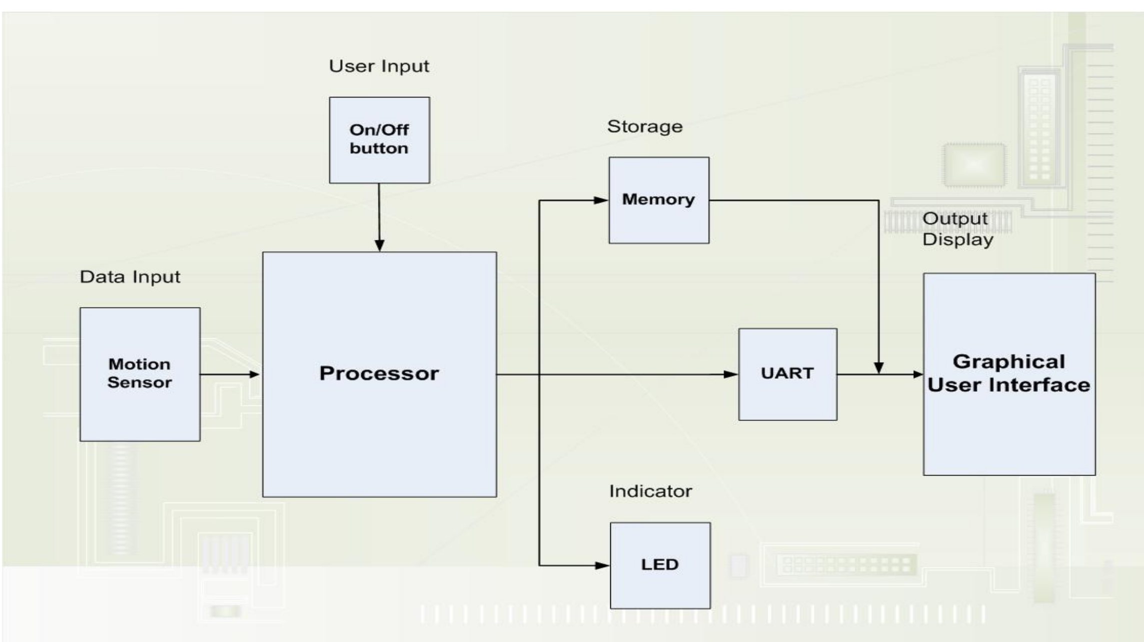


Figure-4: High-Level System Block Diagram for Proof of Concept [1]

System inputs include user input button (On/Off switch), and the digital data from the sensors. The data in turn consists of two types: one the acceleration measurement data from the accelerometer and the other the velocity measurement data from the gyro-meters. These two of types of inputs are conditioned and then digitized for use by the processor through signal amplification, filtering, and A/D sampling and quantization stages. The controller unit consists of the central processing unit, which contains hardware control code that provides the logical means of interaction and communication used to synchronization, monitoring, and activation of all other system components and device units.

The outputs are digital signals that are of two types: the control signal and the data line. The control signals provide the means for controlling and monitoring the memory unit, the UART module and the indicator. Data signals are to be transmitting data from the controller buffer to the memory and to the UART module. The status bits drive the LED directly from the microcontroller.

3.3. Sensing Mechanism

The operation for the Nomad Digital Pen is based on the following types of sensors:

- Acceleration sensor (Accelerometer)
- Angular Rate sensor (Gyro-meter)

Figure-2 illustrates the location of these sensors on the Nomad Pen. The accelerometer and gyro-meter are placed close to the tip of the pen, in order to have the most accurate and the fastest response (sensitivity) to the movements of the tip when writing and/or drawing. A detailed description of the sensors is provided later in this document.

In the proof of concept stage, a single tri-axis accelerometer and three single-axis gyro-meters are employed. This gives the capability of sensing the movements along all three dimensions in space, hence providing the Nomad Pen with the capability of writing on any surface with any slope.

In the prototype stage, however, there is only one tri-axis accelerometer and one tri-axis gyro-meter to be used for sensing mechanism, as in this stage the compact spatial design is a major criteria.

Another option for the sensing mechanism was the ultra-sonic sensor to be used for motion sensing. However, this solution required a minimal set of two pieces: a transmitter, to be installed at the tip of the pen and a receiver, to be installed in the base unit. The operation of this sensing mechanism defeats the purpose of having a stand-alone single-piece solution, and hence failed to be considered in the design.

3.4. Electrical System

The Nomad Digital Pen will be using a maximum power supply voltage of 5V. This maximum voltage supply guarantees that all the units on the board (PCB in the case of the prototype) will be performing properly. Micro-controller is the unit that provides the supply voltage to the rest of the circuitry. Since most of the units on the board make use of typical supply voltage range of between 3.2 V and 3.7 V, diodes are used in the path of the supply voltage to provide the necessary voltage drop for the circuitry. Also, in order to deliver a clean power signal to the circuit, by-pass capacitors are used to immediately clear the input signal to the micro-controller from frequency contents, hence providing a clear DC current.

Note that the input power supply used in the proof-of-concept system is provided by the micro-controller programmer kit. The input voltage is hence adjustable until the desired input voltage is achieved. However, for the prototype stage of development, non-rechargeable batteries are to be used to deliver the necessary voltage supply level.

As for any other electrical/electronic equipment and in order to reduce noise and improve the integrity and clarity of the signal, maintaining a single ground (GND) will be a necessity. Hence, it is planned to create one single ground and carefully connect all other ground levels to it on both the proof of concept and the prototype PCB. This grouping will also make the verification and hence troubleshooting procedures considerably faster and easier.

3.4.1 Noise Considerations

For the proof of concept, since relatively long wires (in the range of 20 cm to 30 cm) are used to route signals to sensors from the MCU, Electro-Magnetic Interference (EMI), and other external noise from LAB equipments are of particular concern in our design in this stage. This however is planned to be reduced in the stage of prototype, although in that the proximity of the units on a single PCB would bring a real challenge in the process of noise reduction. Nevertheless, the following steps are to be taken to reduce the detrimental effects of noises in the electrical system:

- Performing signal conditioning to get stronger more stable signals.
- Maintaining a reasonably achievable signal-to-noise ratio at all times.
- Calibrating in a less noisy environment.
- Designing an optimal layered out PCB.
- Shielding the equipment against EMI noise from LAB electrical equipment

3.4.2 Safety Considerations

TechStyles Inc. will provide safety of use for users, designers and developers and protection for electronic components by strictly enforcing the following precautions:

- Use of insulators and non-conducting material in molding in the prototype
- Practice of Electro-Magnetic isolation
- Proper insulation of wires
- Practice of proper circuitry
- Use of heat sinks in the final prototype design

4. Motion Sensors

When a person writes with a pen, the pen will have the translation and rotational movement. As a result, two kinds of motion sensor are required to capture the completed motion. They are the 3D accelerometer and ideally, the 3D gyro, but due to the cost-effectiveness, three 1D gyros are used instead for the proof of concept. The accelerometer is responsible for capturing the translational acceleration, and the gyro is responsible for capturing the angular velocity. By double and single integration, we will be able to capture the pen's motion in the 3D world.

4.1 Physical Design

For the production stage, the accelerometer and the gyro will be placed close to the tip of the pen to achieve greater accuracy. The following figure in the next page (Figure-5) show the orientation of the accelerometer (button) and the gyro (top). For current development stage, due to the size limitation of the sensor PCB, the sensor will not be placed inside the pen, but their orientation will be the same.

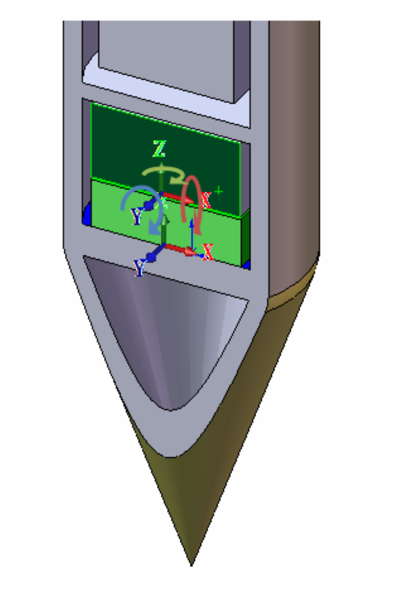


Figure-5, Sensors Placement

4.2 Electronic Design

There are many different accelerometers and gyro-meter in the market, some of them have only analogy output or only digital output, and some of them provide both. For this project, the digital output sensors are preferable; the main reason is they don't require extra circuitry to perform signal conditioning, which greatly reduced the complexity and cost.

4.2.1 Accelerometer

The accelerometer we used in this project is KXPS5-3157 tri-axis accelerometer from Kionix Corporation. It provided both analog and digital output, and it is able to sense the full range +/- 3g acceleration with high sensitivity. Acceleration sensing is based on the principle of a differential capacitance arising from acceleration-induced motion of the sense element, which further utilizes common mode cancellation to decrease errors from process variation, temperature, and environmental stress [3]. Its functional diagram is shown in Figure-6.

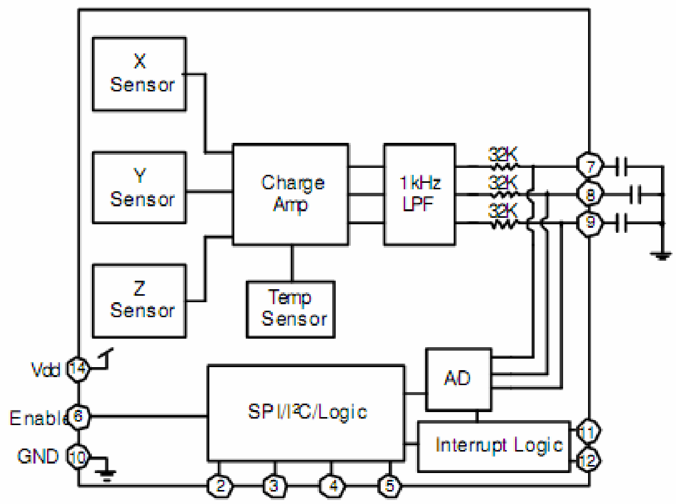


Figure-6, Functional Diagram of KXPS5 – 3157 Accelerometer [2]

This accelerometer provided two most common digital interface, they are the SPI and I2C. The SPI interface is a 4 wire connection, and I2C interface only require two wire connections. Even though the I2C interface is simpler in term of the schematic, its communication rate is lower than the SPI interface. The communication rate of SPI is 1MHz, and the communication of I2C is 400 kHz, as a result, the SPI digital interface is used in this project. Figure-7 shows the schematic for the SPI interface.

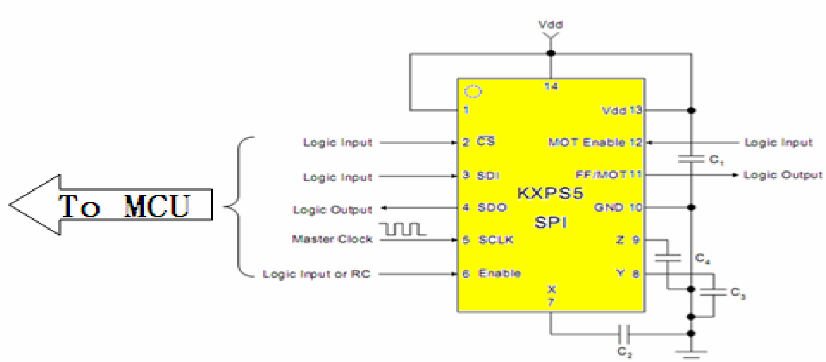


Figure-7, Schematic for the SPI interface [3]

4.2.2 Gyro – The Angular Rate Sensor

Ideally, a single 3D gyro should be used, but as mentioned in [1] and [2], three single axis gyros are used in this project for the proof of concept. The gyro we selected was XV-3500CB angular rate sensor, made by Epson, and it was mounted on the prototype PCB by Sure Electronic. Figure-8 shows the actual sensor and the prototype PCB.

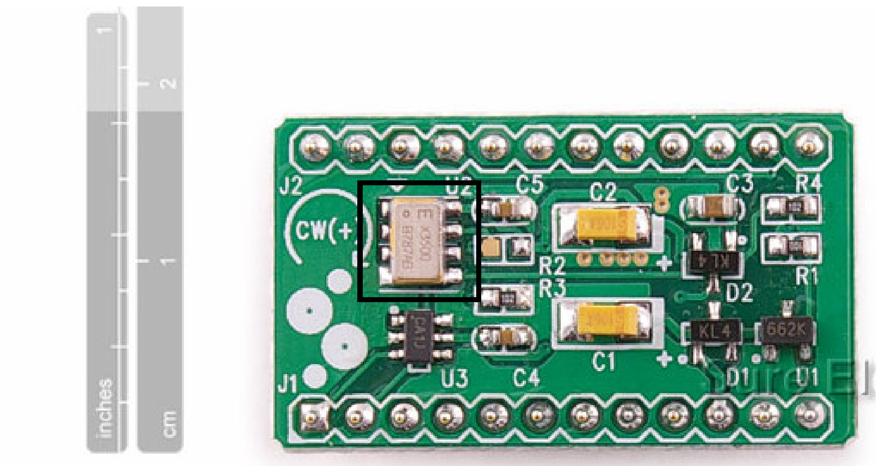


Figure-8, Prototype PCB for XV-3500CB Gyro [4]

The XV-3500CB provide both analog and digital I2C output, as pervious discussed, the digital output is preferable. Its operation range is +/- 100deg/s, compare to the normal rotation range for hand writing, it is more than adequate. To use I2C interface, we need to connect both data and clock with VDD via pull-up resistor, as the gyro spec suggest. Figure-9 is the schematic for gyro interfacing.

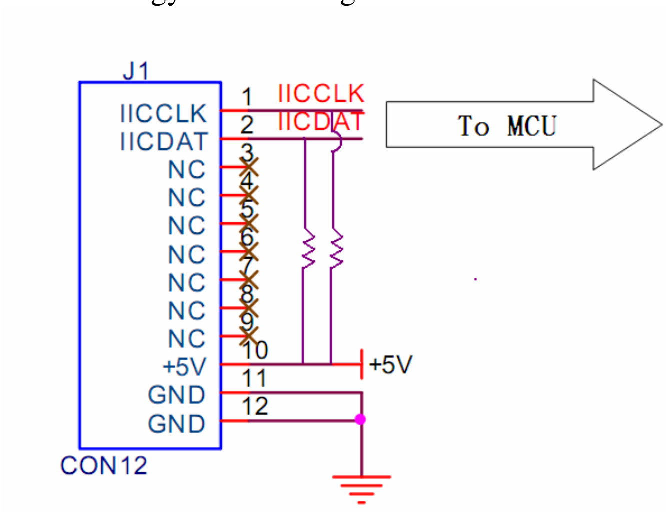


Figure-9, I2C Connection for Gyro [5]

5. Surface Detection Mechanism (SDM)

When the user write or draw, the pen will be moved frequently on and off the surface. Since we only want to display what we draw on the surface, a surface detection logic or mechanism must be employed. In theory, we can use the data capture from the motion sensors to determine if the pen has been lift off or not. But in real world operation, this may not be the best solution, because even the small discrepancies of the position calculation may prevent the proper content to be displayed. As a result, a mechanical surface detection mechanism will be employed. For the prototype, the surface detection mechanism will be implemented by using a push button.

5.1 Physical and Mechanical Design

For the production stage, the surface detection mechanism will be placed as part of the tip of the pen, as shown in Figure-10. A metal rod/disk is wrapped by a small spring, and on top of the disk, there are 2 metal connectors with a potential difference of 5V. When the pen tip is pressed against the surface, small amount of force causes the metal disk move up, and conducts the two isolated metal connector; when the pen tip is not contact with the surface, the spring ensures the metal disk away from the 2 metal connectors.

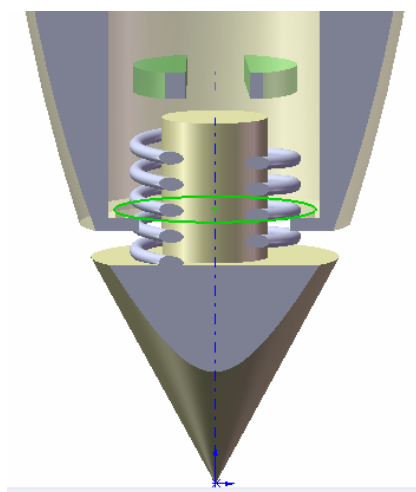


Figure-10, Surface Detection Mechanism

5.2 Electrical Design

The schematic of the surface detection mechanism is shown in Figure-11. One metal connector is connected to the general I/O of the MCU and the VDD through a current limiting resistor; the other metal connector is directly connected to the ground. The metal dish acts as a switch, to indicate whether the pen tip is touching the surface. When the tip is touching the surface, the general I/O port of the MCU will sense a logic low; and when the tip is off the surface, the general I/O will sense logic high.

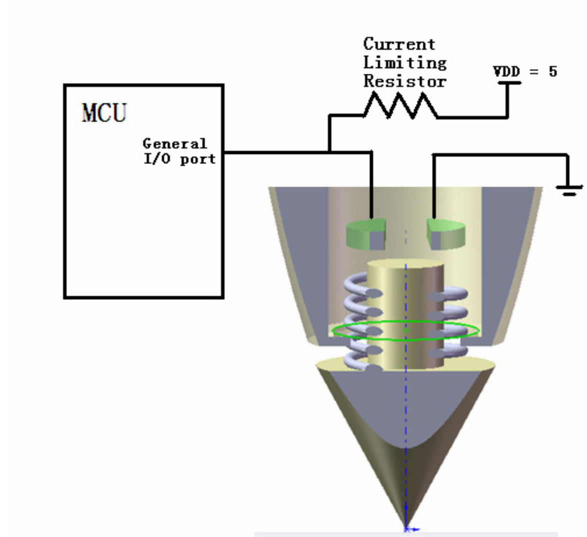


Figure-11, Electrical Schematic for the Surface Detection Mechanism

6. Micro Controller Unit

Microcontroller Unit (MCU) is one of the most important components of the pen. It is responsible for capturing the input data from the accelerometer and gyro, and then either storing the data into a memory unit or sending the real-time data to the computer for display. Also, it is connected to the hardware user interface, which enable to user to control the pen.

6.1 Physical Design

For the production stage, the MCU will be placed in the lower portion of the pen, and right above the sensor component unit. The size and the packaging of the MCU are one

of the important aspects we have to consider. By balancing the feature and size, we have chosen PIC18F2550 MCU from Microchip as the brain of this pen. Figure-12 shows the MCU placement and the actual picture for PIC18F2550.
(Note: Other MCU may also be used in the proof of concept stage, such as PIC18F4685)

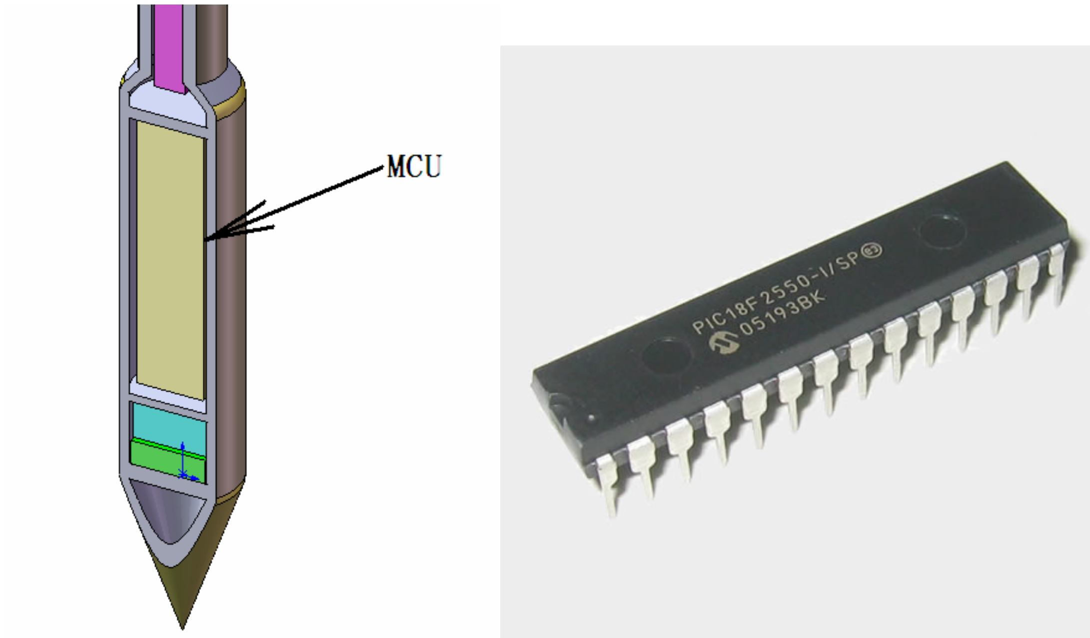


Figure-12, MCU placement and PIC18F2550

6.2 Electrical Design and Component Interface

The MCU is powered by a 5V voltage source, and the maximum power consumption is 1.25W. A 1µF capacitor will be inserted between the VDD and the VSS pin to prevent glitch. The following figure (Figure-13) shows the component connection with different connection interface:

(For detail connection, please refer to each component section)

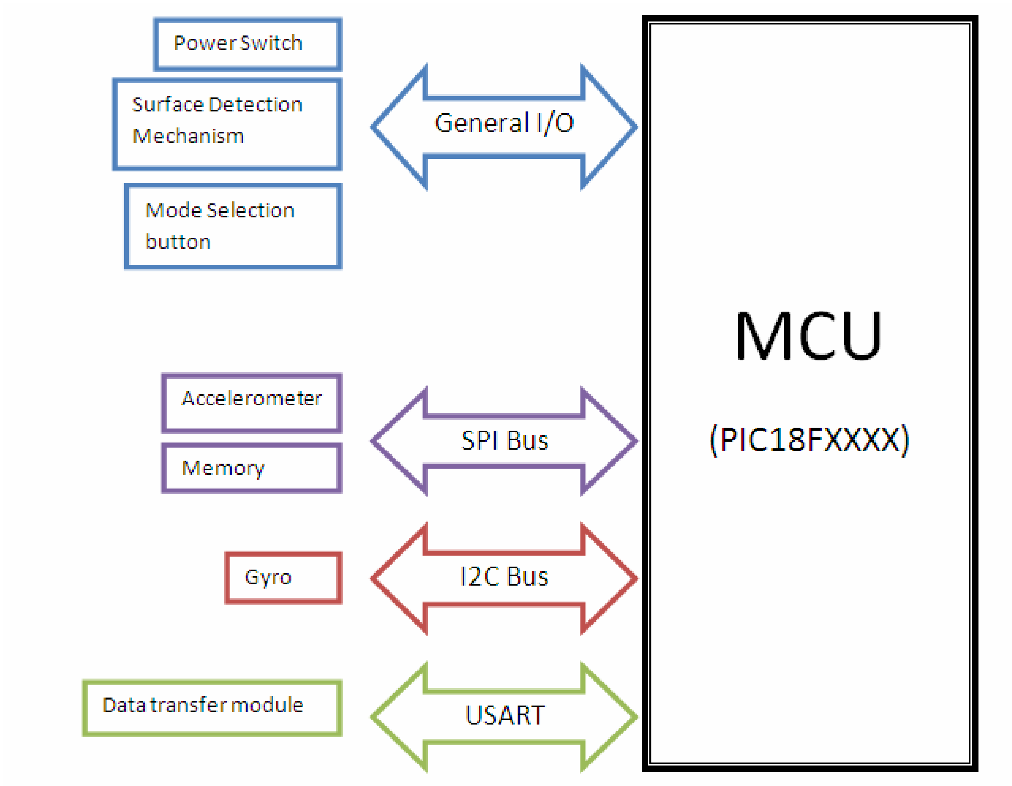


Figure-13, Component Connection Interface

6.3 MCU Operation Flow

The MCU is designed to operate with the clock cycle of 4MHz. With such operation frequency, we are to design a system with the "sequential approach". This approach reduces or eliminates the use of interrupt, which mean we are able to reduce the chance for data corruption and system complexity. The disadvantage for this approach is the pen will constantly consume power, even in idle state. For the current proof of concept stage, will employed the sequential approach; but for the final product, use of interrupt will be the main approach. Figure-14 shows the operating flow of the MCU.

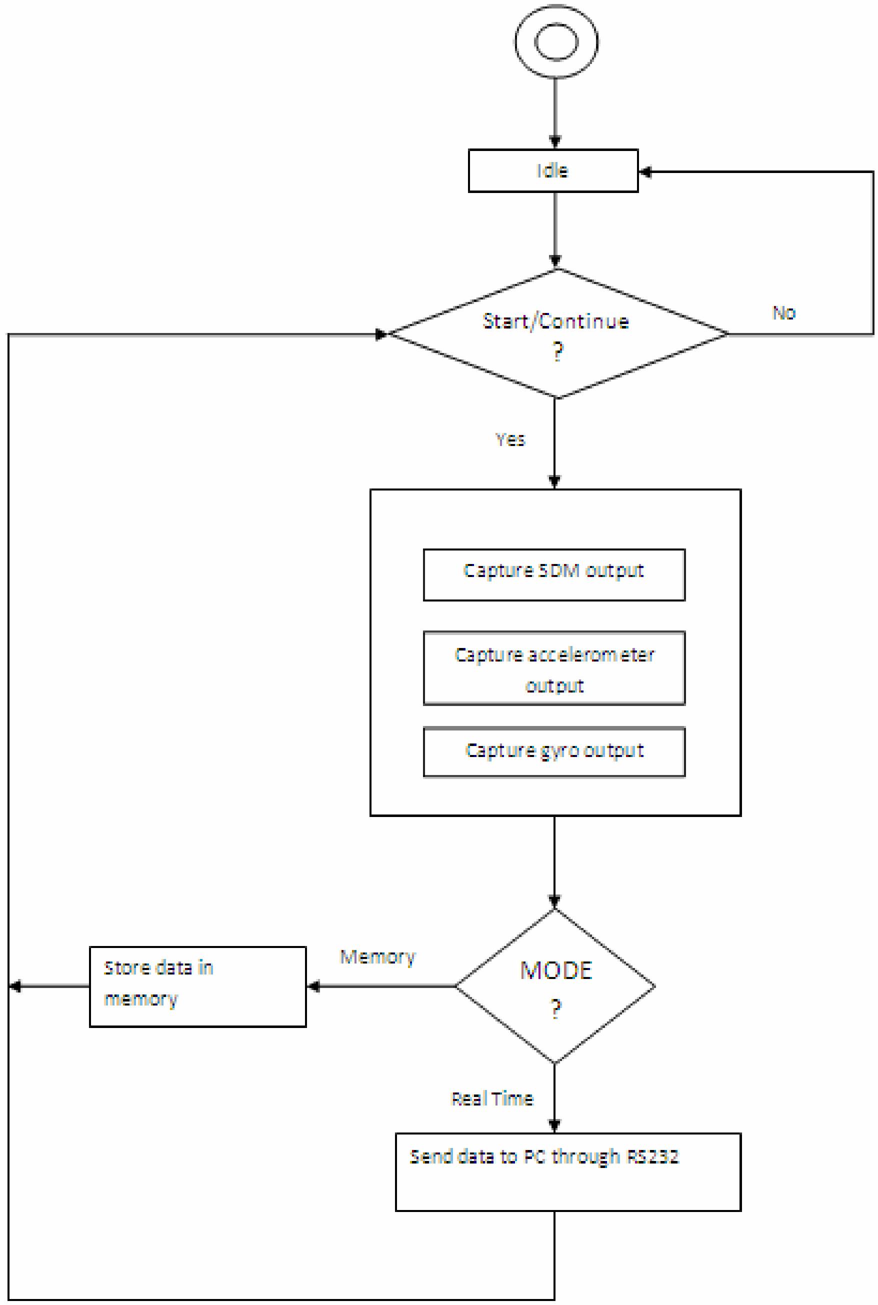


Figure-14, MCU operation flow

Once the power is supplied to the MCU, the pen will enter the idle stage, and wait for the "start". When the user has turned on the start switch, the MCU will change into operation stage.

In the operation stage, the MCU will capture the raw data in following sequence:

- Capture output data from the surface detection mechanism
- Capture output data from accelerometer
- Capture output data from gyro

After all the data is capture, the MCU will format all the data into a single array as one data block. Then depend on the mode that user has selected, the data block will be either send to the PC through the RS232 chip in real time, or store in the memory unit for later display. When the data block is sent or stored, the MCU will check the operation condition, decide whether it should continue to capture data or stop and wait for further command.

7. Memory Unit

A memory unit will be embedded in inside the pen to store sensor data for later implementation. There are many different kind of memory availed, but a Micro-SD memory card is ideal solution, due to its popularity, large storage capacity and the compact size.
(Note: for the proof of concept stage, a standard SD card will be used instead)

7.1 Physical Design

The Micro-SD memory card will be inserted in the neck of the pen as shown in Figure-15. Its physical dimension is 15mm x 11mm x 1mm (L x W x D). In the proof of concept stage, the data will be continued recorded as soon as the power is supplied. A 1GB micro-SD memory card will be able to store data for at least 4 hours of continuous operation [11].

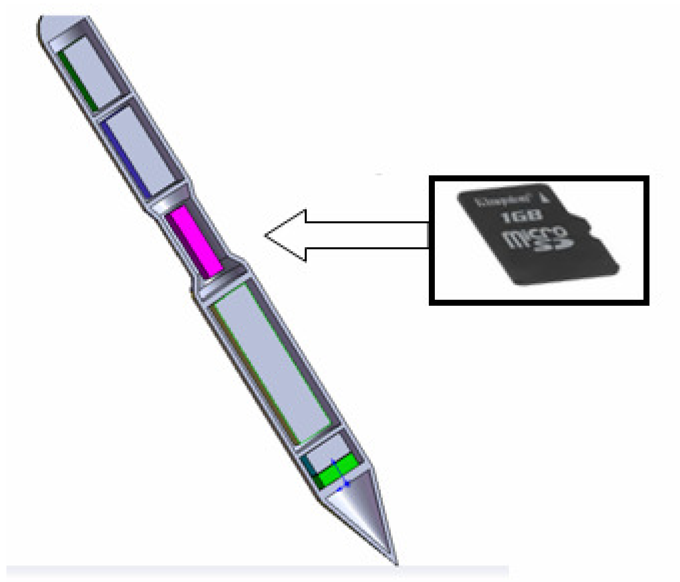


Figure-15, Micro-SD memory card [11]

7.2 Electrical Design and Component Interface

A Micro-SD memory has two interfacing mode, one is the SD mode, and the other one is SPI mode. SD mode uses five wire buses, one for command, and 4 for data transfer; SPI mode uses two wire buses, one for input, and one for output. The main advantage for SD mode is the SD card can operate in a very high speed, which up to 48 Mbps. Compare to SD mode, the SPI mode operates at a much lower speed, normally at 1MHz, but it is easier to interface with MCU, as a result, SPI mode is selected for this project.

A standard Micro-SD memory card must operate under the supply voltage of approximately 3.6V. Since we our supply voltage of the MCU is 5V, a voltage adjustment circuitry must be employed. As shown in Figure-16, two diodes are inserted between the 5V power supply and the VDD of the memory card, which provide a voltage of 3.6 in the VDD pin. The output signals from the MCU are passed through the voltage divider and provide the suitable input signal for the memory card [11].

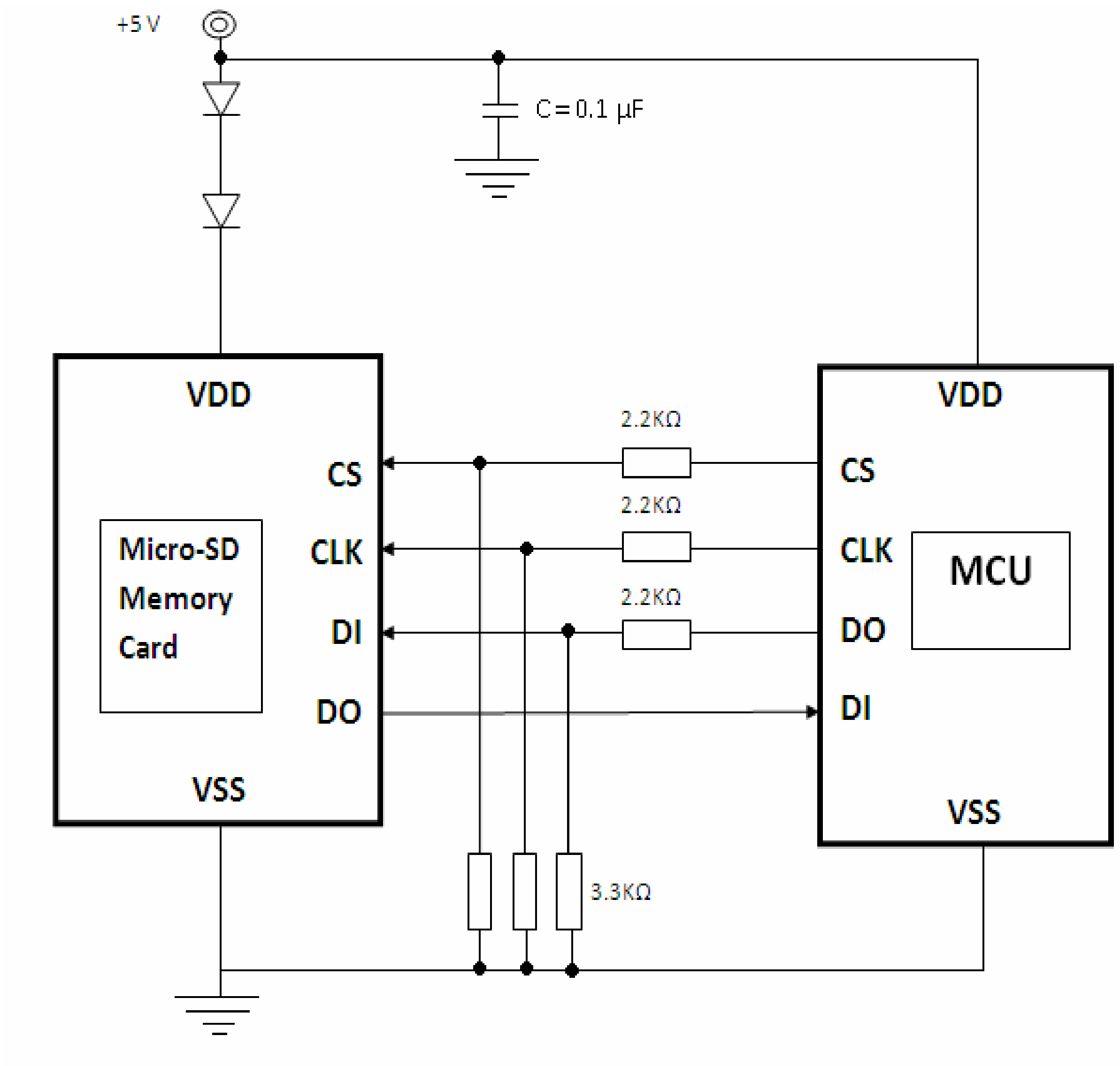


Figure-16, Micro-SD memory card interfacing diagram [11]

8. UART Module

The USART (Universal Synchronous Asynchronous Receiver Transmitter) module provides the interface for serial communications. In the Nomad Digital Pen project (proof of concept) The USART works in conjunction with the EIA RS-232 communication standard.

8.1. Physical Design

UART is implemented as an integrated circuit. In the Nomad project, the use of the PIC18F4685 (Micro-Controller Unit) brings the advantage of using the USART module that is a built-in on-chip feature of the MCU [13].

8.2. Electronic Design

On the PIC18F4685 the USART is introduced as an Enhanced USART (EUSART) module. For the purpose of the Nomad Digital Pen, this module is designed and considered to work with the EIA RS-232 Standard at the baud rate of 9600 bps and in the Full-Duplex Asynchronous mode [13].

9. Battery Unit – Power Supply

The battery unit acts as the gas tank for the MCU specifically and for the entire Digital Pen unit in general. As a design consideration for the prototype stage of development and according to the specifications in the *Functional Specifications for the Nomad Digital Pen* [1], non-chargeable batteries will be used. This makes it easier to work with the power supply as a user and also eliminates the need for extra circuitry and extra hardware pieces to be used in the prototype.

9.1. Physical Design

Based on certain physical constraint such as dimensions and weight the batteries considered for the Nomad Pen are Lithium Ion Coin batteries. The dimensions are each battery unit is 10 mm x 2.5 mm (diameter x height) [12]. These batteries are RoHS compliant and also Lead-free. One single mechanical consideration that should be designed in the Nomad Pen is a holder for the batteries to be implemented inside the body of the pen as shown in Figure-2. Coin batteries are to be stacked up on the battery holder.

9.2. Electrical Design

Each battery unit provides a supply voltage of 3V with the capacity of 30 mAh [12]. Each unit is a non-rechargeable battery. Extra circuitry is to be provided for the batteries on the battery holder to enable the normal flow of electrical current sufficient to feed the Micro-Controller.

10. User Interface Unit

The user interface for the Nomad Digital Pen consists of both a hardware component and a software component. The hardware component helps the user to control the mechanical operations of the pen while the software component allows the user to select the communication port and handle the .jpeg file management.

10.1. User Interface – Hardware

The user interface with Nomad Pen consists of turning on the pen using a push button and receiving visual feedback through a bidirectional LED

10.1.1. Push-button

One push-button shall be designed on the Nomad Digital Pen to enable the users to switch it on or off. The maximum diameter of the push-button will not exceed 4mm and shall be placed on the farthest end of the pen (see Figure-2 page 9). This choice of position prevents the users from accidently turning off the pen while writing. The small diameter of the button maintains the sleek look of the Nomad Pen.

10.1.2. Bidirectional LED

The bidirectional LED gives a visual feedback about the status of the pen at any given time according to the following scheme shown in Table-1 below.

LED State	Colour	Indication
Off	__	The pen is switched OFF
Steady	Red	Battery Low
Flashing	Red	Charging
Steady	Green	The pen is switched ON / Charged
Flashing	Green	Normal Operation

Table 1: Function Table of Bidirectional LED

The users can easily set/change the state of the pen according to their particular requirement and can keep track of the current state using the bidirectional LED.

10.2. User Interface – Software

A Graphical User Interface (GUI) will be designed for the Nomad Digital Pen. This GUI will be developed using Windows API and will be compatible with all WIN32 systems. The decision of selecting Windows API was based on the simplicity and ease of use. The programming will be done such that the users will be able to select a desired COM port, open, save or edit their session and also see the result of all the movements of the pen on the display screen, thus making the Nomad Digital Pen more user-friendly. A confirmation/error message depending on the success/failure of a particular event shall be displayed by a pop-up window on the screen. The GUI uses the RS-232 communication protocol to communicate with the micro-controller.

10.2.1. GUI icon

A unique icon shall be designed for the GUI making it visually convenient for the users to spot the icon among various other icons on the host computer. The users will be able to access the GUI window as soon as they click the icon.

10.2.2. GUI Menu Bar

The GUI window shall have a drop-down menu bar that enables the users to easily control the operations of the Pen and manage files. It presents various options for easy use and understanding as listed below:

File
- *-Open*
- *-Save As...*
- *-Exit*

COM port
- *-COM1*
- *-COM2*
- *-COM3*
- *-COM4*

Help
- *-About*

The File option manages a current session of the Nomad Pen. The "*Open*" sub-menu allows the user to open an already existing .jpg file for viewing. The "*Save As...*" sub-menu allows the user to save the current session to a .jpeg picture format. The "*Exit*" sub-menu closes the GUI and disconnects the Nomad Pen connection to the host computer.

The COM port option selects an appropriate communication port to which the RS-232 serial cable is connected for communication between the Nomad Pen and the host computer. The user shall be able to select from the range of COM ports available in the drop-down sub menu. If the selected COM port is already in use or the connection could not be made due to other reasons, an error message shall be displayed in a pop-up window on the GUI. This error shall clearly state the cause and fix to the problem.

The Help option shall provide licensing information about TechStyles Inc. and the Nomad Digital Pen device.

10.2.3. Display Window

The Display Window of the GUI is designed to display all the movements of the Nomad Digital Pen on the screen. The acceleration data bytes received from the pen shall undergo computation algorithm to provide the position points in x, y and z direction and shall be stored in a *.csv* file. The GUI reads this file and using the x, y and z positions, highlights the appropriate pixels in its display window. This provides the user with feedback of what they write when they are using without-ink mode of the pen. The display window can also show the data saved in the Pen's memory on the screen.

11. Communication Protocol – Pen ⬄ GUI

This section provides the details on the communication protocol between a Nomad Pen and a host computer. Utilizing these protocols, the host computer can acquire bits data from Nomad Pen by reading its in-built memory, conduct calibration and do computations to convert the data bits to position pixels on the GUI.

11.1. Physical Cabling

The user shall connect the female RS-232 connector of the serial cable to the Nomad Pen (in proof-of-concept design) and the male RS-232 connector into a serial port of the computer.

11.2. RS-232 Signals Definition

Out of the 9-pin RS-232 connector, only 3 signals are used for serial communication as can be seen in Table-2 below.

Signal	*Name*	*Direction*	*Function*
TxD	Transmit Data	Host to Nomad Pen	Asynchronous Serial Data from Host
RxD	Receive Data	Nomad Pen to Host	Asynchronous Serial Data to Host
GND	Signal Ground	N/A	Signal Ground Reference

Table-2, RS-232 Host Signals and their functions

11.3. RS-232 Settings

The settings of the RS-232 communication protocol adopted by the Nomad Pen and the host computer are outlined in Table-3 on the next page. Each transmitted character is packaged in a character frame that consists of a single start bit followed by the data bits, no parity bit, and one stop bit.

Parameter	*Value*
Baud Rate	9600
Parity	None
Data Bits	8
Stop Bits	1
Hardware	None

Table-3, RS-232 settings of a character frame

11.4. Data Transmission Format

The host computer receives one byte at a time over the RS-232 serial cable. All valid data is received after two header bytes 0xFF and 0xFE are sent by the Nomad Pen. Upon receiving the header bytes, the host computer receives the next 9 bytes in a buffer. These 9 bytes are the valid acceleration data and are represented as below:

X High	X Low	Y High	Y Low	Z High	Z Low	Ctrl	Ctrl	Ctrl

Figure-17, Sequence of acceleration data bytes received over RS-232 connection

In Figure-17 above, “X high” and “X low” represent the data bytes for the x-axis acceleration, “Y high” and “Y low” represent the data bytes for the y-axis acceleration, “Z high” and “Z low” represent the data bytes for the z-axis acceleration, and the remaining three control bytes provide the accelerometer settings. This acceleration data is integrated twice to provide the position for each axis and the offset value of the accelerometer is removed (as explained in the next section).

11.5. Calibration

The accelerometer provides an offset value which should be compensated for while collecting the accelerometer data. Therefore, as soon as the Nomad Pen is turned on, the initial values received after the valid header bytes are stored in a buffer. These are the offset values that would be used as calibration data. Whenever, the pen moves, this offset is subtracted from the original data to get the actual acceleration values.

12. Testing and Validation

Validation is a MUST in every and any design and implementation process, such that many medium sized and large size corporation that deal with design, prototype and production, have a separate department in the R&D section to be called validation department. TechStyles Inc. is not an exception here either. The following shall guide the verification engineers step by step, through the procedure to validate the design for the proof of concept.

12.1. Graphical User Interface Verification

The GUI shall be tested for its operability on the component level as well as module level. The verification shall be divided into three sections: component level testing, module level testing, and overall testing as can be seen in the diagram below in Figure-18.

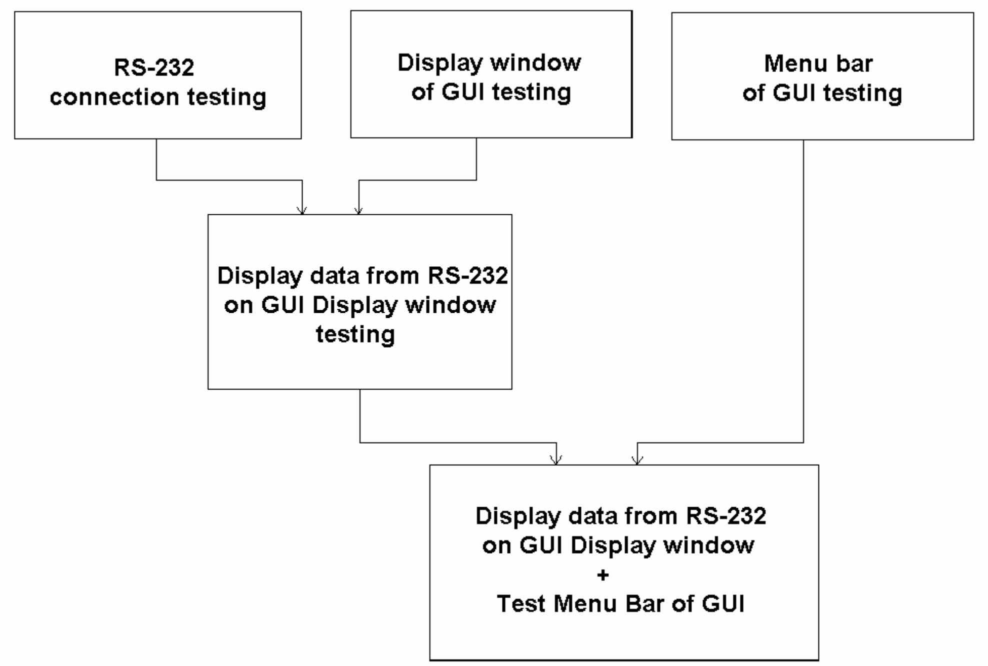


Figure-18, Software testing block diagram

12.2. Component level testing

The component level testing includes testing the RS-232 connection between the Nomad Pen and the host computer. As part of this testing, incorrect ports and already-in-use ports shall be selected to verify the correct error display. The display window shall be tested using a *.csv* file that contains the pixel numbers to be highlighted. The out of bound data shall be inserted in the *.csv* file to test the scroll bars on the display window. In the menu bar, each sub menu shall be tested separately for its correct operation.

12.3. Module level testing

The data shall be collected from the RS-232 serial port and displayed on the display window of the GUI. This includes integrating the two components – RS-232 interface and the display window. Testing shall be done for various writing speeds and tilt of the pen.

12.4. Unit level testing

In this testing, all the modules shall be integrated together and tests for normal and extreme conditions shall be performed. Again, another testing shall be done for various writing speeds and tilts of the pen and the menu bar shall be accessed at the same time. Sudden exiting of the GUI shall be tested to verify that the GUI prompts the user to save the current session.

12.5. System Test Plan

The complete unit shall be tested for compliance with design and functional specifications. System testing shall be done from the user's perspective and shall cover both the normal and the extreme cases. Figure-19 on the next page illustrates the concept and procedure in the diagram.

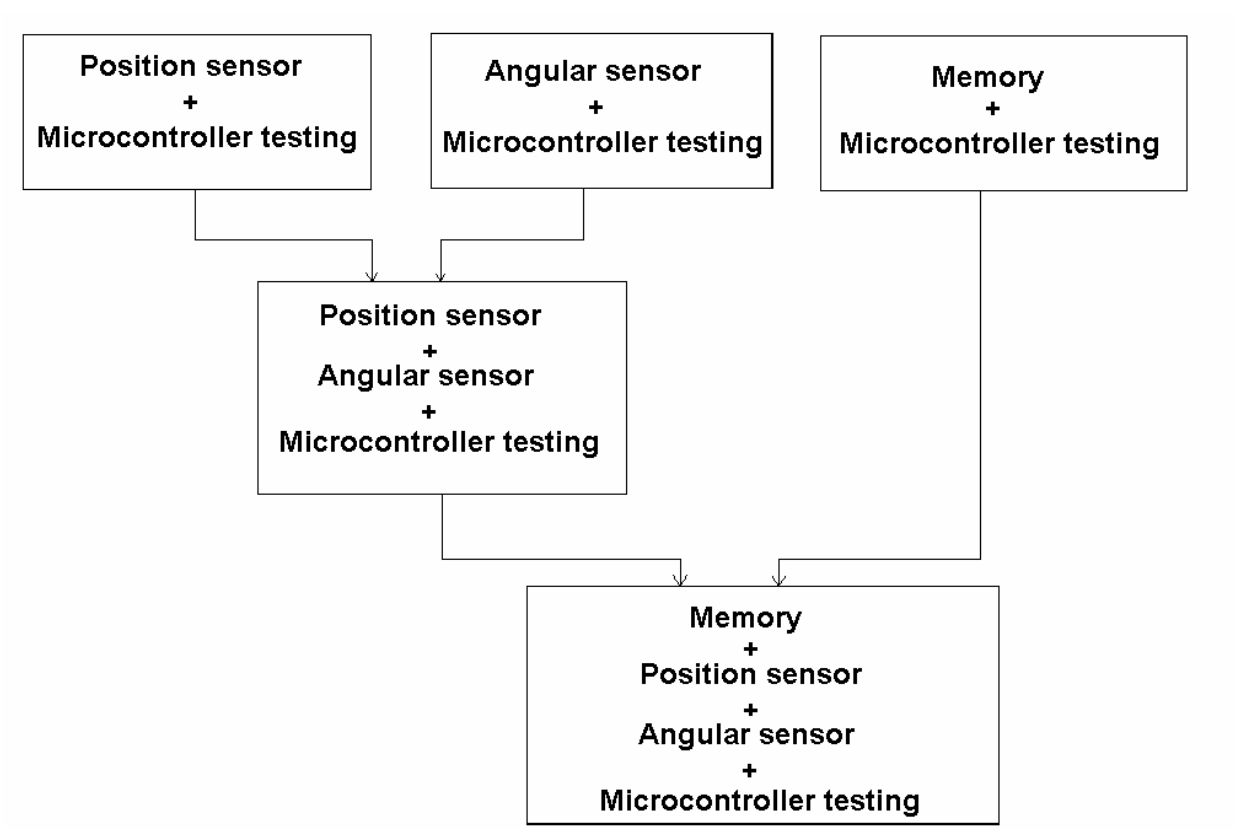


Figure-19, Hardware testing procedure flow diagram

12.5.1. Push Button and bidirectional LED testing – Normal Testing

Push button shall be pressed to turn on the power to the pen and then pressed again to test the power-off to the pen. When the pen turns on, the color of the bidirectional LED is verified according to the design specifications. When the pen turns off, the LED shall also turn off.

12.5.2. Push Button and bidirectional LED testing – Extreme Testing

Push button shall be rigorously pressed to turn on/off as fast as possible and the bidirectional LED colors shall be monitored for the correct operation. The push button and LED shall operate correctly up to an on/off frequency of 100Hz. This frequency is sufficient stimulus that a normal human hand can provide.

12.5.3. Battery charging time – Normal Testing

The charging time for the battery included in the pen shall be tested using a completely discharged battery. The status of the bidirectional LED shall be monitored to check if it indicates the battery low and battery charging status.

12.5.4. Maximum power consumption –Extreme Testing

The power consumption testing shall be performed based on the three different modes of operation of the Nomad Pen. . This test verifies that the power provided by the battery is enough for the functionality of the pen

12.5.4.1. Standby mode

This is the mode of least power consumption. Therefore, other than the functionality of this mode, no testing would be performed for power consumption.

12.5.4.2. Normal mode with real time display

The maximum power consumption shall be tested using this mode. The pen shall be directly connected to the PC while writing

12.5.4.3. Normal mode with data storage

The maximum power consumption shall be tested using this mode where data collected by the pen will be directly stored in the memory of the pen.

12.5.5. Varying speed and varying tilt of the pen – Normal Testing

A test shall be performed for accurate display of data on the screen when the speed of writing and the slope of the surface vary. Also, the tilt of the hand shall be varied to test the proper calibration of the pen by observing the writing on the display window of GUI. This test overall verifies the usability of the pen by users with different writing speeds and styles.

12.5.6. Graphical User Interface – Normal Testing

The GUI icon shall be clicked to verify opening of the GUI on the screen. All menu options shall be tested to ensure the proper functionality. The GUI shall be unexpectedly closed to confirm that "Save As..." message box is popped up to save the current session.

12.5.7. Delay in capturing writing – Normal Testing

A test shall be performed on the time delay it would take for the data to be displayed on the screen while the pen works in Normal mode with real time. The delay shall not be more than 2 seconds so that the quality of service is maintained with minimal delay.

12.6. Typical Usage Scenario

Designed to be used on any surface with any slope, the following typical usage scenario describes the steps that a user would go through to use the Nomad Digital Pen

- The user switches on the power and the session starts
- The user removes the cap of the pen to operate it with ink or leaves the cap
- on to operate in without ink mode
- The user determines to operate the pen in real time mode or the memory
- storage mode
    - Real time mode:
        - The user opens the Graphical Interface to capture the writing
        - The user connects the RS-232 serial cable to start the serial data transfer from pen to the host computer
    - Memory storage mode:
        - The user uses the pen as a standalone device without any connection to the computer. Later, when the access to the computer is available, the user can upload the data from the pen using RS-232 serial cable
- To complete the session, the user turns off the power using the switch

13. Conclusion

The design specifications described in the preceding document clearly define the specification and considerations and design features and requirements of the Nomad Digital Pen. Design, development and implementation of the final proof of concept will take place in two distinct phases, as was mentioned in the Functional Specifications document prior to this. Both phases are proceeded in parallel. The initial-idea model is well on its way to completion and it is confidently expected that all design requirements outlined above applying to the proof of concept development stage will be completed by the target date of April 30th 2009.

TechStyles Incorporated

14. Citations and References

[1]. TechStyles Inc., *Functional Specifications for the Nomad Digital Pen*, Simon Fraser University, Burnaby, BC, Canada, February 2009.

[2]. TechStyles Inc., *the Project Proposal for the Nomad Digital Pen*, Simon Fraser University, Burnaby, BC, Canada, January 2009.

[3]. KXPS5 Data Sheet, *Kionix Corporation*, available at: http://www.kionix.com/Product%20Sheets/KXPS5%20Series.pdf

[4]. PIC18F2455/2550/4455/4550 Data Sheet, *Microchip Corporation*, Available at: http://ww1.microchip.com/downloads/en/DeviceDoc/39632D.pdf

[5]. XV-3500 CB Data Sheet, *SureElectronic,* Available at: http://cgi.ebay.com/ws/eBayISAPI.dll?ViewItem&item=120361031391#ebayphotohosting

[6]. Electronics assembly technology, *IEC 60194 Ed. 5.0 en:2006 Printed board design, manufacture and assembly.* International Electrotechnical Commission, 2006, Updated: 2009.

[7]. ISO TC 159 SC 4 - Ergonomics of human-system interaction, *ISO 14915-1:2002 Software ergonomics for multimedia user interfaces -- Part 1: Design principles and framework*. International Organization for Standardization, 2002, Updated: 2009.

[8]. Ergonomic Requirements for Office Work with Visual Display Terminals (VDTs) - Part 8: Requirements for Displayed Colours (Adopted ISO 9241-8:1997, first edition, 1997-10-01), *CAN/CSA-ISO 9241-8-00 (R2005)*. Canadian Standards Association, 2000.

[9]. Ergonomic Requirements for Office Work with Visual Display Terminals (VDTs) - Part 9: Requirements for Non-Keyboard Input Devices (Adopted ISO 9241-9:2000, first edition, 2000-02-15), *CAN/CSA-ISO 9241-8-00 (R2005)*. Canadian Standards Association, 2000.

[10]. Industrial Micro-SD Engineering Datasheet. *Delkin Devices*, Available at: www.delkin.com/oem/pdf/delkin-MicroSD-engineering-spec-sheet.pdf

[11]. SD Group Technical Committee (September 25, 2006). *SD Specifications, Part 1: Physical Layer Simplified Specification* (Version 2.00 ed.). SD Card Association. p. 19. Available at: http://www.sdcard.org/developers/tech/sdcard/pls/Simplified_Physical_Layer_Spec.pdf

[12]. PANASONIC LITHIUM HANDBOOK. *Manganese Dioxide Lithium Coin Batteries: Individual Specification* (Version 2.00 ed.). Panasonic Corporation, August 2005. Available at: http://www.panasonic.com/industrial/battery/oem/images/pdf/Panasonic_Lithium_CR1025_CR1216.pdf

[13]. PIC18F2682/2685/4682/4685 Data Sheet, *Microchip Corporation*, Available at: http://ww1.microchip.com/downloads/en/DeviceDoc/39761b.pdf

