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Executive Summary

Jeti Media Sense has approached Agfa graphics with a solution to automate the collection of gloss meter samples. Currently a significant amount of time and human resources must be dedicated to obtaining the samples which are neither as accurate nor as precise as desired. The solution proposed within will reduce the human interaction time from 10s of hours to less than 20 minutes. The recorded results will be accurate to within 50 microns versus the millimetre accuracy used with previous methods.

The constraints that the design will meet are set forth by Agfa and limit the size, weight, ability to disassemble, input, output, units, compatibility and range. The design is broken down into its major components and 3 solutions that meet these constraints are considered for each part. These solutions are weighed in a decision matrix and analyzed using sensitivity analysis to definitively and confidently choose the best alternative.

These chosen alternatives are combined and discussed in the Chosen Design section of the report. The gloss meter is found to require inexpensive and easy to implement output conversion to be connected to the micro controller. The pins that will be used for connecting the user interface touch screen LCD, the gloss meter, the motor controllers, and the SD breakout board are defined comfortably.

The intended software design is outlined demonstrating the user's ability to input size, interval, and home position of the scan that is about to take place. This software will also store the collected data in a comma separated values (CSV) file to be easily opened with excel. This file will be stored on a SD card to allow for easy transportation to the computer that it will be analyzed upon.

Due to the amount of human work hours that this system will save the cost of the design is very small compared to the salary it will save. This provides a very short payback period for a very accurate and reliable system.

1. Introduction to the Design

1.1 Problem Statement

The goal of the project is to design an automated system which can accurately and precisely store the gloss measurements recorded at regular space intervals for variable image (media) sizes. Gloss banding is an undesirable phenomenon causing uneven distribution of gloss resulting from uneven curing of UV inks. The print quality of Agfa's high speed UV ink jet printers is substantially degraded by gloss banding. Agfa Inc. intends to analyze gloss measurements to fully understand the phenomenon of gloss banding and improve the image quality by prevent it. The current techniques used to quantify gloss for images produced by varying machine (printer's) settings, fail to produce repeatable and accurate data. Moreover, the data collection itself is tedious process with scope of human errors. Thus, the need for an accurate and precise automatic system which requires minimal human supervision was expressed by Agfa Inc.

1.2 Objectives

- Interface the gloss meter to a microcontroller and continuously record gloss reading for a given media size.
- Provide user interface to choose the size of the media (image) to be scanned and the intervals (in range of 5mm to 10mm) at which gloss measurements should be recorded.
- Ensure accurate positioning of gloss meter over the media through accurate actuators.
- Provide portable storage for the data (gloss values) recorded.

2. Background

Agfa Graphics is a leading supplier of prepress solutions for the commercial, newspaper and packaging printing industries. In addition, they are rapidly expanding their assortments into the growing market of digital inkjet printing with the development of state of art printers and specialized inks. Some of their printing applications include, but are not limited to posters, banners, signage and displays, textiles and decoration.

2.1 Problem Analysis

Agfa Graphics have expertise in UV curable inks specially designed for Agfa's various models of multi-pass, wide format UV inkjet printers. UV curable inks are stable, allow fast curing and are easy to handle. The excellent jetting performance and good adhesion on a wide variety of substrates enable a wide range of indoor and outdoor applications [1]. The high image quality, vibrant colors and perfect edge sharpness combined with good outdoor light stability guarantee heavy duty industrial printing results.

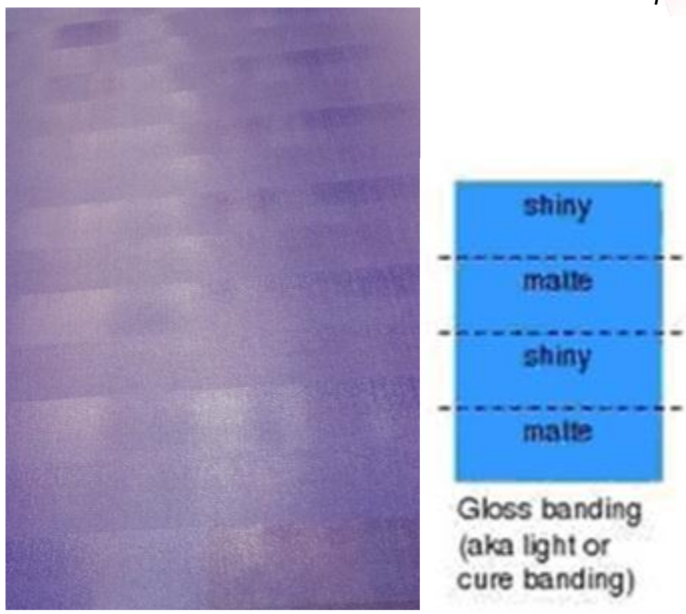

Figure 1: Gloss Banding

However, gloss banding problem degrades the print quality of the UV inkjet printers. Gloss banding occurs during the UV curing of an image (print), when the ink dries unevenly thereby creating uneven gloss distribution. Figure 1: Gloss Banding, shows this problem where one line has shiny finish and the other is dull matte.

In the past Agfa has tried to minimize the impact gloss banding on several older models using tools such as ink restrictions, lamp settings and the overall tuning of the machine. However, in high speed machines like Titan and HDC it is becoming increasing difficult to tackle this problem through the conventional means [2]. Hence, it important to first have a better understanding of this phenomenon. The several factors that can possibly reduce gloss banding are outlined below:

- Speed of the head carriage
- Number of passes (one pass = one side full length motion of the head carriage)
- Type of ink
- Type of UV bulb
- Types of printing used
- Intensity of UV lamps
- Bulb age & the type of bulb used
- EPS power supply output
- Conditions of the quartz and reflector

A gloss meter is used for the taking gloss readings (how shinny) of an UV printed sample. Currently at Agfa, the gloss samples are recorded by placing the gloss meter on the printed sample for every 5mm over the length and width of the printed media (see Figure 2). Before using a gloss meter to measure the gloss value of a printed pattern (image), it needs to be calibrated based on the type of media. Three most common gloss angles used at Agfa are 20°, 60° and 85°. The detail description for each angle is outlined below:

- 20° (degree) angle: It used for very smooth and highly polished surfaces that reflect images distinctly. The incident light is directly reflected on the surface, i.e. only in the main direction of reflection. The angle of incidence is equal to the angle of reflection [4].
- 60° (degree) angle: Generally used for semi smooth surfaces the light is diffusely scattered somewhat in all directions. The image forming qualities are diminished: A reflected object no longer appears super brilliant, but semi blurred [4].
- 85 (degree) angle: Generally used for rougher surfaces where light is diffusely scattered in all directions. The image forming qualities are much diminished: A reflected object no longer appears brilliant, but almost non-existent.

Afga's current gloss measurement methodology requires two technicians working for approximately of 5-6 hours for a period of 1 week [3]. Moreover, with this data collection process it is not possible to produce repeatable results even for identical types of media and machine setting (number of passes, ink density and lamp setting).

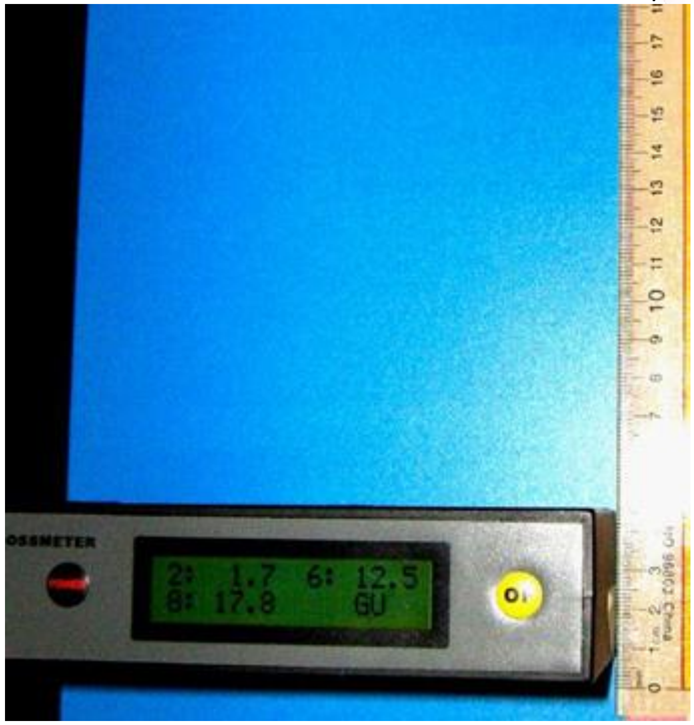

Figure 2: Recording Gloss Samples

Agfa Graphics has expressed a need of an effective and accurate system for quantification of gloss samples to have a better understanding of gloss banding phenomenon. A semi-automatic system that would require minimal human supervision and can collect data for different media sizes was requested by Agfa. This scanner will help Agfa to gather huge gloss data for variety of print samples by varying all the machine settings and thus fully understand the gloss banding phenomenon. In future, they can also use this media scanner for quantifying other factors like density of colors, by just replacing the gloss meter on the scanner.

2.2 Assumptions

The successful operation of the proposed final product will be dependent on a number of simple assumptions about the surrounding environment and peripheral equipment.

It is assumed that the device will be granted access to a standard North American 110V outlet for the power supply. This is required to supply power to the main power source. The main power source will then supply power to all other design components.

The media (pattern) should not be removed during the scanning operation. Any movement of the media will not be sensed by the system and may result into inaccurate results. Additionally, it is assumed that the provided gloss meter will perform accurately as intended and recorded by previous experiments within the company.

It is assumed that the media will be presented on a flat surface at least 2ft by 4ft in size, thereby providing enough space to set up the system over the media. The surface must be flat to allow for accurate translation head movement relative to the media to be scanned.

The computer that will be later used to analyze the gloss results is assumed to have the ability to read from a SD card. This assumption allows additional options to be considered for the data storage component of the system. This is a reasonable assumption due to the cost and availability of SD card to USB devices.

2.3 Constraints and Criteria

The following constraints have been provided by Agfa:

1. Device Mounting
    a. Must accept a standard gloss meter specified by Agfa
    b. Must be able to quickly (under 10 min) remove / mount the gloss meter
2. Measuring
    a. Must take readings in configurable increments
    b. Must be settable in metric
    c. Must be accurate & repeatable in movement within 200 microns
    d. Must work across a 4' x 2' substrate (can be extendable)
    e. Must save gloss data at settable angle, independent of the measuring device
    f. Must work with standard Material List: Coroplast, Foam board, Styrene
3. Device Mechanical Design
    a. Must be able to be setup easily
    b. A maximum of 3 tools used for assembly
    c. Must be durable - withstand small drops (waste level to concrete floor)
    d. Must be compact when not assembled - fit in an easy to carry case / box
    e. Must be light weight - under 30 lbs. - lighter is better
    f. Must have setup time under 20 min. - shorter is better
    g. Must have tear down time under 20 min - shorter is better

The following criteria have been provided by Agfa:

1. Device Mounting
    a. Have a modular design such that its easy (under 20 min) to mount other devices for similar measurement exercises
        i. Compatible with Eye One device
        ii. Compatible with densitometer

2. Measuring
    a. Imperial conversion capability
    b. Should be accurate & repeatable in movement within 50 microns if possible
    c. Should work across a 2m x 3m substrate
    d. Configurable work area – i.e. works in 2' lengths so large work area is not always required

2.3 Criteria for Evaluation

The foremost important criterion that the design will be evaluated on is the accuracy of the results. The final design must be accurate and repeatable within 200 microns. The system will be tested under different conditions upon several different types of media and measured on the scale of 100s of microns to ensure that the measurements are not only accurate but precise far beyond the ability of the human hand.

To accomplish this measurement a very small point will be mounted in the gloss meter clamp. This point will make multiple impressions on a material that can then be microscopically measured. The distances between these points will be measured and compared to the anticipated results and the formula for movement will be adjusted to ensure repeated accuracy. This will be carried out over a range of distance increments from the smallest possible increment to the largest anticipated request.

The secondary purpose of this design is to save the time of the employees of Agfa Inc. While the majority of this criterion will be accomplished by the automation of thousands of readings it is also essential that these readings take place in a timely manner. The speed of one reading will be a measurement benchmark for the valuation of our design. The speed goal of the design is to be faster than the gloss meter can take readings in all aspects, making the scanning device attached the bottleneck in the speed. This will ensure that the design saves as much time as possible versus the manual method.

The design will only be considered successful if it is easily transportable. This entails being able to fit in a carrying case of appropriate size and weight to carry easily when the device is disassembled. Conversely the design will be evaluated based on the time it requires to be assembled. While this criterion has a hard deadline of 20 minutes this is an outside maximum and less lengthy assembly times will have significant benefit.

3. Design Methodology

3.1 Design Ideas

Due to the nature and sensitivity of the media to be scanned it became apparent immediately that that the sensor should not be dragged across the media. To compensate for this, a distance sensor is to be mounted onto the head and calibrating it with media thickness will insure that dragging is not occurring. The following sections outline different designs and how they can be used in the system.

3.1.1 Drive Track

There was a multitude of drive mechanisms that were contemplated for use with this design. Each of the mechanisms described below can transfer rotational motion, and they have their sets of qualities.

3.1.1.1 Chain Drive

The chain drive alternative allows for easy length extensions. This option creates the possibility for slack in the chain which will decrease accuracy. The effectiveness of the chain design in comparison to the belt drive is that the life expectancy is much greater thus allowing for longer periods between service intervals. A significant difference between the chain drive and the thread drive is the implications for step size. Because there is always some slack in the chain, even if one were to micro-step a motor, the chain would not be as accurate.

Agfa has requested a design that has the potential to expand and scan larger pieces, using a master link and an extension; it would be very quick and simple to do in a portable environment.

3.1.1.2 Threaded Drive Rod

This chosen method offers a variety of advantages that make it more feasible for this design. It includes increased efficiency due to the reduced friction thereby reducing noise, longer life time, and precise positioning. Additionally there is negligible slack to the drive stiffness due to the motor's magnetic poles. Because this design requires a stepper motor to be directly coupled to the rod, it must be capable of higher torques, making it more costly to implement as described in the cost matrix. It does however guarantee precision. In this system, there are two ways to extend threaded rods; coupler, or separate threaded rods with different dimensions. A coupler has to allow the threads to continue.

3.1.1.3 Belt Drive

This alternative, while similar to the chain drive, would be significantly quieter. A disadvantage that it shares with the chain drive is the potential for slack in the configuration lowering the accuracy of the overall design.

The belt drive is not expandable to larger sizes, and would thereby need to be manufactured to specifications prior to any extensions.

3.1.2 Motors/Motor Controllers

Dependent on the implementations used above, it is necessary to further narrow the range of desired motors, with respect to size, cost, and power consumption. It is important to be confident in the position of the head and therefore an accurate account of the current position is imperative to the functionality of the system.

3.1.2.1 Stepper Motor

The stepper motor that was looked at is an industrial quality that has the capability of an open loop design. The drivers acquired with this motor are state of the art drivers known as "Sure Step" which has the capability of step sizing between 200 (full step) and 10,000(micro step) which insures the accuracy constraints are met. For example using 2,000 steps/rotation with a 5 pitch lead screw, allows a precision of 0.0001 inches/step. However with great precision comes decreased speed, this motor is capable of being precise up to about 500 rpm.

3.1.2.2 Agfa Motor (Teknic Nema 3411-3432)

This was a very high quality motor that was offered to Agfa for the possibility of use with the design. It's industrial strength and built in encoder design make it an ideal candidate for the system. This motor has a maximum operating speed of about 5000 rpm which is greater than any stepper motor is capable of.

However because this is a servo motor, it requires a very expensive driver that allows it to mimic the behaviour of a stepper motor.. Since the motor driver comes with its own software and is patented, interfacing it with the controller choice is difficult. Only option to use this system would require ground up programming and building the library which given the time constraints of this project is not feasible.

3.1.2.3 Norma motor (Servo Motor + feedback)

The servo motor is essentially a DC motor combined with feedback, which in this case consists of an encoder. Like the Agfa motor above it has high rpm capability, but is difficult to implement because it would require different types of drivers, extending the amount of programming required.

3.1.3 Microcontrollers

The microcontroller unit of the scanner design is programmed to move the motors the appropriate distances at the appropriate times. It sends the command to the gloss meter to perform a reading and records the reading sent back from the meter.

During the setup of a scanning sequence the microcontroller allows the operator to specify the distance over which gloss data needs to be measured and the increment that the meter shall take. Jeti Media Sense explored several microcontrollers before choosing the optimal controller for the scanner design. A detailed description of each microcontroller alternative is outlined below.

3.1.3.1 LPC1768 ARM Core Controller

This controller comes with a touch screen user interface on the top of the board which would provide easy integration. However the touch screen requires extensive character encoding and comes with no standard libraries making it a massive time commitment. Similarly the micro SD breakout circuitry comes hardwired to the board which would provide easy access to additional storage space.

By itself this controller also has a large amount of available memory with 64K static ram and 512K flash memory. This board operates with a variable operating speed up to 100MHz making it the fastest controller being considered for implementation.

There are 22 general purpose IO ports with easy to connect standard headers. Due to the integration of the touch screen user interface and the SD card slot onto the board itself these pins are free to be used for motor control in the design.

3.1.3.2 Adruino Mega 2560

The Arduino Mega 2560 had a total of 54 digital IO pins 15 of which provide pulse width modulated output and 16 analog input pins. This small inexpensive board operates on 5V at 16Mhz. The processor comes pre burned with a boot loader that allows the user to upload new code to it without the use of an external hardware programmer.

This open source board has countless resources, tutorials and libraries dedicated to making it easy to use and compatible with a wide range of peripheral equipment. The Arduino programming language is similar to C in many ways and has extensive material covering all the operations available.

The Mega 2560 has 256kb flash memory 8kb of SRAM and 4kb of EEPROM memory available. As a common board used in today's robotics projects it is readily available for purchase from many distributors.

3.1.3.3 68HC12 Motorola Controller

This 16-bit programmable board has 32kb EEPROM 32kb ROM and 36kb static RAM memory. The board runs at up to 8Mhz bus speed at 5V making it the slowest board being considered for implementation. The 68HC12 is programmed using assembly language which poses more difficulty and accuracy in everything from memory storage to basic arithmetic operations.

The HC12 is offered with 63 general purpose IO lines and is available in an 80-pin quad flat pack. There are no existing touch screen user interfaces that are designed for easy implementation on this board which implies having this method of user input would require significant programing and wiring time.

This board is readily available from many distributors and is familiar to members of the development team. Due to the long history and many revisions of this board it has well established and documented usages.

3.1.4 Data Storage

While considering data storage the transportation of the data from the system to the computer where it is to be analyzed is a highly weighted consideration. Additionally only those methods of data storage which provide sufficient space are considered for implementation.

3.1.4.1 Local Storage

The first design considered entails storage of the gloss meter readings directly on the board. While the software for many boards can be expensive, it often allows for easy array extraction. This design would introduce size of storage on the board as a new constraint.

Additionally the controller would be required to be connected directly to the computer that would be used to analyze the collected data. This means disassembling the head to extract the controller or transporting the computer to the device making the information highly un-portable.

3.1.4.2 Removable Storage

An alternate design entails the use of a SD card breakout board that would allow the chosen microcontroller to write to directly to the card. This approach allows for the greatest portability of the information. The card can be removed from the SD slot and easily carried to the workstation where the information is to be analyzed.

The implementation of the SD card breakout board would vary from microcontroller to microcontroller with one of the controllers discussed in section 3.1.3 above having built in breakouts already in place. In all cases this is an easy, inexpensive, well established functionality that provides massive amounts of space to store data.

3.1.4.3 Direct Storage

The final method of data storage for consideration is to transfer the data immediately to a laptop. This would require the laptop be present during the entirety of the scanning process but offers unlimited storage potential. The transfer of data would take place through serial communication which is likely to cause a bottleneck in the speed of data storage.

It has been made known that there are laptops available for this implementation making it a reasonable assumption that this component is available at Agfa.

3.2 Analysis Techniques

3.2.1 Determining Number of Ports Required

Each motor controller must be connected to the microcontroller with 3 pins. These pins correlate to: enable(+/-), forward or reverse, and step(+/-). The gloss meter is connected to the controller through 4 pins: ground, signal, and two pins to issue the command to scan, meaning that there will be a total of 16 general purpose input output pins required.

The touch screen user interface is attached to boards in different configurations. The LPC1768 board comes with an integrated touch screen user interface that requires no additional ports to be occupied. The HC12 board has no available libraries nor can specifically designed touch screen available, but compatible screens take 4, 6, or 8 pins on the board based off of implementation. There are many touch screen kits and libraries available for the Arduino board that also come with an integrated SD card breakout board. These boards typically take approximately 12 pins, 6 of which are required to be analog.

3.2.2 Gloss Reading Format from Meter

It is required to determine the pin out of the gloss meter to design the communication techniques. This gloss meter was provided by Agfa without any further components, it proved to be very difficult to obtain schematics from the manufacturer. Because of this issue manual procedures to find communication must be found.

The first step to accomplish this is to use a voltmeter to find the closed loop between the ground on the bottom of the battery holder and the ground pin on the output.

To find the signal port an oscilloscope is used in conjunction with a probe. This is connected to each port in turn while the gloss meter takes and "sends" readings through the port. While there was a significant amount of noise on each pin the signal pin was clearly identified by the large pulse in voltage.

Furthermore the type of output must be determined. It is essential to know if the output from the gloss meter is -12V - 12V or 0V - 5V. This is done while the probe is in the signal pin. When a signal is sent the output is observed. It is determined that the output from the gloss meter is -12V - 12V.

This introduces the necessity of a max232 chip if a 0-5V port on a board would be desired. This is not a significant setback due to the relative inexpensiveness of the max232 chips and the corresponding small capacitors that are used in its implementation.

3.2.3 Order of Component Selection

In the selection of which components are to be utilized in the design, compatibility is a highly weighted factor.

It is important to begin the design centered on the most highly constrained component, that is, the gloss meter provided. The outputs and inputs of the gloss meter are analyzed to determine an appropriate controller.

The appropriate controller is chosen and this is the core component to determine the communication connections that will govern the control and data management of the final design. Once the list of controllers is narrowed to those which communicate effectively with the gloss meter, motors, controllers, user interfaces, and data storage devices are chosen which will be compatible.

3.2.4 Calculations for Motor and Linear Movements

Using a 5/8" 16 thread, this is a National Coarse Standard thread, results in the following configuration for the resolution using our unipolar motor:

$$1.80/step \; = \; 200steps/3600$$

There are 16 turns per inch along the length of the threaded rod.

$$(16turns/inch) * (200steps/degree) \; = \; 3200steps/in.$$

$$3200 \; (step/in) \; / \; 25.4 \; (mm/in) \; = \; 125.98 \; steps/mm$$

Due to the fact a direct drive to the motor using full steps is desirable it will take roughly 126 steps to move 1 mm of linear motion.

$$1/125.98 \; = \; 0.008 \; mm \; = \; 8 \; micron$$

The constraint for this system states that the design must be accurate and repeatable in movement within 200 microns.

$$1 \; micron \; = \; 0.001 \; mm$$

$$200 \; micron \; = \; (0.001) * 200 \; = \; 0.2mm$$

It is observed that this configuration results in a resolution of 8 micron which is significantly smaller than the maximum resolution of 200 microns. This constraint will be satisfied.

3.2.5 Model Validation

The gloss data previously recorded by Agfa will be required for comparison with the results of the system. Ideally the same media used in the extraction of the gloss readings will be available for testing of the automated system. In the case where the same media cannot be delivered the sample to be measured should be created using the same printer settings that resulted in the original media.

An accurate benchmark with which to compare the output of the design is imperative to the overall accuracy of the system.

3.3 Alternative Evaluation Procedure

The design was divided into several components for the ease of comparing and evaluating different types of components. The evaluation was done using simple additive weighting decision (SAW) rules and creating dedicated decision matrix for each component. Simple additive weighting is one of the most popular and commonly used decision rules. It is based on additive aggregation of criteria outcomes outlined in Equation 1.

$$\emptyset_{SAW} \; (a_i) = \sum_j^n w_j * \; u_{ij} \; ; \qquad w_j \; is \; weighting \; factor \qquad \text{Equation 1}$$

A criterion is weighted based on its importance and each alternative is rated (compared with other alternatives) for that criterion. An alternative's performance over a particular criterion is the weighting factor of the criterion multiplied by rating of the alternative for that criterion. The overall performance of an alternative will be the sum of all individual performances. Table 1 was used to as reference rating scale for all the design alternatives.

Table 1: Reference Rating Scale

Rating Scale	
Rating	Meaning
-2	Highly inferior compared to other alternatives
-1	Somewhat inferior
0	Satisfactory
1	Good - somewhat superior
2	Excellent - highly superior

3.4 Evaluation of Alternatives

4.2.1 Drive Mechanism

Table 2: Decision Matrix for Drive Mechanics

Decision Matrix for Drive Mechanics							
Criteria	**Weight**	**Chain Mechanism**		**Belt Mechanism**		**Thread Mechanism**	
		Rating	Score	Rating	Score		
Re-sizable (Extendable)	0.3	2	0.6	-1	0.3	2	0.6
Set up time	0.2	-1	-0.2	0	0	2	0.4
Size and Weight	0.2	0	0	1	0.2	-2	-0.4
Life Span- Durability	0.2	1	0.2	-2	-0.4	1	0.2
Cost	0.05	0	0	1	0.05	1	0.05
Friction	0.05	0	0	0	0	1	0.05
Total Score	**1**	**0.6**		**0.15**		**0.9**	
Rank		**2**		**3**		**1**	

Table 3 displays a decision matrix for evaluating the potential options of the drive mechanics that will be used to connect the actuators (motors) in the final design and facilitating motion of the gloss meter over the media. It is extremely important for the drives to be easily extended (have variable size) thereby allowing the scanner to operate for various media (image) sizes. Considering the importance of this criterion it is weighted maximum. The set-up time, size and weight and life span (durability) criterions are equally weighted. However, the cost criterion was weighted lowest since short term; financial benefits and long term; improvement of image quality benefits, are more significant. Thus the system is worth an initial investment. The decision matrix also outlines the rank and total performance for each alternative.

4.2.2 Motors

Table 4: Decision Matrix for Motors

Decision Matrix for Motor							
Criteria	**Weight**	**Stepper Motor 125 oz**		**Teknic Motor 3411, 3432**		**Servo Motors**	
		Rating	Score	Rating	Score	Rating	Score
Performance (Precision)	0.3	2	0.6	2	0.6	-2	-0.6
Accuracy (Torque)	0.3	1	0.3	2	0.6	1	0.3
Complexity of Design Built	0.2	2	0.4	-2	-0.4	-1	-0.2
Size and Weight	0.1	2	0.2	-2	-0.2	-1	-0.1
Power Consumption	0.05	1	0.05	-2	-0.05	0	0
Cost	0.05	0	0	-1	-0.05	1	0.05
Total Score	**1**	**1.55**		**0.5**		**-0.55**	
Rank		**1**		**2**		**3**	

Table 4, displays the decision matrix for evaluating the motor alternatives. The performance (precision) of the motors is an important factor in determining the repeatability of the gloss measurement for identical media (pattern) with the same printer settings. Currently, one of major problems the technicians face while recording gloss data is, the inability to produce repeatable results even for identical images (media). Hence, fulfilling this criterion is of key importance in determining the success of the design model. Therefore, this criterion is given a higher weighting factor. Accurately measuring gloss data for step interval range of 5mm to 10 mm is require to fully understand gloss banding and; then, develop methodology to overcome it. The accuracy criterion depends on the torque or the ability of the motor to hold (maintain) the gloss meter at specified position. It also depends on the resolution of the motor (for example 1.8 degree precision for Nema 125 oz). This explains the maximum weighting score for accuracy criterion. The complexity of building the design especially synchronizing the motors with the micro-controller and gloss meter affects timely delivery (Nov 29th) of working design model. This justifies higher weighting for the complexity criterion. The power consumption criterion has relatively lower weighting since it is assumed that the system will be provided with constant power supply (through plug in). Also, solving the gloss banding artifact is more important that the initial investment on the design.

4.2.3 Micro-Controller

Table 5: Decision Matrix for Micro-Controller Unit

Decision Matrix for Micro-controller Unit							
Criteria	**Weight**	**ARM Core LPC1768 Controller with Touch Screen LCD**		**Arduino Mega 2560**		**68HC12 Motorola Board**	
		Rating	Score	Rating	Score	Rating	Score
Complexity of programming	0.3	-1	-0.3	2	0.6	-2	-0.6
Ability to interface actuators	0.3	2	0.6	1	0.3	0	0
User Interface	0.2	-1	-0.2	1	0.2	-1	-0.2
Power Consumption	0.1	0	0	0	0	0	0
Local Memory	0.05	2	0.1	-1	-0.05	-2	-0.1
Cost	0.05	-2	-0.2	1	0.1	2	0.2
Total Score	**1**	**0**		**1.15**		**-0.7**	
Rank		**2**		**1**		**3**	

The decision matrix for micro-controller unit is outlined in

Table 5. As discussion in the section 3.1.3, micro-controller is critical component for data collection and synchronization of the actuators. All the major design components communicate through the micro-controller. Hence, level of complexity in programming the microcontroller (that connects to large number of input /output) will directly affect the on schedule completion of the design model. Therefore, complexity in programming the board criterion has larger weighting factor. Furthermore, the ability of the microcontroller to provide sufficient number of pins for interfacing the actuators determines the success of the design. Therefore needs to be weighted more than the rest of criterions. Allowing the user to interface with the micro-controller for specifying the size of the media and intervals for measuring gloss measurement is crucial, hence weighted more than other criterions. Finally, power consumption, local memory and cost are relatively of less likely to affect the functionality of the microcontroller and hence lower weighting factors are assigned to them.

4.2.4 Data Storage

The alternatives for data storage method were evaluated as shown in Table 6. Portability criterion is weighted the highest, as eliminates the need to removing any design component for data transferring purpose. Furthermore, makes the data transfer process independent of the scanning procedure. Format of data criterion is given a higher weighting factor as can make analysis of data collected quicker if in proper (compatible) format. External hardware required for data storage is intended hinder the motion of the scanner (in case of laptop – wires connecting to the microcontroller) and can also increase the complexity in data storage procedure. Hence, weighted higher than storage and cost criterion. Although, we might think storage should be the most important criterion for this section but in reality storing numbers (gloss data) might not require huge storage capacity.

Table 6: Decision Matrix for data Storage

Decision Matrix for Data Storage								
Criteria	**Weight**	**Direct Laptop Connection**		**Local Storage**		**SD (Secure Digital) Card**	
		Rating	Score	Rating	Score		
Portability	0.3	-1	-0.3	-2	-0.4	2	0.6
Format	0.2	1	0.2	-2	-0.4	1	0.2
Hardware Required	0.2	-2	-0.2	2	0.4	-1	-0.2
Storage Capacity	0.1	2	0.2	0	0	1	0.2
Cost	0.1	-2	0.2	-1	-0.1	1	0.1
Total Score	**1**	**-0.3**		**-0.4**		**0.6**	
Rank		**2**		**3**		**1**	

4.3 Sensitivity Analysis

Multi-criteria decision making process usually involves sensitivity analysis for validation of the final decision to be either robust or weak, depending on how the change in the criterion weighting affects the final decision. Jeti Media Sense performed sensitivity analysis on all four components with the aim of investigating of any potential changes and errors and their impacts on the results of the chosen alternative. Sensitivity analysis method involved identifying the critical criterions first and, then verified, if even minimal change in the weighting of the critical criterion changes the rank of the chosen alternative. While performing sensitivity analysis, only the best and second best options were compared for rank changes.

Sample Calculations for Motor

1. Listing all the possible changes in the ranks of the alternatives caused by changing the weighting factors.

Possible changes to rank = $n\ x\ m\ (m-1)/2$; n is number of criterions, m is number of alternatives Equation 2

$$= 6 * 3\ (2/2) = 18$$

2. Calculating the difference of total performance for top two alternative's rank
$A1 - A2 = 1.55 - 0.5 = 1.05$

3. For each criterion value calculating the difference between the rating for the top two alternatives. The criterions C1 to C6 represents the list of criterions (top to bottom) in Table 4.

Table 7: Criterion Rating Difference Table

Motor Alternative ∆rating	C1	C2	C3	C4	C5	C6
Rating1-Rating2	0	-1	0	0	1	-1

4. Calculating the new matrix by dividing the total performance with the criterion difference listed in Table 7.

Table 8: Matrix for P1-P2/ Rating1 –Rating2

C1	C2	C3	C4	C5	C6
N/A	-1.05	N/A	N/A	1.05	-1.05

5. Discard the values in Table 8 that are less than the actual weighting of the criterion.
6. The smallest absolute value in Table 8 represents the critical criterion, which for the motors are C2, C5 and C6.
7. Varying the weighting of the critical criterions to check the change in the rank of the two alternatives.
   Critical Criterion = 1.05
   Total Weight = 1.05 + 0.7 = 1.75

Table 9: Modified Decision Matrix Treating C2 as Critical Criterion and changing weighting for other Criterions

For Critical :C2	**Modified Weight**	**Score A1**	**Score A2**
W1 = 0.3-1.05/total W	0.42	0.84	0.84
W2'= 0.3/total w	0.171	0.17	2.34
W3 = 0.2-1.05	0.48	0.96	1.38
W4= 0.1-1.05	0.542	1.08	-1.1
W5 = 0.05-1.05	0.57	0.57	-1.1
W6 = 0.05-1.05	0.57	0	-0.6
Total		**3.62**	**1.77**
Rank		**1**	**2**

Table 10: Modified Decision Matrix Treating C6 as Critical Criterion and changing weighting for other Criterions

For Critical: C6	modified Weight	Score A1	Score A2
W1 = .3-1.05, 75/T	0.375	0.75	0.75
W2 = 0.3-1.05/total	0.375	0.38	0.75
W3 = 0.2-1.05	0.425	0.85	-0.9
W4= 0.1-1.05	0.475	0.95	-1
W5 = 0.05-1.05	0.5	0.5	-1
W6' = 0.05/total W	0.25	0	-0.3
Total		**3.43**	**-1.6**
Rank		**1**	**2**

Table 11: Modified Decision Matrix Treating C5 as Critical Criterion and changing weighting for other Criterions

For Critical:C5	Modified Weight	Score A1	Score A2
W1* = .3-1.05, 75/T w	0.375	0.75	0.75
W2 = 0.3-1.05/total w	0.375	0.38	0.75
W3' = 0.2-1.05	0.425	0.85	-0.9
W4= 0.1-1.05	0.475	0.95	-1
W5 =0.05/total W	0.25	0.25	-0.5
W6 = 0.05-1.05	0.5	0	-0.3
Total		**3.18**	**-1.1**
Rank		**1**	**2**

After changing the weighting factors based on the critical criterion the rank of the chosen alternative (Stepper Motor) remains unchanged. This proves the final design option is robust and free from any uncertainties in the design model.

Sensitivity analysis calculations based on critical criterion were carried out for each design component; however the rank of the best alternative for all the design components remained unchanged. Refer to digital appendix for detailed sensitivity analysis for micro-controller, drive mechanism and data storage.

3.6 Proposed Design

The Arduino Mega 2560 is chosen to be the microcontroller responsible for the operation and management of the final design. Based on the decision matrix found in section 3.3.3 it clearly performs the best under the criteria that are considered most important for our design. This board will be mounted on the head of the scanner and connected to the meter, all three motor controllers, and the touch screen LCD/SD card shield as shown in Figure 3.

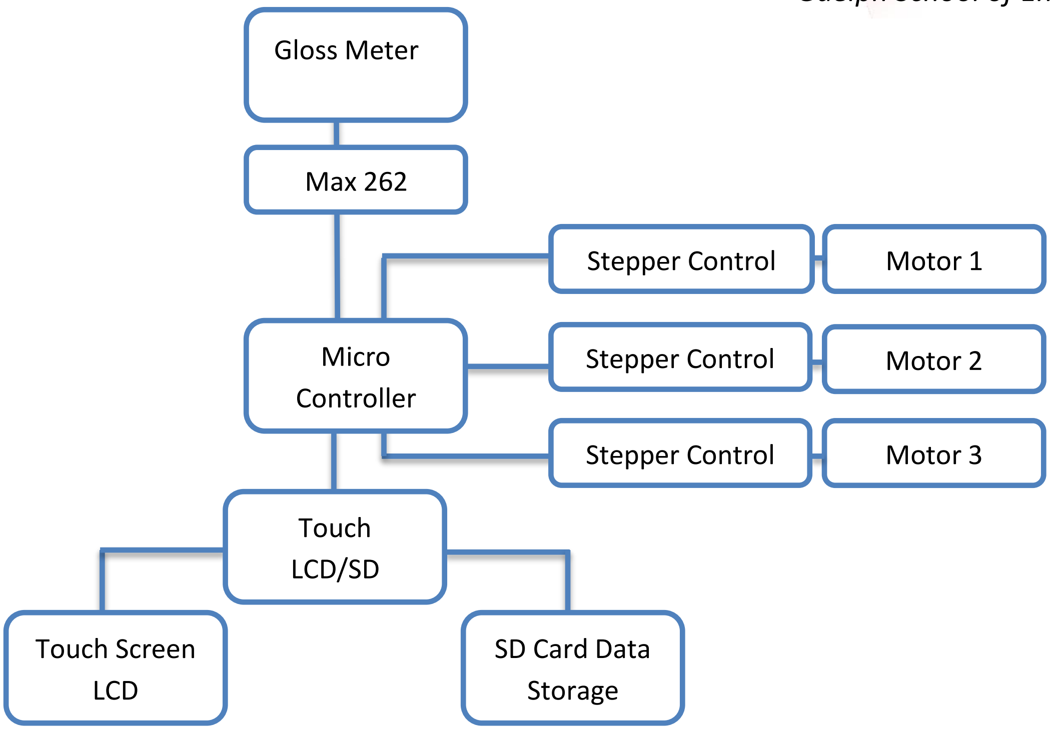

Figure 3: Communication and Signal Diagram

The proposed LCD touch screen to be mounted on the Mega 2560 is a 2.8" TFT Touch Shield specifically designed to be used with the Arduino board. This will use an 8 bit digital interface, plus 4 control lines. This controller uses digital pins 5-13 and analog 0-3. This means one can use digital pins 2 and 3 and analog pins 4 and 5 in addition to the higher numbered digital IO pins. Refer to the Arduino Mega 2560 Pin Map in the digital appendix. This shield incorporates the SD card breakout circuitry which allows for micro SD cards to be read and written to from the board.

The data obtained during scanning is stored on a mini SD card. These cards provide more than enough storage capacity for the number of results that would be obtained in the largest scan scenario possible. These cards can be easily removed and taken to the computer where they will be analyzed. The data will be written in a comma separated values (CSV) file which can be opened directly in excel.

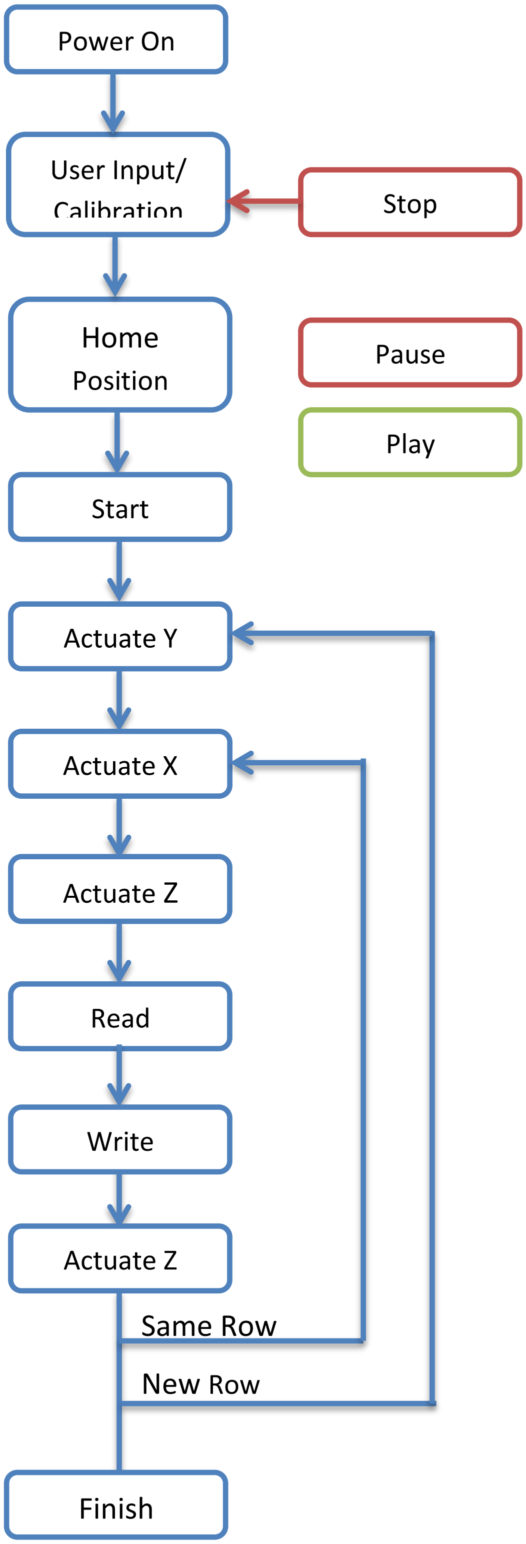

Figure 4: Software Flow Chart

The design for software implementation consists of two major parts: the initialization, and the scanning portion as shown in Figure 1.

The initialization begins by requesting the user input the height and width of the area to be covered. The user is then prompted for the x interval and y interval that the meter will take readings at. These values are all stored and can be input in metric or imperial units.

The user is then granted manual control over the X and Y motors and asked to position the head in the origin position. Finally the user is given control of the Y axis motor and asked to place the meter against the media. The IR sensor reads this relative distance to be used during the scan. Multiple speeds are available during both steps for accurate calibration. A file is created to receive the readings. The user is then prompted if they are prepared to start the scanning process.

The scanning process begins with the meter taking a reading at the origin position. The meter is lifted off the media then the main loop begins.

- The head moves along the X axis the predefined interval desired by the user.
- The meter is lowered in the Z axis to the previously defined height for contact with the media.
- A signal is sent to the meter to perform a reading.
- The reading is written to the file.
- The head lifts off the media along the Z axis.
- If the row is complete the arm moves along the Y axis the predefined interval.

This loop is repeated until the final row has been scanned. At this point the program gracefully finishes the CSV file and returns to the home position. A notification is displayed to the user that the SD card is ready to be removed.

A threaded rod is chosen as the actuator for both the X and Y direction as shown in Figure 5 and frame.jpg in the digital appendix. The rod is made available in 2ft or approximately 61cm lengths. These lengths can be combined to create any size in intervals of 2ft. The arm will be mounted to the exterior rods on a threaded bolt. As the exterior rods rotate the arm will climb the threads. Using only full steps with the proposed motor and the National Coarse thread allows for a resolution of 8 microns as shown by calculation in section 3.2.4.

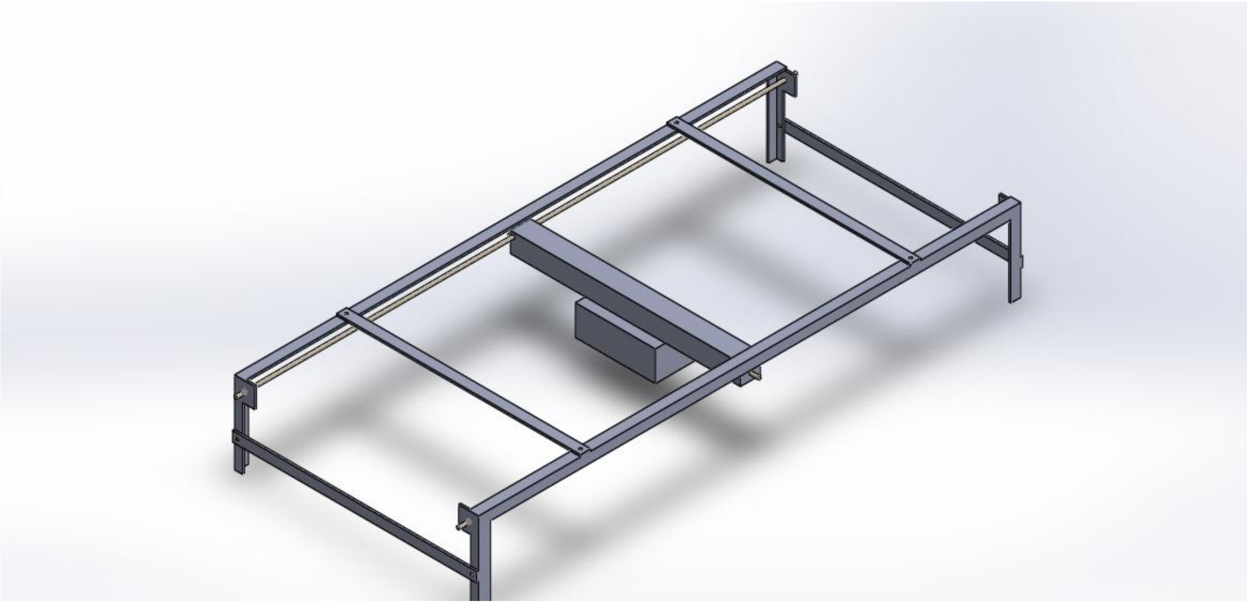

Figure 5: Approximate Model of Frame with Drive Rods

A 12V stepper motor with a resolution of 1.8^0 per step is chosen to actuate the drive track. This motor will be attached by coupling to the end of the threads. This design reduces the error by imperfect meshing of gears or chains that might otherwise be used to connect the motor to the drive thread. The motors will be controlled by a 2 phase bipolar stepper drive of 3.5A and 32VDC which are in turn controlled by the Arduino microcontroller.

The head of the device will be equipped with a clamp like holster capable of firmly holding a meter in rigid position. Mounted alongside this clamp will be an infrared distance sensor. This sensor will be calibrated before the device begins scanning to ensure a consistent and accurate placement of the gloss meter upon the media.

3.6 Details of Design Plan

The completion of the ideal design is divided into phases to allow for significant milestones and ease of continuation of the project for future developers should all phases not be completed by Jeti Media Sense before November 29th 2012.

3.6.1 Phase 1

The initial implementation will meet the constraints outlined in section 2.3 Constraints and Criteria with a capability of scanning a 4’x2’ media using strictly a gloss meter. It will allow the user to interface with the scanner and pre-set the interval readings, size, and origin of the scanner. This is the minimum requirement to be completed for the 29th of November.

3.6.2 Phase 2

This phase will implement compatibility of different measuring sensors such as the Eye one and the densitometer. While phase one is designed with this goal in mind and the physical securing of the head will already be compensated for, the digital connection of the head must be customized. Additionally parts can be manufactured to extend the frame to a larger dimension up to 4’x8’ in intervals of 2’.

3.6.3 Phase 3

This phase would be strictly software oriented and would consist of many trials. The goal of this phase is to implement an “Intelligent Specification Unit” for the different media, ink, speed etc. This unit would be able to scan the media and output the optimized settings of the printer to the user. There are many ways to implement this unit, some of which is known to include neural networks.

Additionally a direct digital comparison between the values returned from the sensors and the digital image could be made. This would allow for more accurate assessment of the settings used to print the media and the corrective action that should be taken if any.

3.7 Budget

3.7.1 Cost analysis

The approximate cost of each component is recorded and totaled in Table 12 below.

Table 12: Component Costs

Component	Cost (CAD$)
Motors	3 x 35.50 = 106.50
Motor Controllers	3 x 149.00 = 447.00
Microcontroller Board	65.00
LCD Touch Shield and SD Breakout	59.00
IR Distance Sensor	14.95
Electrical Cables and Adapters	~30.00
Electrical Devices	~2.00
Metal Frame Components	~20.00
Drive Threads	~20.00
Power Source	~100.00
Total	**864.09**

The cost of electrical cables and adapters, electrical devices, metal frame components, drive threaded bars, and the power source will be subject to availably. The total cost of materials to build the proposed prototype is approximately $784.45. This cost excludes the price of the gloss meter which is counted as a sunken cost.

3.7.2 Funding

Jeti Media Sense will receive funding from Agfa Inc. for the purpose of creating a deliverable working model. This funding is of the form of fulfilling purchase orders put forth by Jeti Media Sense.

3.7.3 Payback Period

To measure the issue of gloss banding it currently takes 2 technicians a 40hr work week to scan one sample at approximately $20/hr.

$$80hr * \$20/hr \;= \$1600$$

$$16hr * \$20/hr \;= \$320/day$$

With the use of the designed system it will now take approximately 5min of technician attention to start the scanning process and another minuet to collect the SD card after the scanning process is complete.

$$0.1hr * \$20/hr \ = \$2$$

Should the system be running for approximately 24hrs a day at approximately 500W resulting in approximately 12kWh. This is a pessimistic outside estimate assuming the power supply draws 500W continuously, which it will not.

$$12kWh * \sim 12cent/hr = \$1.44$$

The equation for payback period can then become:

$$Payback\ Period = \frac{First\ Cost}{Daily\ Savings - Diatly\ Cost}$$

$$Payback\ Period = \frac{\$864.09}{\$320.00/day - \$3.44/day}$$

$$Payback\ Period = \sim 2.7days$$

3.8 Schedule and Deliverables

The following reports and presentations will be prepared for the dates associated with them and will be an accurate reflection of the accomplished design.

Interim Report……………………………………………………………………………………………October 17, 2012

Final Report………………………………………………………………………………………….November 29, 2012

Poster Presentation……………………………………………………………………………November 28, 2012

As of October 17th the design has proceeded as per the schedule outlined in Table 13 and Figure 6 below.

Table 13: Schedule of Tasks

Tasks	Start Date	Duration(Days)	End Date
Research	30-Aug	40	09-Oct
Hardware Design	14-Sep	25	09-Oct
Software Design	14-Sep	25	09-Oct
Interim Report Writing	01-Oct	15	16-Oct
Building Prototype	17-Oct	30	16-Nov
Testing	05-Nov	15	20-Nov
Refining	10-Nov	15	25-Nov
Final Report and Poster	13-Nov	15	28-Nov

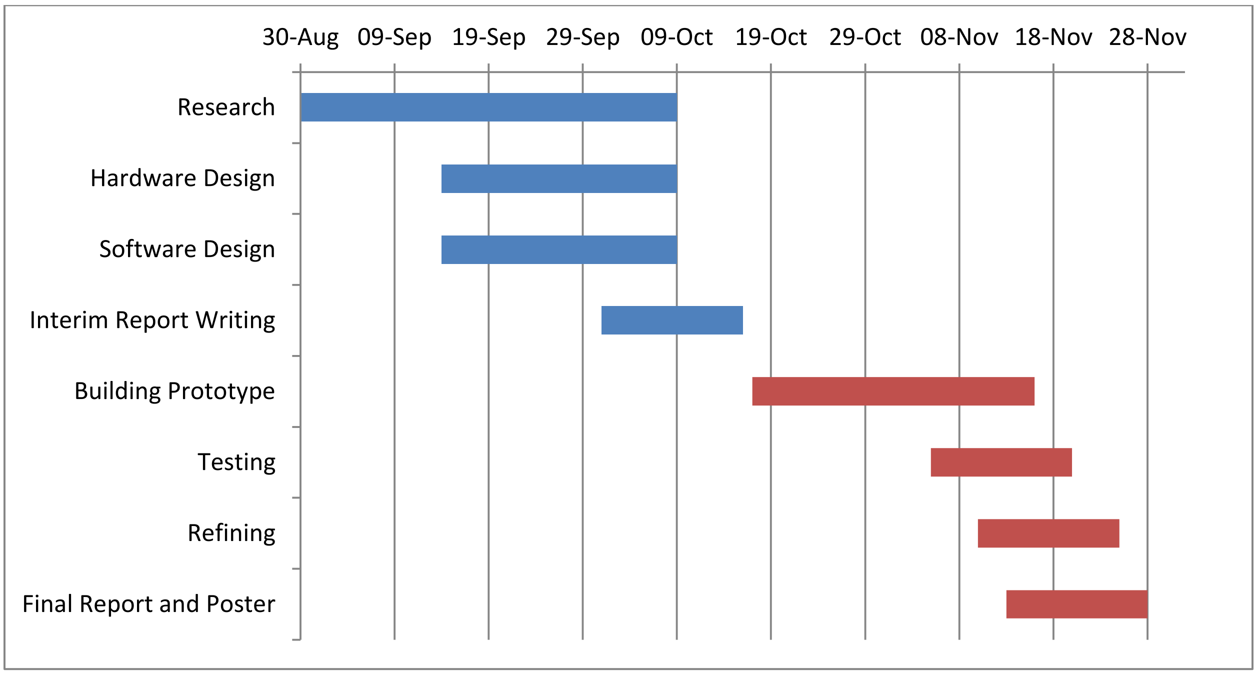

Figure 6: Gantt Chart of Tasks

As shown in Figure 6 the design is proceeding on schedule. With the completion of the Interim report the prototype is now under construction. The prototype will be completed by November 16th and ready for delivery on the 28th.

4. Conclusions

The automation of collecting gloss meter readings will immediately and significantly benefit Agfa Inc. The final design takes less than 20 min to assemble, set up and start and can be used in place of 80 hrs. of labour to collect gloss samples for one large media. These samples will be accurate within 50 microns which far surpasses the accuracy obtainable by previous methods.

Upon reviewing the available alternatives for the major system components, the best choices are selected based on the decision matrices. Drive mechanic methods are discarded based on setup time and life span. Motor options are discounted due to inaccuracy and size and weight of the corresponding controllers. The microcontroller is chosen based on complexity of programing and and which user interfaces are available. Alternate methods for the data storage are discarded based on portability. The results of sensitivity analysis make the selections confident ones.

The chosen components are tested for compatibility. The Arduino Mega 2560, the 2.4'' TFT LCD SD Touch Shield for Arduino, the NEMA 17 Single Shaft 125 oz-in Bipolar Stepper motors, the 3.5A 32VDC Micro stepping Bipolar 2 Phase Stepper Drivers, the threaded drive rod for actuation and the IR sensors used for feedback will work well together to provide the core of the final design.

There have been few deviations from the original proposal and Jeti Media Sense is on schedule with the originally proposed timeline. By November 29th 2012 phase one of the long term plan will be completed and meet all of the constraints posed by Agfa Inc. This will result in a deliverable prototype in working condition and all relevant components and software required for its immediate and effective implementation.

5. Recommendations

It is recommended that Jeti Media Sense increase the hours spent per week on the project from 15 hrs. each to closer to 20 hrs. each. This will be required during the prototype building phase to ensure significant time remaining for testing, tuning and refining of the device. The building of the prototype will begin as soon as the ordered parts are received.

Jeti Media Sense will continue to remain in close communication with Agfa Inc. to ensure that the needs of the client continue to be met after each significant decision is made. Additional resources when required will go through the appropriate methods to procure them.

6. References

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7. Appendix

Please see attached appendix folder.