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November 6, 2000

Dr. Andrew Rawicz
School of Engineering Science
Simon Fraser University
Burnaby, BC
V5A 1S6

Re: ENSC340 Project *Drying Machine Auto-Stop Upgrade* Design Specifications

Dear Dr. Rawicz:

Thank you for your interest in the products developed by the EaStar Group. The attached document, *Drying Machine Auto-Stop Upgrade Design Specification*, outlines the design requirements of our ENSC340 Project. Our goal is to design and implement a device that allows consumer to prolong fabric lifetime, to enjoy more convenience, and to conserve energy with their use of drying machines.

This document lists the required electronic components and design specifications of the various subsystems in our *Drying Machine Auto-Stop Upgrade* module. The design specifications of various subsystems will be revealed according to their functions, including Signal Acquisition, Signal Conditioning, Signal Processing, and Actuation. In addition, the Enclosure and Testing method for our prototype will be discussed.

EaStar Group consists of five motivated, innovative and talented fourth-year engineering students – Edward Chen, Jeffrey Chien, Eric Jen, Steven Liao, and Chris Lo. If you have any questions or concerns about this document, please feel free to contact us by phone at (604) 961-6028 or by e-mail at *ensc340-jesec@sfu.ca*.

Sincerely,

EaStar Group

Enclosure: *Drying Machine Auto-Stop Upgrade* Design Specifications

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Drying Machine Auto-Stop Upgrade

Design Specifications

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Issued date:	November 6, 2000
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Abstract

Drying Machine Auto-Stop Upgrade module is a device that measures the moisture and temperature inside a dryer and automatically stops the dryer when the moisture inside the dryer has reached the desired value input by the user. When the module is active, the RH and Temperature sensors attached to the inside of the dryer door constantly monitor the interior conditions of the dryer. These data are passed through a filter and a signal amplifier, and then sent to the Signal Processing stage. At the Signal Processing stage, pre-filtered and pre-amplified moisture and temperature sensor signals will be compared with the desired dryness level input by the user. When the desired dryness level is reached, the Signal Processing stage outputs a DC voltage for a short period of time to the Actuation stage. Once a DC voltage is detected by the Actuation stage, the actuator is triggered to open the dryer door.

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1. Introduction

Recent advancement in technology has enabled companies like Whirlpool and Maytag to incorporate the automatic-stop functionality into their next-generation dryers. However, this technology is fairly recent and expensive. Because an average dryer has a life span of 13 years and this technology was first introduced to the public in 1996, dryers in most households still do not have the automatic-stop function.

Our goal is to design and implement a device that incorporates the moisture-detection automatic-stop function onto existing dryers. This device allows consumers to optimize their current machine with an inexpensive and convenient mean, and at the same time, help protect fragile fabrics from arid conditions.

The *Drying Machine Auto-Stop Upgrade* module is a standalone module that monitors the moisture level within the dryer. This device constantly detects the moisture level through its Sensor subsystem. The Control Unit subsystem will constantly update the User Interface subsystem with the current dryer status. When a user-preset level has been reached, the Control Unit subsystem will send an electrical signal to the Actuator subsystem, which will open the dryer door and thus bringing the dryer to a stop.

The purpose of this document is to describe the design requirements of the *Drying Machine Auto-Stop Upgrade* module. The design specification at different signal processing stage will be discussed and the selected components for each subsystem are also described. The intended audiences of this document are Dr. Andrew Rawicz, Mr. Steve Whitmore, the design engineers of EaStar Group, and various external third party design consultants.

2. System Overview

The *Drying Machine Auto-Stop Upgrade* takes the inputs from the RH and Temperature sensors located inside the dryer, and stops the dryer whenever the desired dryness input by the user is reached. Figure_1 illustrates the detailed functional block diagram of the *Drying Machine Auto-Stop Upgrade*.

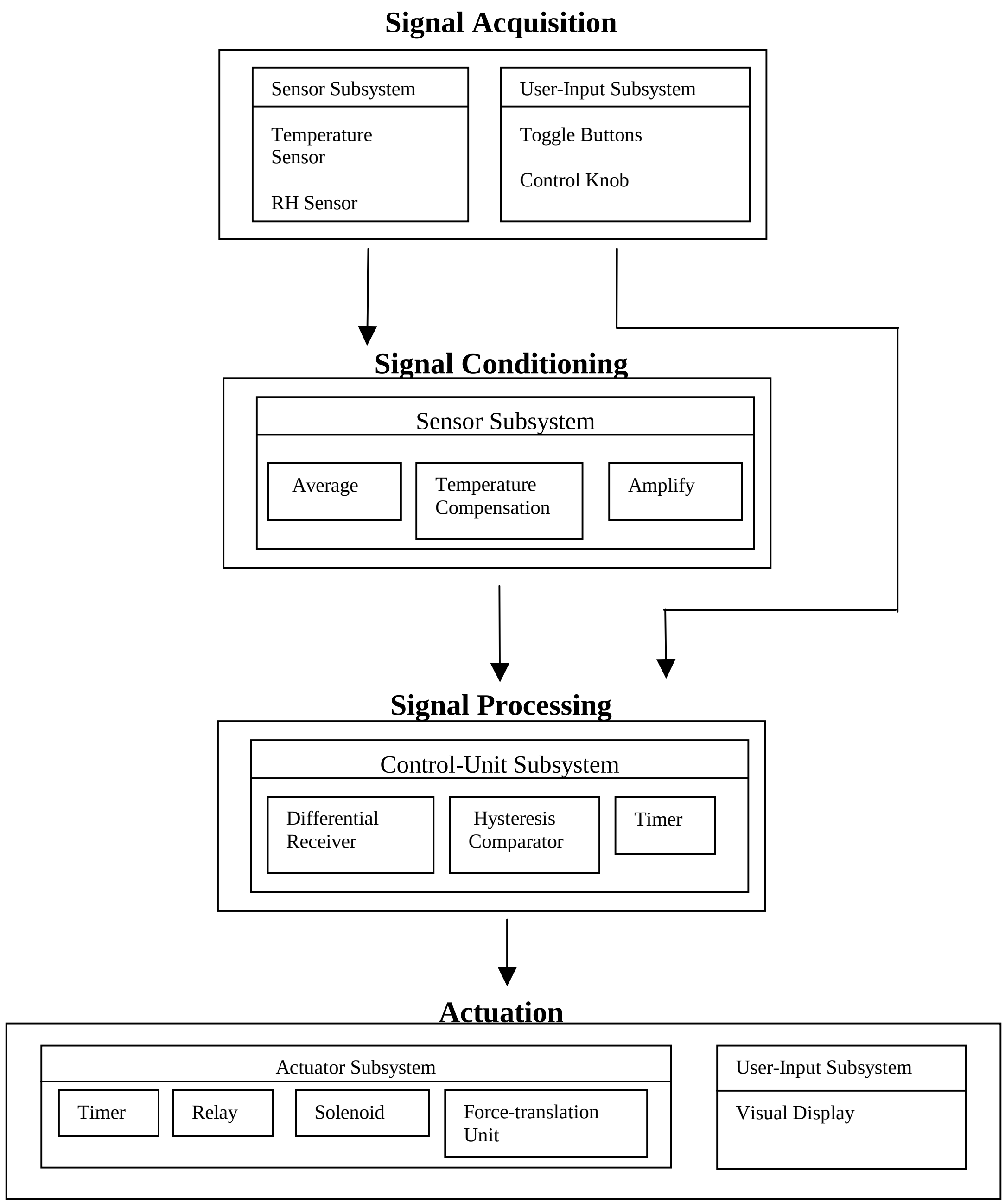

Figure_1: Detailed *Drying Machine Auto-Stop Upgrade* Functional Block Diagram

First, in the Signal Acquisition stage, the moisture and temperature inside the dryer will be recorded constantly through the RH and Temperature sensors located inside the dryer door. These data are sent to the Signal Conditioning stage, where the raw data are averaged and amplified. Through a differential transmitter, these pre-processed data are then sent to a differential receiver in the Signal Processing stage. During the Signal Processing stage, a hysteresis comparator is implemented to compare the pre-processed sensor data against the user input. When the humidity inside the dryer matches the desired dryness input by the user, an output voltage is generated to activate the actuator, which opens the door and thus stops the dryer.

3. Signal Acquisition

The Signal Acquisition stage obtains the input signals from the sensors and the user. Figure_2 shows the context diagram of this stage.

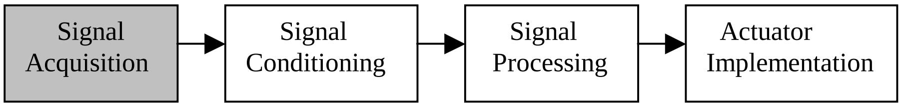

Figure_2: Context Diagram of the Signal Acquisition Stage

RH and Temperature sensors are mounted inside the dryer to constantly monitor the humidity and temperature. After reviewing various specifications and data sheets, EaStar Group has decided to use the IH-3605 Temperature sensor and the Honeywell HIH-3605-B RH sensor for their performance, reliability and durability.

Both the humidity and temperature data will be recorded and monitored to ensure accurate readings. These data will then be modified in the Signal Conditioning stage.

3.1 Humidity Sensor

The HIH-3605-B is a monolithic IC (Integrated Circuit) humidity sensor designed specifically for applications such as refrigeration, OEM assemblies and drying. This sensor is ideal for low drain system, such as the *Drying Machine Auto-Stop Upgrade.*

Table_1 below summarizes the characteristics of the sensor.

TABLE_1: CHARACTERISTICS OF THE HONEYWELL HIH-3605-B HUMIDITY SENSOR

Parameters	**Honeywell HIH-3605-B**
RH Accuracy	±2% RH, 0-100% RH non-condensing, 5V supply
RH Interchangeability	±5% RH, 0-60% RH; +8% @ 90%Rh typ.
RH Response time, 1/e	15s in slowly moving air @ 25 degree Celsius
RH Hysteresis	±1.2% of RH span max.
Operating Humidity Range	0 – 100% RH, non-condensing
Operating Temperature Range	-40 to 85 degree Celsius
Temperature Compensation	True RH = Sensor RH/(1.0546-0.00216T) T in degree Celsius
Supply Voltage	4.0 V dc to 5.8 V dc

3.2 Temperature Sensor

By utilizing the circuit shown in the Appendix (10.1), a linear relationship between the output voltages versus temperature can be found. This ensures that fairly accurate temperature readings can be obtained at any time.

The output voltage signal is then amplified by an Operational-Amplifier having low power consumption and high open-loop gain. The LF442CN Op-Amp from National is chosen for its various desired characteristics shown below.

TABLE_2: CHARACTERISTICS OF THE LF442CN OP-AMP

Parametric Table	
Channels (Channels)	2
Input Output Type	Not Rail to Rail
Bandwidth, typ (MHz)	1
Slew Rate, typ (Volts/usec)	1
Supply Current per Channel, typ (mA)	0.15, 0.20
Minimum Supply Voltage (Volt)	10
Maximum Supply Voltage (Volt)	40
Offset Voltage, Max (mV)	1,5
Input Bias Current, Temp Max (nA)	3,20
Output Current, typ (mA)	6.80
Price	$0.55US for 1K+

4. Signal Conditioning

Once the input signals from the sensors have been successfully acquired, they must then be conditioned to the appropriate format required by the Signal Processing stage. However, the user input signals do not require any conditioning since the direct use of user input signal is possible. Figure_3 below shows the context diagram for this stage.

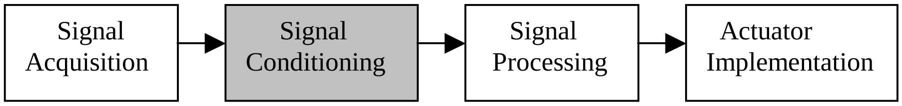

Figure_3: Context Diagram of the Signal Conditioning Stage

Figure_4 below shows the functional block diagram of the Signal Conditioning stage. Each functional block is described in detail in the following paragraphs.

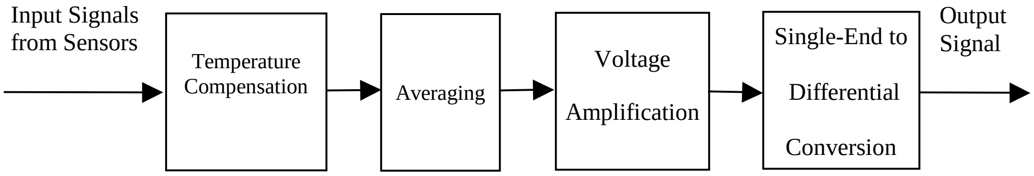

Figure_4: Functional Block Diagram for Signal Conditioning Stage

4.1 Averaging

The first required signal-conditioning process is to average the input signals over time. The reason is that the input signals coming from the Signal Acquisition stage fluctuate with significant amplitude, and only the mean values of the input signals (with respect to time) carry the desired average temperature and relative humidity information. The averaging-process is implemented by 2 simple first-order RC low-pass filters. The low-pass filter removes any significant fluctuations by passing only the low frequency (slow varying) components of input and attenuating the high frequency (fast varying) components of input. Detailed schematics of the 1^{st} order RC filter will be included in the Appendix (10.2).

4.2 Temperature Compensation

Due to the nature of the Relative Humidity sensor used, the relative humidity signal sensed depends on both the true moisture level and the current temperature. In order to obtain the true relative humidity, the sensed relative humidity signal must be compensated for the effect of temperature change once both signals are stabilized by the low-pass filter. The approximate relationship between the true relative humidity, sensed temperature, and the sensed relative humidity signal is described by the following equation.

$$RH_{true} = \frac{RH_{sensed}}{1.0546 - 0.00216 \cdot Temperature\left({}^{o}C\right)} \qquad \text{Eq.1}$$

Although the true relative humidity differs from the sensed humidity due to temperature variations, the difference will be insignificant for our particular application. The reason is that the temperature inside the dryer drum reaches a steady state temperature (around 40^{o}C) after the initial 15 to 20 minutes heat-up, and the variation of the steady state temperature is small (approximately 5~10%). In addition, the relative humidity region of interest is well below 60% RH. Thus the worse case error of the sensed relative humidity from the true relative humidity is calculated to be 4.76% . Figure_5 below shows the True RH vs. Sensed RH plot for 5 different temperatures, and Equation 2 below shows the calculation for the worse case RH error.

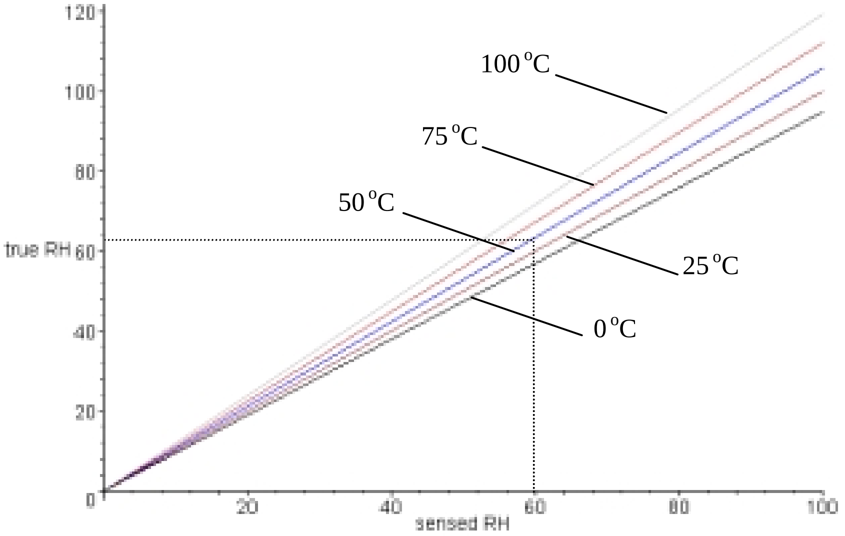

Figure_5: True RH vs. Sensed RH plot for 5 different temperatures

$$\frac{\%RH_{true} - \%RH_{sensed}}{\%RH_{true}} = \frac{63\% - 60\%}{63\%} \times 100\% = 4.76\% \qquad \text{Eq.2}$$

Since the error of the sensed relative humidity from the true relative humidity is below 5%, temperature compensation implementation is not required for our specific application.

4.3 Voltage Amplification

After the averaging process, the compensated moisture level signal is amplified to an appropriate voltage level as required for the next signal-conditioning process, the single-end to differential output conversion. The signal voltage amplification is implemented using a low power Operational Amplifier, LM158. The LM158 is selected due to its low power consumption, low cost, and wide operating temperature range. Table_3 below quantifies these characteristics.

TABLE_3: CHARACTERISTICS OF LM158

Parameter	**LM158**
Supply voltage requirement	3V to 32V
Power consumption	1.2mA maximum (V_{ss}=5V)
Operating temperature	-65°C ~ 150 °C
Cost	$0.1630US ea. for quantity of 2500+

The detailed voltage amplifier schematic is included in the Appendix (10.3).

4.4 Single-End to Differential Conversion

The last signal-conditioning process is the single-end to differential conversion. Because the physical signal transmission from the Sensor subsystem to the Control Unit subsystem is through a conducting wire of approximately 50cm in length, noise will be easily picked up by the conducting wire from the operating environment of the module. For this reason, the signal is to be converted to differential form before the transmission.

The single-end to differential conversion is implemented using the SSM2142 Balanced Line Driver made by Analog Devices. The SSM2142 is selected due to its low power consumption and good output signal balance performance. Table_4 below lists major characteristics of the SSM2142 Balanced Line Driver.

TABLE_4: CHARACTERISTICS OF THE ANALOG DEVICES SSM2142 BALANCED LINE DRIVER

Parameter	**SSM2142**
Power consumption	5.5mA with no load
Output signal balance ratio	typically –40dB
Output common-mode rejection	typically –45dB
Differential gain	typically 5.98dB
Output impedance	typically 50 Ohm
Operating temperature	-40°C ~ 85 °C
Cost	$3.38 US ea. for quantity of 100+

The detailed balanced line driver schematic is included in the Appendix (10.4).

5. Signal Processing

The Signal Processing stage processes and interprets the appropriately formatted sensor information from the Signal Conditioning stage, and then sends the result to the Actuation stage. Figure_6 below shows the context diagram for this stage.

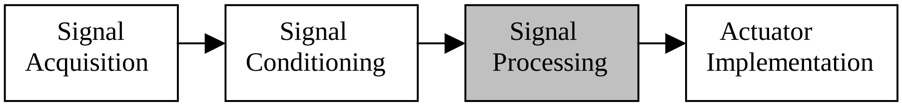

Figure_6: Context Diagram of the Signal Processing Stage

Figure_7 below shows the functional block diagram of the Signal Processing stage. Each functional block is described in detail in the following paragraphs.

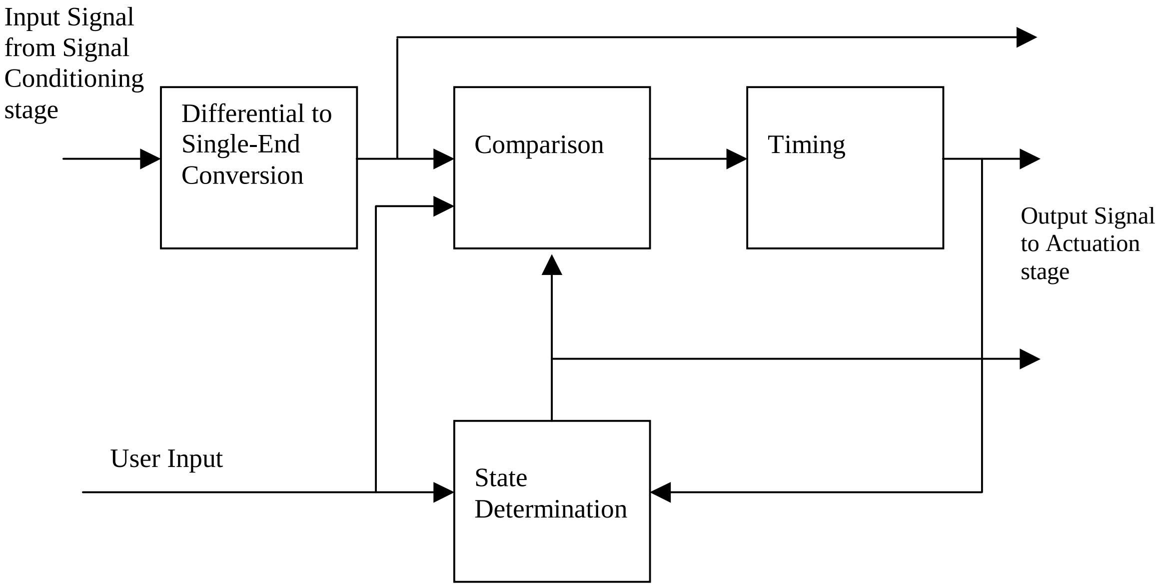

Figure_7: Functional Block Diagram of the Signal Processing Stage

5.1 Differential to Single-End Conversion

The signal received from the Signal Conditioning stage is a differential signal, which must firstly be converted to a single-ended signal in order for further processing. The single-ended signal not only goes to the comparison process but also directly goes to the Actuation stage for driving the set of LEDs on the User Interface subsystem to indicate the current moisture level inside the dryer. The Analog Devices SSM2143 –6dB Differential Line Receiver is used for the implementation of differential to single-end conversion. The SSM2143 is chosen because of its good common mode rejection, low power consumption, and low cost. Table_5 below shows the major characteristics of SSM2143.

TABLE_5: CHARACTERISTICS OF SSM2143

Parameter	**SSM2143**
Common mode rejection	typically 90 dB
Power consumption	maximum 4.0 mA
Cost	$2.01 US ea. for quantity of 100 to 499
Power supply voltage range	min. ±6V, max. ±18V
Input voltage range	typically differential ±28V

5.2 Comparison

After the signal is converted to single-ended form, it is compared with a voltage that represents the desired dryness level input by the user. If the signal voltage level exceeds the user-input voltage level, then a signal is sent to the timing process. Also, the comparison process will carry out only if the state determination process sends a signal representing the “active” state. If the state determination stage sends a signal representing the “standby” state, the user-input voltage level will be disabled, so no comparison can be made. Hence there will be no signal sent to the timing process.

For the comparison between the signal voltage level and the user-input voltage level, the National LM311 Voltage Comparator. The LM311 is selected for its low power consumption, large differential input voltage range, and low cost. Table_6 below shows the major characteristics of LM311.

TABLE_6: CHARACTERISTICS OF LM311

Parameter	**LM311**
Power consumption	135mW at ±15V (9mA)
Differential input voltage range	±30V
Cost	$0.2070 US ea. for quantity of 2500+

The comparison process will be enabled or disabled according to the input from the state determination process. This is implemented with the National LMC6024 Low Power CMOS Quad Operational Amplifier because of its low power consumption, low slew rate, suitable operating voltage range, and low cost. Table_7 below shows the major characteristics of LMC6024.

TABLE_7: CHARACTERISTICS OF LMC6024

Parameter	**LMC6024**
Power consumption	1mW
Slew rate	0.11 V/µs
Operating voltage range	+5 to +15V, –0 to –10V
Cost	$0.7200 US ea. for quantity of 1000+

5.3 Timing

Once the timing process receives a signal from the comparison process, the timing process outputs a signal for 3 seconds to the Actuation stage and the state determination process. The timing process is implemented with the National LMC555 CMOS Timer. The LMC555 is chosen because of its low power consumption and reduced supply current spikes (comparing to LM555). Table_8 below shows the major characteristics of LMC555.

TABLE_8: CHARACTERISTICS OF LMC555

Parameter	**LMC555**
Power consumption	max 400µA for 12V supply voltage

5.4 State Determination

The state determination process determines the current state of the module (active or standby) according to the desired state input by the user and the output of the timing process. The output of the State Determination process dictates whether or not the Comparison process will carry out or not. Also this output goes to the Actuation stage to drive the set of LEDs that indicates the current state of the module. This process is implemented by the TI SN54AC74 Dual D-Type Positive Edge-Triggered Flip Flop. SN54AC74 is used because of its asynchronous set and clear and its low cost. Table_9 below shows the major characteristics of SN54AC74.

TABLE_9: CHARACTERISTICS OF SN54AC74

Parameter	**SN54AC74**
Power consumption	max 40µA for 5.5V supply voltage
Cost	$3.5 US ea. for quantity of 1000+

6. Actuation

The Actuation stage performs appropriate physical actions according to the signals received from the Signal Processing stage. Figure_8 below shows the context diagram of the Actuation stage.

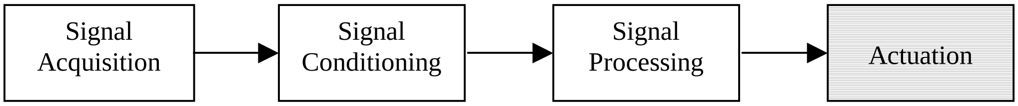

Figure_8: Context Diagram of the Actuation Stage

The Actuation stage includes 2 functions that involve 2 subsystems. When the moisture level in the dryer reaches the input desired moisture level, the Control Unit subsystem triggers the Actuator subsystem to stop the dryer. During the operation, moisture level data are continuously delivered to the User Interface subsystem, triggering the LEDs on the display.

6.1 Halting the dryer

The *Drying Machine Auto-Stop Upgrade* halts the dryer operation when the humidity inside the dryer drops to the desired level. Since the module is intended for all existing home dryers and to be installed easily by consumers, a simple solution, without requiring modification to the dryer, is necessary. The fact that most of the existing drying machines stop the operation whenever their doors are opened, makes it possible to halt a dryer by opening its door, which is accomplished by an actuator triggered by a signal sent from the Control Unit subsystem. Figure_9 illustrates the operation of the Actuator subsystem.

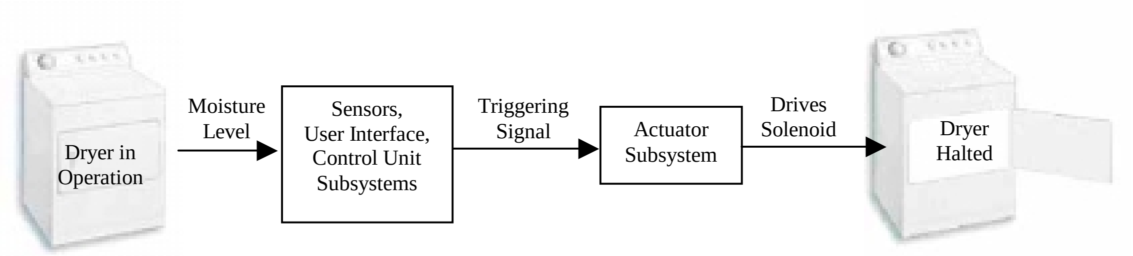

Figure_9: Operation of Actuator subsystem

6.2 Actuator Implementation

The Actuator subsystem includes 3 major subunits: an actuating circuit, a linear solenoid, and a force translation unit. The actuating circuit is responsible for receiving the triggering signal from the Control Unit subsystem and converting the signal into power that drives the solenoid for a fixed period of time. The linear solenoid is a simple solenoid that exerts a linear force when a certain current is supplied. The force translation unit redirects the linear force, generated by the solenoid, to the desired direction.

6.3 Actuating Circuit

The actuating circuit receives a 15V DC voltage signal from the Signal Processing stage. Through a 555 timer based circuit, the voltage signal drives a relay that controls the driving current for the solenoid. A high power relay is necessary since the driving current for the solenoid is in the order of Amps. The schematic of the timer circuit is provided in the Appendix (10.5). The 555 timer is selected for its low-cost, large operating voltage range, high currents driving capacity, and ability to be reset by small currents. Table_10 illustrates the characteristics of the chosen SE555N. Since a stronger solenoid can open the door in a shorter time, the solenoid output force decides the minimum timer output pulse duration.

TABLE_10: CHARACTERISTICS OF SE555N

Parameter	**SE555N**
Supply voltage requirement	1.5V to 18V
Power consumption	600mW maximum
Maximum trigger current	0.9µA
Minimum output voltage	V_{CC} – 2V (@ I_{out} = 100mA)
Operating temperature	-55°C ~ 125 °C
Cost	$1.130US ea. for quantity of 50+

6.4 Solenoid

The linear solenoid must exert a force that doubles the minimum force necessary for opening the dryer door. The minimum required force is measured to be 8 lbs on the door handle over a minimum displacement of 0.5 in. The force requirement is therefore 16 lbs for 0.5in. However, displacement can be traded off for a smaller required force. Hence, for example, any solenoid that could output 8 lbs for an inch is sufficient for the application. Note that a solenoid that exerts minimum force should be chosen because its force dictates its size and weight.

6.5 Force Translation Unit

The force translation unit redirects the force generated by the solenoid. The length dominates the dimension of a linear, tube-shaped solenoid, which exerts a force parallel to the centre axis of the tube. The attempt of utilizing the solenoid force directly to open the door requires mounting the long tube perpendicular to the surface of the door. The force translation unit not only allows a friendlier package dimension but also provides the ability to lever, which provides more flexibility for the choice of solenoid. The schematic of this unit is included in the Appendix (10.5).

6.6 Displaying Moisture Level

As the *Drying Machine Auto-Stop Upgrade* is activated, it starts sensing moisture level data inside dryer. This information is delivered to the end user through the display of the User Interface subsystem. The purpose of this functionality is to acknowledge the user the remaining time of the drying process. The display contains LEDs which lights up or blinks according to the moisture level signal received from the Control Unit subsystem. The exact implementation of the display layout is yet to be decided. Figure_10 Shows the operation of displaying the moisture level inside the dryer.

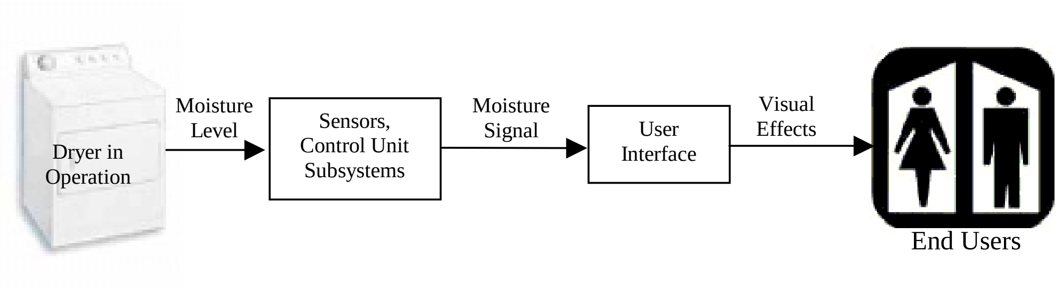

Figure_10: Operation of Displaying Moisture Level

7. Enclosure

For our prototype, several plastic enclosures will be employed. The enclosure will not possess sharp corners or edges that would pose a danger to the user. Moreover, the enclosure will not contain protrusions or odd extensions of any form. The plastic enclosure is chosen since plastic is light-weighted and resistive to most chemicals that the module may be exposed. The plastic enclosure will also ensure electrical isolation from the internal circuitry. All electronic components of the module will be shielded and protected from external static voltage sources.

8. System Evaluation

This section outlines the criteria and possible test methods for evaluating the *Drying Machine Auto-Stop Upgrade* module. The purpose of the system evaluation is to verify that every subsystem meets the required specification and functions properly.

8.1 General Testing for Components

As a start, every electronic component of the module will be tested to ensure proper functionality. In specific, the various stages of operation including Signal Acquisition, Signal Conditioning, and Signal Processing will be tested by applying test signals and comparing outputs with expected results. Furthermore, the actuator will be also tested by a test signal to ensure that it is properly activated.

When all of the above testing of individual components has passed, the second stage of testing, which is overall system testing, will be conducted.

8.2 Overall System Evaluation Criteria

The completed module will be tested against all of the following criteria. However, the prototype module will be tested for all of the following criteria except the Vibration test, since proper equipment for the Vibration test is very costly.

- **Operating Temperature:**
  The module will be verified to be fully functional under extreme temperature environment.

- **Operating Humidity:**
  Since the Sensor subsystem will be placed inside the dryer drum, it is necessary to verify that the module is fully functional under full ATM humidity range inside the dryer drum.

- **Vibration:**
  In order to ensure the high durability, the entire module will be tested under vibrations. A drop test will also be performed.

- **Accuracy:**
  The accuracy of moisture detection is to be within 5% of the true value. A calibrated moisture detector will be utilized for the accuracy test.

- **Reliability:**
  The module will have a minimum lifetime of 5 years. Reliability of the module will be proven by a stress test.

- **User Interface and Installation:**
  The user interface of the module will be verified for clarity and usability. The installation process and instructions will be verified to be clear and easy-to-follow.

Table_11 summarizes the testing ranges for our module.

TABLE_11: DRYING MACHINE AUTO-STOP UPGRADE MODULE TESTING RANGE

Operating Temperature Range:	-20^{o}C to +70^{o}C (except Sensor subsystem)
	-20^{o}C to +110^{o}C (Sensor subsystem)
Shipping Temperature Range:	-30^{o}C to +85^{o}C
Operating Humidity Range:	Full range of ATM humidity
Vibration Resistance:	Withstand a minimum vibration of 1 in. displacement, 10 cycles per second
Heat Dissipation:	Minimal

8.3 Overall System Test Methods

- **Operating Temperature:**
  To achieve the lower limit of the specified operating temperature range, the prototypes of the Sensor, Actuator, and Control Unit subsystems will be cooled down to the specified lowest operating temperature by applying a cooling spray directly on the prototype boards. Likewise, the upper limit of the specified operating temperature range will be achieved by heating up the module to the specified highest operating temperature using a hair dryer or other heating device. The module is then tested for full functionality under these 2 extreme environmental conditions.

- **Operating Humidity:**
  The module is tested against its full functionality when the humidity level inside the drum varies from the lowest to the highest achievable value. The lowest humidity limit will be achieved by running the dryer with no load and the highest humidity limit will be achieved by running the dryer fully loaded with completely wet fabrics.

- **Accuracy:**
  The accuracy of moisture detection will be tested in two stages: the Sensor subsystem testing stage and the module testing stage. When testing the Sensor subsystem, 3 target moisture values will be included. These values will be widely spread over the range of possible user input moisture levels. With a drying machine and a calibrated moisture detector, desired controlled moisture environment will be created for testing. 3 trials are run for each controlled values and the Sensor subsystem has to be within 5% accuracy for 9 trials in each value. When testing the

entire prototype module, 10 trials should be run for all possible input moisture level values provided on the control panel. In each trial, the test will be a simulation of the true operation of the finished product. When the module stops the dryer, the moisture inside must be within 5% of the user input value.

- **Reliability:**
  The reliability of the module is tested by a stress test. The stress test will mainly be continuous operation of the module with extra heat and vibration simulated in the test. This test maybe combined with the accuracy test.

9. Sources and References

1) Dr. Andrew Rawicz
Professor of the School of Engineering Science SFU

2) Patrick Leung
Lab Instructor of the School of Engineering Science SFU

3) Lucky One
Lab Instructor of the School of Engineering Science SFU

4) Wayne Gibson
APEG Opportunity Fund

5) BC HYDRO

http://eww.bchydro.bc.ca/

6) Sears Canada Inc
http://www.sears.com/

7) WHIRLPOOL

http://www.whirlpool.com/wp_home.html

8) EnergyGuide
http://energuide.nrcan.gc.ca/

9) General Electrics
http://www.ge.com/index.html

10) Kenmore
http://www.kenmore.com/

11) Maytag
http://www.maytagcorp.com/

12) Canada Office of Energy Efficiency
http://oee.nrcan.gc.ca/english/index.cfm

13) General Eastern
http://www.protimeter-usa.com/geiindex.html

14) Philips Semiconductors Linear Products
Product specification 853-0036 13721 - NE/SA/SE555/SE555C Timer

15) 555-Timer Application - K. Papathanasiou, Ph.D of Edinburgh University
http://www.ee.ed.ac.uk/~kap/Hard/555/aplications.html

16) Magnetic Sensor Systems, CA
http://www.solenoidcity.com/solenoid/tubular/tubularcatalog.htm

10. Appendix

10.1 Temperature Sensor Circuit in Signal Acquisition Stage

The following shows the circuit diagram for the Temperature sensor, Figure_11.

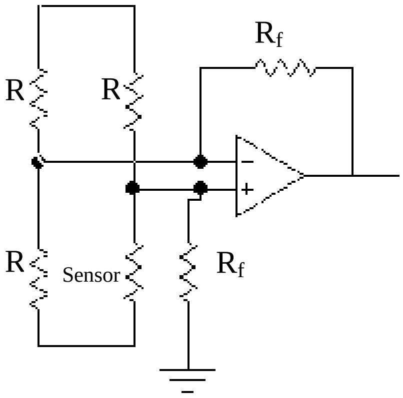

Figure_11: Circuit Diagram for the Temperature Sensor

10.2 Averaging Process in Signal Conditioning Stage

The cut-off frequency of the low-pass filter is determined by the following formula.

$$f_c = \frac{1}{2\pi \cdot RC} \qquad \text{Equ.1}$$

Although the exact value of the cut-off frequency is unknown in the current development stage, it will be determined by the actual measurements of the input signals. The exact component values of the resistor and capacitor will then be determined to meet the required cut-off frequency. Figure_12 below shows the schematic of the low-pass filter to be used.

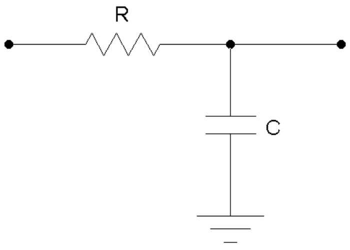

Figure_12: 1st Order RC Circuit

10.3 Voltage Amplification in Signal Conditioning Stage

Figure_13 below shows the schematic of the amplifier to be used.

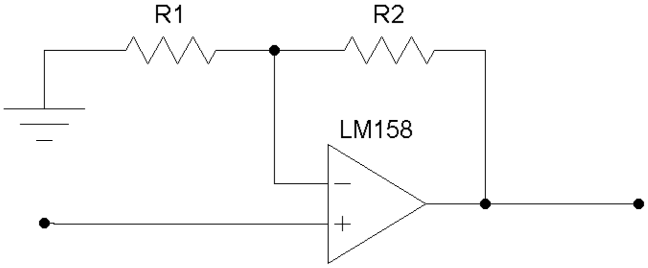

Figure_13: Schematic of the Voltage Amplifier

The exact gain required is determined so that the output voltage range of the low-pass filter will be amplified to meet, but not exceed the input voltage range of the next stage, namely the single-end to differential conversion process. The gain of the amplifier is set by the following formula.

$$G = 1 + \frac{R_2}{R_1} \qquad \text{Eq.3}$$

10.4 Balanced Line Driver in Signal Conditioning Stage

Figure_14 below shows the schematic of the balanced line driver to be used.

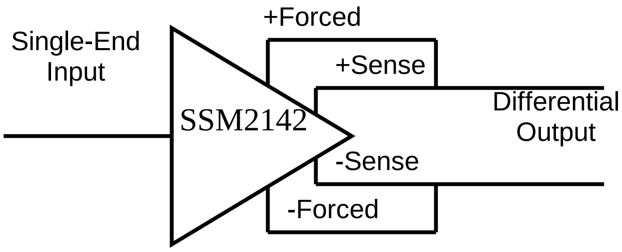

Figure_14: Schematic of the Balanced Line Driver SSM2142

10.5 555 Timer Circuit in Actuation Stage

The 555 circuit is consisted of two comparators, one voltage divider, one flip-flop and a discharging transistor, as it is shown in Figure_15.

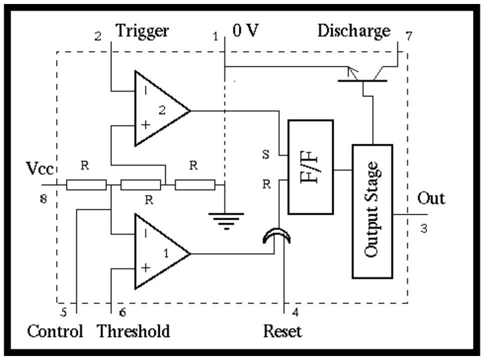

Figure_15: 555 Timer Internal Circuitry

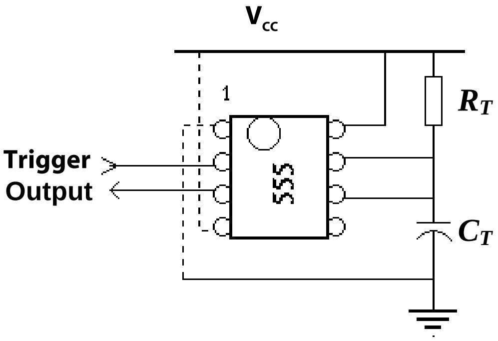

Figure_16: 555 based Timer Circuit

The 555 circuit in Figure_16 is connected as a monostable multivibrator. In this mode of operation the trigger input sets the flip-flop which drives the output to high. The discharge transistor is turned off and therefore the capacitor C_T is charged via R_T. When the voltage on the capacitor reaches the control voltage, which is defined by the three resistor voltage divider (*Vcont=2/3 Vcc*), the flip-flop is reset. This turns the discharge transistor on, which discharge the capacitor. Thereafter the circuit can be charged again by a new pulse at the *trigger* input. We can thus adjust the activation time period by choosing appropriate resistor and capacitor values with the equation (Eq.4):

$$T=1.1\, R_T \times C_T \qquad \text{Eq.4}$$

The output pulse then drives a relay turns on the solenoid with a very high current.