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November 5, 2001

Dr. Andrew Rawicz
School of Engineering Science
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Re: *Design Specification for FloSafe: Automated Water Quality Assurance System*

Dear Dr. Rawicz:

The attached document, *Design Specification for FloSafe: Automated Water Quality Assurance System*, outlines the design specifications for our product. Our goal is to implement a product which will automatically measure and balance the chemicals in a hot tub. The device will require minimal effort from the hot tub owner, and will alert bathers of unsafe water.

This document describes the intended implementation of each subsystem of FloSafe, as well as alternatives considered.

Sundance Systems consists of four ambitious engineering students –Denesh Pohar, Keith Phu, Karine Le Du, and Ryan Kirk. Please feel free to contact us by email, or visit our website for further information

Sincerely,

Ryan Kirk
Contact Person

sundance-systems@sfu.ca

Enclosure: Design Specification for FloSafe: Automated Water Quality Assurance System

Sundance Systems

FloSafe™
An Automated Water Quality Assurance System

Design Specification

By
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November 4, 2001

Executive Summary

FloSafe is a self-contained, automated water quality assurance system. Chemical content in water affects many different fields of interest such as drinking water, hot tubs, swimming pools, and fish tanks. FloSafe is a general open-ended technology that monitors and controls the chemical content in water. The first application using FloSafe technology is a fully automated hot tub chemical balancer.

FloSafe will eliminate the need to test and retest your hot tub before going in for a nice warm bath. With virtually no user interaction, the hot tub chemical balancer keeps your hot tub's chemicals at the appropriate usage levels.

The first prototype for FloSafe shall have the following features:

1. Automated tests that will detect the levels of Chlorine, Bromine and pH in the hot tub water.
2. Extremely simple interface with minimal user interaction.

This prototype will be ready for demonstration by December 2001, at which time a second phase of development will be implemented. The production phase of development will include making the prototype consumer ready by minimizing size, improving packaging, and gaining approval for electrical standards for both industrial and residential usage. No specific completion date has been set for the second phase of development.

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1 Introduction

As with most well designed systems, FloSafe's design is inspired by the functional parameters that the system is to adhere to. Of course, other issues such as severe cost constraints also affect the design, and all issues are addressed in this document as they arise.

This document assumes that the reader has read and is familiar with Sundance Systems' FloSafe system, as specified in *Functional Specification for* FloSafe*: An Automated Water Quality Assurance System*, as published on October 15, 2001.

All functional specifications will not be reiterated in this document in order to maintain brevity. Instead, important ramifications from specifications will be summarized, and individual functional specifications are referenced by number.

1.1 Design Overview

FloSafe's role as an *automated* system that monitors *water* necessitates use of intimately linked mechanical, electrical, and firmware components to conceive the overall system quality that we at Sundance Systems desire.

Due to the distinct design motivations and challenges offered by the mechanical systems and the control systems, the two are discussed separately in Section 2 - *Mechanical System: Design Specifications* and Section 3 - *Embedded System: Design Specifications*.

2 Mechanical System: Design Specifications

Before delving into specifics of FloSafe's physical design, a schematic depicting FloSafe's internal design at a high level is given below in Figure 1.

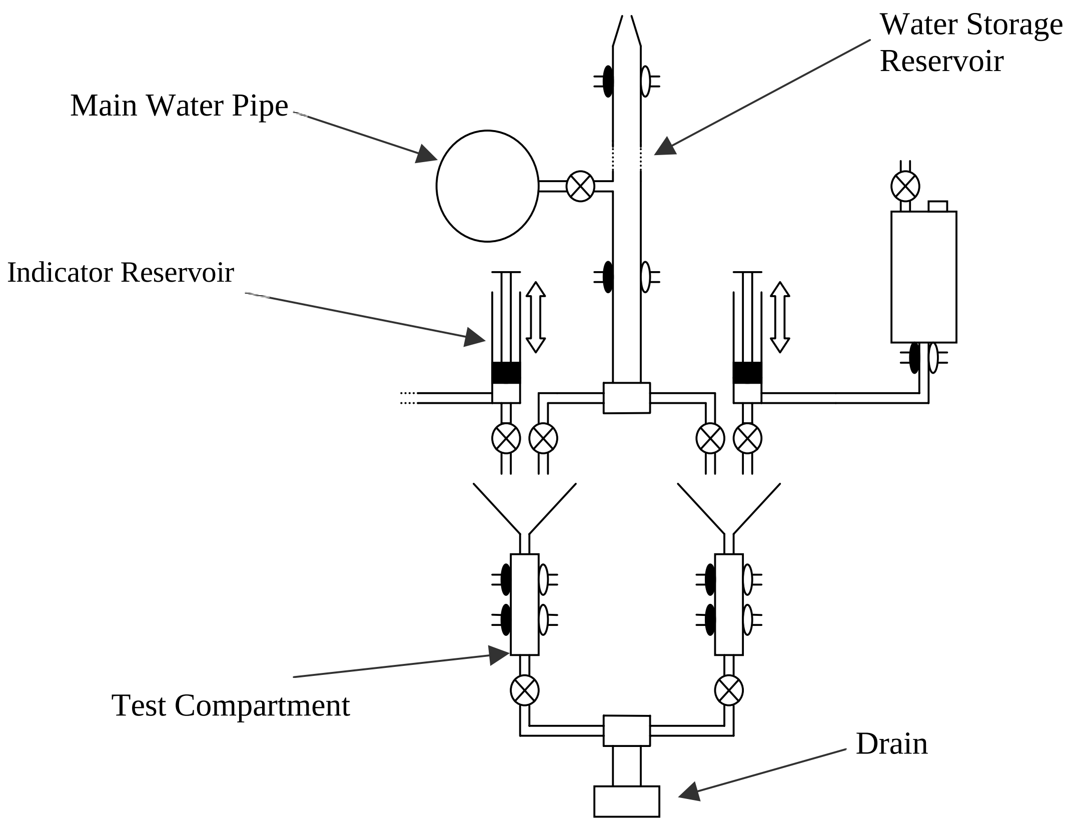

Figure 1: Physical schematic of FloSafe's internal design.

Note that for brevity, only the most critical elements of the schematic are labeled. For a more detailed version of the same drawing, see Figure 5 in the Appendix.

Note that in this section, we assume that the FloSafe system has an embedded control system to preside over all external I/O and process automation in FloSafe. This embedded system is discussed in detail in Section 3 - *Embedded System: Design Specifications*.

2.1 User Interface

The user interface is designed to be simple to use while clearly conveying all important information to the user. Input is taken from the user using a four button keypad, and output is given to the user using an LCD.

Addresses Functional Specifications: **U7 – U9**

If FloSafe needs any maintenance or user intervention, the LCD will display specific messages to the user. These messages will be short and to the point, such as “pH Reagent Needs Refill”.

Addresses Functional Specifications: **U10**

By default, FloSafe will balance the hot tub water every 48 hours, but the user can change this number. FloSafe is designed to keep the current time internally, and automatically perform chemical testing at the correct time.

2.2 Water Testing System

FloSafe’s water testing system was designed to minimize the number of sensors & actuators needed while maintaining simplicity, modularity, and safety. One of the cornerstones of FloSafe’s water circulation system design is to use gravity and valves, rather than pumps, to drive and control water flow.

2.2.1 Water Collection

Addresses Functional Specifications: **C1 – C3**

FloSafe requires that the water samples it takes accurately represent the water content of the hot tub, addressing depth and reasonable cleanliness issues. To address these needs, and to lend physical separation to FloSafe as a distinct entity within a hot tub system, FloSafe will be connected to the hot tub’s main flow pipe.

FloSafe’s design solution is to have a water storage reservoir to store the required 5 cc[1] of water. The reservoir will be filled by opening the main water intake valve.

Water Storage Reservoir

The water storage reservoir will be constructed out of 0.95 cm (3/8”) diameter transparent vinyl tubing. The tubing will be mounted vertically, and with an air intake at the top. The water collection intake will be connected near the bottom of the reservoir to fill the

[1] See Functional Specifications S2 & S3.

unit from the bottom. This configuration minimizes turbulent disturbances at the top of the water, where volume detection will be performed.[2]

Main Water Intake Valve

The main water intake valve is the gateway between the hot tub water and FloSafe. The valve itself is a normally closed, electrically controlled valve. The valve is selected to allow a slow outflow into the storage reservoir to facilitate accurate, even though the water in the main flow pipe will be at a high pressure.

2.2.2 Sampling And Preparations

Once water has been collected from the main water pipe, samples are put into test compartments, and drops of chemical reagents are added before sample analysis.

2.2.2.1 Dispensing Collected Water To Test Compartment

Addresses Functional Specifications: **S1, S6**

FloSafe will have two separate test compartments – one for pH testing, and one for Chlorine/Bromine testing. Chlorine/Bromine testing will be performed first, followed by pH testing.

Addresses Functional Specifications: **S2 – S3**

For both the pH and Chlorine/Bromine test compartments, FloSafe will extract a 5 cc sample of water from its water storage reservoir. Reservoir sampling will be performed by opening one of the water storage reservoir's drain valves.

Test Compartments

FloSafe includes two test compartments – one for pH testing, and one for Chlorine/Bromine testing – in which the chemical analysis of the water will actually be carried out. The test compartments are actually transparent 5 cc test tubes with their bottoms drilled out. Tubing connects from the bottom of the compartments to the test compartment drain valves, which are discussed in detail in Section 2.2.4.2 - *Test Compartment Cleansing & Spent Water Release*.

Water Reservoir Level Sensors

Instead of localizing independent volume detection in each test compartment, volume detection sensors will only be placed in the sample reservoir in order to minimize

[2] Main Water Reservoir Level Detection is discussed in more detail in Section 2.2.2.1 - Dispensing Collected Water To Test Compartment.

hardware. With its narrow cross-sectional area, the changes in the water level will be used to detect water volume displacement.

The actual level sensor mechanism consists of a float that is detected externally from the reservoir, using an LED and photodiode. The LED-photodiode pairs will be placed at distinct discrete levels to measure for the occurrence of specific volumes of water.

The float will be constructed of foam. The float will be spherically shaped, with a diameter of 0.7 cm.

2.2.2.2 Adding Chemical Reagent

Chemical reagents will be added to the test compartment in a strictly controlled manner. The physical implementation of the reagent dispensing system is illustrated in Figure 2.

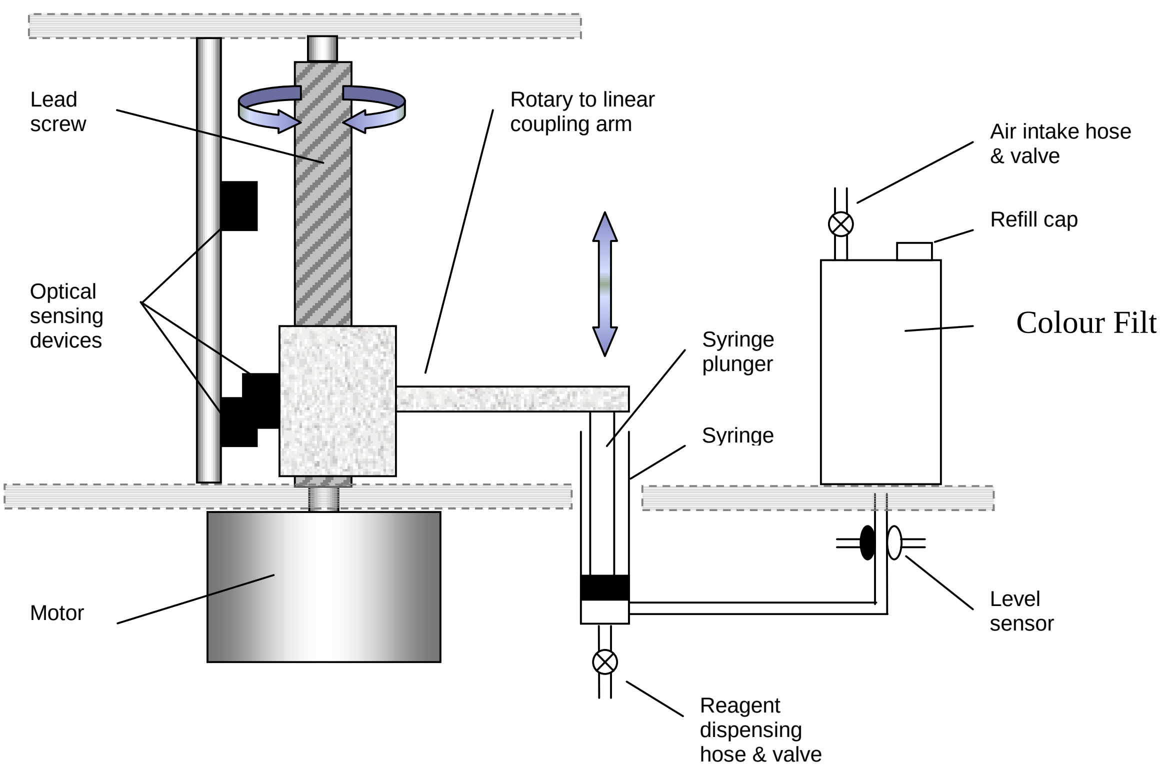

Figure 2: Detailed diagram of reagent dispensing system.

The above design will be replicated for each test station (i.e. pH, Bromine).

Addresses Functional Specifications: **S7**

Functional Specification S7 has been revised to ensure reliable dispensing of reagent. A 1.0mL syringe will be used to dispense the reagent. A motor will actuate the syringe plunger indirectly and two optical sensors will monitor the position of the plunger. The motor and sensors will automate dispensing reagent from the syringe as well as refilling the syringe from a reagent storage reservoir. The user will be prompted to refill the reagent storage reservoir when it is empty.

Addresses Functional Specifications: **S8 – S9**

A volume of 0.4mL, equivalent to 5 drops from the manufactured reagent dropper, will be dispensed from the syringe.

Addresses Functional Specifications: **S12 – S13**

The reagent will be stored in an air tight, opaque, thermally insulated reservoir.

Addresses Functional Specifications: **S14 – S15**

The user will be notified of expiration of the reagent. The thermal insulation of the reagent storage reservoir will ensure that the reagent will not incur freezing damaged.

2.2.3 Sample Analysis

Once the chemical reagent has been added to the water sample, FloSafe must determine the level of measured chemical in the sample. The FloSafe prototype will measure pH and Bromine levels, which will be measured in the same way.

Chemical levels will be measured by detecting color changes in the sample after the chemical reagent has been added. The color detection process uses white LED's, paired with photoresistors and various light filters to detect different colours. Photoresistors are optical devices, which have a resistance inversely proportional to the amount of light at the front of the sensor. They have a spectral response that peaks at approximately 600nm, and falls off just outside the boundaries of visible light.

The color detection process will take place under zero-ambient-light conditions to obtain controlled results. The test setup can be seen below in Figure 3.

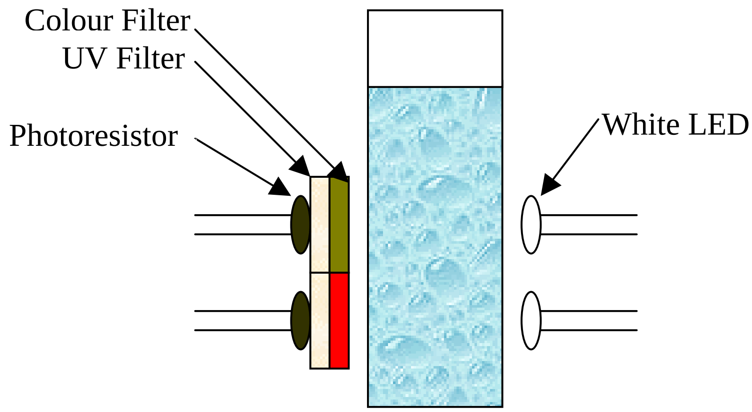

Figure 3: Sample Analysis.

Due to the spectral response of the photoresistors, experimentally the best results were obtained using UV filters, as seen in the diagram. In Figure 3, the photoresistors are set up to measure the intensity of red and green light. Using a combination of red and green we are able to uniquely compare the measured intensities to the intensities measured from known samples, to determine if the chemical levels need to be adjusted.

The test will be controlled by the microprocessor, which will power the LED's and collect sample data when the sample container is full. Voltage across the photoresistors will be measured by the Analog-to-digital converter for interpolation to chemical contents. This voltage will be in the range of approximately 2 to 4V.

2.2.4 Water Disposal

2.2.4.1 Spent Water Neutralization

Addresses Functional Specification: **D1**

FloSafe produces minimal hazardous chemical byproducts from its chemical detection processes. A big threat to FloSafe is discolouration to its test compartments. Simple dilution with water is adequate to keep FloSafe durable, and safe to the environment.

Note that this design specification is implemented purely in the water disposal algorithms, not with additional hardware.

2.2.4.2 Test Compartment Cleansing & Spent Water Release

Addresses Functional Specification: **D2, D6**

To clean the test compartments, they will be filled with clean water, and then drained. This filling and draining cycle will be repeated for three total iterations. The clean water is that from the main water reservoir.[3]

The test compartment drain valve will be opened to drain out the contents of the test compartments.

Test Compartment Drain Valve

The test compartment drain valve is an electrically controlled, normally open valve. In particular this valve has a minimal threshold pressure in order to allow drainage of all water out any content

[3] One may argue that the reservoir water is not "clean", but the cleaning process aims mainly to wash away indicator residue, so reservoir water will suffice.

3 Embedded System: Design Specifications

The main function of the embedded system is to automate the water testing process. This involves setting control lines and reading sensor inputs. The system is also designed to operate the user interface, which consists of a 24x2 LCD and a 4 button keypad. A high-level block diagram of FloSafe's embedded system is shown below in Figure 4. A detailed schematic that shows all pins and data lines can be found in the Appendix.

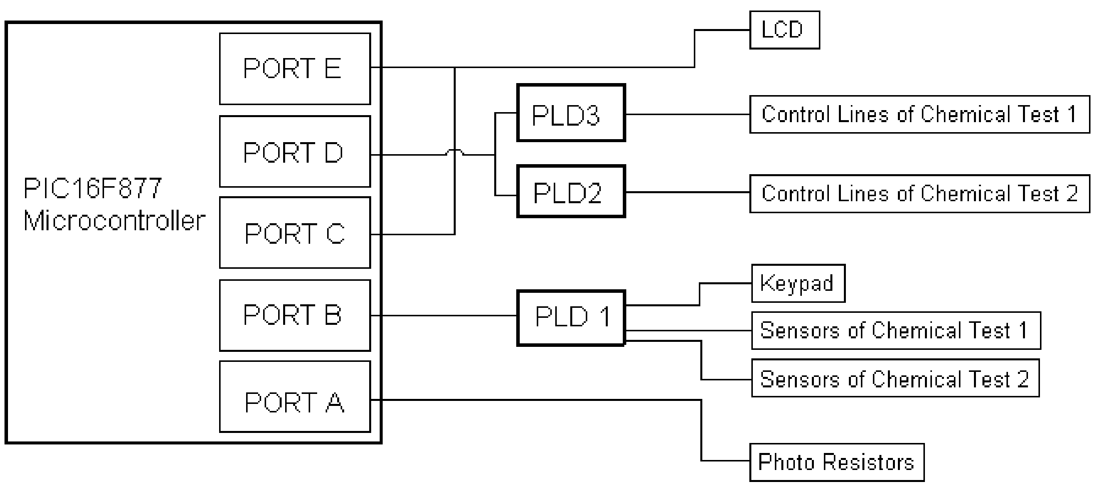

Figure 4: Block diagram of FloSafe's Embedded System.

Microcontroller

The Microchip PIC16F877 microcontroller was chosen to be the central processing unit of the FloSafe embedded system because of two important factors. The first factor was the number of I/O pins. We require a microprocessor with many I/O lines to control the numerous motors, valves, and sensors contained in FloSafe. It also has to handle the user interface. With the help of three PLDs, the PIC16F877 offered the right number I/O lines for the system. The second factor was instruction memory. We chose to write the firmware in C, which is more modular and easier to work with with multiple developers. C requires more instruction memory than assembly so a microprocessor with moderate instruction memory is required. The list below shows the important features of the PIC16F877.

- 33 I/O pins
- 8k of Instruction Memory
- 8 port, 10-bit A/D
- In Circuit Programmable EEPROM

Programmable Logic Devices

Three PLDs were needed to perform the logical tasks of multiplexing the control lines and sensor input of each test, and handling the keypad buttons. The 22V10 PLD was chosen because it is cheap, extremely common and simple to program. An FPGA was not used because of cost, and complexity of the available packaging. The two tasks of the PLDs are summarized below.

- The control lines and sensors of the individual chemical tests are redundant, so PLDs are used to multiplex the signals.
- A PLD is used as a handler for the 4 button keypad. Instead of polling for a button press, whenever a button is pressed the PLD will generate an interrupt and give the status of the buttons to the microcontroller.

4 General Design Details

4.1 Mechanical And Structural

The FloSafe prototype does not conform to ideal structural restrictions that are outlined for the production stage in the FloSafe Functional Specifications. However, where possible, Sundance System has carefully considered materials and building techniques to create a cost-effective and reasonable stepping stone to production development.

4.1.1 Valves

All electrically controlled valves used in the FloSafe prototype are 3-way valves, with single input and normally-open and normally-closed outputs. These valves give the developers the freedom to configure whether a valve act as normally-open or normally-closed by plugging one of the output ports. All valves are chosen for low-volume and low-pressure fluid flow, and minimal electrical power requirements.

4.1.2 Tubing

Transparent vinyl tubing will be used to construct the main reservoir. The transparency of the tubing lends itself well to the fluid level detection scheme described in Section 2.2.2.1 - *Dispensing Collected Water To Test Compartment*.

For the majority of the remaining tubing in the system, medical tubing will be used due to its small diameter and availability of fixtures to interface to larger diameter tubing. The small diameter of the medical tubing minimizes volume, allowing greater control over flow. Finally, the medical tubing has the same diameter as the valves.

4.1.3 Frame & Housing

FloSafe's physical components will be mounted vertically on plywood to allow for simple modifications and additions that are common throughout the development process.

FloSafe will be housed in Plexiglas to showcase the prototype's internals while still shielding it from the outside world.

4.2 Electrical

This section discusses design details for the unit's power supply and amplification of microprocessor signals for high current consumption in valves and motors.

4.2.1 Power Supply

There are two main requirements for the FloSafe power supply. The supply must have a low current output of 5 ± 0.5V, and a 12 ± 3V output capable of delivering up to 2A for up to one minute at a time. For the first stage of development the FloSafe power supply will consist of a simple regulated 5V source for the microprocessor and low current circuitry, and a 12V unregulated source for the valves and motors.

The microprocessor's supply will be generated from a 12V transformer, bridge-rectified and filtered, with an LM7805 Voltage Regulator to control the voltage to the processor. This supply is capable of delivering up to 1A and will also be used to power the Sample Analysis circuitry and the sensors throughout the system.

The motors and valves used as actuators throughout FloSafe all require approximately 12VDC and 300mA each. In the worst-case scenario, three of these valves will be operating at one time, requiring a total of approximately 1A from the supply. As such, to avoid overloading the supply we will design the supply to operate safely at up to 2A. This supply will consist of a separate large transformer with a 12VAC output. This can be rectified and filtered to approximately 17VDC under no load. A voltage regulator may then be applied to the output to supply voltage to the valves.

4.2.2 Signal Amplification

Since the microprocessor is not capable of supplying enough current (or the appropriate voltage) to power the actuators used in FloSafe, additional circuitry must be used to step up the power from the processor. We will use normally-open relays, controlled by the microprocessor, to deliver power to the actuators. The OMRON G5V-1-DC5 is a common and suitable relay because of its low pick up current of 96mW (requiring approximately 19mA from the processor). A voltage follower can be implemented to further decrease the current required from the processor. This will be implemented only if required.

4.3 Performance

In regular use, FloSafe is always easy to use, easy to maintain and unnoticeable to the bather.

Addresses Functional Specification: **P1, P2**

All the devices and components used to build FloSafe were chosen so that their operable temperature is within the specification of FloSafe, 2°C to 40°C in a dry environment.

Addresses Functional Specification: **P3**

Chemical reagents were chosen that take no longer than 10 minutes for the reaction to take place. Waiting time for the reaction is the speed bottleneck. None of the test reagents used by FloSafe take longer than minutes to react.

Addresses Functional Specification: **P4**

The cartridges that hold the chemical reagents provide 60 test cycles, which last 6 months through normal use. A cartridge large enough to hold this amount of reagent was chosen.

Addresses Functional Specification: **P5**

FloSafe must take an amount of water that will not be noticed by a bather. One test cycle is designed to take much less than 250mL. Since an average sized hot tub has over 1000L of water, 250mL is negligible.

5 Conclusion

The design specifications described in this document are both thorough and complete for a fully automated and reliable water test system. Budget constraints have forced us to design reusable, modular subsystems. This cost-effective approach promotes optimization and efficiency in each subsystem of the entire design. The working prototype will be slightly larger than the actual consumer product but will provide the basic, reliable functionality that the end product will provide.

Sundance Systems adheres to these specifications to ensure that FloSafe is the most dependable and simple to use solution for hot tub maintenance on the market. Designs outlined in this document will be implemented by December 2001, and will be available for demonstration at that time.

Appendix

Table 1 below describes the naming conventions used in labeling Figure 5 on the following page.

Table 1: Naming Conventions for Hardware Components.

Naming Convention	Description
v_XXX	System name for normally-closed fluid valve XXX.
s_YYY	System name for digital sensor YYY.
c_ZZZ	System name for undetermined signal, input or output.
PhRes#*	Photoresistor sensors for color detection of samples for test # (two per test).

Also note that only Test 2 is fully labeled, and that system components are symetric between the two tests.

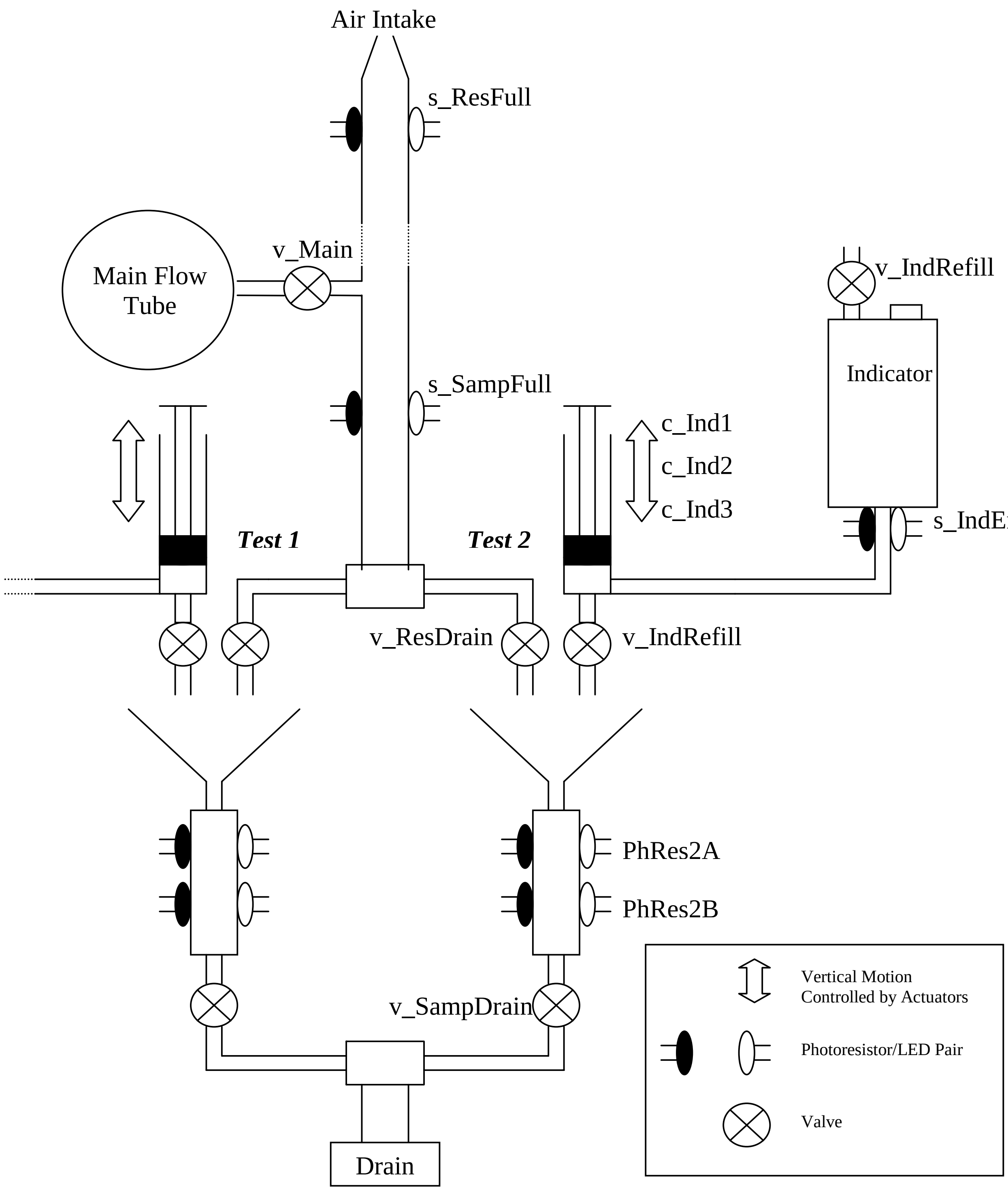

Figure 5: High Level System Overview

Figure 6 on the following page gives the detailed schematic of FloSafe's embedded system, as discussed in Section 3 - *Embedded System: Design Specifications*.

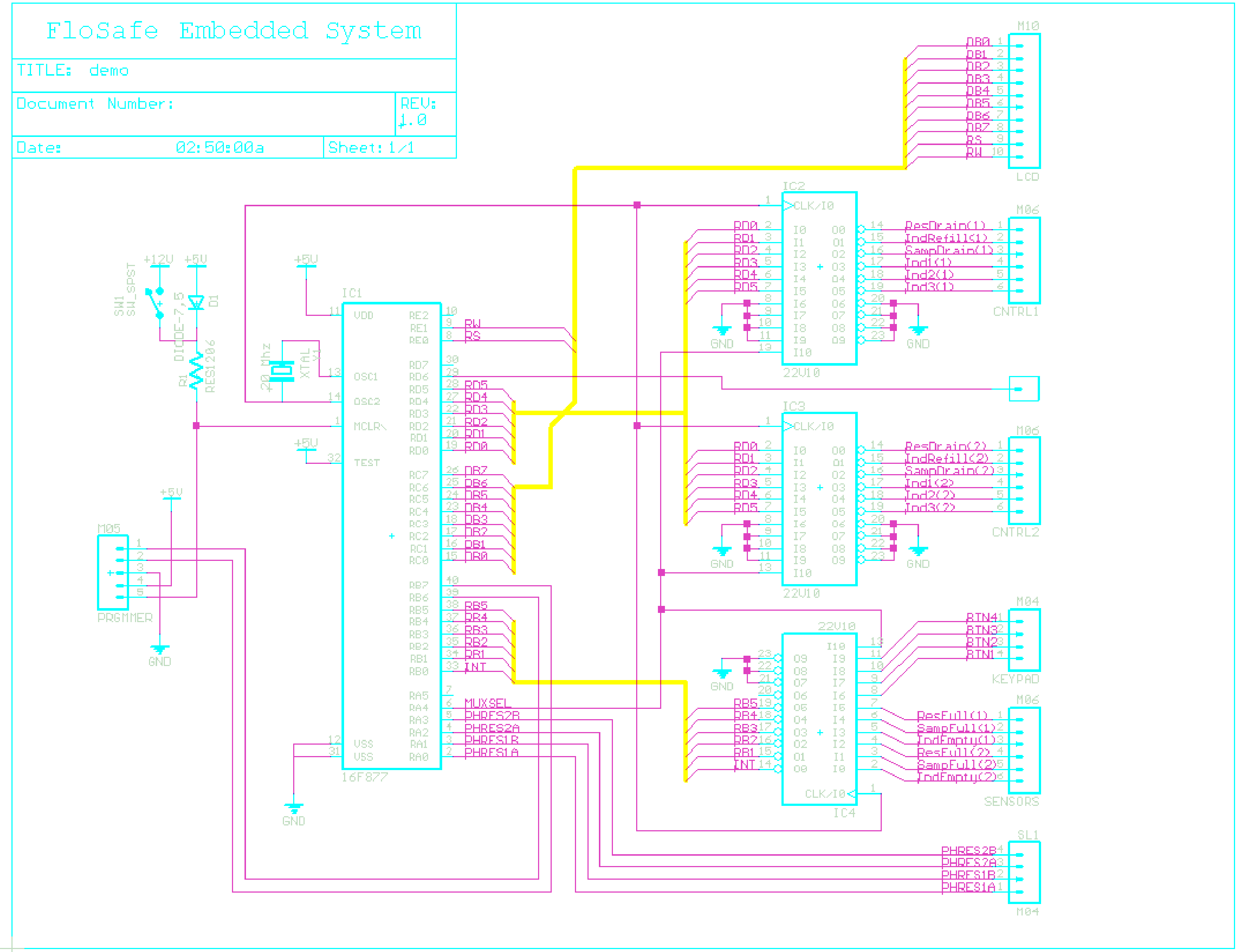

Figure 6: FloSafe Embedded System Schematic.