Automated Water Sampler Design

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Summary

This report contains the design details associated with the automated pier sampling system. It highlights the overall system, PCB design, software, necessary corrections, future design improvements and a parts list for all necessary components. The document is to be used with the EAGLE PCB design files and arduino code for a complete understanding of the system mechanism.

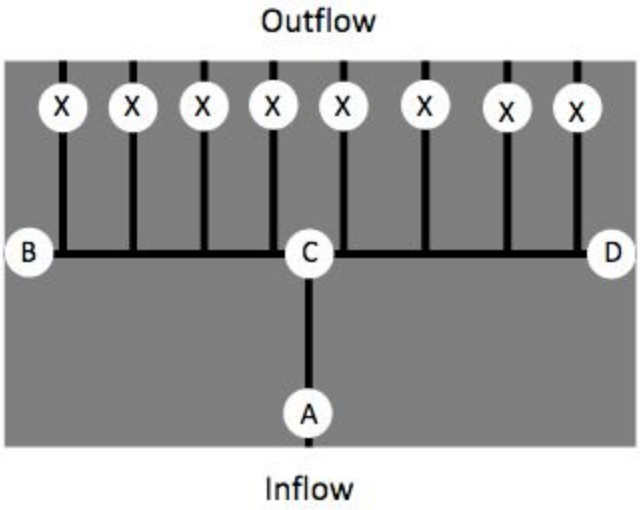
Table of Contents

1. Mechanical System and Control Flow:

The sampling system consists of a total of 11 solenoids, described as follows:

- Solenoid A for water inflow
- Solenoid B and D for water outflow
- Solenoid C for fixative injection
- Solenoids X for sampling

This is as shown in the image below:



The system has 3 time based modes of operation:

1. Normal Operation: Solenoids A, B, D are in the open state and all the other solenoids are closed until a preset time has been reached.
2. Sampling:
   After the preset normal mode time has elapsed:
   - ➢ One of the X sampling solenoids open
   - ➢ B and D close
   - ➢ Water continues to flow through sampling solenoid X until a preset sampling time has elapsed

3. Fixative Injection:
   - ❖ Sampling solenoid X remains open
   - ❖ Inflow solenoid A closes
   - ❖ Solenoid C opens to inject the fixative through sampling solenoid X

This process runs on a continuous time based loop, with the only change being in the sampling stage where the solenoids are iterated through.

Additionally, a pump is used in the fixative mode of operation to ensure proper flow of the fixative solution into the system.

2. Additional Capabilities:

Additional components are to be successfully integrated into the system to allow capabilities such as temperature based sample triggering, as well as a timestamp mechanism for when these samples are triggered. The current mechanisms are outlined in the PCB section, and are achieved using pre-made breakout boards that attach to the PCB.

3. PCB Design:

The PCB Design can be referenced with the schematics and board designs made on EAGLE and manufactured by PCB Minions. The system consists of the following major components:

a. Microcontroller: An arduino Nano which uses an ATmega328P processor is used as the on-board microcontroller to achieve the necessary control for the system. The reasons for picking this specific controller are as follows:
    i. Space: The Nano is the smallest arduino available with adequate pins and processing abilities needed to control the system.
    ii. Ease of programming: The Nano uses the same development platform as any Arduino and is thus easy to program for the necessary control flow.
b. Power Supply: The circuit is entirely powered through a 12V DC source obtained from an AC-DC supply. The arduino's built-in voltage regulator allows it to be safely powered by this source as well.

c. Solenoid Driver Mechanism:

The Solenoids are driven by Bipolar Junction Transistors connected to the arduino digital pins for control using the following components:

i. BJT: TIP120 BJTs are used to drive the solenoids and pump. They fundamentally act as switches to turn on/off the solenoids when commanded by the microcontroller. The solenoids cannot directly be connected to the arduino because it would not be able to provide the necessary current for switching the solenoids without damage. The BJTs however, have low current draw when connected to the arduino, and are able to withstand the high current pulled by the solenoids. The base pin is connected to the arduino, the emitter is connected to ground and the collector is connected to the power source.
ii. Diodes: 1N4007 Diodes are connected in parallel to the solenoids to avoid damage to the microcontroller when the solenoid generates back-emf causing current to flow in the direction opposite to that intended. The diode provides an alternate and safe path for the current to flow.

d. Temperature Sensing:
    i. Temperature probe: A Campbell Scientific probe is used for temperature sensing. It is powered from the arduino using an internal 1.1V supply. It has 4 connections required with 2 grounded (white and purple wires), a voltage excitation wire (connected to the 1.1 supply) and a voltage sensing wire (connected to an Analog pin on the arduino).
    ii. Amplifier: A TI LM358 amplifier is needed in the system. The purpose of this is to allow accurate temperature change measurement, since the voltage change due to temperature in the probe is on the mV scale. This cannot be accurately read by the arduino due to low resolution. The

amplifier takes the low voltage signals and amplifies them to the a V scale that can be better read by the arduino analog inputs. This is done by setting the gain of the amplifier by selecting adequate resistor combinations.

e. Timestamp mechanism:
    i. Real Time Clock (RTC): An RTC breakout board is added to the system for timekeeping purposes. The RTC is a device used for independent timekeeping, ensuring that real time (including mm/dd/yyyy) is kept in the system even when the microcontroller is turned off/reset. It requires 4 connections, Power from the 3.3V supply on the arduino, Ground, Serial Data (SDA) and Serial Clock (SCL), both connected to the SDA and SCL pins on the arduino. It communicates with the arduino using the I2C/TWI standard, and has a backup coin cell battery to ensure timekeeping.
    ii. SD Card: An SD card breakout board is added to the system for recording data. It uses a Serial Peripheral Interface (SPI) to communicate with the arduino. It requires 6 connections: 3.3 V Power from arduino, Ground, Clock (CLK) connected to the arduino clock (pin 13), Digital Output (DO) to Master In Slave Out (MISO, pin 12) , Digital Input (DI) to Master Out Slave In (MOSI, pin 11) and Clock Select (CS) to Pin 10 of the arduino. This breakout board enables reading and writing to/from the system.

4. Code:

The code associated with the system is attached in the folder, however the overall mechanism consists of important functions such as:

1. Millis function: The arduino millis function is used to keep track of time through the entire sampling process and to switch between normal, sampling and fixative states. These time intervals are user defined and thus added as definitions at the beginning of the code allowing simple alterations.
2. RTC Initialization and reading: The RTC is initialized before entering the main loop. A function is written for the arduino to read the date and time from the RTC. The RTC header files are required for this and are taken from online arduino libraries.
3. SD Card Initialization and writing: The SD Card is initialized before entering the main loop. A function is written to write the time step data onto the card from the RTC. The SD card header files are required for this and are taken from online arduino libraries.
4. Temperature Probe Calculations: A function is written to relate the voltage change in the probe to temperature change. This value is checked constantly to trigger additional samples if required. The sensing threshold is set to $\pm$ 2 degrees C.

5. Corrections:

The current system is able to go through the sampling states, however needs corrections to incorporate the temperature and data recording abilities. The following corrections need to be made:

1. SD Card breakout board: A ground connection was missing on the SD Card breakout board, therefore needing a new PCB with this connection made. The PCB file has been corrected to ensure this connection was made, and needs to be remanufactured.
2. Temperature sensing probe/amplifier: In the current design, the amplifier outputs extremely inaccurate values voltage and is unable to hold a steady voltage over time, changing abruptly. The reason for this is probably voltage fluctuations in the power supply causing amplified noise, or noise in the PCB traces. To correct this problem, a suitable capacitor may be useful in the amplification feedback loop to ensure smoother output trends. Once steady voltages are achieved, the temperature readings will automatically become accurate and usable.

6. Future Improvements:

This section highlights potential future improvements to the system to allow a smaller form factor and more robust system:

a. ULN2803A for control: A TI ULN2803A IC can be used to effectively replace all BJTs and diodes on the current circuit. This integrated circuit chip contains BJTs and diodes built into it and can drive upto 8 solenoids, resulting in a much smaller form factor than the current configuration. The datasheet can be found here :http://www.ti.com/lit/ds/symlink/uln2803a.pdf

b. Wireless communication/data storage: Another interesting and challenging modification to the system would be to add wireless communication capabilities to store and communicate data. This could be done using WI-Fi with the ESP8266 module (https://www.sparkfun.com/products/13678) , giving the arduino capabilities to communicate with a simple server and transmit information. The code associated with this is relatively complex compared to the existing set up, however a plethora of references are available online to reduce the learning curve.
   The information can also be communicated using a GSM module, in which case live alerts could be sent to a mobile phone. Again, adding this functionality is challenging, however can be done with extensive research. The module can be found here: https://www.adafruit.com/product/1946

7. Parts List:

Part	Link
Solenoids	http://www.electricsolenoidvalves.com/1-8-12v-dc-electric-plastic-solenoid-valve/
Arduino	https://www.amazon.com/ATmega328P-Microcontroller-Board-Cable-Arduino/dp/B00NLAMS9C
Power Supply	https://www.amazon.com/LEDMO-Power-Supply-Transformers-Adapter/dp/B01461MOGQ/ref=sr_1_fkmr0_2?s=musical-instruments&ie=UTF8&qid=1516981471&sr=1-2-fkmr0&keywords=daisen+adapter+transformer
Power Jack	https://www.digikey.com/product-detail/en/PJ-102BH/CP-102BH-ND/408449?WT.mc_id=IQ_7595_G_pla408449&wt.srch=1&wt.medium=cpc&WT.srch=1&gclid=CjwKEAiA0fnFBRC6g8rgmICvrw0SJADx1_zA1Gka6c0Qni3HKnfF7uQnWZlSWiEPP-php0FJkI1KyBoCuDHw_wcB
BJTs	https://www.digikey.com/product-detail/en/on-semiconductor/TIP120G/TIP120GOS-ND/920325
Diodes	https://www.digikey.com/product-detail/en/diodes-incorporated/1N4007-T/1N4007DICT-ND/76454?WT.srch=1&gclid=CjwKEAjw9MrIBRCr2LPek5-h8U0SJAD3jfhtI8nCA4J25pju84Sn8Nyw9ctS61S790tJrAT-YG2L9hoC4xfw_wcB
Resistors	https://www.digikey.com/product-detail/en/stackpole-electronics-inc/CF14JT330R/CF14JT330RCT-ND/1830338
Temperature Probe	https://www.campbellsci.com/107
Amplifier	http://www.mouser.com/ProductDetail/Texas-Instruments/LM358AN-NOPB/?qs=sGAEpiMZZMtCHixnSjNA6JlKxGj6zye%252bYMj%252bywvLW%252bQ%3d
SD Card breakout board	https://www.amazon.com/Adafruit-MicroSD-breakout-board-ADA254/dp/B00NAY2NAI/ref=sr_1_1?s=electronics&ie=UTF8&qid=1502748137&sr=1-1&keywords=arduino+sd+card+breakout+board
RTC	https://www.amazon.com/Adafruit-DS1307-Clock-Assembled-Breakout/dp/B01MS40AOD/ref=sr_1_4?ie=UTF8&qid=1502748094&sr=8-4&keywords=arduino+rtc