Conductivity water sensor

Application Note

Revision 0

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1 Introduction

A design of a simple, rugged and reliable water sensor is presented. The sensor uses two small carbon electric motor brushes for probes which are used to detect the presence of water when submersed. A sense voltage is applied across the probes through a pull-up resistor and this sense voltage is monitored by the sensor input circuit.

When the sensor probes are submerged, the water conductivity provides a path for a tiny sense current to flow between the probes, causing the sense voltage across the probes to fall. This change in sense voltage is used to generate a detection signal that is processed in a novel way by a uTile Programmable Logic Controller.

2 Theory of operation

The sensor system consists of the sensor element with two probes made of carbon brushes. The two probes are connected to any two of the of the six available inputs A0 through A5 uTile digital inputs. In this application, inputs A0 and A1 are used. Each uTile input has the pull-up resistor enabled, so the voltage level at each input is normally held at 5 V(dc), unless the input is pulled low by an external signal.

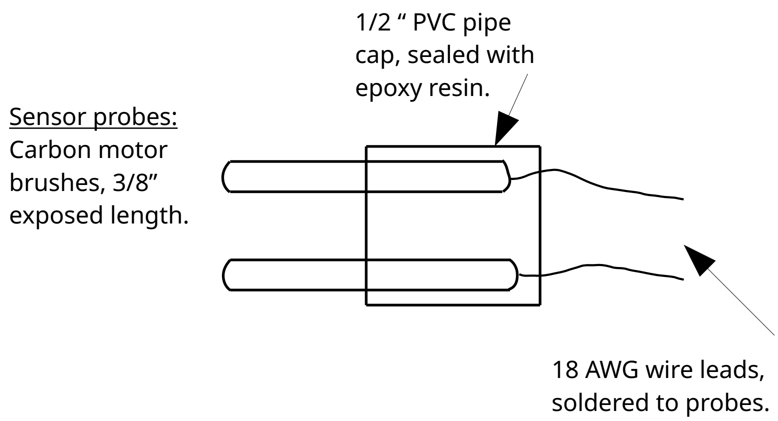
The sensor probes digital inputs are periodically scanned every 300 ms. During any scan cycle, one of the probe inputs is clamped at one diode drop (~ 0.5 V) above ground, while the other probe input is pulled up to the Vcc supply voltage level by the input port pull-up resistor.

When the probes are submerged in water, the inter-probe resistance drops as the water provides a current path between the probes. The voltage at the digital input on the unclamped input falls below the Vin low threshold voltage level (around 2.5 V). This causes the digital input to be read as a logic low. Normally, there still exists a small voltage difference across the sensor probes when they are immersed in water that will eventually lead to electrolytic corrosion/plating effects on the probes. The positive probe (anode) will be corroded while the negative probe (cathode) will be plated.

The corrosion/plating effect, although tiny, over time will result in the sensor cathodic probe becoming plated and performance will degrade to the point of failure. The sensor control program in this design mitigates the corrosion/plating effect by switching the assignment of the active and clamped probes on alternate scan cycles. Each probe alternatively switches between being anode and cathode on alternate scan cycles. The net result is that deleterious corrosion/plating effects on probe performance is greatly reduced over long term operation.

2.1 Sensor probe design

The sensor design consists of two electrically conductive probes mounted on in suitable insulated holder assembly such as a small 1/2 inch PVC pipe cap. A suggested sensor design is shown in the diagram below.



The sensor design with carbon brush probes and the uTile sensor management control program has demonstrated reliable operation with no noticeable probe degradation during a 12 month period of continuous operation. The probes were fully submerged in water and the sensor output signal was constantly monitored during the test.

3 Sensor control program

The sensor management program is entered and stored into the uTile PLC user file area UF0. During operation, the sensor signal is processed by a periodic scanning routine for changes in the inter-probe resistance level. A drop in resistance below a low threshold level indicates the probes are submerged and the program outputs a high logic level signal to indicate the detection of water.

During each 300 ms scan cycle the program generates several timed pulses to control the probe scanning operation. During a scan cycle one of the probes is clamped to GND and the other active probe is scanned. In the subsequent scan cycle, the grounded probe is unclamped and becomes the active probe, while the active probe is clamped and becomes the grounded probe.

The following sections explains the control program operation in more detail.

3.1 Logic diagram

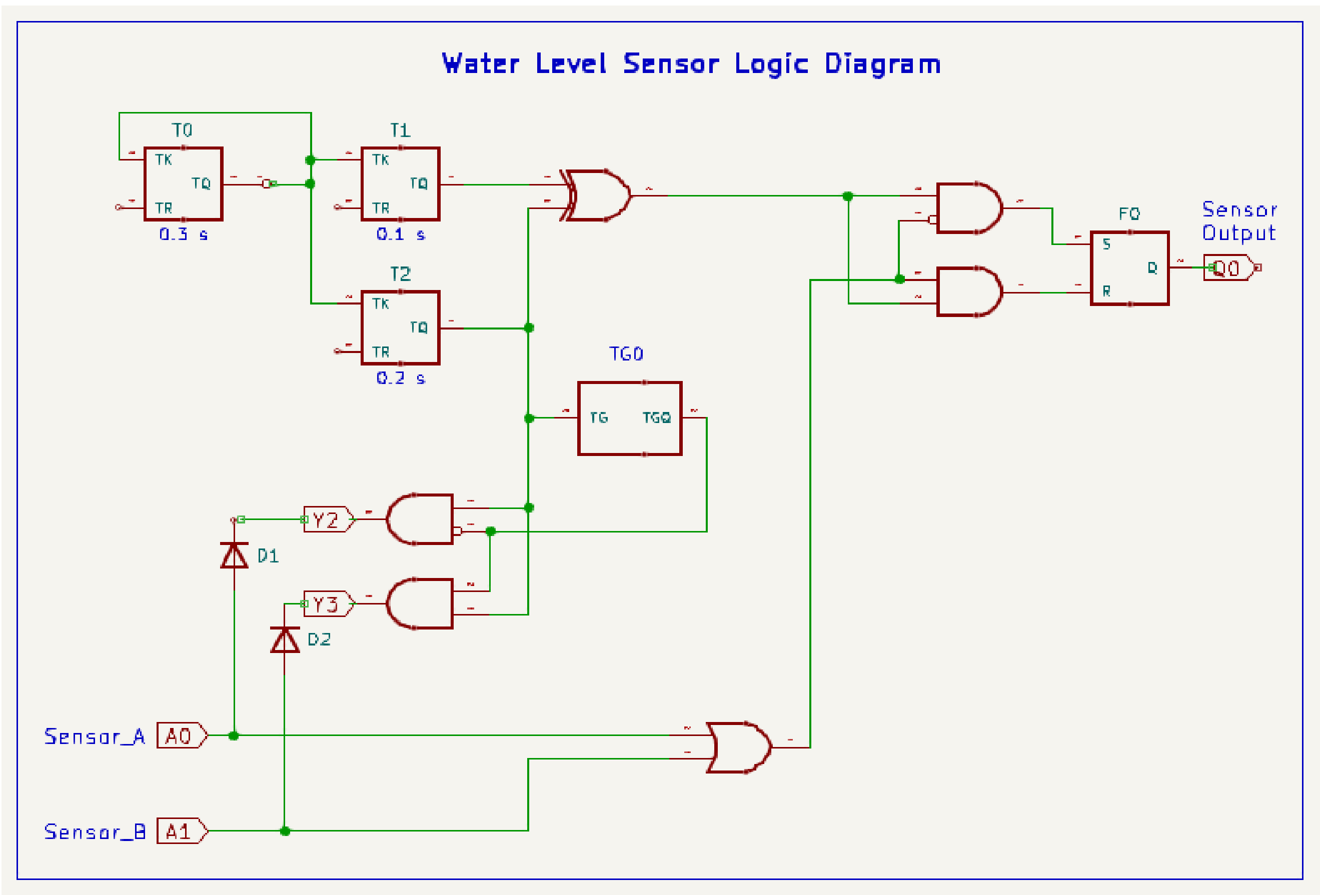
The logic diagram below shows the probes connected to two uTile digital inputs, A0 and A1. The sensor output signal is presented on digital output Y7.

The processing logic consists of delay timers, flip-flop latches and a number of AND, OR and XOR gates.

Two 1N914 signal diodes D1 and D2 (anode side) are connected to A0 and A1 inputs as shown in the diagram.

Digital outputs Y2 and Y3 connect to the cathode side of D1 and D2 respectively.

Details of the logic processing functions are provided in the following sub- sections.

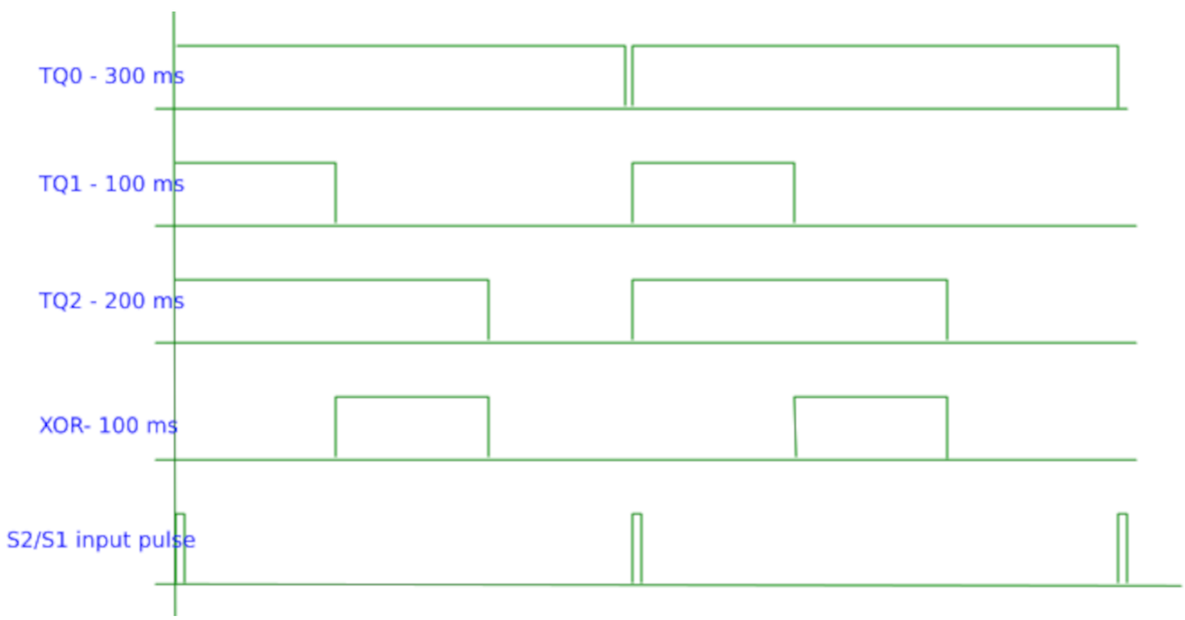


Logic diagram

3.2 Sensor scan timing generation

The three delay timers T0, T1 and T2 count in units of 100 ms. Timer T0 is configured to automatically re-trigger itself at the end of each 300 ms cycle. This timer is the main sample cycle timer that also triggers the 200 ms Gate timer T2 and the 100 ms Gate delay timer T1.

The timing diagram below shows the timer outputs TQ0, TQ1 and TQ2. Note that TQ1 and TQ2 outputs are of less duration than TQ0. The TQ0 output is inverted and used as the trigger signal for all three timers so they all start their timing cycles at the same time. He trigger pulse is shown as the S1/S2 input pulse in the timing diagram.



Sensor Timing Diagram

The 200 ms TQ2 output defines a gate window during which the probe sensing process is enabled. The 100 ms TQ1 output provides a short delay before the probe sample signal is read. This delay allows the probe switching transients to settle down and not interferes with the signal sampling phase of the detection.

The outputs TQ1 and TQ2 are fed to an XOR gate to generate a 100 ms delayed sample gate window, in the middle of every 300 ms scan cycle.

The 200 ms TQ2 gate signal output is fed into toggle function TG0 which divides the TQ2 pulses by two. The TGQ0 output toggles for every rising edge transition on the input TG0 as shown in the timing diagram..

The TGQ0 output therefore selects which probe acts as the anode which as the cathode.

3.3 Sensor probes toggling control

The inputs A0 and A1 are configured with internal pullup resistors enabled. Under open circuit conditions the voltage level at A0 and A1 is close to the Vcc power supply level.

When digital output Y2 is at a logic high level, D1 cathode is held high, allowing input A0 to swing from GND to Vcc. When Y2 is at a logic low level, the D1 cathode is grounded, effectively clamping the A0 input to around 0.5 V above GND. Similarly, the same applies to input A1, diode D2 and digital output Y3. Input A1 is clamped to around 0.5 V above GND when Y3 is low, otherwise A1 is allowed to swing between GND and Vcc.

The probe that is free to swing between GND and Vcc is the “active” probe and can therefore respond to resistance changes between itself and the clamped GND probe.

Digital output Y2 is driven by an AND gate, with one input from the toggle output TGQ0. The other input to the AND gate is from TQ2, the gate window pulse output. The net result is that Y2 is driven high during the time when the gate window pulse is high, **and** when TGQ0 is **high**. At all other times, Y2 is low and the A0 input is clamped to ground.

Digital output Y3 is driven by an AND gate, with one input from the i**nverted** toggle output TGQ0. The other input to the AND gate is from TQ2, the gate window pulse output. In this case, Y3 is driven high during the time when the gate window pulse is high, **and** when TGQ0 is **low**. At all other times, Y3 is low and the A1 input is clamped to ground.

During a scan cycle when the TGQ0 output is high, the probe connected to A0 input is active during the gate window pulse while the probe connected to A1 input is clamped low. During the next scan cycle when the TGQ0 output is low, the probe connected to A1 input is active during the gate window pulse while the probe connected to A0 input is clamped low.

The digital input A0 and A1 are fed to an OR gate which outputs a high signal when either of the inputs are high. The OR gate output can be high under the following conditions:

- Gate window pulse **high**, and
- Sensor probes **not** submerged

The toggling action that determines which probe is active and which probe is clamped during a scan cycle is transparent to the signal at the OR gate output.

3.4 Generating the sensor output signal

The sensor output signal is captured at the Q0 output of latch F0 and available at digital output port Y7. The Nano's onboard LED is connected to Y7 and provides a visual indication of the state of Y7.

The latch's S0 set input and R0 reset input are driven by AND gates. The 100 ms delayed gate signal from the XOR gate drives one input of each of the AND gates, allowing the F0 latch to respond only when the delayed gate pulse is high.

Consider the case when the sensor probes are submerged in water (sensor active condition). The output of the sensor OR gate during the gate window pulse high condition is low. The OR gate output is inverted and fed to the other input of the AND gate driving the S0 latch input. The latch output Q0 is set high, indicating the presence of water.

Consider the case when the sensor probes are not submerged in water (sensor inactive condition). The output of the sensor OR gate during the gate window pulse high condition is now high. This high signal is fed to the other input of the AND gate driving the R0 latch input. The latch output Q0 is cleared low, indicating the absence of water.

3.5 Setting up the uTile PLC

The uTile PLC has to be flashed to a Nano board. The procedure for installing uTile is a one-time only operation and is fully described in the m328-uTile-Manual.

With uTile installed and running, the sensor control program can be entered and stored on uTile in EEPROM. Ground the D8 Autostart input to enable stand-alone operation of the sensor program when the board is powered up.

3.5.1 Entering the sensor control program

The sensor management control program must be entered into the UF0 program space by entering each uTile command as per the program listing below.

000 TQ2.	008 AND	016 OR	024 .S0
001 .TG0	009 .Y3	017 DUP	025 TQ0.
002 TQ2.	010 TQ1.	018 V0.	026 !
003 TGQ0.	011 TQ2.	019 AND	027 DUP
004 2DUP	012 XOR	020 .R0	028 DUP
005 AND	013 .V0	021 !	029 .TK0
006 .Y2	014 A0.	022 V0.	030 .TK1
007 !	015 A1.	023 AND	031 .TK2

032 Q0.
033 .Y7
034 KEY
035 END
036 NOP
037 NOP
038 NOP

Enter the timer settings shown below. These are suggested settings for a reasonably fast sensor response and can be changed to suite particular application requirements.

T0	T1	T2	T3	T4	T5	T6	T7
003	001	002	000	000	000	000	000

T8	T9	TA	TB	TC	TD	TE	TF
000	000	000	000	000	000	000	000

After entering and checking the program and timer settings, the program should be saved to non-volatile EEPROM storage. Remember to ground the D8 Autostart input pin to enable the uTile to start running the stored program when it is powered-up.

Test the water sensor system by connecting a sensor to the Nano and check the response to dipping the sensor in some water. The 'L' LED should turn on when the probes are submerged and turned off otherwise.

4 Conclusions

The sensor design is relatively simple, uses only a few components and is rugged and reliable in operation. The uTile sensor management control program is processing quite a bit of logic, yet the program is quite compact and uses 35 of the available 256 lines of programming space.

This conductivity water sensor application is just one example of the type of control application that you can easily design, build and test using the versatile uTile PLC. Please refer to the github repository for uTile for further information:

https://github.com/lynf/ATMega328_programmable_logic_controller/tree/master

5 License

The m328-uTile program is not intended for use in commercial, industrial, medical or safety-related applications.