

From: Robert Lieb

To: Christoph Gorder, Robin Cho --Charity Water

David Laone – Mindinspire Inc.

CC: Gianfranco Bonanome, Hilary Farnsworth, Bob Wild

IPS

Date: Aug 3, 2017

Subject: Temperature Analysis on Water Detection Algorithm

# Problems Observed

On yesterday’s conference call, we discussed findings from David that when the unit was operated in the hot sun (approx. 90 degree F) that he saw innacuracies in the measurement data.

To help recreate the failure, on Aug 2 I ran an experiment using a Thermocoupler to measure the air temperature inside the housing near where the capacitive sensors reside, and a heat gun to raise the ambient temperature at the pads. With the temperature changes, I was able to see an increase in “unknown” measurements that increased in frequency as the temperature approached 49C (120F). When the temperature returned to room temerature 26C (78F), the occurrence of “unknowns” decreased.

An “unknown” measurement is an instance when one or more pads report “water” above pads that report “air”. “unknown” measurements may cause an inaccurate water flow calculation depending on which algorithm we use for determining the highest water level.

Looking at the Water Detection Algorithm, I see an explanation of why the problem is occurring.

I observed in the data that **the capacitance value measured by the ADC went down at higher temperatures**. The following chart shows some sample ADC measurements at several temperatures over 800+ seconds. The dark blue line shows the ambient temperature measured by the thermistor inserted in the housing near the pads. Note how the ADC values dip as the temperature changes.

The lower ADC value could result in a false “water” detection should the measured data go below the “midpoint”. This would account for the type of problems reported by David in his outdoor well test setup”.

The Water Detection Algorithm is based on measuring accurate “air” and “water” target values where the location of a current ADC value determines whether the pad is covered with water and what percantage of the pad is covered with water. In the experiments today, I measured that the Target Range between “air” and “water” was growing as the air temperature increased.

The following chart shows the width of the target range and how it changes as the temperature goes from 26C to 53C over 800+ seconds. The dark blue line shows the temperature of the air within the housing right next to where the pads reside. The other lines show how the target range width changes over temperature changes over time.

What I saw was that the target range grew as the temperature increased, but it did not “contract” back to its original level once the temperature decreases again.

# Solution Developed and Tested

## Expanding Target Range Problem

To help find a solution to the expanding range problem, I did some tests to see if the range is expanding at the higher temperatures or is it growing as measured – it is not. The numbers shaded in yellow are the ranges of ADC values seen during a pumping session. The “Meas” values came from the existing Water Detect Algorithm.

*Table of Target Ranges by Temperature: Update targets continuously*

|  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | Pad 0 | | Pad 1 | | Pad 2 | | Pad 3 | | Pad 4 | | Pad 5 | |
| Temp | Meas | Actual | Meas | Actual | Meas | Actual | Meas | Actual | Meas | Actual | Meas | Actual |
| 22 | 637 | 413 | 609 | 431 | 663 | 471 | 627 | 539 | 706 | 627 | 576 | 311 |
| 36 | 981 | 219 | 819 | 236 | 803 | 332 | 745 | 550 | 820 | 643 | 651 | 327 |
| 45 | 1306 | 779 | 985 | 640 | 939 | 628 | 839 | 603 | 923 | 675 | 707 | 359 |
| 54 | 1369 | 520 | 1133 | 517 | 1113 | 488 | 976 | 546 | 1073 | 688 | 798 | 410 |

From the raw testing data, it was clear that the introduction of water to the heated pads caused the error in establishing Target levels for water and air. So I decided to try changing the code to determine these target levels while in a pumping session. When the system detects all pads covered with water (which happens when they pumping begins), then the ADC values seen are the new “Target Water” level. When the pads are no longer covered with water, then the ADC values are the new “Target Air” level. To be safe, the code will not set a target range less than 600 counts.

Using this methodology, the ranges tracked with the actual ADC values as the pads are heated and cooled alternately each pumping event.

*Table of Target Ranges by Temperature: Update targets while pumping*

|  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | Pad 0 | | Pad 1 | | Pad 2 | | Pad 3 | | Pad 4 | | Pad 5 | |
| Temp | Meas | Actual | Meas | Actual | Meas | Actual | Meas | Actual | Meas | Actual | Meas | Actual |
| 22 | 403 | 571 | 412 | 570 | 475 | 617 | 496 | 582 | 677 | 656 | 489 | 257 |
| 32 | 703 | 297 | 657 | 393 | 687 | 432 | 649 | 558 | 706 | 661 | 489 | 263 |
| 42 | 722 | 402 | 712 | 553 | 659 | 628 | 681 | 597 | 717 | 666 | 530 | 305 |
| 52 | 816 | 545 | 800 | 536 | 684 | 624 | 743 | 931 | 713 | 690 | 561 | 345 |

## Frequent “Unknowns” at Higher Temperatures Problem

After studying the data gathered so far, I saw a pattern that the excessive “unknown” determinations at higher temperatures was caused by using “OUTLIER” data that was not caught by the screening algorithm.

As known from the beginning, the TI Capacitance Measurement library has a bug where every 20 samples, the ADC value measured is way off. This was causing great innacuracy in both the original AfriDev software as well as the new V2 software. The V2 code had a filter that weeded out samples that deviated more than 1500 counts from the last measurement.

Unfortunately this filter allowed some OUTLIER data to reach the target setting code. I tried today to reclassify outliers using a tighter algorithm based on the “Target Air” and “Target Water” values. Unfortunately this caused a number of problems.

I decided to keep the existing filter and apply a new limitation on determining Target values. When the current second’s Pad measurements has any OUTLIER values, I skip the whole second’s worth of data for the purpose of updating the Target Levels.

When this change is made, in conjunction with the Expanding Target Range fix, the occurrence of unknowns virtually disappeared (just a few over the full test.

There still may be some value in trying to solve the bug in TI’s library code, but the amount of time required to find the bug is not easily estimated.

## Ambient Temperature Sensor Problem

The exising unit design (old and new board designs) has a measurement of ambient temperature, but it is measured in the MSP430G2955 processor nowhere near the pad area. In my measurements, the ambient temperature at the micro got no higher than 31C, eventhough the Pad area reached over 49C.

If Charity Water wants to use Ambient Temperature to evaluate field conditions, then it would require a hardware change.

# Next Steps

Now that we have some algorithm changes that work with varying ambient temperatures, the code changes will need to be integrated into the V1 software and tested.

To test the code the same way as we did in NY, a thin thermocoupler probe needs to be inserted into the probe housing. We used a data logger device to monitor the temperature. To run the test, we used a heat gun to blow very high heat into the top of the well.

When the temperature reached 32C, 42C and 52C respectively, we pumped the well 10 times and looked at the debug trace data to see how the algorithm is performing.

Once we know that the new algorithm works well in the lab, we should send a code image out to a few units in the field to be sure they are performing as planned.