AN12768

Using a stability algorithm in a cold-chain use case

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Document information

Information	Content
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Abstract	How to build up a stability algorithm

Revision history

Rev	Date	Description
v1.0	20200312	Update for SDK 12.4
Modifications:	• Major format update and refresh of contents	
v0.2	20170113	Update for SDK 9
v0.1	20161215	Initial version

1 Introduction

All ICs of the NHS31xx family, especially the NHS3100 IC, are ideally suited for cold-chain logging and monitoring use cases. The HW provides the building blocks for complex and standalone operations. An internal RTC driven by a free-running oscillator, an accurate temperature sensor, and plenty of volatile and non-volatile memory. The NHS31xx ICs also include an open Arm Cortex M0+ processor where the firmware can be fully tailored for each customer and use case.

To decide after each measurement if the attached drug or perishable good is still good for consumption, the firmware must typically implement logic. This validation is captured in a so-called "stability algorithm".

When creating a use-case stability algorithm, the notes below speed up the development and help in deciding on some algorithm parameters.

1.1 Typical cold-chain use case

This document assumes the following generic situation:

- An NFC-enabled Android phone (or any tag reader) taps a label containing an NHS3100 IC is. It is configured by sending specific commands over the NFC interface. Among others, it is instructed to start monitoring and logging by making a measurement every x minutes.
- From that moment on, the NHS3100 IC wakes up every x minutes to check the current situation.
  - The current situation is assessed by making a temperature measurement and coupling this value with the current IC time.
  - At least, excursions and anomalies are recorded to allow later corrective actions.
  - Between two measurements and corresponding calculations, the IC is put in a low-power mode (NHS31xx's deep power-down mode).
- To validate the situation after each measurement, a stability algorithm is used.
  - When fed with a new measurement, it executes all required checks. Its output indicates the validity of the attached product.
  - A check consists of a series of calculations, using the current time, the current temperature, and the past temperature values.

1.2 Example

As an example, an algorithm could be designed to validate a product that must be kept in a fridge. Outside a fridge, the product slowly deteriorates. We can then imagine two thresholds have been determined:

- The temperature cannot exceed 20 °C for more than 60 minutes
- The temperature cannot exceed 8 °C for more than 10 hours

For simplification, we ignore freezing temperatures in this example.

Combinations of the two thresholds mentioned above must also be checked. For example, the following situations also render the product invalid:

- After having exceeded 20 °C for half an hour and having been between 8 ºC and 20 °C for 5 hours
- After having exceeded 20 °C for 15 minutes and having been between 8 °C and 20 °C for 7.5 hours

- …

When the temperature exceeds a threshold, a so-called "excursion" occurs. The length of an excursion can vary widely. One long excursion can render a product invalid or the same result is only reached after multiple smaller disjoint excursions. The stability algorithm must add up all these excursions correctly.

2 Pitfalls

Each time the firmware requests a new temperature measurement, the temperature sensor block is only powered for a short time. The exact length depends on the required resolution with 100 milliseconds required to reach the highest resolution. When a measurement is complete, the temperature sensor HW block is powered off again.

Between two measurements, the temperature sensor block remains powered off. Temperature fluctuations can pass unnoticed. The temperature sensor block is different from a chemical sensor which is continuously observing the temperature.

The configured measurement interval, which is use-case specific, defines the granularity of the measurements. When set too high, fast fluctuations are not detected. When set too low, unnecessary current is consumed.

2.1 Excursion length uncertainty

When measuring every x minutes, each excursion, a temperature value above a use-case specific threshold, translates to a duration of x minutes in which the IC exceeded that threshold. The basis for the decision making done in the stability algorithm is counting temperature values during an excursion.

One long excursion is easily detected. Take, for example, Figure 1 below, with a measurement interval of 15 minutes:

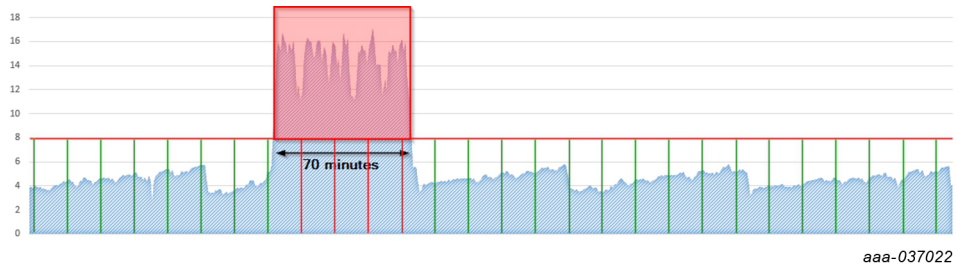

Figure 1. One long excursion with marked measurement times

In this case, four measurements give temperature readings that are too high. The stability algorithm can conclude that the temperature was too high for $4 \cdot 15 = 60$ minutes. In reality, the length of the excursion can be anywhere within $]60+15,\ 60-15[$.

Note: *For a measurement interval of x minutes, the uncertainty of any excursion length is almost 2·x minutes.*

2.2 Combining multiple excursions

Excursions can come in different forms:

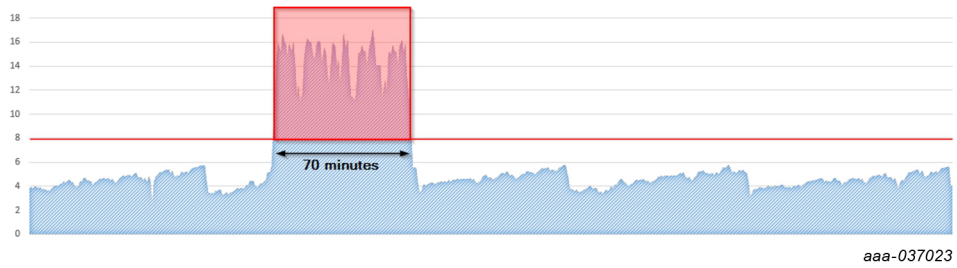

Figure 2. Temperature curve with one long excursion

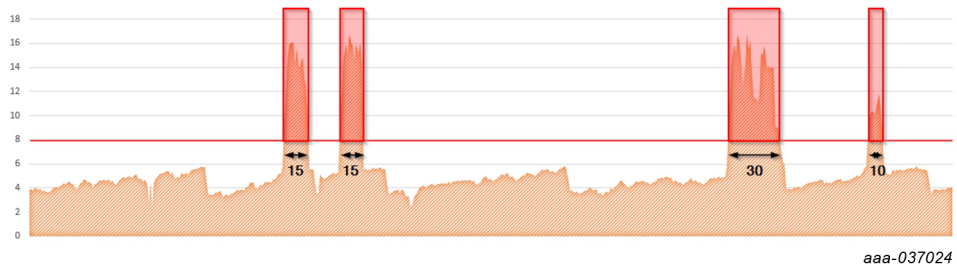

Figure 3. Temperature curve with multiple shorter disjoint excursions

In reality, the measurement period is close to, but different from, x minutes due to the RTC accuracy fault. As an example, suppose that the RTC deviates 2.5 % from the temperature range the IC is within:

- For an interval of 10 minutes, the maximum error is then 15 seconds (in either direction). Instead of the expected 600 seconds, the real value is somewhere between 585 seconds and 615 seconds.
- For an interval of 15 minutes, the maximum error is then 22.5 seconds (in either direction). Instead of the expected 900 seconds, the real value is somewhere between 877 seconds and 923 seconds.

The RTC deviation does not get worse over time. When looking at excursion lengths, the past lifetime, or the past excursion of the RTC does not affect the RTC deviation. Each time one interval of x seconds has passed, the maximum time deviation during that interval remains 2.5 %.

So, it is possible to detect one large excursion with the same level of accuracy as multiple smaller excursions. A bigger problem than the RTC deviation is the uncertainty of the excursion length due to the measurement.

Note: *For decision making in a stability algorithm, the RTC deviation is low compared to the measurement interval.*

2.3 Missed and misjudged excursions

A more capricious temperature curve can cause multiple misjudgments:

Figure 4. Less predictable temperature curve

- Several smaller excursions are not captured, yet they may or may not add up to the deterioration of the attached good.
- The stability algorithm considers two shorter excursions (near the end of the graph) as one longer excursion.

These errors are inherent to the digital nature of the NHS31xx temperature measurement block. So, to ensure that all fluctuations are captured, setting the measurement interval to a short interval is preferred. However, intervals that are too short tax the battery too much. To attain an estimate of the required battery capacity, given the different parameters that can be tweaked, check the *CurrentConsumption.xlsx* tool in the SDK.

Note: *The thermal inertia of the product determines the optimal measurement interval.*

3 Mitigations

Knowledge of the specific use case and the end-product, makes it possible to avoid the pitfalls.

3.1 Reducing false positives

The stability algorithm can make two types of errors. It can either flag products which are still OK or it can pass products which are no longer OK.

- A false positive occurs
  - When the stability algorithm decides a product is still good for consumption, but in reality has expired or has suffered reduced effectiveness.
  - When the RTC is running too slow, that is, when the RTC clock reports x minutes have passed, more than x minutes have passed in reality, more false positives can occur, since the stability algorithm passes a product which has already expired.
- A false negative occurs
  - When the stability algorithm decides a product is not good for consumption anymore, while in reality it was still fully effective (or effective enough).
  - When the RTC is running too fast, that is, when the RTC clock reports x minutes have passed, less than x minutes have passed in reality, more false negatives can occur, since the stability algorithm prematurely concludes that a product has expired.

If the error due to the RTC deviation is considered too high for some strict criteria checked in the stability algorithm, the configured measurement interval can be adjusted to eliminate false positives.

Picking up our example from the previous section: For an interval of x minutes, the wake-up interval can be configured to expire after x - 2.5 % minutes. The stability algorithm still assumes an interval of x minutes per time. This configuration is enough to eliminate false negatives due to the RTC error. As a result, the stability algorithm is a bit more restrictive. It flags and rejects faster, which means the number of false positives is increased.

3.2 Reducing RTC deviation

When timestamps can be repositioned, the extra, manually introduced, RTC deviation can be corrected during a readout. For more information, see the application note AN12769 (Ref. 1).

3.3 Shortening the measurement interval

A straightforward and effective way to reduce the effects of the sampling uncertainty is to reduce the measurement time. However, reducing the measurement time has two downsides:

- Higher power consumption:
  If the interval is chosen to be a few minutes or more, the dominant factor is the current consumption between two measurements. To check the impact of the estimated required battery capacity when playing with the measurement interval, use our tool, *CurrentConsumption.xlsx*, which is part of the SDK.
- More logging space required:
  Depending on the active lifetime of the IC, the logging space may or may not be a concern. To reduce the storage space, lossless and lossy compression can be

employed. For example, an algorithm may measure every 5 minutes, but only store one out of three measurements (for more information, see *1018DataStorage.pdf*, which is part of the SDK).

3.3.1 Adaptive periods

Another possibility that reduces the uncertainty while avoiding the downsides of the above suggestion is to use adaptive periods.

The next wake-up period can be adjusted based on the last temperature measurement:

- When the current temperature is close to a threshold value or when a decision point is almost reached, use a shorter period.
- When the current temperature is in the middle of the optimal temperature range, use a longer period. Note that the thermal inertia determines the maximum period and should not be set too high.

The use of adaptive periods increases the complexity of the logic of the stability algorithm. Also, a significant increase of the required storage space must be avoided. "Replaying" the logic employed to define the next interval between measurements can avoid the necessity to store a timestamp for each measurement value. This "replaying" can be done either on-chip, shielding implementation details; or on the tag reader, improving readout time.

The amount of adjustment in the interval is use case-specific. It must be tweaked in alignment with the expected thermal behavior. At the cost of complexity, it provides a compromise between accuracy, power consumption, and data logging storage.

4 References

[1] **AN12769 application note** — NHS31xx RTC - On the RTC deviation; 2020, NXP Semiconductors

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