



FeverGuard



Fever: The Canary in the Coal Mine

FeverGuard Technical White Paper

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1.888.SOLOS.HA
info@solosanalytics.com
solosanalytics.com

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Solos Health Analytics mission is to leverage individualized machine learning and predictive analytics to develop wellness products that provide an early indication of potential illnesses, improving health safety, aiding in the containment of infectious disease, and reducing healthcare delivery costs.

The Ubiquity of Viral Infections

Viral infections affect everyone. Each year, even with targeted vaccines, thousands of people still die from the seasonal flu – a viral infection.

COVID-19 has raised awareness of viral infection to the forefront of the public's attention. Yet it's been on the radar of epidemiologists, medical professionals, and scientists for decades. They knew this was coming. Just not when.

Despite social distancing and sheltering in place, COVID-19 is still spreading and leaving death in its wake. The reproduction number (R0) for COVID-19¹ is somewhere north of 5 depending on who's estimating. For SARS it was 2-4. For MERS less than 1.

COVID-19 has created an immediate need for an innovative solution that can offer a reliable, early indicator of potential illnesses. This protects public health by accelerating early containment of an infectious disease while lessening its economic impact, reducing healthcare delivery costs, and giving our healthcare system time to effectively respond to an outbreak.

Fever: The Canary in the Coal Mine

According to the Centers for Disease Control & Prevention (CDC), and the National Institute of Health (NIH), a fever is often the first sign of an impending illness. Fever presents in 99 percent of COVID-19 patients². Almost all mild cases involve an elevated temperature.

But there are three prevailing myths about temperature that right now reduce its effectiveness as a diagnostic tool:

- **Myth 1:** 98.6 °F is “normal” body temperature.
- **Myth 2:** A temperature of 100.4 °F or greater means you have a fever.
- **Myth 3:** Thermometers and thermal cameras accurately measure human body temperature.

Traditionally, medical professionals have relied on oral, rectal, or axillary (under the arm) measurement of the body's core temperature with an assumption that “normal” temperature is 98.6 °F. But assuming every individual has a core body temperature of 98.6 °F is misleading. In fact, no single metric for baseline temperature exists. And, if it did the number would be closer to 97.7 °F. And, several recent studies have suggested that human body temperatures have been dropping over the last century³.

Body temperature is not fixed. Temperature varies across the day, peaking in late afternoon and bottoming out in early morning. It drops at bedtime during the onset of sleep and is slightly higher for women than men. Consequently, no two people have the same temperature pattern.

So, what is a fever? Solos Health Analytics works on the premise that fever is a sustained abnormal temperature higher than an individual's baseline. Fever is our “canary in the coal mine” for infectious disease.

The key word here is “baseline.” No matter where you measure temperature on the body, when you measure it, and what you use for measurement – thermometer or thermal scanner – you're only getting a single, point-in-time value. To establish a baseline, you need continuous measurement over time. Without a baseline, you cannot see the full picture of fever detection.

Detecting the Early Onset of Fever

Early fever detection benefits everyone by more rapid identification of those who may have a viral infection and risk spreading it to others. This allows faster time to self-isolation or quarantine and faster medical intervention, which means more effective containment.

How can fever be detected early? Whatever the solution, it must be practically applicable to large groups. It's certainly not practical to have multitudes of nurses and nurse's aids following everyone around taking their temperatures every hour. So, collection of temperature data needs to be automated. And, the data needs to be continuously analyzed in real time.

That is what FeverGuard does. Developed by Solos Health Analytics, FeverGuard addresses the translational and technical hurdle of detecting fever onset using wearable sensors that are practical for everyday use. Leveraging simple cloud-based machine learning (ML) and thermodynamic modeling of the human body, our biometric data can be tuned for individual fever detection.

FeverGuard is a small, wearable health aid that fits comfortably on the upper arm. It monitors an individual's temperature continuously and uses machine learning to analyze the data via a highly scalable, cloud-based, predictive analytics platform.



1. Forbes, The COVID-19 Coronavirus Disease May Be Twice As Contagious As We Thought, April 7, 2020
2. Business Insider, 80% of COVID-19 patients experience 'mild' symptoms – but that likely still involves a fever and cough, March 12, 2020
3. Decreasing human body temperature in the U.S since the Industrial Revolution, Protsiv, Ley, Lankester, Hastie, Parsonnet, January 7, 2020

The Technology Behind Fever Guard

FeverGuard collects, maps, analyzes, and models baseline data, including circadian, diurnal, and hormonal temperature variances and other idiosyncratic characteristics of individuals. This data creates a personal temperature baseline, which can be used to detect discrepancies and abnormalities. In this case, fever. FeverGuard users are alerted to potential onset of a fever via a smartphone application.

The FeverGuard solution uses AI and machine learning techniques. Temperature data is captured as a time series, employing deep learning models and statistical analysis to personalize and understand an individual's temperature baseline.

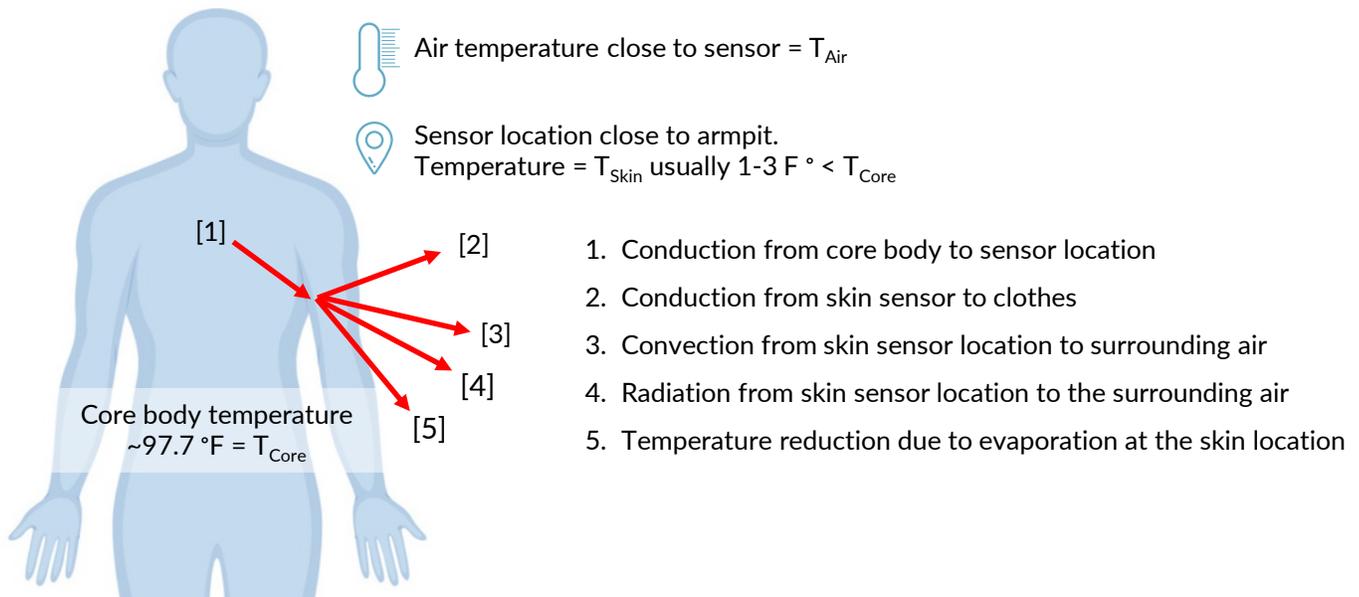
In addition, many Bluetooth temperature devices are worn on the wrist, and according to medical research⁴ this method provides poor, inaccurate, and inconsistent temperature measurements compared to core temperatures. Also, measurements taken at the wrist are more prone to be affected by changes in ambient temperature and relative air velocity.

The Solos team has researched, calculated, and tested several ways of taking temperature measurements as close to the ideal core body locations as possible while still facilitating the comfortable wearing of a temperature sensor. Axillary was chosen because it is a medically accepted location and offers good correlation to core body temperature. While axillary measurements can be 1 °- 2 ° below actual core body temperature, the FeverGuard system automatically factors in this variable.

As we deploy this solution across a large sampling of the population, the more temperature data points we collect, the more accurate our predictions will be. The temperature differentials and data collected will result in algorithms that can be used in determining the onset of fever.

The Solos research team developed a FeverGuard prototype to collect human temperature data. Models were run on the collected data and the researchers determined it was repeatable and showed useful data trends for differential temperature baselining. Temperature data discrepancies are tracked and are eliminated from the data source by carefully identifying erroneous data points through baseline modeling.

Analysis of Heat Transfer from Core Body to the Armpit and Ambient Air ⁵



Heat transfer from the human body occurs in four ways:

1. **Conduction:** Through solids or non-moving fluids
2. **Convection:** Heat diffusion from a surface through movement of fluid
3. **Radiation:** EM waves emitted from the surface of a body
4. **Evaporative Cooling:** If the skin becomes wet due to sweat or other moisture sources



If a temperature sensor is placed on the skin on the upper arm, the heat flow from the core body to that point can be modeled as conduction from the core to the skin surface. At the location of the sensor on the skin, there can also be thermal transfer from the skin/sensor to the surrounding environment through conduction, convection, radiation, and evaporative cooling. This thermal transfer to the surrounding environment changes the temperature at the skin/sensor location.

The rate of heat transfer due to conduction, convection, radiation, or evaporation can be expressed as $dQ/dt = C(T_{\text{Skin}} - T_{\text{Air}})$ where "Q" is heat, "t" is time, T_{Skin} is the skin temperature and T_{Air} is the ambient air temperature. C is a constant that differs for conduction, convection, radiation and evaporation.

- For conduction $C = K_{\text{Cond}} A/L$ where " K_{Cond} " is the thermal conductivity, "A" is the cross-sectional area that the heat moves through and "L" is the path length that the heat travels.
- For convection $C = K_{\text{Conv}} A$ where K_{Conv} is a factor that depends on the velocity of the air moving over the surface "A".
- For radiation "C" is the product of the emissivity of the skin, the exposed body area and the Stephen-Boltzmann constant. Note that the actual radiation heat transfer equation is a function of the 4TH power of both the T_{Skin} and T_{Air} . However, in normal temperature ranges, this can be linearized.
- For evaporation "C" is a function of temperature and the presence of liquid on the surface of the skin, humidity, and air movement.

Note also that when a person's body creates an elevated temperature (usually in reaction to sickness), the body may not produce sweat as it tries to increase core temperature. This, in turn, produces elevated skin temperature.

In summary, from a thermal management standpoint the five red arrows in the figure represent main heat transfer through and from the body. Therefore, the effectiveness of the skin temperature sensor in indicating the person might have a fever necessitates consideration of several factors.

Changes in core body temperature create changes in skin temperature. In general, the further the skin temperature sensor location is from the body's core, the more difference there will be between the core and skin temperature. Also, correlation between the skin and core temperature becomes more difficult when the skin

temperature sensor is farther away from the body's core as there are additional opportunities for the other heat transfer mechanisms (conduction through clothes as well as convection and radiation to the ambient air) to affect the skin temperature.

Other critical variables that can affect skin temperature are:

- Temperature, humidity, and velocity of the ambient air close to the skin
- Clothing (type and thickness) covering the skin at the skin temperature sensor location
- Direct radiation source (ex: sunlight or other bright light)
- Perspiration or other fluid on the skin
- Time of day
- Biological factors such as gender

FeverGuard mitigates the negative effects of most of the variables listed above in its design and intended use.

First, the selection of the upper arm is an ideal measurement site. A sensor placed near the axillary is unobtrusive, largely hidden under clothing, comfortable, and easy to access. This area is superior to more peripheral regions of the body (e.g., wrist) because skin temperature near the axillary is a better approximation of core temperature and will therefore more accurately reflect core temperature.

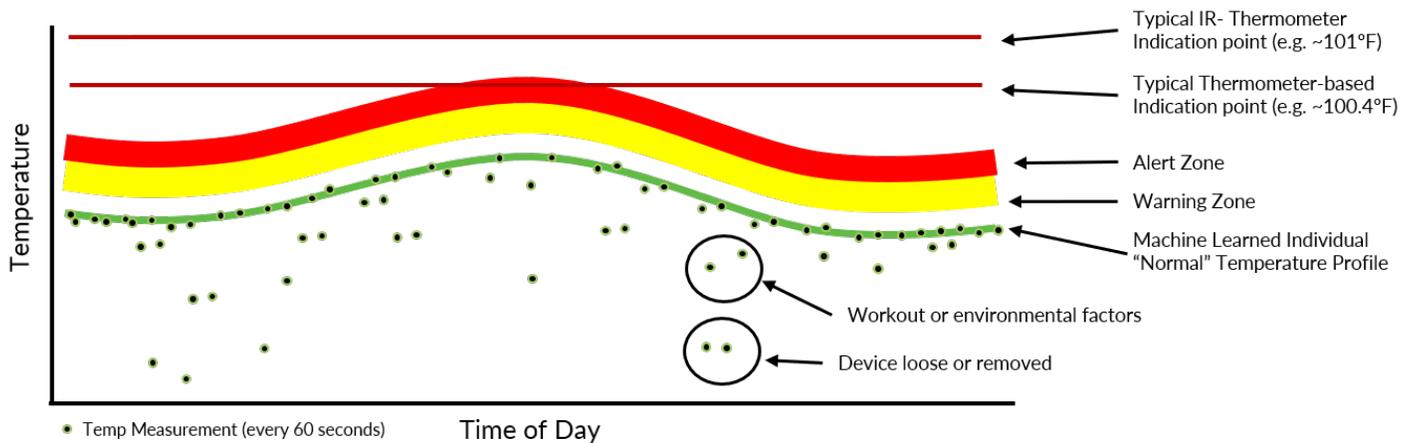
The medial side of the upper arm has thin skin for better conductivity and is near the large brachial artery that carries warmed blood. Not surprisingly, this location has been a widely used location in previous studies correlating skin temperature with core temperature⁶.

The initial intended use for FeverGuard is for indoors (warehouses, work environments) with ambient temperatures below that of the core temperature and within a narrow range (65 °F - 75 °F). This setting means that air velocity will be minimal and false positives in fever detection from hot ambient air are not a problem.

Moreover, we anticipate consistency in the environment from day-to-day use which will greatly simplify data interpretation and will allow for inter-subject variations. The location of the sensor (under clothing and near the upper arm) will limit radiation and convection in the near vicinity of the sensor.



How FeverGuard Works



Temperature patterns vary by person and time of day. FeverGuard learns your unique temperature pattern. Alerts are provided instantly if a fever starts to develop.

A Closer Look at the Role of Machine Learning in Early Fever Detection

Solos Health Analytics is developing a new, scalable, cloud-based data ingestion and analytics platform that can model a large number of inputs using machine learning (ML) to rapidly build unique temperature baselines for each individual from the smallest dataset.

Throughout the day, typical internal body temperature gradually varies about 0.8 °C, with the average core temperature around 36.6 °C (97.8 °F). This average temperature is considered the body's set point and temperature regulation is modeled as a feedback loop. The set point varies across gender and people as much as 1.5 ° to 5 °, depending on the location of measurement⁷.

Fever essentially raises the body's set point to fight pathogens. Distinguishing variation in temperature due to natural fluctuations versus a change in set point due to fever requires an individualized baseline estimate. Our initial plan for baseline and comparison to fever is as follows:

- Collect data over 24-hour periods with a sampling rate of one sample per minute. Our algorithm will automatically eliminate data above or below normal physiological ranges (below 29 °C and above 41 °C (~85 °F and 106 °F, respectively). Note, in cases of long-term use, a new baseline should be completed every two months to account for seasonal variations.
- All statistical comparisons across time epochs are relative to baseline. Time epochs are one hour. Any statistically significant increase in temperature that also exceeds 1.5 ° from the baseline is flagged as a

potential fever. The dual criteria reflect individual statistical variability and current clinical practice, which is based on absolute temperature changes (100.4 °F threshold for fever).

- If data is not normally distributed, then 0.2 ° "bins" will be created and the number of temperature occurrences within each bin is calculated to find the median. Then FeverGuard will determine if temperature in the time epoch exceeds the 1.5 ° median value and is statistically significantly greater.

FeverGuard Can Deliver an Immediate and Profound Public Health Benefit

FeverGuard is a vital tool for protecting the health of a population at risk. Wearable, real-time fever surveillance is a game changer and an important resource now as well as in the future as society faces new challenges that ravage our health and economy. The availability of modern technologies; the cloud, distributed computing, IoT, artificial intelligence (AI), Bluetooth, smartphone apps, and sophisticated analytics means that we can bring this powerful capability to everyone. FeverGuard can benefit humanity one person at a time.

For the essential workforce – warehouse workers, delivery drivers, hospital staff, food preparation services, police and fire departments – FeverGuard can monitor their temperatures while they stay on the job, secure in the knowledge that they can be removed from the population at the first sign of infection, protecting organizations, employees, and the public.

