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TEMPERATURE MONITORING APPLICATIONS FOR COVID-19 PANDEMIC: YEAR ONE REVIEW

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Situation Appraisal: Severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) is the virus that causes coronavirus disease 2019 (COVID-19). The first case of COVID-19 identified in the U.S. occurred in Washington State on January 19, 2020, when a 35-year-old man entered a clinic with cough and fever symptoms[1]. He disclosed to medical personnel he had recently returned from Wuhan, China. This encounter set the stage, and subsequently confirmed, international transmission of SARS-CoV-2 to the United States. The patient was isolated and eventually recovered. However, just over one year later (as of March 31, 2021), a worldwide chain of events had unfolded resulting in 545,022 U.S. deaths and 2,796,561 global deaths attributed to COVID-19[2].

Q2 2021 numbers continued to climb with hotspots appearing globally on a regular basis as evidenced by the outbreak in India[3]. Typical symptoms reported include (but have not been limited to), fever or chills, cough, shortness of breath or difficulty breathing, fatigue, muscle or body aches, headache, new loss of taste or smell, sore throat, congestion or runny nose, nausea or vomiting, and diarrhea[4].

The sudden onset and rapid spread of COVID-19 has spurred the development of identification, treatment and mitigation tools to help slow the spread of the disease.

Mitigation Strategies: Efforts to mitigate the spread of COVID-19 have included city, state and country-wide lockdowns with mandated restrictions on work, school and travel. A major shift across the entire spectrum of human

[1] https://www.pbs.org/wgbh/frontline/article/how-americas-first-known-coronavirus-patient-recovered/

[2] https://covid19.who.int/

[3] https://www.nytimes.com/interactive/2020/world/asia/india-coronavirus-cases.html

[4] https://www.cdc.gov/coronavirus/2019-ncov/symptoms-testing/symptoms.html

engagement has resulted in near-overnight adoption of virtual meetings, learning and communication. Face masks and social distancing have been mandated (in most jurisdictions) to help slow the spread of COVID-19. Spot temperature checks have also been implemented to identify individuals who have a fever and may be restricted from entering a building (without additional screening). All of these strategies have reported mixed results at one time or another. As this review paper is being finalized, it remains to be seen whether current vaccine strategies will completely replace other mitigation efforts currently in use[5]. As a consequence, one of the biggest challenges to emerge has been understanding the inherent limitations of the tools being used.

Temperature Monitoring: Although numerous mitigation strategies have been identified, this year one pandemic review will focus on temperature checks and the emerging innovative use of (near) continuous temperature monitoring applications (smartwatch utilization) for COVID-19 (and beyond).

Fever Thresholds: The first challenge in measuring temperature is to determine the correct threshold(s). Many symptoms can indicate the presence of SARS-CoV-2, including fever[6]. CDC guidelines define fever (in non-healthcare settings), as a temperature of 100.4°F (38.0°C), or higher[7]. In healthcare settings, the CDC defines fever as a temperature greater than or equal to 100.0°F (37.8°C)[8]. Some states and companies have adopted the CDC healthcare threshold (≧100.0°F)[9]. For example, Texas recommends a fever threshold of 100.0°F as does Walmart. On the other hand, Delaware has set its fever threshold to 99.5°F in an effort to increase sensitivity for COVID-19 screening. In all cases, these are referred to as population thresholds (i.e. one threshold that applies to a given population). Under normal circumstances, these numbers are reasonable to use for guidance because healthcare personnel have time to explore a patient's (other) symptoms. During a pandemic, however, doctors need tools that can quickly provide intelligence and insights into a person's condition. Therefore, what has been learned about temperature measurement becomes critically important.

Non-Contact Infrared Thermometer (NCIT): During year one of the pandemic, most people have had spot temperature checks taken prior to entering a store, office, school or airport using (primarily) a non-contact infrared thermometer (NCIT). NCITs have become a commonplace tool for COVID-19 screening because they require no direct contact, no

5 https://www.cdc.gov/coronavirus/2019-ncov/vaccines/fully-vaccinated.html

6 https://www.clinicalcorrelations.org/2019/06/18/the-definition-of-a-fever/

7 https://www.cdc.gov/quarantine/maritime/definitions-signs-symptoms-conditions-ill-travelers.html

8 https://www.cdc.gov/coronavirus/2019-ncov/hcp/infection-control-recommendations.html#anchor_1604360738701

9 https://www.washingtonpost.com/business/2020/05/15/fever-screening-coronavirus/

sterilization, no disposables and emit no harmful radiation. If an elevated temperature is detected (and confirmed upon re-check), the person is typically denied entry to the facility and sent home or referred for additional screening.

Problems with NCIT spot temperature checks include dependence on potentially untrained individuals (e.g. security guard vs. healthcare professional), operating in an uncontrolled environment (typically not a clinic), and reliance on a *single* data point to identify fever. A single temperature measurement cannot identify changes that *may* occur *before* or *after* a person enters a facility, which leads to inaccurate screening. This creates a *false* sense of security resulting in *more* spread and *less* containment of COVID-19. Unfortunately, this is not limited to NCITs, but any method used for spot temperature measurements (even traditional mercury thermometers).

An editorial published on December 14, 2020, by researchers at Johns Hopkins Medicine and the University of Maryland School of Medicine[10] in *Open Forum Infectious Diseases* describes why temperature screening, performed primarily with a non-contact infrared thermometer, doesn't work as an effective strategy for stemming the spread of COVID-19[11]. The discussion focused on variables that can affect the accuracy of NCIT-generated temperatures including ambient temperature, subject-to-sensor distance, and humidity. Other NCIT variables include age, gender, current medications (especially antipyretic drugs like Tylenol), and when temperature is measured (morning vs. evening). Conclusions outlined support expanded use of innovative tactics for public health surveillance. These include lower temperature thresholds to identify symptomatic infected persons and the use of "smart thermometers" for fever acquisition (i.e. thermometers paired to mobile devices). What we can interpret from this is that single, isolated measurements rarely provide the correct outcome because of measurement inaccuracy and/or untrained individuals taking temperatures. Ultimately, when one depends on a single point temperature measurement, *any* inaccuracy can lead to a failed outcome.

Continuous Temperature Monitoring: According to research published in *SN Computer Science*[12], temperature measurement used as an instant test to determine if travelers or citizens have been infected with SARS-CoV-2 is ***not adequate***, as COVID-19 can be spread *before* a fever is ever present, or can be *measured*. However, the continuous monitoring of skin temperature can be a good approach in this regard, which is currently used by some hospitals (and

10 https://www.hopkinsmedicine.org/news/newsroom/news-releases/covid-19-story-tip-physicians-say-non-contact-infrared-thermometers-fall-short-as-covid-19-screeners

11 https://academic.oup.com/ofid/article/8/1/ofaa603/6032722

12 Islam, M., Mahmud, S., Muhammad, L.J. *et al.* Wearable Technology to Assist the Patients Infected with Novel Coronavirus (COVID-19). *SN COMPUT. SCI.* **1,** 320 (2020). https://doi.org/10.1007/s42979-020-00335-4

available through SensorComm Technologies[13]). Wearable devices are considered an efficient solution for this purpose. Many researchers have already proposed wearable devices for continuous body temperature monitoring which can be used for COVID-19 patients. Feature sets for some of these systems include temperature monitoring for fever tracking during illness, fever alerts for users and clinical staff, and a cross-section of other modalities including ECG, blood glucose and blood pressure. An expanded universe of smart wearable devices is envisioned to facilitate the management of COVID-19 patients that will include identification, prevention, diagnosis, treatment and rehabilitation. Despite the transitory challenges in migrating to such data-intensive applications, the authors in the referenced article conclude there is no doubt that wearable technologies can not only work as an early warning system, but also as life-saving devices[12].

2020 NBA Bubble: The first high-profile use of continuous temperature monitoring was an isolation zone (aka Orlando/Disney/NBA bubble) created by the National Basketball Association (NBA) to protect its players from COVID-19 during the final eight games of the 2019–20 regular season and throughout the 2020 NBA playoffs[14]. One tool utilized by players, coaches and staff (~25%) as part of the NBA bubble was a $300 Oura smart ring, a wearable device that can measure skin temperature and heart rate, among other metrics[15]. Use of the smart ring was an optional part of the bubble ecosystem and did not allow for complete analysis/attribution of players/staff health to usage of the ring. Some players were concerned about their data privacy[16]. Still, the NBA ended the start of the resumed 2019–20 season until the end of the NBA Finals with *no recorded cases* of COVID-19 for the teams participating in the bubble. This was one of the most effective (yet very costly), large-scale mitigation strategies implemented during COVID-19.

Personal Temperature Thresholds: In June of 2020, SensorComm Technologies initiated the first of several global webinars to discuss the emerging role of personalized temperature profiles for employers and schools in response to the COVID-19 pandemic. As a smart IoT company in transportation and energy, recent efforts were aligned and redirected toward (near) continuous temperature monitoring using a smart wearable device. Because of the early-warning capability built into its systems for other market verticals (transportation and energy), SensorComm has often referred to its smart IoT monitoring as a "check engine light" for pollution, for pipelines, and now — for people.

[13] https://www.sensorcommtech.com

[14] https://en.wikipedia.org/wiki/2020_NBA_Bubble

[15] https://www.businessinsider.com/nba-bubble-oura-smart-ring-used-by-quarter-of-campus-2020-8?op=1

[16] https://www.usatoday.com/story/sports/nba/2020/06/19/nba-tech-wearables-used-for-health-not-tracking-data-at-disney-complex/3223065001/

The system focuses on personal temperature profiles to determine individualized thresholds, rather than relying on population thresholds, and provides insights into the overall well-being of the individual. In addition, it measures temperature on a (near) continuous basis, and therefore does not rely on any individual measurement, but rather on the aggregate trends and behaviors of the personal temperature profile. The system acts as an early warning system for COVID-19 and beyond, while maintaining privacy.

Early-Detection Study: A *Wall Street Journal* article[17] published on September 22, 2020, announced a joint study between the U.S. Department of Defense and Koninklijke Philips NV (a global health-technology company), to use bio-measuring devices like smartwatches to identify people infected with (barely perceptible) symptoms of COVID-19, quarantine them, and treat the illness. The early-detection study, which is designed to collect data (temperature, pulse, blood oxygen) on more than 5,000 (largely U.S.-based) troops, seeks to identify a noninvasive method of detecting COVID-19 symptoms, even before a patient feels sick. According to head of Philips research in the Americas, Joseph Frassica, "There are subtle changes in physiology that aren't easy to detect under regular clinical means. You can see these changes before they become symptomatic." Of the first 1000 troops participating in the pilot study wearing smart rings and smartwatches, Defense officials report multiple cases where troops have been flagged who later tested positive for COVID-19. The study can't diagnose illness, but it can show a problem might exist (and thus, *action can be taken* to prevent additional spread). Ultimately, researchers hope to learn more about what it means to be asymptomatic.

Asymptomatic vs. Pre-symptomatic: COVID-19 mitigation efforts present a practical dilemma. When you are out in public, how is it possible to know if you might have symptoms that are undetectable, or if you might go on to develop symptoms over the next several days? One of the biggest challenges during the pandemic has been to understand the terminology. An asymptomatic case of COVID-19 is an individual infected with SARS-CoV-2, who *does not exhibit* symptoms during the course of infection. A pre-symptomatic case of COVID-19 is an individual infected with SARS-CoV-2, who has not exhibited symptoms at the time of testing, but who *later exhibits* symptoms during the course of the infection. In terms of transmission, "asymptomatic" refers to a person who transmits the virus but never develops COVID-19, while "pre-symptomatic" refers to a person who develops COVID-19, but transmits the virus before their symptoms develop. When it comes to temperature, the authors of this review paper have found that asymptomatic and presymptomatic do not mean an *absence* of movement in a person's temperature. Rather, the temperature movement that *does* occur, does not meet the clinical definition of a fever[6] (i.e. population threshold).

[17] https://www.wsj.com/articles/thousands-of-american-troops-to-take-part-in-covid-19-early-detection-study-11600772402

CDC Planning and Preparedness - 30% of COVID-19 Infections Asymptomatic: As data and planning models evolved throughout the first year of the pandemic, the impact of "asymptomatic" vs. "pre-symptomatic" was often a source of confusion and debate[18]. However, on March 19, 2021, the CDC released the final update[19] to its COVID-19 Pandemic Planning Scenarios. These are not predictions or estimates of the expected impact of COVID-19, but rather, are intended to advance public health planning and preparedness for hospitals and communities. Of the five (5) scenarios presented by the CDC, number five (5) is the *Current Best Estimate* whose parameters include: **1) percent of infections that are asymptomatic: 30%**; 2) infectiousness of asymptomatic individuals relative to symptomatic: 75%; 3) percentage of transmission occurring prior to symptom onset: 50%. With the current planning and preparedness scenario utilizing a 30% infection level for asymptomatic SARS-CoV-2, the need for innovative solutions to help identify at-risk individuals, potentially before they become symptomatic, has never been greater.

Complex Communication: As a result of the pandemic, the myriad of guidance and real-time updates required by the public has left the CDC struggling to communicate effectively. According to a CDC statement referred to in a May 11, 2021, *New York Times* article[20], "CDC estimates may err on the side of protection when it comes to recommending steps to protect health". This was in response to claims the CDC may have overstated outdoor transmission rates of COVID-19 at or near 10%. The CDC responded by saying that "It is important for people and communities to consider their own situations and risks and to take appropriate steps to protect their health." Indeed, after a year of pandemic uncertainty and the amassing of large troves of actionable data, a policy shift that includes more regional and local involvement has begun. This will enable response strategies that can be customized to maximize the health, safety and wellness of communities, businesses and schools.

Smartwatch Consumer Wearable Devices: A *Nature Biomedical Engineering* article[21] discussing pre-symptomatic detection of COVID-19 from smartwatch data, examined consumer wearable devices that continuously measure vital signs (heart rate, number of steps, sleep time), and have been used to monitor the onset of infectious disease. The authors show that data, identified from a cohort of nearly 5,300 participants wearing consumer smartwatches, can be used for the pre-symptomatic detection of COVID-19. The findings in this study reflect an expanding body of

[18] https://www.snopes.com/fact-check/asymptomatic-covid-patients/

[19] https://www.cdc.gov/coronavirus/2019-ncov/hcp/planning-scenarios.html

[20] https://www.nytimes.com/2021/05/11/briefing/outdoor-covid-transmission-cdc-number.html

[21] Mishra, T., Wang, M., Metwally, A.A. *et al.* Pre-symptomatic detection of COVID-19 from smartwatch data. *Nat Biomed Eng* **4,** 1208–1220 (2020). https://doi.org/10.1038/s41551-020-00640-6

knowledge indicating that consumer wearable devices may be used for the large-scale, real-time detection of infections, often pre-symptomatically.

Wearable Monitoring Applications: In the early months of the pandemic, a Gizmodo article[22] asked the question: *Can A Smart Watch Detect COVID-19?* Like similar discussions, this focused on the latest offerings from Apple, Fitbit, Oura, and several others. The devices profiled offer a range of features (heart rate, temperature, blood oxygen, and activity tracking). Researchers testing these devices are looking to identify unique data signatures that will lead to the development of specific algorithms enabling the early detection of COVID-19.

Detection or Diagnosis? Current research efforts involving Stanford, Johns Hopkins, Apple, Google, Fitbit, DoD, and a host of other public and private organizations (large and small), are focused on creating what could ultimately be considered the functional equivalent of a medical (i.e. "algorithmic") diagnosis for COVID-19. As variants of COVID-19 emerge[23], will algorithms that are developed need to be updated in a manner similar to annual flu vaccines? What challenges will this pose? If researchers are successful in creating algorithms that can detect data signatures unique to COVID-19 (and other specific illnesses), what happens next? In today's healthcare paradigm, Illness can only be diagnosed by licensed healthcare providers (e.g. doctors, nurse practitioners, etc.). No matter how precise, algorithms do not (yet) diagnose illness. Their adoption and acceptance to (potentially) do so requires an advanced level of professional coordination (medical, legal, technological, and regulatory) that is presently underway, but has not yet been achieved. If it had, year one pandemic reports would be dominated by Big Tech rollouts, instead of research.

What's Possible Now? One company, Whoop, offers a sleep tracker and discusses the potential relationship between breathing rate and COVID-19[24]. They specifically state their product is ***not*** a medical device, nor is it intended to diagnose ***any*** disease or condition, especially not COVID-19 or the flu. They help users become aware of their baselines. If something suddenly changes, it may indicate the need for further investigation.

SensorComm Technologies offers a smartwatch temperature tracker (EvexiaBand™) and discusses the potential relationship between temperature anomalies and COVID-19. They too, specifically state their product is ***not*** a medical device, nor is it intended to diagnose ***any*** disease or condition. They help users become aware of, and make decisions based on, their personal temperature profile. Users can track their temperature with a smartphone app, or opt-in for

[22] https://gizmodo.com/can-a-smart-watch-detect-covid-19-1833409102

[23] https://www.mayoclinic.org/diseases-conditions/coronavirus/expert-answers/covid-variant/faq-20505779

[24] https://www.whoop.com/thelocker/podcast-67-respiratory-rate-covid-19/

temperature anomaly alerts via paid subscription. If something suddenly changes, it may indicate the need for further investigation (with a qualified healthcare provider). Unlike the inefficiencies previously discussed with (single-point) NCIT temperature screening, SensorComm's EvexiaBand™ smart wearable technology system samples multiple data points per hour. Temperature anomalies have been detected in the personal temperature profiles of users up to three (3) days prior to symptom onset for illnesses (including COVID-19). Anomalies, especially elevated temperatures, have appeared in people who have received the COVID-19 vaccination (Figure 1). This data is analyzed to help identify signatures in personal temperature profiles and provide additional insights into an individual's health and well-being.

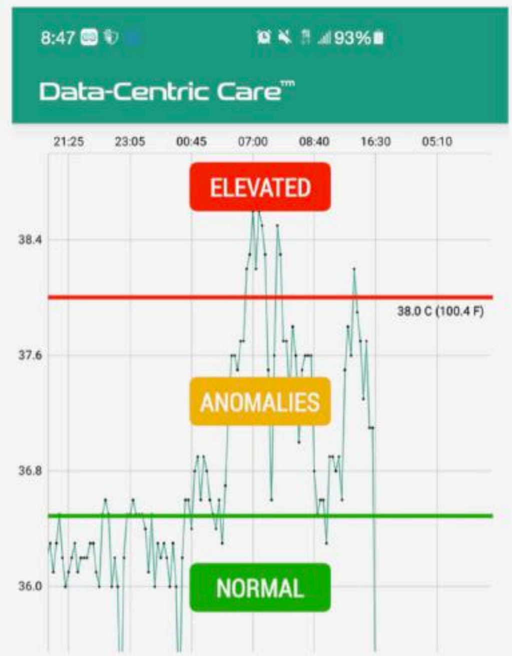

Figure 1. Personal temperature profile showing elevated temperature in a person *after* receiving COVID-19 vaccination.

Like Whoop, SensorComm's focus is on helping users track their personal profile, identify anomalies, and potentially investigate further. This encourages a model of direct accountability that benefits users, families, and communities. Their expertise in smart IoT is to extract, analyze, and transform data, into information and intelligence, leading to operational efficiencies for people and organizations. Concurrent with their work on personal temperature profiles, SensorComm is leveraging projects that will speed the adoption, integration, and acceptance of smart IoT for healthcare through research with corporate, government, and university partnerships.

Challenges Identified: The first year of the pandemic has been fraught with challenges. From not knowing the correct protocols (or medications) with which to treat infected people, to understanding what tools are effective for identifying and preventing viral spread. What we have learned is that many of the current tools that were already in use (like spot temperature measurements), did not easily migrate to identifying individuals with COVID-19. What we also learned is that *data is paramount*.

Data-Centric Care™: SensorComm's focus on Data-Centric-Care™ is their core approach to COVID-19 identification. By identifying individuals that have movement in their personal temperature profile (referred to as anomalies), the person can be alerted. EvexiaBand's early warning capability enables the user to take preventative measures that can help slow the spread of COVID-19 (see appendix for case study).

Early-Warning Systems: The challenge, in general, with early warning systems, is that they require intervention (from the user). In other words, if an individual receives a temperature anomaly alert, and continues their daily activity without taking any preventative measures (such as isolation or masking), the system provides little benefit. However, if an individual receives a temperature anomaly alert, and takes preventative measures immediately, they can potentially stop the spread of the virus, not only to their immediate family, but also to their wider social and professional networks, depending on the situation.

Future Applications: The future is a rapidly evolving destination between what is possible *now*, and what *can be* achieved. New tools are being developed and refined. New capabilities are being reported. The next year of the pandemic will bring even more insights into what is working and what isn't. Big Tech efforts to create what could ultimately be considered the functional equivalent of a medical (i.e. "algorithmic") diagnosis for COVID-19 require an advanced level of professional coordination (medical, legal, technological and regulatory) that is presently underway, but has not yet been achieved. These kinds of efforts have many variables to integrate on what is typically a long acceptance curve.

Innovation Now: In the meantime, small, practical, innovative steps are being advanced by companies like Whoop and SensorComm, who help users track their personal profile, identify anomalies, and potentially investigate further. This encourages a model of direct accountability that benefits users, families, and communities. These efforts help facilitate adoption of smart wearable technology now, as well as larger initiatives already underway. Initiatives that companies like Whoop and SensorComm will be prepared to accelerate. The question now is: *how can tools currently being utilized effectively be scaled for COVID-19 — and beyond?*

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SensorComm website: https://sensorcommtech.com/evexiaband/
EvexiaBand™ page: https://evexiaband.com

Appendix: As this review paper was being finalized, a family member of one of the paper's authors was exposed to COVID-19 on 4/25. A contact tracing notification was received 2 days later on 4/27. No initial symptoms were reported, but minor symptoms began to appear on 4/28. A negative COVID-19 test was reported on 4/29. Temperature was monitored using the EvexiaBand™ smart wearable technology system and the user received a temperature anomaly alert on 4/30, 1 day after receiving a negative COVID-19 test result. This prompted the individual to mask and isolate on the same day. Additional onset of symptoms began the next day on 5/1. A second alert appeared on 5/2 prompting a second COVID-19 test, which was positive. Subsequently, everyone in the household began wearing masks and took additional precautions for isolation. The individual tested positive again on 5/4 with peak (mostly mild), overall symptoms between 5/4 and 5/7. Although the first negative test was on 5/9, significant fatigue remained an issue through 5/15. Full recovery is expected and family members continued to test negative throughout.

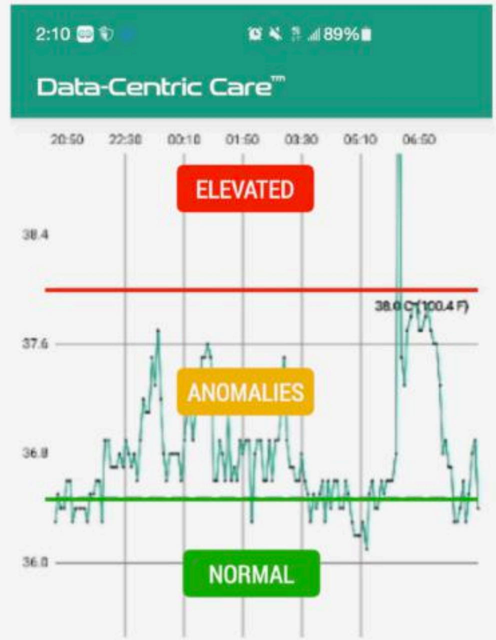

Figure 2. Personal temperature profile showing elevated temperature in a person who *subsequently* tested positive for COVID-19.

A temperature anomaly is shown in Figure 2. Note that the solid red line is the CDC recommended population threshold of 100.4 °F (38 C), and the green line is the personal average temperature for that individual. Although there is significant movement in this individual's temperature, this snapshot of the temperature profile would be considered asymptomatic. This example illustrates an individual who subsequently tested positive for COVID-19, was likely contagious, and would *not* have triggered any kind of spot temperature screening process, since the temperature anomalies occurred at night.

Conclusion: Even after an initial (negative) COVID-19 test, receipt of the temperature anomaly alert (next day) prompted the user to wear a mask and self-isolate. This provided a 2 day notice prior to a confirmed (positive) COVID-19 test on 5/2, and a 4 day notice prior to peak symptom onset on 5/4. Without the advance warning of a temperature anomaly alert, the user would have exposed all family members, and potentially (many) others, prior to receiving a confirmed (positive) test on 5/2, and peak symptom onset on 5/4. Smartwatch applications with (near) continuous temperature monitoring provide powerful *intelligence* that can help *slow the spread* of COVID-19.