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A Robust, Inexpensive Solution for Alarm Monitoring of Freezers, Incubators, and Other Biobanks Equipment Based on Readily Available, Easy-to-Deploy Home Alarm Equipment

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Equipment monitoring (e.g., freezers, incubators) plays a vital role in specimen storage infrastructure. Monitoring solutions are often associated with a significant initial expense and short-term operational lifespan due to expensive contracts or suppliers going out of business. Numerous incidents of "monitored" lab equipment failing without notice have been reported. This has led to the loss of irreplaceable research material and severely impacted careers. In pursuit of a universally accessible solution, we deployed and now have over 15 years of continuous experience using residential alarm systems for laboratory monitoring. In this communication, it is presented how home alarm systems, designed for robust, fail-safe monitoring, can be used to augment commercially available solutions. Provided are high-level descriptions of how to deploy these solutions for equipment monitoring and how to expand their use into other monitoring tasks.

Keywords: robust biobank equipment monitoring, automated monitoring alerts (email/SMS), low cost

Introduction

In recent years, there have been several prominent biorepository facility failures that have led to incalculable loss of tissue and blood samples[1] and harm to persons, including the loss of irreplaceable ova stored for fertility treatments.[2] A common thread in many of these failings is lack of or failure in effective alarming (e.g., at the Karolinska Institutet[3]). As an augmentation to professional monitoring solutions, commercially available, residential burglar alarms (designed for untrained self-installation) offer features making them very appealing as an addition to professional monitoring solutions. Functionally, wireless home alarms typically have a central "brain" unit, a collection of sensors, and a means by which the brain communicates "trouble" states. They are robust in design, built to withstand adversarial attacks and fail in an "alarm" state. Power outages, failed sensors, low or dead batteries, disconnected wires, etc. all result in alarm states that will be communicated. Home alarm notifications are geared towards activating first responders, be it to quench fires or to apprehend ne'er-do-wells before permanent damage occurs. Alarm reporting can be performed through audible alarms as well as routed through the internet or cellular service. If linked to a monitoring company, alarms can activate a human that will continue to make phone calls until the alarm is acknowledged.

As a use case, our initial implementation (academic environment where finances were inadequate to maintain the original commercial solution) involved monitoring 11 incubators, 7–80°C freezers, 3 refrigerators, a cold room, and an equipment room at an initial expense of roughly $500 and a monthly fee of $10, covering connectivity between the panel and the monitoring service. The alert mechanisms, including SLACK, email, and SMS, have demonstrated remarkable reliability and durability. To date, no failures of the monitored devices have gone unnoticed.

Home alarm sensors can integrate with biobanking infrastructure easily through the "alarm relay contacts" that are integrated in most commercial laboratory equipment. While incredibly reliable (faults fail into alarm), there are some disadvantages, most notably, device alarms are reported, but there is no mechanism for temperature logging. Additionally, the maximum distance from sensor to panel is about 200 ft.

Methods

The basic process to deploy a home alarm-based monitoring system for equipment monitoring is as follows:

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Assess

Determine the number of devices to be monitored/number of sensors required. Confirm that the devices to be monitored provide alarm relay contacts—electrical connections that close or open a circuit to signal an alarm condition (see Fig. 1). Assess whether all devices are within approximately 200 feet of the alarm panel. If not, either multiple alarm panels or range extenders (devices that amplify or retransmit the wireless signals) will be needed.

Determine monitoring/alerting mode

Decide between a simple stand-alone audible alarm or an active monitoring system that leverages cellular and/or Internet-based connectivity to connect to a central monitoring station, which can then trigger SMS and email alerts. For a higher cost, active monitoring can also trigger a call center to work through a phone tree until an individual responds. Note that instead of a call center, one can connect to a dialer, such as a Sensaphone,[4] which will relentlessly call people until the alarm is acknowledged.

A concern of all alarm systems is a "silent failure" in which the system quietly goes offline without warning, leaving equipment unmonitored. Home alarm systems, by design, are robust against silent failure. The sensors are actively monitored by the alarm panel. If the sensor is destroyed or disabled, the panel will sense this and go into alarm. The primary panel is also designed to be robust against fault—as an example, all common alarm panels are equipped with dual power (AC and battery) and will alarm if the primary power fails or if the battery is low. Further, with active monitoring, any fault (such as a failed sensor or power to the panel) will alert the central station, leading to emails/SMS/calls, etc., as has been configured. Systems can be configured to redundantly use WiFi/Internet and cellular connectivity. While unlikely, if there is a concern regarding catastrophic failure, with active monitoring, one can configure the panel to generate time-based test messages to the central monitoring office on a regular cadence. If the monitoring office misses scheduled timed test messages, that will trigger the system to go into alert. Typically such tests are scheduled 1–3 times per day.

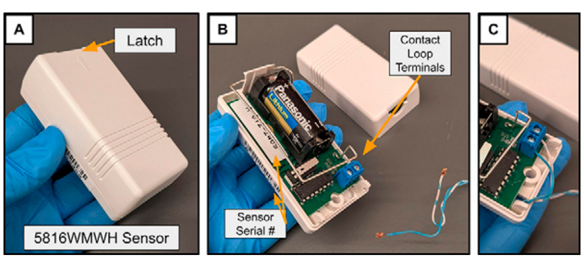

FIG. 1. Connection to the alarm sensor. **(A)** shows a Honeywell 5816 door/window sensor. **(B)** shows the sensor with the cover removed and the contact wires before connection. In addition to the contact loop terminal block, it also shows the serial number that would be used for manual sensor enrollment. For laboratory monitoring, one would typically not use the magnet sensor that would be most common in-home use, but the magnet sensor can be used for functions such as making sure a door is closed within a reasonable time. **(C)** shows the wires connected to the loop terminals—shown in Figure 2 is the completion of the circuit that includes the sensor and the equipment to be monitored.

Acquire hardware

In this section, it is described how to connect equipment to a home alarm system—while the general solution is vendor agnostic, for purposes of example, a solution via Honeywell alarm panels and sensors (e.g., Lynx 5210 and 5816, Fig. 1A) is described. Essential to the selection of a sensor is the availability of a hard-wire contact pair for connection to the equipment's alarm relay. Such connections, also known as a contact loop (a pair of wires that form a circuit to detect alarm conditions), are available on the 5816 sensor as well as the newer SiXCT Contact Sensors[5] (see Figs 1B, 1C).

Without endorsement, these authors have experience procuring/deploying equipment from alarmgrid.com and geoarm.com. As of this writing, this functionality is not available on the SimplySafe nor Ring line of products (however, there are workarounds).[6,7]

System configuration

Most of these systems are designed for "at-home, end-user installation." Conceptually, there are three parts to integrating your system: configuring the alarm panel (the "brain" of the system), connecting individual sensors to the alarm panel, and connecting the sensors to equipment that is to be monitored. Most alarm panels will have an integrated siren and will have the capability to attach additional sirens. For connection to a central monitoring service, one will need to purchase a panel with internet/WiFi and/or cellular capabilities. The stepwise process of connecting the panel to the monitoring service will be guided by the monitoring company during a scheduled telephone appointment; as such, details are omitted here. Most monitoring services also provide mobile "apps" to communicate with the alarm system (details of which will be provided during the installation call).

Individual sensors need to be paired to the main alarm panel. This is done by putting the panel into "installer mode" and then individually pairing each sensor. If a sensor can communicate multiple alerts, those alert types will be called "loops"—this is a distinction that most home users will not have to deal with. For example, and important here, the magnetic sensor (as one might use on a doorway) might be loop 2 and the hard-wire contact pair might be loop 1. When the instructions to pair a 5816 sensor to the panel say "move the magnet close to and away from the sensor," instead one would touch and separate a wire connecting the hard-wired terminals or manually type in the sensor serial number and loop number. YouTube has a walkthrough of enrolling wired loops into a Honeywell alarm panel[8] and a stepwise walkthrough is provided in the Supplementary Data section for our particular panel.

When connecting sensors, a wire will connect from one terminal on the equipment into one terminal on the sensor, then out the other terminal on the sensor and back to the second terminal on the equipment, creating an electrical loop (see Fig. 2). The sensor is going to monitor if this loop is electrically connected or if there is a break in this loop. When one configures sensors, if available, it is best to use the "normally closed" (NC) contacts on the equipment. An "NC" loop is one in which there is a complete circuit when

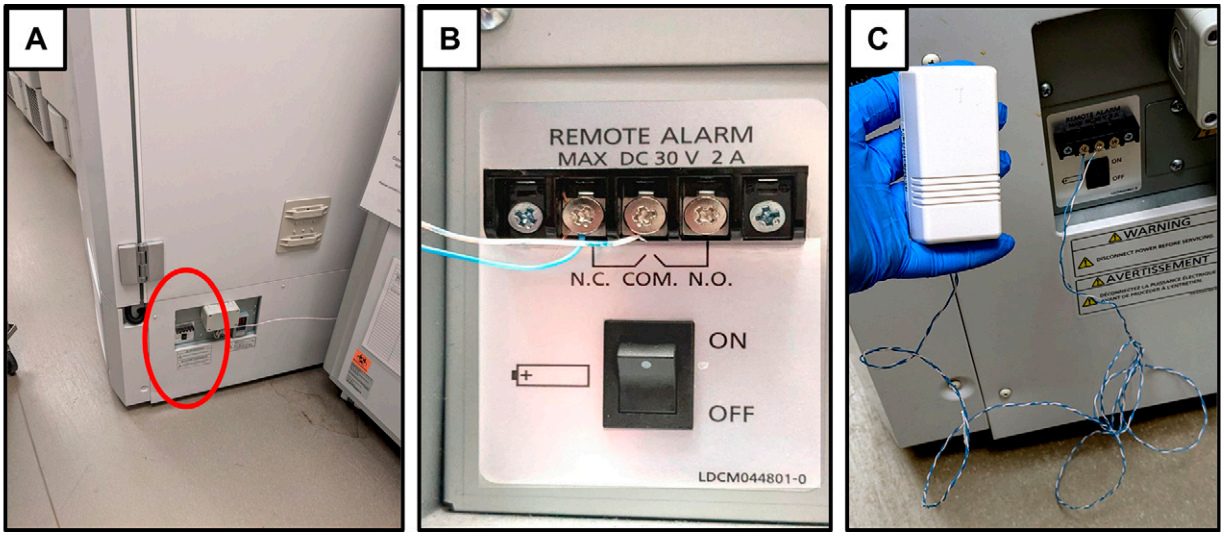

FIG. 2. Connection to the laboratory equipment. Electrically, a signal will flow in a loop from one terminal on the equipment into one terminal on the sensor then out of the second terminal on the sensor and into the second terminal on the equipment. If the loop is "normally closed," electricity will flow when the equipment is not in alarm. **(A)** shows a typical laboratory freezer with the alarm relay block highlighted by the *red circle*. **(B)** shows an enlarged view of the freezer relay block—notice the connection to the COMMON and NC (normally closed) terminals. **(C)** shows the full loop with the equipment and the sensor. The sensor would then typically be mounted on the freezer itself (*double-stick tape*).

the system is not in alarm; when the system goes into alarm, the circuit is broken. This has the very strong advantage in that if the wires come loose, the system will go into alarm. "Normally open" (NO) means that the wires in the circuit are not connected in the normal state, and when the system goes into alarm, the circuit becomes connected—while it can work with "normally open," if the wires become disconnected in an NO configuration, there will be no indication—this is like a wall switch for a lamp; if the switch becomes disconnected, there is no indication until the switch is activated.

A second consideration is that, since this is a home alarm, it probably has a concept of armed and disarmed, but, for the laboratory environment, one wants notifications all the time (even if the system is "disarmed"). The key is to configure all the sensors as 24/7 zones. In our case, with a Honeywell panel, this is accomplished by choosing the day/night zone instead of a door or window.[9] These zones are built into home alarm panels to cover use cases such as monitoring a jewelry box 24/7, even when the system is not armed.

Expanded use cases

This solution has application to any sensor that can drive a change of relay state. For example, in Figure 3, it is shown how a ~\$5 W1209 thermostat module (sample source here[10]) can be coupled to a 5816 sensor to monitor temperature in an equipment room and a cold room.

Conclusions

The use of commercially available home alarm systems for biobank monitoring represents a tremendous value proposition in terms of cost versus robustness. We actively encourage you to consider this solution if you cannot afford a more bespoke solution or if you are looking for an additional layer of redundancy. We cannot overstate how valuable this system has been for us—relying on no facility infrastructure (it even includes battery backup) and minimal ongoing service contracts, it has kept our samples monitored without failure.

In spite of its utility to us over the years, one should consider the failure modes of this solution. Perhaps most notably, as robust as the alarm system components are, they are still reliant on the intrinsic alarm circuitry of the equipment you

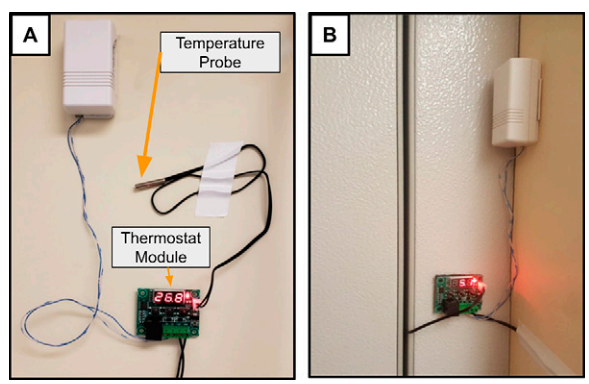

FIG. 3. Expanded use cases—Temperature monitoring. **(A and B)** show a Honeywell 5816 door/window sensor coupled to a W1209 thermostat module. The thermostat module reads the temperature and changes the state of relays based on the settings and the measurement from the temperature probe. In this configuration, the relay is set to "heat," and the temperature is set to the critical temperature for the environment. In **(A)**, the ambient room is set to 27°C, for the cold room in **(B)**, it is set to 6°C. The thermostat "thinks" it is controlling a heater, but it has no impact on temperature. If the temperature rises above the set point, it opens the relay—this doesn't turn off a heater, but it does trigger the 5816 and sends the panel into alarm, letting us know the environment is too hot.

are monitoring. For example, if the freezer thermostat fails into an "acceptable" window, there will be no alarms. To be completely efficient in a biobank setting, all other aspects of the biobanking best practices need to apply (please see the recommendations both from ISBER[11] and from the NCI[12]). Therefore, standard operating procedures need to be in place that address what staff need to do when an alarm is received, backup freezers need to be available for the transfer of samples in the event of a freezer failure, and all other relevant contingency plans are needed to successfully manage an alarm situation in a biobank. In our lab, we configured all alerts to the monitoring station to be emailed into a dedicated Slack channel that was monitored by all the key lab personnel. All actions taken for each event would be documented in a thread associated with the initial alert email. Additionally, lab managers were sent text messages for each alert, and we triggered a SensaPhone dialer through the alarm panel to call the same lab managers. While the SensaPhone would continue dialing people until the alert was acknowledged, there was no way for the SensaPhone to communicate what was in alarm (hence the email and SMS). We chose the SensaPhone solution because the monitoring call centers are used to dialing numbers that have guaranteed pickup at some point in their call tree (such as the police department or an alarm response company).

In conclusion, the above-described solution is both cost-effective and easy to deploy. For organizations already using commercial systems, it may serve as a potential backup. However, for those without a current solution nor the budget for a commercial installation, we strongly recommend this as a practical and viable alternative.

Authors' Contributions

Conceptualization: Primarily by J.E.K. with expansions by S.S. Initial work was done in J.E.K.'s lab and then refined by workshop meetings with S.S. and from jointly run workshops at ISBER. Methodology: Primarily by J.E.K. with refinement by S.S. Initial design and deployment was by J.E.K. with practical refinements by S.S. Validation: Primarily by S.S. Preliminary "function" by J.E.K., but, assessment for deployment in professional biobanks was performed by S.S. Visualization/Writing/Review and Editing: Initial draft and figures by J.E.K., Edits and joint refinement by S.S. and J.E.K. toward submission.

Author Disclosure Statement

No competing financial interests exist.

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Supplementary Material

Supplementary Data

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