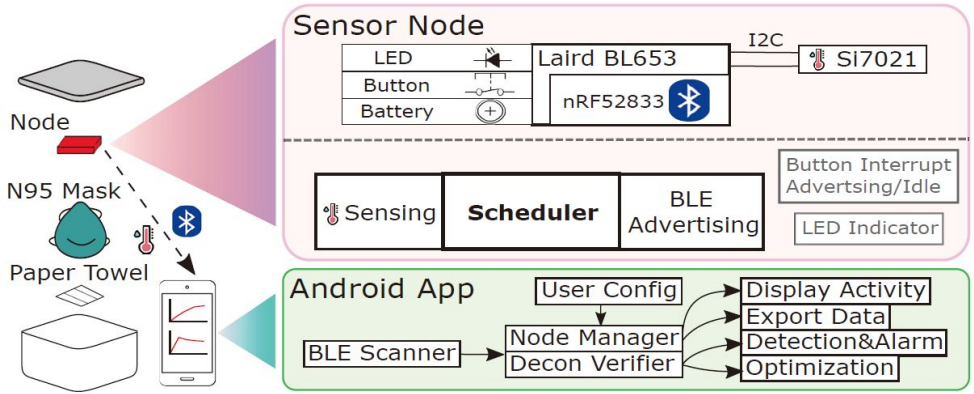
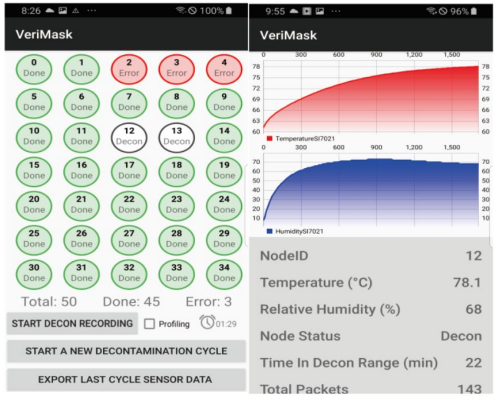
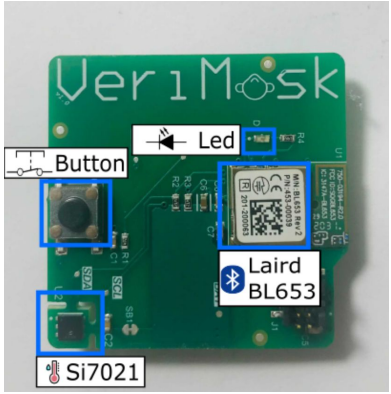
VeriMask: Facilitating Decontamination of N95 Masks







- **Sensor nodes**: One-for-one dense sensing topology, low-power (>1000 hrs), low-cost (<$15.66), scalable, high-temperature-resistant
- **Android App**: Automatic per-mask decontamination verification, throughput-maximization algorithm

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VeriMask: Facilitating Decontamination of N95 Masks in the COVID-19 Pandemic: Challenges, Lessons Learned, and Safeguarding the Future

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Nurses Survey: N95 Mask Shortages Still the Rule

— "Not sure I can do this much longer"

by Cheryl Clark, Contributing Writer, MedPage Today September 2, 2020

3M CEO on N95 Masks: 'Demand Exceeds Our Production Capacity'

As coronavirus crisis mounts, manufacturers ramp up to meet huge demand for protective equipment

Los Angeles Times

Column: Why the U.S. still hasn't solved its mask and glove shortages

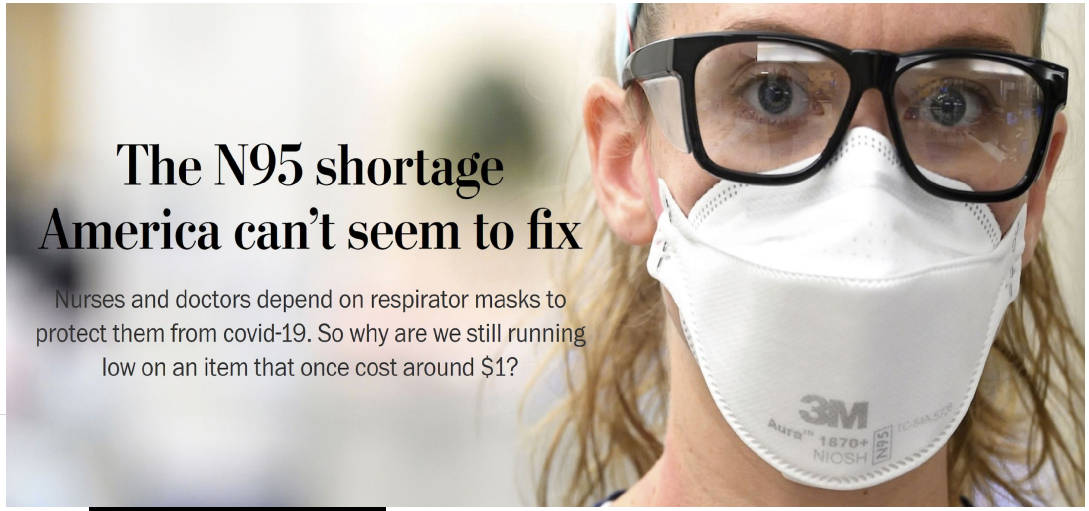
Doyle McManus

December 16, 2020 · 5 min read

Remember the N95 mask shortage? It's still a problem.

"The supply chain problem is not resolved."

By Lois Parshley | Jun 17, 2020, 9:30am EDT



The Washington Post Sept. 21, 2020

Last Updated : Mar 05, 2020 06:26 PM IST | Source: Moneycontrol.com

Coronavirus: India faces massive shortage of N95 masks, sanitisers

N95 Decontamination Methods

Decon Method	SARS-CoV-2 inactivation*	Filtration efficiency & fit	Chemical residue removal required	Operator hazard**	Costs	Max reuse cycles
Moist-heat	✓	✓	**no**	**no**	**$**	**5**
Hydrogen Peroxide	✓	✓	yes	chemical	$$$	10-20
UV-C	✓	✓	no	Ozone exposure	$$	5
Steam Autoclave	✓	✗	no	no	$$$$	1-10
Alcohol submersion	✓	✗	yes	no	$	Not recommended
Bleach submersion	✓	✗	yes	chemical	$	Not recommended
Ethylene Oxide	✓	✓	yes	chemical	$$	Not recommended

* Demonstrated to inactivate SARS-CoV-2 or similarly-resistant viruses by at least 3-log of bioburden reduction

** Assuming standard protection procedures are followed (e.g. wearing mask, gloves, long-sleeved gown, eye protection)

Source: N95Decon.org

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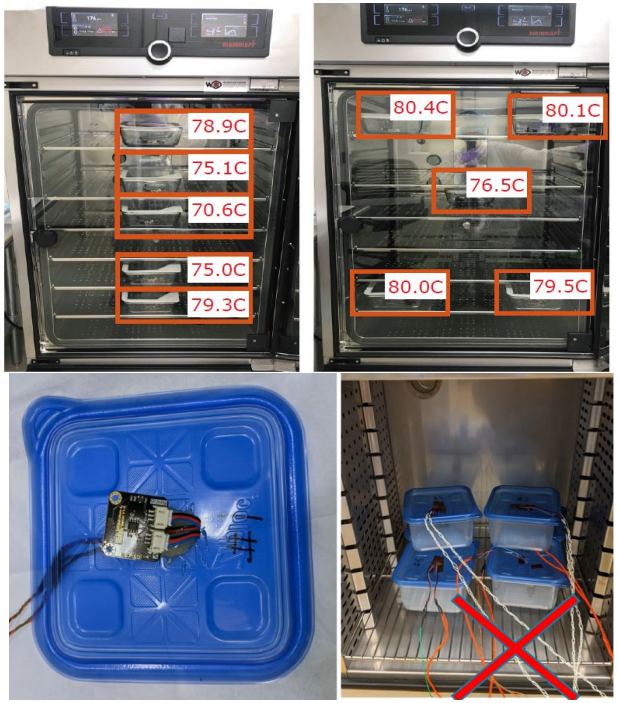
Moist-heat Decontamination Challenges

Temperature (70-85°C) and relative humidity (> 50%) suitable for heating devices in hospitals

CHALLENGES:

- Lack of specialized heating equipment:
  - Non-uniform heating, unpredictable humidity leakage, etc.
- Lack of scalable per-mask monitoring & verification methods
  - Wired sensors cannot be deployed in a rapid and scalable way
- Lack of throughput maximization mechanisms
  - Readings in each container are not used for feedback control

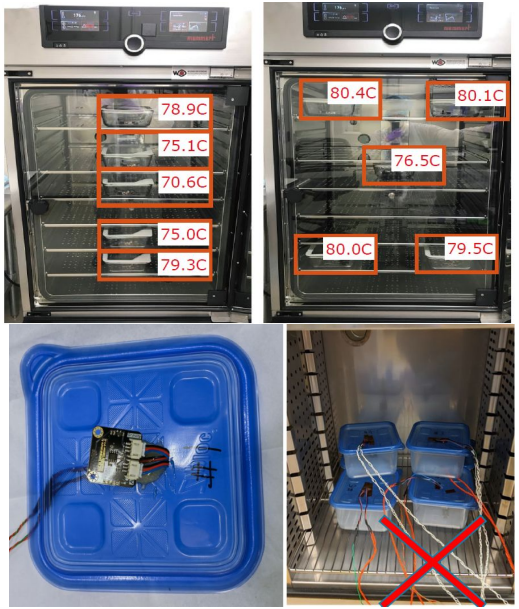


Moist-heat Decontamination Challenges

Temperature (70-85°C) and relative humidity (> 50%) suitable for heating devices in hospitals

CHALLENGES:

Need a scalable sensor-based technology to do constant per-mask verification of temperature and humidity level and provide feedback for throughput maximization.



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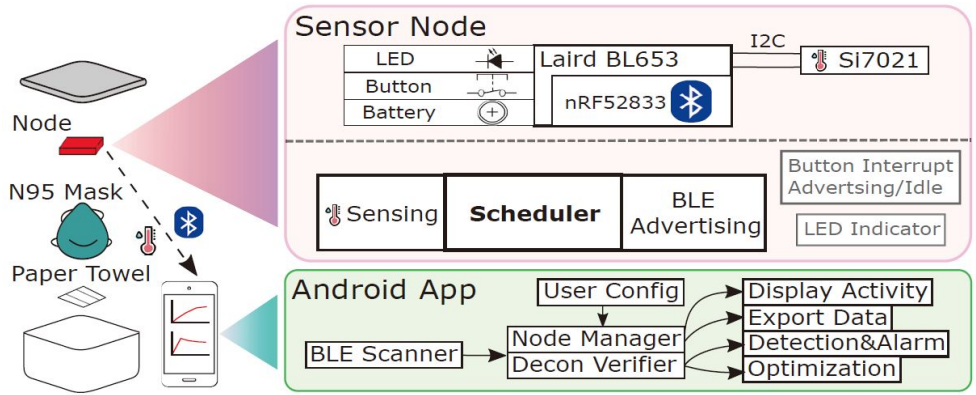
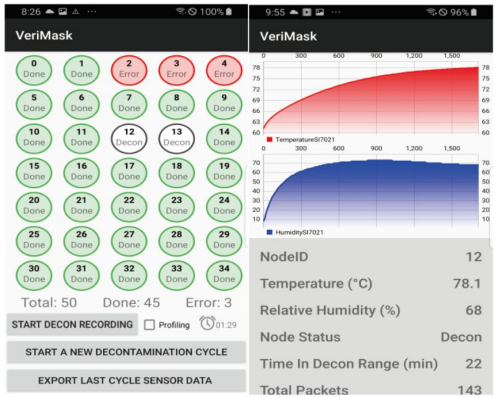
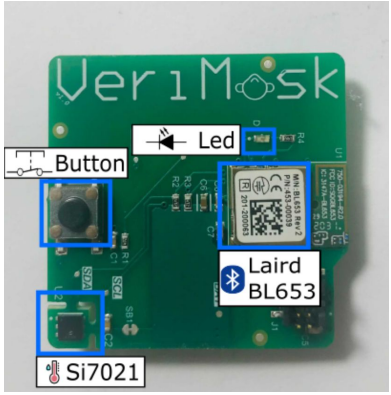
VeriMask Wireless Sensor Platform







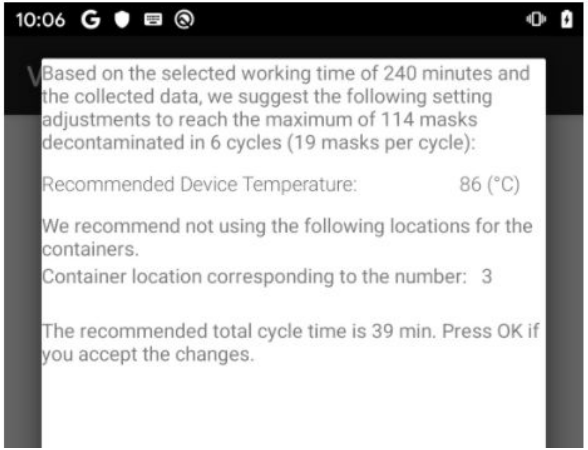
- **Sensor nodes**: One-for-one dense sensing topology, low-power (>1000 hrs), low-cost (<$15.66), scalable, high-temperature-resistant
- **Android App**: Automatic per-mask decontamination verification, throughput-maximization algorithm
- **BLE advertising**: Scalable, safe, low power consumption

Throughput Maximization

Input: selected total working time t_{work}, profiling cycle temperature data matrix D_{prof}, profiling cycle heating device temperature $T_{dev}^{(0)}$, required in-range decon time t_{decon}, decon temperature thresholds $[T_l, T_h]$, optimal heating device temperature (candidate) vector $\underline{T}_{dev}$ and MH process time (candidate) vector $\underline{t}_{MH}$

Output: $t_{MH}^{optim}, T_{dev}^{optim}, n_{work}^{optim}$

Initialization: $t_{MH}^{optim} \leftarrow 0, T_{dev}^{optim} \leftarrow 0, n_{work}^{optim} \leftarrow 0$
for *each candidate* T_{dev} **do**
    $D_{stretched} = stretchTemps(D_{prof}, T_{dev}^{(0)}, T_{dev})$
    for *each candidate* t_{MH} **do**
        $n_{work} = countTotalSuccessfulMasks(t_{work}, D_{stretched}, t_{MH}, [T_l, T_h])$
        if $n_{work} > n_{work}^{optim}$ **then**
            $n_{work}^{optim} = n_{work}$, $t_{MH}^{optim} = t_{MH}$, $T_{dev}^{optim} = T_{dev}$
        else
            Do Nothing
        end if
    end for
end for
return $t_{MH}^{optim}, T_{dev}^{optim}, n_{work}^{optim}$



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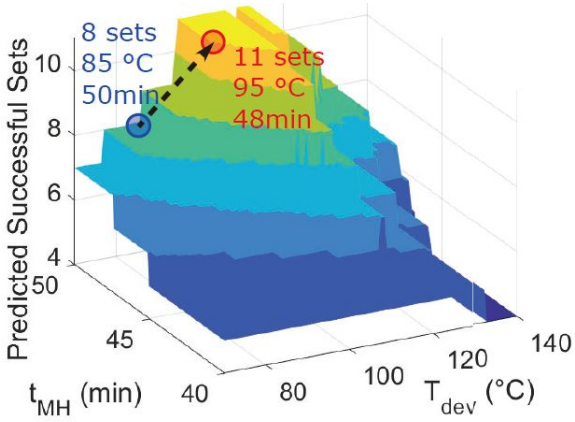
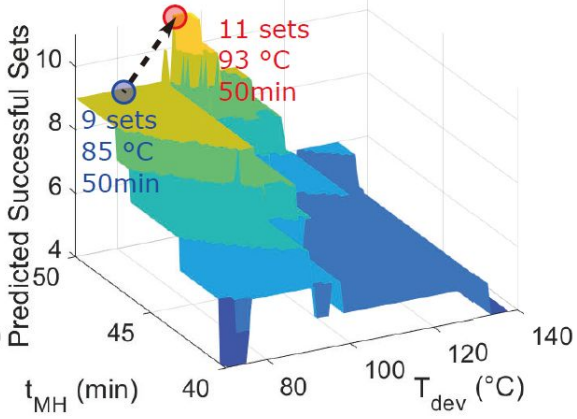
Throughput Maximization



20 containers



15 containers

- Successfully increased the number of successfully decontaminated masks.
- Counter-intuitively, we find that more masks (containers) in the heating device does not necessarily lead to more successfully decontaminated masks.

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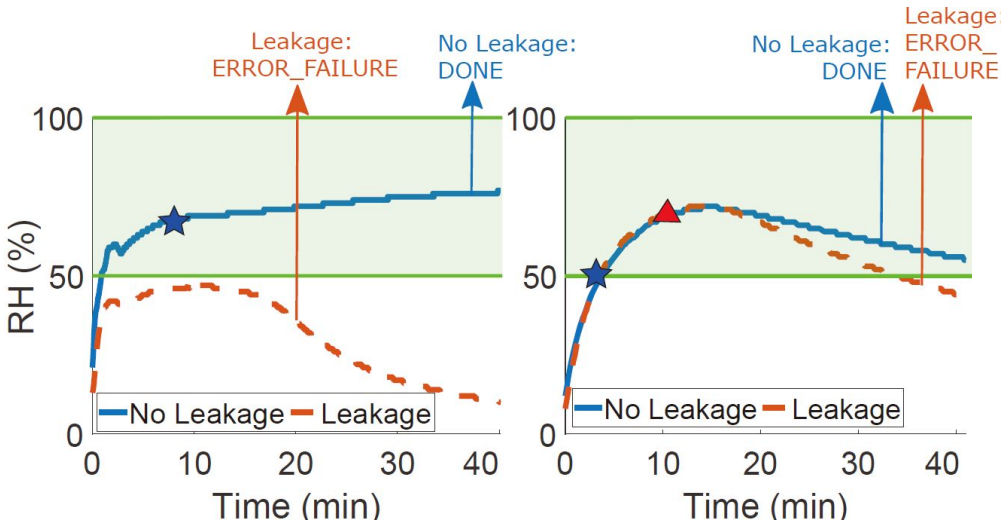
Decontamination Failure Detection



Tests in lab and clinical settings show that VeriMask is able to reliably detect various decontamination failures such as unpredictable humidity leakage

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Lessons Learned

- Emergency response designs should be prepared long in advance to avoid need-response mismatch due to supply chain disruptions and clinical access regulations
- Designers should plan for the worst case and design for modularity to avoid out-of-stock components
- Mobile computing researchers should engage early with medical professionals and end users to enable efficient and down-to-earth specifications.

Project links:

Open-source design at **https://github.com/longyan97/VeriMask_Designs**
Visit the project website: **https://spqrlab1.github.io/N95deconProject.html**
Please feel free to contact **Yan Long**: yanlong@umich.edu

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