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

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

Yan Long (yanlong@umich.edu), Alexander Curtiss, Sara Rampazzi, Josiah Hester, Kevin Fu
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.

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 N95 shortage America can’t seem to fix

Nurses and doctors depend on respirator masks to protect them from covid-19. So why are we still running low on an item that once cost around $1?

Coronavirus: India faces massive shortage of N95 masks, sanitisers
# N95 Decontamination Methods

<table>
<thead>
<tr>
<th>Decon Method</th>
<th>SARS-CoV-2 inactivation*</th>
<th>Filtration efficiency &amp; fit</th>
<th>Chemical residue removal required</th>
<th>Operator hazard**</th>
<th>Costs</th>
<th>Max reuse cycles</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moist-heat</td>
<td>✓</td>
<td>✓</td>
<td>no</td>
<td>no</td>
<td>$</td>
<td>5</td>
</tr>
<tr>
<td>Hydrogen Peroxide</td>
<td>✓</td>
<td>✓</td>
<td>yes</td>
<td>chemical</td>
<td>$$$</td>
<td>10-20</td>
</tr>
<tr>
<td>UV-C</td>
<td>✓</td>
<td>✓</td>
<td>no</td>
<td>Ozone exposure</td>
<td>$</td>
<td>5</td>
</tr>
<tr>
<td>Steam Autoclave</td>
<td>✓</td>
<td>X</td>
<td>no</td>
<td>no</td>
<td>$$$$</td>
<td>1-10</td>
</tr>
<tr>
<td>Alcohol submersion</td>
<td>✓</td>
<td>X</td>
<td>yes</td>
<td>no</td>
<td>$</td>
<td>Not recommended</td>
</tr>
<tr>
<td>Bleach submersion</td>
<td>✓</td>
<td>X</td>
<td>yes</td>
<td>chemical</td>
<td>$</td>
<td>Not recommended</td>
</tr>
<tr>
<td>Ethylene Oxide</td>
<td>✓</td>
<td>✓</td>
<td>yes</td>
<td>chemical</td>
<td>$</td>
<td>Not recommended</td>
</tr>
</tbody>
</table>

* 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

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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.
• **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 $T_{dev}^{optim}$, and MH process time (candidate) vector $t_{MH}^{optim}$

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

1. Initialization: $t_{MH}^{optim} \leftarrow 0, T_{dev}^{optim} \leftarrow 0, n_{work}^{optim} \leftarrow 0$

2. for each candidate $T_{dev}$ do

3. $D_{stretched} = stretchTemps(D_{prof}, T_{dev}^{(0)}, T_{dev})$

4. for each candidate $t_{MH}$ do

5. $n_{work} = countTotalSuccessfulMasks(t_{work}, D_{stretched}, t_{MH}, [T_l, T_h])$

6. if $n_{work} > n_{work}^{optim}$ then

7. $n_{work}^{optim} = n_{work}, T_{dev}^{optim} = T_{dev}$

8. else

9. Do Nothing

10. end if

11. end for

12. end for

13. return $t_{MH}^{optim}, T_{dev}^{optim}, n_{work}^{optim}$

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Throughput Maximization

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