# Analysis of the Use of Robots for the Second Year of the COVID-19 Pandemic

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***Abstract*—This article examines 152 reports the use of robots explicitly due to the COVID-19 pandemic reported in the science, trade, and press from 24 Jan 2021 to 23 Jan 2022 (Year 2) and compares with the previously published uses from 24 Jan 2020 to 23 Jan 2021 (Year 1). Of these 152 reports, 80 were new unique instances documented in 25 countries, bringing the total to 420 instances in 52 countries since 2020. The instances did not add new work domains or use cases, though they changed the relative ranking of three use cases. The most notable trend in Year was the shift from a) government or institutional use of robots to protect healthcare workers and the Public to b) personal and business use to enable the continuity of work and education. In Year 1, Public Safety, Clinical Care, and Continuity of Work and Education were the three highest work domains but in Year 2, Continuity of Work and Education had the highest number of instances.**

***Index Terms*—robots, rescue robots, ground robots, aerial systems, technological innovation, technology transfer**

## I. Introduction

This paper summarizes the use of ground, aerial, and marine robots explicitly for COVID-19 applications from 24 Jan 2021 to 23 Jan 2022, the second year following previous publications covering the first year (24 Jan 2020 to 23 Jan 2021) [1], [2]. The intent is to compare Year 2 with Year 1 in terms of:

- Were there changes in countries reporting robot use?
- Were there changes in applications, for example, did disinfection, telepresence, and delivery remain top cross-cutting priorities?
- Were there changes in modality, did uncrewed ground or aerial system use increase or decrease?
- Where there changes in overall international trends?

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The paper contributes both to robotics and to robotics policy. The results help roboticists to understand what is being used. The results also can aid the development of robot policies by projecting the pattern of technology investments during a pandemic or disaster. It should be noted that is beyond the scope of this paper to address research gaps or long-term research directions as it concentrates only on documenting what was used.

## II. Related Work

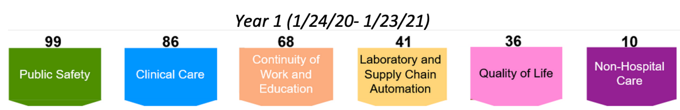


Fig. 1: The six work domains established in [1]–[3].

This paper extends data collected and analyzed in our previous works [1]–[3]. Those publications established a methodology for work domain and use case analysis based on iteratively clustering [4], identified international trends, and identified demand pull model for adoption during a disaster. The results showed that there were 338 clearly documented instances of robots used explicitly for COVID starting on 24 Jan, 2020, with 221 of these for ground vehicles, 117 for aerial systems, and 2 for marine vehicles. The instances clustered into six work domains shown in Fig. 1:

- Public Safety
- Clinical Care
- Continuity of Work and Education
- Laboratory and Supply Chain Automation
- Quality of Life, and
- Non-Hospital Care.

The formal clustering methodology and criteria for inclusion or exclusion distinguishes this paper from similar compendiums using ad hoc categorization of use cases, notably Wang and Wang [5], which identified 280 papers in the literature through November 2020 to determine 22 theoretical use cases and Shen et. al [6] with 200 reports. As will be described in the next section, this work used the iterative clustering method in [4] to establish socio-economicwork domains with distinctly different i) stakeholders who make the adoption decision, ii) interactants with different skills and expectations, iii) unique regulatory or budget constraints, iv) overall objectives, v) work envelopes, and vi) -types of use cases.

This paper differs from speculative uses such as Yang, et. al [7] by restricting consideration of only robots in actual use for COVID related applications. It differs from domain-specific examinations, such as Sarkar et. al [8] which concentrate on a particular work domain, e.g., clinical care. This paper concentrates on establishing the actual use cases and international trends, which differs from papers such as Wang and Wang [5] which focused on identifying research gaps.

## III. Data Collection Methodology

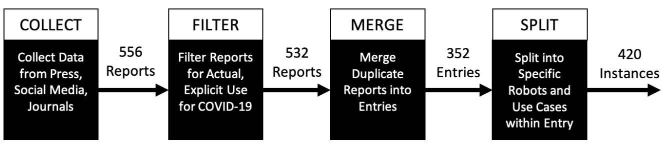


Fig. 2: Data collection methodology.

Fig. 2 illustrates the data collection methodology. Reports of robot use are collected then filtered for actual robot use. Some reports do not discuss a specific robot but highlight an ethical concern about robots for particular use cases; these reports are retained but will no be discussed here. The remaining reports are examined to see if there are duplications and if so, merged. Finally, the entries are split into work domains and use cases using the clustering method in [4]. As noted in [1]–[3], the data is certainly noisy but it is valuable because the large number of instances should smooth out noise and trends are likely to be underreported, not overreported.

This methodology is a variant of the PRISMA method for systematic reviews [9] but with five major differences:

- It is not trying to assess the quality of reports only determine the existence of robot use.
- Press and social media reports are included, not just scientific papers and industry publications.
- The screening phase is more specific and divided into three steps: filter ("reports accessed for eligibility") but also merge and split.
- The elimination of duplicates occurs in a special "merge" step. The viral nature of social media post produces duplicates that would distort the counting of actual instances. However, some duplications are not verbatim but are clearly reposts, thus removing duplicates is harder and deferred to the screening phase.
- The method permits splitting. Articles which described several models of robots would be counted toward each model, not assumed that the models had to be discussed together.

## IV. Changes by Country

Fig. 3 shows the 53 countries, the number of instances, and the date of first reported adoption. The total number of countries changed from 48 in Year 1 to 53 in Year 2. Twenty of the Year 1 countries reported new instances in Year 2 with five new countries being added to the list: Cape Verde, Indonesia, Saudi Arabia, Vanuatu, and Vietnam. However, as seen in Fig. 4, the countries who had embraced robotics in Year 1 continued to lead instances in Year 2. Indonesia was the only country added in Year 2 to break into the top eight countries.

## V. Changes by Application

As detailed below, Year 2 did not see changes in the six work domains or present new uses cases, but it did indicate a shift in the relative ranking of the work domains and use cases. Fig. 5 shows how the cumulative instances are divided among the work domains and use cases.

### A. Shift in Relative Ranking of Work Domains

Fig. 6 shows that in Year 2, the use of robots for Continuity of Work and Education went from third place in Year 1 to first place and Quality of Life exchanged places with Laboratory and Supply Chain Automation. It remained in third overall at the end of Year 2, but it is interesting to see the shift from reports about public health and safety applications to more business and routine work related efforts and personal uses. This may reflect the lessening of the lockdown and return to work during Year 2.

### B. Shift in Relative Ranking of Use Cases

Following [1], 18 of the 29 use cases in Fig. 5 can be grouped into three major cross-domain activities: delivery (5), disinfection (3), and telepresence (10). The largest increase in Year 2 was for delivery (22%) followed by disinfection (18%), and telepresence (16%).

**Delivery.** Delivery use cases saw a 22% increase in Year 2, from 90 instances to 110. The majority of new instances (10 out of the 20) were in Delivery for Laboratory and Supply Chain Automation. Going into more detail, there are five delivery use cases:

i) Delivery & Inventory (Clinical Care), ii) Delivery (Laboratory and Supply Chain Automation), iii) Delivery food (Quality of Life) and iv) Delivery non-food purchases (Quality of Life), and v) Delivery to Quarantined (Non-Hospital Care). In Year 2, the relative position of Delivery & Inventory remained the same in Clinical Care, the Delivery dropped one level in Laboratory and Supply Chain Automation, and Deliver to Quarantine in Non-Hospital Care had no new instances. Of the 20 new instances of delivery, only 7 were with aerial systems. This may indicate that aviation regulatory agencies did not extend emergency waivers to fly in urban areas on Year 2 as people returned to work and moved about their cities.

Disinfection use cases saw a 18% increase in Year 2, from 104 instances to 123. The majority of new instances (8)

| Country | Total | Date of Reported Use |
|---|---|---|
| **United States** | **126** | **1/24/2020** |
| **China** | **81** | **1/26/2020** |
| **India** | **37** | **3/23/2020** |
| **Great Britain** | **18** | **3/26/2020** |
| **Italy** | **16** | **3/23/2020** |
| **South Korea** | **13** | **2/11/2020** |
| **Spain** | **13** | **3/13/2020** |
| **Thailand** | **10** | **3/19/2020** |
| Singapore | 9 | 3/5/2020 |
| Japan | 9 | 3/28/2020 |
| Canada | 7 | 3/1/2020* |
| United Arab Emirates | 7 | 3/16/2020 |
| South Africa | 5 | 11/1/2020 |
| Kenya | 4 | 1/22/2021 |
| France | 4 | 3/19/2020 |
| Australia | 4 | 9/14/2020 |
| Ireland | 3 | 4/6/2020 |
| Nigeria | 3 | 4/6/2020 |
| Indonesia | 3 | 8/11/2021 |
| Germany | 3 | 4/4/2020 |
| Philippines | 3 | 3/19/2020 |
| Belgium | 2 | 3/16/2020 |
| Rwanda | 2 | 5/19/2020 |
| Vietnam | 2 | 6/1/2021 |
| Greece | 2 | 5/16/2020 |
| Denmark | 2 | 6/9/2020 |
| Mexico | 2 | 4/17/2020 |
| Equitorial Guinea | 2 | 9/24/2020 |
| Netherlands | 2 | 6/1/2020 |
| Colombia | 2 | 4/14/2020 |
| Ghana | 2 | 4/17/2020 |
| Chile | 1 | 4/20/2020 |
| Croatia | 1 | 3/1/2020* |
| Cyprus | 1 | 3/23/2020 |
| Czech Republic | 1 | 11/16/2020 |
| Estonia | 1 | 4/30/2020 |
| Honduras | 1 | 4/6/2020 |
| Jordan | 1 | 5/5/2020 |
| Kuwait | 1 | 3/12/2020 |
| Lithuania | 1 | 5/13/2020 |
| Malaysia | 1 | 3/1/2020* |
| Norway | 1 | 4/1/2020* |
| Poland | 1 | 11/16/2020 |
| Russsia | 1 | 11/6/2020 |
| Sweden | 1 | 5/15/2020 |
| Tunisia | 1 | 3/25/2020 |
| Turkey | 1 | 4/14/2020 |
| Egypt | 1 | 11/25/2020 |
| Saudi Arabia | 1 | 7/20/2021 |
| Cape Verde | 1 | 12/31/2021 |
| Vanuatu | 1 | 2/4/2021 |
| Austria | 1 | 2/1/2020* |
| Israel | 1 | 4/16/2020 |
| **Total** | **420** | |

Fig. 3: List of countries adopting robots for Year 1-2, organized by frequency, then date of first reported use.

| **Year 1** (1/24/2020-1/23/2021) | | **Year 2** (1/24/2021-1/23/2022) | | **Year 1-2** (1/24/2020-1/23/2022) | |
|---|---|---|---|---|---|
| US | 95 | US | 31 | US | 126 |
| China | 72 | China | 9 | China | 81 |
| India | 33 | India | 3 | India | 37 |
| Great Britain | 16 | Italy | 3 | Great Britain | 18 |
| Italy | 13 | Thailand | 3 | Italy | 16 |
| South Korea | 12 | South Africa | 3 | South Korea | 13 |
| Spain | 12 | Indonesia | 3 | Spain | 13 |
| Singapore | 7 | Singapore | 2 | Thailand | 10 |

Fig. 4: Top 8 countries adopting robots for Year 1, Year 2, and combined Year 1 and 2. Blue highlighting indicates new entries. Yellow indicates that the only change in countries from Year 1 to combined Years 1 and 2.

were in Disinfecting Public Spaces for Public Safety but Sanitation Work/School saw a similar surge (7). There are three disinfection use cases: Disinfecting Public Spaces (Public Safety), Disinfecting Point of Care (Clinical Care), and Sanitation Work/School (Continuity of Work and Education). In Year 2, Disinfecting Public Spaces rose to the top use case for Public Safety, but remained in the same relative position for Clinical Care and Continuity of Work and Education. The increase in Public Safety may be due to the previous most highly ranked use case, Quarantine Enforcement, dropping from first to fourth place in Year 2. Quarantine Enforcement most likely fell in Year 2 as the lockdowns were lifted.

Telepresence use cases saw a 16% increase in Year 2, from 148 instances to 171. The majority of new instances (12) were in Telepresence for Continuity of Work and Education. There are 10 telepresence use cases: Quarantine Enforcement (Public Safety), Observational Telepresence, Patient Intake & Visitors, Patient & Family Socializing, and Interventional Telepresence (Clinical Care), and Telepresence (Continuity of Work and Education), Attend Public Events, Interpersonal socializing, and Other personal actitivies (Quality of Life), and Quarantine Socializing (Non-Hospital Care). The increase in telepresence for Continuity of Work and Education may be the continued push to work remotely even as Year 2 saw relaxing restrictions.

## VI. Changes by Modality

The blue (aerial), brown (ground), and gold (marine) boxes in Fig. 5 give the numbers of instances by modality for the work domains and use cases. The use of uncrewed aerial systems (UAS) decreased from 34% in Year 1 to 15% in Year 2 and 30% cumulatively. The decrease was notable in each of the four work domains that had reported UAS use: Public Safety, Continuity of Work and Education, Laboratory and Supply Chain Management, and Quality of Life. 96% of the UAS instances for Public Safety were reported in Year 1, suggesting that the major use cases– quarantine enforcement, disinfecting public spaces,

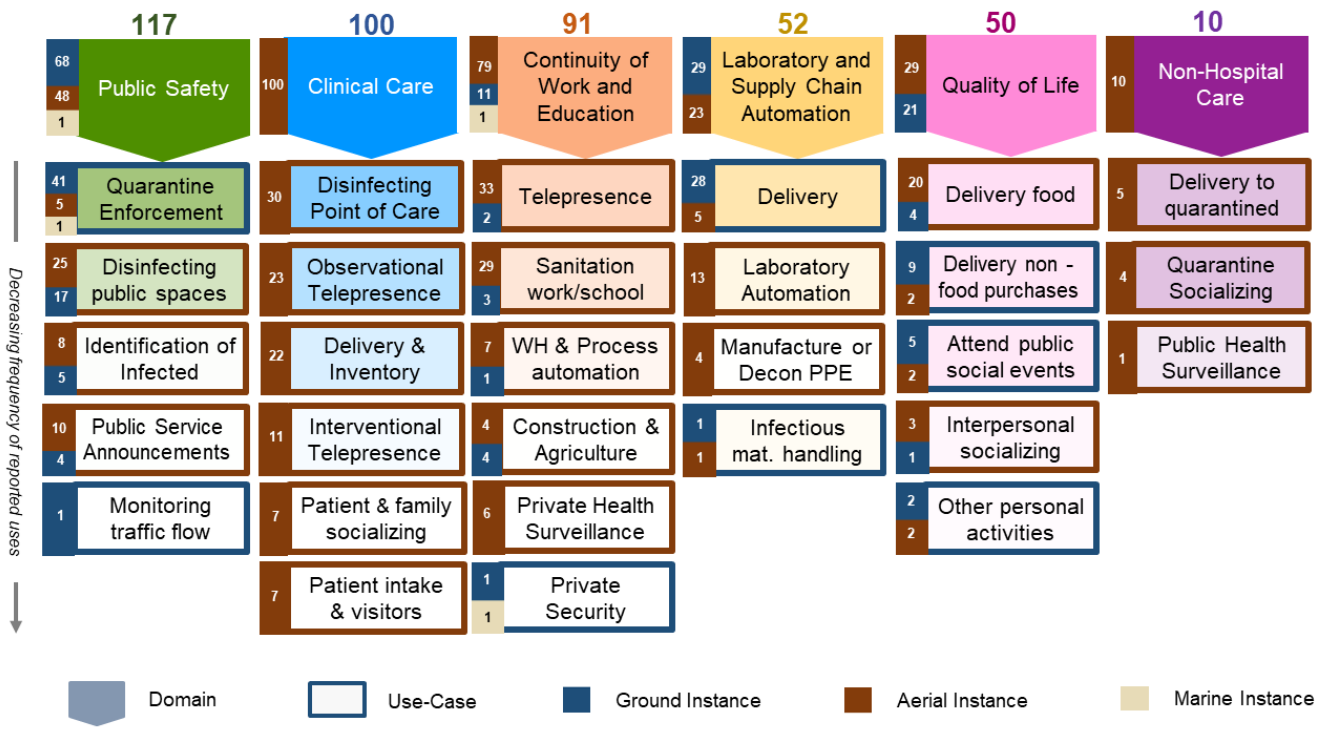


Fig. 5: Cumulative distribution of instances for Years 1 and 2. The dark blue, brown, and gold boxes on the sides indicate the number of instances of aerial, ground, and marine vehicles for that work domain or use case.

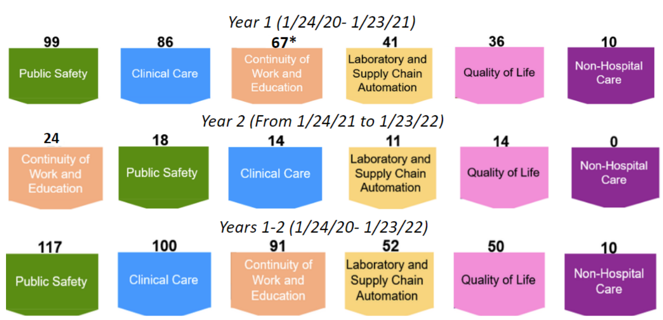


Fig. 6: Change in relative ranking of work domains based on number of instances per year.

and identification of infected– were not needed in Year 2 as lockdowns were relaxed. Marine vehicles were not reported in Year 2 and overall marine use appears to have been highly limited.

## VII. Overall Trends

Fig. 7 shows a cumulative plot of the number of instances by work domain superimposed on the epidemiological curves for the world. As noted in [3], the plot shows that robots were used for all six work domains in the first four months, with Public Safety and Clinical Care use exhibiting a sharp rise and long taper. However, Continuity of Work has exhibited a steeper slope after the initial pandemic and has almost overtaken Clinical Care. This could indicate that a) the use of robots is more newsworthy for Continuity of Work while the interest in Clinical Care had reached a plateau, b) the need for robots for Clinical Care has lessened or c) robots for Continuity of Work became more available and acceptable. Regardless, interest in robots in use for Continuity of Work continues to grow.

## VIII. Discussion

The data, especially how it relates to the progression of the pandemic response, yields four observations and policy recommendations. First is that Year 2 did not see new work domains or use cases. This is consistent with the demand-pull model of technology adoption during disasters [3], which states that emergency managers generally know the use cases that would be of benefit and do not rely on robotics companies to push innovation.

Second, instances of robots for Continuity of Work and Education were more frequently reported than for the public health aspects of either Public Safety or Clinical Care. Furthermore, Continuity of Work and Education showed a higher sustained slope in international trend. This suggests that small businesses and consumers are engaging with robotics, even as pandemic lockdowns decrease. This may because individuals are seeing government and big business use proliferate and becoming comfortable with robotics use. It could also be a reflection of the decreasing cost of robots for the pro-sumer market.

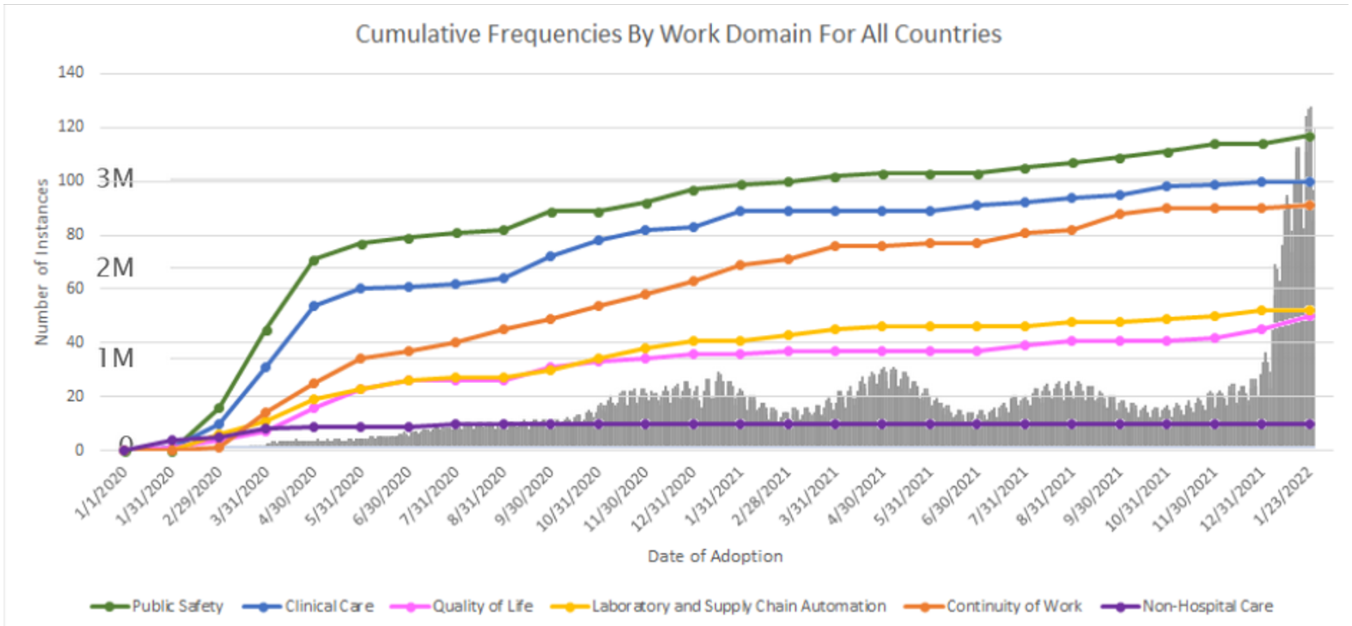


Fig. 7: Cumulative frequencies of robot use by work domain for all countries.

Third, the three big groups of use cases– delivery, disinfection, and telepresence– all increased about the same (17 – 22%). Delivery instances increased the most in Year 2 (22%) but the majority of new instances (13 of 20) were ground robots. Delivery remained same in CLINICAL CARE and dropped in LABORATORY AND SUPPLY CHAIN AUTOMATION, while delivery to NON-HOSPITAL CARE facilities was no longer reported. The shift from institutional delivery to home QUALITY OF LIFE delivery, combined with a lack of concomitant increase in UAS suggests that aviation waivers either expired or no longer applied when urban areas resumed daily life. Disinfection instances increased 18% in Year 2. Interestingly, instances dropped in PUBLIC SAFETY, perhaps driven by concerns over the health and environmental impacts of spraying large outdoor areas with disinfectant [10]. Disinfection use cases remained in same position in CLINICAL CARE and CONTINUITY OF WORK AND EDUCATION. Telepresence instances increased the least (17%), with a decrease in relative frequency in PUBLIC SAFETY and elimination in NON-HOSPITAL CARE. This may be due to the elimination of quarantine camps and hospitals, re-opening of nursing homes, and the use of laptops for remote social interaction.

Fourth, aerial vehicle use waned in Year 2 by (from 34% of total to 18%, for cumulative use of 30%), while ground robot use increased. UAS appeared to be primarily PUBLIC SAFETY driven; it could be that the need or opportunity for UAS use decreased as quarantine measures were relaxed. The increase in ground robots could indicate a lag in acquisition; ground robots are generally more expensive than small UAS and there were supply chain issues with disinfecting robots.

The data also offers insights for robotics policy and technology investments. In terms of robot policy, the initial timely use of robotics is associated with multi-domain and sustained use. Previous work [3] showed that six of the top eight countries in Year 1 had national robotics policies or major initiatives for investing in robots. As seen in Fig. 4, these countries continued to dominate reports of robot use in Year 2. In terms of projecting tech investments during a pandemic or disaster, it should be noted that majority of use cases needed in response to the pandemic or disaster are known or quickly established [1], [2]; therefore, having a ready supply of robots appropriate and available for that response is important. The delivery, disinfection, and telepresence instances continued to grow, building on the existing companies and how they were able to ramp up. While the pandemic offered opportunities to accelerate innovation, such as with aerial delivery, those innovations may not be sustained and indeed reports of aerial delivery were slight in Year 2.

## IX. CONCLUSIONS

In conclusion, while the data is noisy and not well-suited for statistical predictions, it offers observations for robotics research, development, and policy. A key observation is that the clustering of work domains and use cases did not change from Year 1 to Year 2, though with a slight altering of relative frequency of use cases within a domain. This change illustrates a shift from robotics used by government or institutional entities to protect healthcare workers and public at large at the height of increasing infections to robotics use by businesses and individuals to re-establish and sustain efforts work, education, and quality of life similar to what existed prior to the pandemic. One interpretation of the decrease in use of aerial systems, especially for delivery, is that adoption of novel technology requiring relaxing the aviation, or other, regulations may only be temporary and as a result does not predict longterm institutional adoption after the event is over. Current work is interviewing public safety and health officials in the US as to the reasons behind their adoption of robots. Future work will examine the differences in models and manufacturers and the overall technical readiness assessment of robots reported for the first time in Year 2.


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## References


[1] R. R. Murphy, V. Gandudi, J. Adams, A. Clendenin, and J. Moats, "Adoption of robots for disasters: Lessons from the response to covid-19," *Foundations and Trends in Robotics*, vol. 9, no. 2, pp. 130–200, 2021.

[2] R. Murphy, "How robots are helping with covid-19 and how they can do more in the future," in *2020 IEEE International Symposium on Safety, Security, and Rescue Robotics (SSRR)*, Conference Proceedings, pp. 1–1.

[3] R. R. Murphy, V. B. M. Gandudi, T. Amin, A. Clendenin, and J. Moats, "An analysis of international use of robots for covid-19," *Robotics and Autonomous Systems*, vol. 148, p. 103922, 2022. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S0921889021002074

[4] B. G. Glaser, "The constant comparative method of qualitative analysis*," *Social Problems*, vol. 12, no. 4, pp. 436–445, 1965. [Online]. Available: https://doi.org/10.2307/798843

[5] X. V. Wang and L. Wang, "A literature survey of the robotic technologies during the covid-19 pandemic," *Journal of Manufacturing Systems*, vol. 60, pp. 823–836, 2021. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S0278612521000339

[6] Y. Shen, D. Guo, F. Long, L. A. Mateos, H. Ding, Z. Xiu, R. B. Hellman, A. King, S. Chen, C. Zhang, and H. Tan, "Robots under covid-19 pandemic: A comprehensive survey," *IEEE Robotics and Automation Magazine*, pp. 1–1, 2020.

[7] G.-Z. Yang, B. J. Nelson, R. R. Murphy, H. Choset, H. Christensen, S. H. Collins, P. Dario, K. Goldberg, K. Ikuta, N. Jacobstein, D. Kragic, R. H. Taylor, and M. McNutt, "Combating covid-19—the role of robotics in managing public health and infectious diseases," *Science Robotics*, vol. 5, 2020.

[8] S. Sarker, L. Jamal, S. F. Ahmed, and N. Irtisam, "Robotics and artificial intelligence in healthcare during covid-19 pandemic: A systematic review," *Robotics and Autonomous Systems*, vol. 146, p. 103902, 2021. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S0921889021001871

[9] M. J. Page, J. E. McKenzie, P. M. Bossuyt, I. Boutron, T. C. Hoffmann, C. D. Mulrow, L. Shamseer, J. M. Tetzlaff, E. A. Akl, S. E. Brennan, R. Chou, J. Glanville, J. M. Grimshaw, A. Hróbjartsson, M. M. Lalu, T. Li, E. W. Loder, E. Mayo-Wilson, S. McDonald, L. A. McGuinness, L. A. Stewart, J. Thomas, A. C. Tricco, V. A. Welch, P. Whiting, and D. Moher, "The prisma 2020 statement: an updated guideline for reporting systematic reviews," *BMJ*, vol. 372, 2021.

[10] D. Ghafoor, Z. Khan, A. Khan, D. Ualiyeva, and N. Zaman, "Excessive use of disinfectants against covid-19 posing a potential threat to living beings," *Current Research in Toxicology*, vol. 2, pp. 159–168, 2021. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S2666027X2100013X