Fighting Pandemics Using Non-Pharmaceutical Technologies and IoT Solutions: A Systematic Literature Review

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ABSTRACT Covid-19, ever since it culminated into a full-on global pandemic, has been the focus of much human endeavour. These have mainly come in one of two forms: as pharmaceutical (i.e., vaccines) or non-pharmaceutical interventions like social distancing, and contact tracing. While both were partially successful, the overall image of the Covid-19 pandemic has been one of failure, with an inability to fully stop the virus from spreading. Besides, many problems were had even dealing with its consequences, as health systems got overwhelmed, and governments generally could not respond appropriately, or in time. Vaccines were not made available in due time in many nations worldwide. In most developing countries vaccination rates are still low, showcasing the inequity that was brought by this pandemic, and the issues with administrating vaccines at a global level, across many cultures. Perhaps even worse, we know that there is an appreciable chance that the SARS-CoV-2 virus will not be the last, with new viruses as possible threats to humanity, and new variants evolving, constantly eluding the scope of otherwise static vaccines. Therefore, in this systematic literature review, non-pharmaceutical technological interventions (NPIs) and IoT technologies are explored as perhaps the most viable solutions for curbing current and subsequent pandemics, trying to overcome inequity of resources, and transitioning into a society that is pandemic resistant, rather than prone. METHODS: Papers were retrieved from three databases (Scopus, IEEE, ACM) after various inquiries. Inclusion criteria for papers selection were that they mention NPI, technological solutions, in general, successfully tested, or utilized in real-world cases, or studies. Scientific publications considering pharmaceutical technologies were excluded. RESULTS: A wide range of technological solutions were highlighted as partially (as in the case of Iran) or fully implemented. Several challenges were identified as 1) the need for further adoption of a larger variety of technologies, and 2) better integration among pre-existing solutions via software and hardware, culminating in the creation of the smart cities. DISCUSSION: One of the limitations of this study is that while there were a lot of solutions found aimed at improving many NPIs the actual comparisons of effectiveness between these different tools in the same study were limited. Reflecting the research literature, many proposals were discussions of singular biosensors or technologies. There was a lack of integrated systems with numerous sensors in the literature, limiting current IoT research. This paper was also limited by the number and organization of papers. On top of those specific to each technology and areas discussed, further research areas were identified as the need for testing of more integrated solutions utilizing a large number of sensors and NPIs. OTHER: No funding was received.

1. INTRODUCTION

Fighting the Covid-19 pandemic and the SARS-CoV-2 coronavirus that causes it is crucial. The characteristics of the virus itself have been documented intensively. However, it is important to acknowledge for the purposes of this paper, that the main transmission methods are through respiration and contact with infected individuals and surfaces.

Currently, there have been 527,463,066 confirmed cases, and 6,300,164 deaths (May 22, 2022, 21:14 GMT) [1]. These statistics are especially bad considering the experience we have gained in dealing with pandemics from previous virulent epidemics, putting the Covid-19 pandemic as one of the worst in history despite our better efforts[2]. The economic impact projections -their limited reliability notwithstanding- have naturally been overwhelmingly negative [3, 4, 5, 6, 7]. Conversely, and more importantly, the pandemic has taken a massive, unquantifiable toll on the population at the psychosocial and psychological levels [4]. The impact has been disproportionately worse for marginalized people [4, 8]. Worse yet, the longer the pandemic goes on, the higher the chance for new variants to evolve, like Delta and Omicron. The total freezing of many aspects of daily life and habits has been another pressure factor. In trying to amend such problems, many countries have implemented different combinations of specialized measures.

These measures have been largely divided into two categories: pharmaceutical interventions (vaccines, drugs, etc.), and non-pharmaceutical interventions (NPIs). Non-pharmaceutical interventions are characterised by their preventive nature, aimed at avoiding the transmission of the virus, while pharmaceutical interventions usually only act after an infection has occurred. However, while pharmaceutical measures are undeniably invaluable tools in fighting a pandemic [9], current experience and context have shown that drugs and therapies are not enough to fully stop the Covid-19 even after almost three full years since the outbreak [1].

Vaccination rates in Low-Income Countries (LICs) have also been severely lacking, as High-Income Countries (HICs) stockpiled vaccines, at times to the point of wastage [8]. This was allowed by a nationalistic approach to the production and selling of vaccines, and the inability of technologies to be shared because of intellectual property (IP) laws [8]. As a result, while 75-80% of HICs populations were vaccinated, in LICs the vaccination rates of could reach only 10%, even despite schemes such as COVAX (through donations) trying to sidestep the profiteering actions of companies [8, 9].

However, even when effectively applied, the long-term effectiveness of vaccines in stopping the virus transmission is not complete. Around 5 months after the second dose, “breakthrough transmissions” can still happen, and are considerably more common than within the designated times after vaccination [9]. The vaccine still successfully reduces the severity of the sickness, and possible death [9].

Moreover, in the initial stages of the pandemic, health systems were caught off-guard, both under-supplied and understaffed. This situation has slowly improved as vaccines were rolled out and supplies caught up with demand. However, this was also a showcase of how unprepared countries’ health systems could be against sudden highly contagious pandemics. This points us to the usefulness of preventive strategies such as NPIs, in reducing the number of people having to go to hospitals, to begin with [10]. The positive impacts of NPIs have also been demonstrated in research [10, 11], investigating the impacts of NPIs.

Yet another case to be made against fully relying on vaccines concerns the generalizability of vaccines and the critical time frame in which they are not available. With how intensive medical testing is, even in the best of scenarios expecting effective vaccines in the first critical months of a pandemic would be unrealistic. Even with positive interactions between vaccine development processes, like how HIV vaccine development attempts have accelerated the creation of Covid-19 vaccines [12], the minimum time necessary for safety testing leaves a good amount of time for viruses to spread. Even worse, in many cases, the emergence of a new virus does not mean we can immediately identify it, giving it an indeterminable time to spread even before proper identification. Lastly, vaccines can become ineffective and require even further testing in the face of mutations, variants, and completely new viruses. In fact, conceptual models showing variants being altered, slowed, or even contained by NPI exist [13]. NPIs ultimately hold the potential to be better than linearly more effective ways of reducing transmission numbers.

Therefore, five major problems motivating the brunt of the objectives of the present document have been identified: i) pharmaceutical problems with vaccines, ii) possibility of subsequent pandemics, iii) limited generalizability of vaccines, iv) the fact that many health systems were overwhelmed, v) and the consequent urgent need to prevent transmissions, rather than deal with them later, in medical and health contexts.

These problems point us towards a general, critical bottleneck to the effects of the SARS-CoV-2 virus, and all similar viruses that would mainly travel via contact and respiration between humans. All these problems could be avoided or lessened if non-pharmaceutical interventions could reach a good level of effectiveness in preventing and blocking transmissions. Therefore, considering NPIs by improving existing technologies and Internet of Things (IoT) solutions could be a suitable approach. Methods for sanitizing surfaces and objects, monitoring social distancing, gatherings, and the presence of wearable Personal Protective Equipment (PPE), and effective organization minimising transmission already exist 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32]. Technologies that reduce viral loads in indoor environments, opening windows and doors, and Air Conditioning (AC) systems, could be automatised for optimal air salubrity. Further still, integration into IoT would be the next logical step, as technologies could cooperate and being applied to a greater variety of dynamic real-life situations more effectively, from healthcare contexts, to workspaces, and private homes.

The objectives, moving from these points, have been defined as follows:

- Providing a review of non-pharmaceutical interventions aimed at supporting the fighting against pandemics focusing on IoT technologies;
- Ascertaining the suitability of approach;
- Identifying potential gaps in the scientific studies;
- Providing suggestion for the future researches.

2. METHODS

This systematic review was written applying the PRISMA (Preferred Reporting Items for Systematic reviews and Meta-Analyses) methodology. This is a systematic approach for conducting literature reviews and meta-analyses [33].

A. SELECTION CRITERIA

Eligibility criteria are a good way of systematizing the identification, selection, and assessment of research papers included in a systematic review. Indeed, therefore they are proposed as a necessary step by the PRISM guidelines [33]. In this case, it was used as a guide in filtering the massive amount of literature on the matter. The application of these criteria is incremental, and step-by-step. As such, if a paper could not pass a prior criterion, it was disposed of, and compared to no further criteria.

Inclusion criteria (IC)

IC-1 – The paper has one of the following terms in the title, abstract, or keywords: "Covid-19" or "SARS-CoV-2" and:

"IoT"
"Internet of Things"
"technologies"
"robotics"
"program" or "software"
"smart cities"

Exclusion Criteria (EC)

EC-1 – The paper proposes a pharmaceutical intervention

EC-2 – The paper does not discuss any non-pharmaceutical intervention, or relevant subjects

EC-2 – The study does not include tested technologies, or technologies whose applicability has not been discussed

EC-3 – The paper has no English version

EC-4 – The study is not rated as Q1 or Q2

EC-5 – The paper includes the keyword "review" in the title, abstract, or keywords

B. SEARCH STRATEGY

Data retrieval consisted of repeated inquiries into the Scopus, ACM, and IEEE databases based on the Inclusion criteria inserted in section Eligibility Criteria. These databases were chosen for their direct relevance to the subjects of IoT and technology, and their high-quality publications concerning.

Data collection was conducted using a simple sentence structure and swapping keywords to extract the most relevant papers for the review. This method was preferred because the multidisciplinary scope of the review prevented large, automatic inquiries from yielding relevant papers, especially within manageable numbers. As such the format of the string: "X against Covid-19" was defined, where X was switched out for every remaining keyword provided in the IC-1 list. There were two exceptions to this rule, with the following strings (both inquiries were made in addition to the other searches):

- TITLE-ABS-KEY (technologies AND against AND covid-19) AND LIMIT-TO (SUBJAREA,"COMP") OR LIMIT-TO (SUBJAREA,"ENGI") OR LIMIT-TO (SUBJAREA,"CENG") OR LIMIT-TO (SUBJAREA,"MULT") OR LIMIT-TO (SUBJAREA,"PSYC"))
- TITLE-ABS-KEY (programs OR software AND solutions AND for AND covid-19) AND (EXCLUDE (SUBJAREA, "MEDI")) AND (LIMIT-TO (SUBJAREA, "COMP"))

No year limits were established, however, the inclusion of the keyword "Covid-19" naturally limited most papers into the 2019-2022 period. Where possible, the first 100 papers were considered in each inquiry, as the relevance of the papers fell sharply around this number. Nonetheless, this resulted in a total number of 1507 papers to be considered. The collected papers were filtered using the selection criteria, and compared against papers' keywords, titles, and abstract sections. The information concerning the resulting papers was moved into an excel file.

C. STUDY SELECTION

The first pool of papers (n= 1507) was initially filtered using the inclusion/exclusion criteria except EC-5, and EC-6. Because of the large size of the resulting number of relevant papers (n=603), EC-5 was later added. This was to make the corpus of papers more manageable while keeping the highest quality of papers (n= 246). After further analysis, motivated by the topology of the literature (high number of both research articles and review articles) EC-6 was added [34]. The remaining papers (n= 41) were considered in further depth through the analysis of the full text. Because of problems with access 4 papers had to be removed, while 2 were duplicates, and 2 were irrelevant, making the final number of included full-text papers n=33. Later, through manual screening 5 papers were added, bringing the full number to n = 38.

D. DATA COLLECTION PROCESS

In terms of data collection, no quantitative data was extracted as per the aims of the review. However, a type of quality assessment has been inadvertently applied to the papers gathered. The quartile system that is based off of the Impact Factors (IF) of journals were used as a measuring stick for quality. Included papers, excluding manual additions, were all from Q1 and Q2 categories.

3. RESULTS

A. STUDY SELECTION

1507 papers were initially identified. The papers were screened for their adherence to the inclusion criteria as they were extracted, except EC-5, and EC-6. The inclusion of many duplicates was avoided because of this. After this initial screening, 603 papers were left. At this point, the exclusion criteria were expanded to capture a more relevant, higher quality set of papers. Thus, EC-5 was added, using the Impact Factors of journals to filter out research with a lower impact factor, in hopes of increasing quality. Of the 603 papers, 246 which fell into the Q1 and Q2 categories were picked. At this junction, upon analysis of the remaining papers, a further criterion was added: EC-6, focusing on the review papers within the corpus of articles. This addition was motivated by the topology of the literature (i.e., a high number of published research and literature reviews, leading to a "need for a review of reviews" as advised by [34]), and to keep the article corpus at a manageable number. As a result, 41 papers remained for comprehensive, full-text analysis. Of these, 4 could not be accessed, and 2 were duplicates. while 2 papers were deemed irrelevant upon further analysis.

At the end of this process, the number of full-text papers was increased from 33 to 38 with the 5 additional chosen by manual analysis.

Figure 1 shows this process as a flow diagram. Table 1 gives a list of the articles included because of this process.

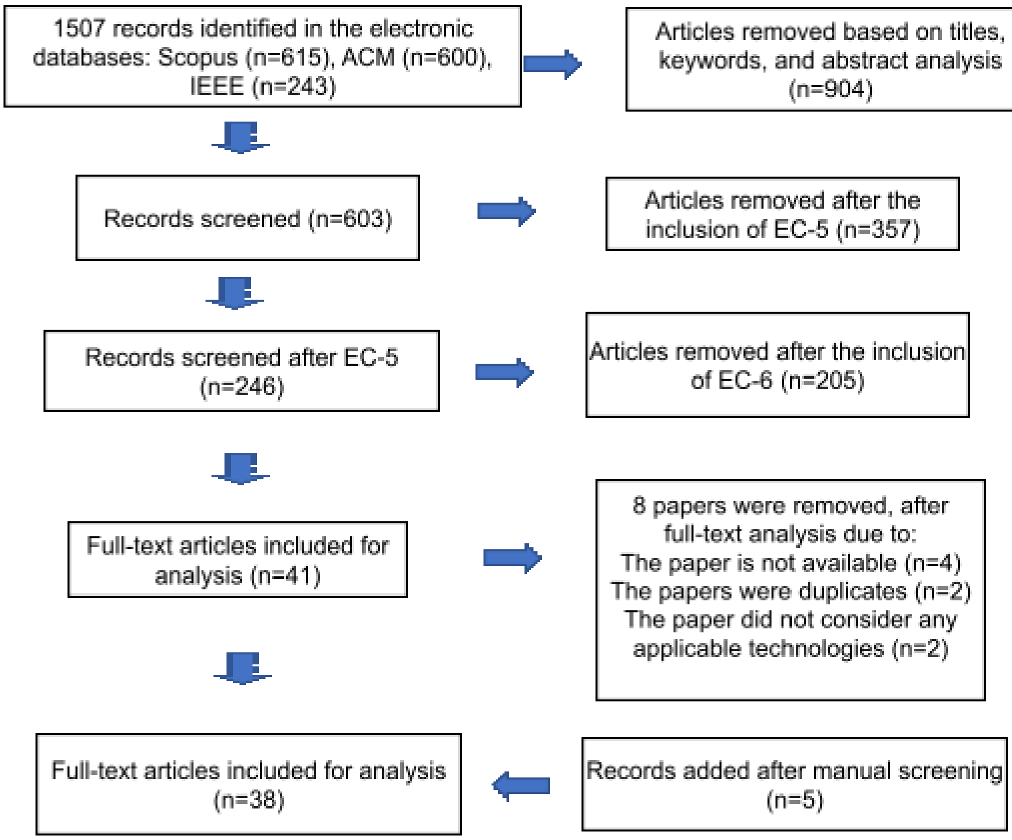

FIGURE 1. Flow diagram of the study selection.

TABLE 1. Selected articles.

Articles selected and analysed: [14-32],[36-49], [51-55]

B. STUDY CHARACTERISTICS AND RESULTS

Here is shown a general scoping of the articles included, and the topics covered within.

1) WHAT TYPES OF TECHNOLOGY WERE CONSIDERED

In the literature many technologies are considered, both because of the interdisciplinary nature of the situation, and the fact that all remaining papers included contained a review or were a review themselves. In fact, several creative exploitations of current technology exist (for example, using low energy Bluetooth (BLE) for contact tracing, or Wi-Fi signals for monitoring respiration), all at various stages of development and testing. This is especially true concerning solutions for battling a disease as prevalent and young as COVID-19.

Therefore, the plethora of technologies were classified according to their goals rather than structure during consideration. If one were to consider the actual types and structures of technologies themselves, they could find hundreds (22 alone were implemented in Iran, as an example [24]). However, in the end, these technologies are gathered under similar areas, characterized by similar, often overlapping goals. That is, while photo-catalytic paints and

UVC lights might be fundamentally different technologies, they are brought under the same technological umbrella of Object Sanitization: technologies for inactivating viruses on various surfaces to prevent transmission. Similarly, several technologies can overlap. As an example, AI can be used both for privacy, IoT, or monitoring goals. Or, simply “by itself” as a decision-maker, taking input from monitoring systems.

Here we classified these technologies under different areas: Object sanitization, Air Sanitization, Monitoring, IoT, AI-Based Interventions, and Privacy Issues and Concerns. These are taken as the goals one would want to achieve using reported technologies to successfully combat an epidemic like COVID-19. In Figure 2, a pie chart showcases the number of technological areas considered by an amount of papers . For example, it was seen that 19 out of the 38 papers mainly considered only 1 technological area. This could be Monitoring, or Object Sanitization, or AI-Based Solutions, however in any of these cases, only one technology is included in the research.

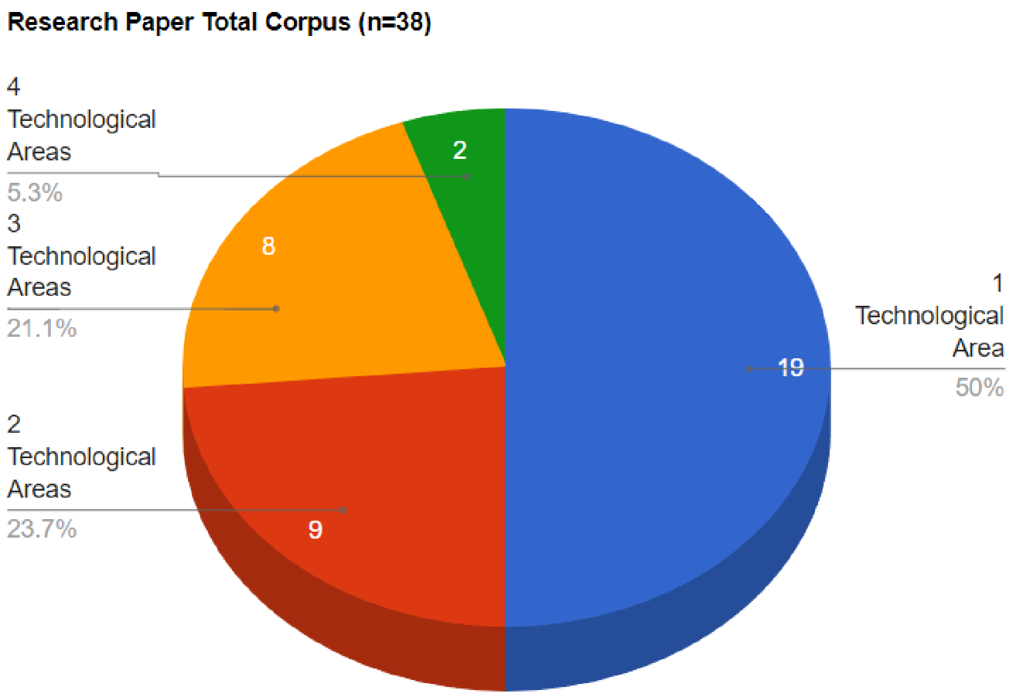

Figure 2. How many of the six technological areas (Monitoring, Object Sanitization, Air Sanitization, IoT, AI-Based Solutions, Privacy) were discussed by how many papers?

As can be seen, just about half of the research papers were focused on only one of the technological areas (for example, a paper that discusses only Object Sanitization). 23.7% of the papers were found to discuss 2, 21.1% of the papers discussed 3, and only 5.3% of all papers discussed 4 technological areas. As such, many papers where more than one technological area were discussed were reused across several chapters. The review-heavy form of the research acquired can also be seen by this chart, with half of the papers including several technologies.

2) HOW MANY PAPERS COVERED A TECHNOLOGY?

18 papers out of 38 involved a discussion of Monitoring. 9 papers out of 38 included a discussion of technologies concerning Object Sanitization goals. 4 papers out of 38 addressed Air Sanitization. 11 papers out of 38 looked at IoT systems. 15 out of 38 discussed AI, and 7 out of 38 papers were discussing Privacy concerns.

This meant that Monitoring was 47.37%, Object Sanitization was 23.68%, Air Sanitization was 10.53%, IoT was 28.95%, AI-Based Solutions were 39.47%, and Privacy Issues and Concerns papers were 18.42% of the complete research corpus. Table 2 is provided, showing which papers involved a discussion of each technological aspect.

Monitoring (Basic Sensors & CTA and Social Distancing)	**Object Sanitization**	**Air Sanitization**	**IoT**	**AI-Based Solutions**	**Privacy Issues and Concerns**
[22], [23], [24], [17], [18], [25], [26], [27], [28], [29], [30], [31], [32], [21], [37], [53] ,[39], [47]	[14], [15], [16], [17], [18], [19], [20], [21], [40]	[14], [15], [20], [40]	[49], [23], [24], [46], [27], [28], [48], [36], [44], [38], [47]	[51], [24], [18], [54], [27], [28], [52], [30], [31], [32], [36], [44], [42], [47], [53]	[45], [26], [55], [30], [31], [32], [42]

Table 2. A table of all technological aspects considered, and the papers that included a consideration of these technologies.

4. DISCUSSION

The discussion is organized under the six technological aspects deemed important in combatting pandemics.

4.1) MONITORING

Monitoring is critical in containing the COVID-19 disease. Fundamentally, it is the first line of defense we have against any virus. Monitoring gives us the basic information we need to perceive the virus. Thus, without any monitoring, it becomes quite literally impossible to manage the statuses of pandemics [24]. Monitoring can take many forms. It involves not only keeping track of the people who have caught or transmitted the disease, but also monitoring whether people stick to hygienic practices and use their PPEs. In its essence, monitoring is keeping track of anything that could help us prevent the impacts of a virus. This can even be sewer systems ([14], [35]), or the peoples' physical locations. The information gathered from these various sources is then used to develop useful interventions to curb the impacts of the virus. In IoT systems, these interventions could be using various technologies to act on the environment, such as giving off an alarm that tells two individuals they are too close for respecting the social distancing.

4.1.1) BASIC SENSORS

As a result of monitoring being such a critical part of prevention, many papers have investigated and collated the findings of the scientific literature ([22], [23], [24], [17], [18],

[25], [26], [27], [28], [29], [30], [31], [32], [21]). The basics of monitoring is found to have been generally handled via biosensors ([23], [17]), cameras, or other techniques such as Bluetooth or Wi-Fi. The research by ([23]) gives us an especially comprehensive look at the techniques used for monitoring. These were found to be: Smart Cameras, Inertial Sensors, Magnetometer, Microphones, Commodity Wi-Fi, mmWave RADAR, and Radio Frequency Identification (RFID) ([23]). A good portion of these technologies is commonplace in smartphones. Microphones and cameras can be used to detect human activity, and propositions using these methods exist. Indeed, China has utilized its system of CCTV cameras well in this way to monitor its citizens to limit transmissions [36]. A similar method using CCTV is reported in [36], evaluated on the dataset of peoples' movements through Oxford. Magnetometers are considered for proximity sensing, building into contact tracing applications, and social distancing. Inertial sensors are similarly used to calculate orientation, potentially helping us in guessing human behavior. Wi-Fi itself has been a newer, but promising proposition for sensing respiration. Such an example is a proposal using Wi-Fi and a smartphone, in conjunction with a Wi-Fi card dedicated to collecting such data. It is relatively easy to use and has detection ranges of up to 4m [37], effectively using ripples created in WiFi signals to detect respiration. This is in contrast with Bluetooth Low Energy (i.e., BLE) solutions which spot generally smaller areas of detection, closer to 1-2m ([26], [31], [21]). A good example of this type of monitoring is the GCG application [38]. However, while they may seem less powerful, they are a more efficient and easy-to-apply choice, as most common smartphones readily have these features and are easy to use. This contrasts with a specialized, somewhat niche Wi-Fi chip that would need installation into a modem and the subsequent centralization of that gathering of data [37]. This has potential drawbacks, as well as positives, which are touched on later in the Privacy Issues and Concerns section. BLE, in the end, has been designed specifically for low-energy environments that need continuous functionality, such as an IoT, making it a critical technology in the literature. Some Contact Tracing Applications (i.e., CTAs) such as the Immuni app use this technology. Moreover, an integration of these technologies has been used to obtain a more efficient distance estimation, in the case of [39]. In this case, both Wi-Fi and Bluetooth sensors were utilized to get a much more accurate location of the person. Lastly, RFID is already "widely applied in healthcare and human activity recognition" [23]. It is made up of an antenna, reader, and a tag, and is a great form of common sensors for monitoring, and integration into an IoT system.

This is the level of basic sensors that intake information, making up our basic monitoring capabilities. It has been seen in the literature that we can also monitor the blood oxygen saturation (SpO2), telling us the amount of oxygen our red blood cells can carry. This is compromised for COVID-19 patients, being critical if falling under 90%. As such, implementations that monitor this parameter are critical. Camera systems that measure SpO2 are discussed in [23], one using a two-cameras system under ambient light to monitor SpO2 levels, while others used a single RGB camera to monitor blood SpO2 levels of a person from 1.5m away. Some wearable systems can also monitor SpO2 levels [29]. It must be stated that the SpO2 is a critical piece of information for healthcare situations, as low levels can go unnoticed by the person.

A large presence of wearable solutions can also be found in the literature [21], [29]. One of the papers [21] focused on commercially available wearable technologies, while [29] reported non-integrated and fully integrated wearable systems. In a world where comfortable and non-obstructive construction of wearable solutions are important, fully integrated wearable systems generally allow such lightweight wearable solutions. These were found to enable comprehensive and continuous monitoring, their small dimensions were unobtrusive, and comprised a feasible solution for long-term, in-home monitoring while being cost-effective. Their cons were found to be limited by their low power requirements. Non-Integrated wearable solutions on the other hand were found to enable more comprehensive and continuous monitoring while incurring negatives such as being obtrusive, uncomfortable, expensive, and infeasible for long-term in-home monitoring. A further variety of wearable technologies are discussed [29], [21], and it was observed that many wearable systems were limited by their monitoring capabilities of only a few physiological parameters at a time and restriction of physical independence. The paper [29] then proposes a wearable sensor that monitors the person within 6 categories: Heart (HR, HRV), Blood pressure (SBP, DBP), Breath (SpO2 and RR), Lung (capacity and function), and Temperature and Cough (frequency). A fast prototype was put together, and the goal of the system was to identify patients before, or as they turned critical to provide them with timely healthcare assistance. This was found to be one of the few proposed systems in the literature that incorporated more than 2-3 sensors, addressing an important need for testing sensors and systems simultaneously, especially for the goals of the future integration. Some other examples of these types of research were the CREW System, or the single-use biosensor developed by LifeSignals Co., both incorporating an appreciable number of sensors [21].

We can also measure body temperature. Because they are contactless, infrared sensors were found to be more effective than traditional thermometers. An intervention that integrates drones and infrared sensors for the identification of infected individuals is discussed [23]. Some studies are exploring RFID technologies for more accurate measuring of body temperature [23].

Lastly, upholding quarantine is critical for proper control of the epidemic. To make sure people stick to quarantine an IoT sensor-based system using ear, blood, and motion sensor is discussed. A proposition for a wearable band to track real-time locations of people is also discussed. Another system, using the built-in sensors of smartphones to ensure quarantine was proposed [23].

4.1.2) CONTACT TRACING AND SOCIAL DISTANCING

Along with monitoring individuals for health-related factors, we can also utilize technologies such as GPS, magnetometers, and microphones to conduct contact tracing and social distancing. This should be the “other half” of our strategy for preventing transmissions via monitoring, as they are a good way of avoiding the droplets in the air that may cause further infections. GPS is the most intuitive method, however, comes with privacy concerns as it inevitably must deal with location data. CTAs can be classified into Proximity-based Contact Tracing (PCT), Location-based Contact Tracing (LCT) and Mobile Operator Contact Tracing. Other technologies such as BLE and Wi-Fi also let us conduct contact tracing and social distancing [31]. In general, PCTs utilize BLE, LCTs utilize GPS, and MOCTs utilize mobile operator infrastructures to conduct contact tracing [26]. Because of the usage of GPS and infrastructure, LCTs and MOCTs are deemed as inherently insecure [26]. In fact, in many cases like the Immuni app, which functions using BLE, applications and programs can entirely sidestep having to deal with sensitive information, and only use fabricated IDs and proximity data.

In [31] an extensive catalogue of the use of technologies as a non-clinical measure against COVID-19 is given. Bluetooth, GPS, AI, Wi-Fi, Smartphone Magnetometer Traces, Cellular Networks, Near Field Communication (NFC), RFID, Blockchain and Ultra-Wide Band are listed as the contemporary technologies able to be used. Smartphones were identified as the most preferred platform for implementing CTAs for their cost-effectiveness, while nevertheless having problems with conducting consistent high-quality monitoring. The use of BLE in proximity sensing was shown to be similarly driven by the cost-effectiveness of the technology. Bluetooth-Based Protocols and Apps for contact tracing have been divided into three major data management methods by the researchers: centralized, decentralized, and hybrid architectures. In centralized structures, the single point of failure creates security concerns. Decentralized protocols may therefore be favoured for their use of random anonymous keys (i.e., pseudonyms), and their local storing of data. Nevertheless, BLE, GPS, and Wi-Fi were found to have inherent privacy vulnerabilities. Centralized systems were found to especially have this problem, as misuse by hosting companies, or single points of failures made them more vulnerable compared to a decentralized system [26]. To remedy these security problems, blockchain systems were proposed, however, it was found that it "is not, in itself, a panacea for contact tracing solution." [26]. Blockchain systems were vulnerable to threats such as "Paparazzi attacks" and came with trade-offs in efficiency, applicability, and sustainability.

Lastly, social distancing was reported by the researchers [31] to be made up of five major approaches: keeping a distance, crowd control, face mask, isolation/quarantine, and virtual interactions. It was reported that computer-vision technologies were used in monitoring fixed location, while smartphone and wearable devices were employed in "individual-centric" tracking methods where users are mobile and locations change. Concerning face mask detection, proposals of computer vision systems (names Face Mask Detection) [25], or even robots conducting monitoring and warning those without a mask exist [18]. Furthermore, two major approaches in conducting quarantine of infected people were identified in [31]: landmark-based, and geofencing methods. It is reported in the same paper that both methods were employed in some countries, like Kyrgyzstan, and Hong Kong, for geo-fencing-based measures.

A synergistic combination of both CTA and social distancing, when properly implemented, is very important in minimizing the transmission, of all diseases. Further utilizing the basic sensors, we are at a point where could potentially get a nearly complete picture of a virus' transmission while limiting its contagion. However, these solutions are limited by several factors, such as their applicability, efficiency, economic aspects, ease of use during daily activities, and perhaps most importantly stakeholder interest and knowledge. After all, masks caused much unrest in daily life, and has become one of the reasons for peoples' discontent with lockdowns and dealing with the virus. As such, similar discontent must be avoided when designing a monitoring system, making all aspects that actually make a technology preferable and safe to use in daily life. Indeed, privacy is a real issue in designing interventions, especially concerning CTAs. Therefore, an approach that considers these factors, and others, can improve CTA designs. For this purpose, the proposed C3EF Framework could be used [22]. It is a holistic assessment framework that categorizes desirable (or undesirable) aspects of a potential CTAS under Characteristics, Usability, Data Protection, Effectiveness, Transparency, Technical Performance, and Citizen Autonomy. It is a system that is descriptive in nature but can be used prescriptively. It provides a potential way to not only streamline CTA designs, but also improve them.

5) OBJECT SANITIZATION

The main idea of preventing transmission of the SARS-CoV-2 virus is to make it as hostile and impossible for the virus to jump from one host to another. Making the outside world unviable for the survival of these viruses would therefore act as a great step in reducing transmissions. Object Sanitization is then taken as the technology with the scope of sanitizing objects and surfaces, inactivating virulent and bacterial threats. This should include everything from masks to door knobs that we interact with, as indirect contact is one of the ways through which the virus is transmitted. As far as we currently know the SARS-CoV-2 virus can stay active anywhere from a day on cardboard, to three days on plastics [40]. Moreover, recently a new aspect of transmission has been indicated: the fecal-oral way, hinting that sewage monitoring and control may be critical in containing the spread of the virus [14]. Material sciences especially were found to be very prominent in the sanitization, as long-term solutions naturally require new and more viable materials for a given purpose. Now the 8 review papers that discussed object sanitization will be presented.

Researchers [14] found that primarily recommended disinfection strategies (i.e., use of disinfectant by the staff in a healthcare facility) were “energy exhausting, chemically driven, and cause severe impact on the environment”. Disinfection routes were determined as being “physical” and “chemical”. The physical routes included heat sterilization, adsorption, UV-irradiations, electronic radiations, and exposure to gamma rays. The chemical route was the use of chlorination, which is carcinogenic and has mutagenic by-products. Chemical-free UV radiation (photolysis) was discussed and found to have cost-inefficiencies caused by the electrical supply, and toxic mercury lamps with a short lifespan. In its stead UV-LEDs did not use these toxic lamps, but had nonetheless comparatively high costs, hurting its widespread applicability. An alternative route, called AOP (Advanced Oxidation Process) was indicated. These were: ozonation, photo-Fenton, ultrasound, and photocatalysis. Ozonation was found to be a strong method that utilized O3, with excellent results in dealing with waterborne viruses, as well as rotaviruses. Solar-driven semiconductor photocatalysis is reported as being a renewable, environment-friendly, and cost-effective process that overcomes the issue of producing harmful by-products during sanitization. This is seen as a newer area of research in case of its applicability and therefore is still in its infancy. Comparatively, usage of antiseptics and disinfectants are well recorded to disrupt the SARS-CoV-2 virus, however, suffer from problems stated beforehand. However, chemical by-products from UV chambers, UV-driven sterilization devices, honeycomb air heater-based systems, fogging towers, and UV-disinfection trolleys necessitate a greater alarm against the usage of these methods. This was especially the case as a lack of safety protocols was found to accompany these technologies. Photo-catalysis is therefore proposed as a good contender for sanitization. The set of potential materials (transition metal oxides) to be used was presented, corroborated by another paper [16] TiO2 being the most well-known. Further applicability has been discussed in medical, industrial, and wastewater treatment. Another paper, [15] provided an account of polymeric materials in combatting the SARS-CoV-2 virus. While the proposed applications ranged from masks to supporting vaccines, the main list of potential candidates was given. These were natural polymers (i.e., cyclodextrin, chitosan, and carrageenans), and synthetic polymers (i.e., polyethleneimine; PEI), poly (i.e., dl-lactide-co-glycolide; PLGA), dendrimers, and metal and metal oxide NPs (i.e., silver, copper, titanium, zinc, and gold [15]). These were found to be effective antiviral agents. Most pressing challenges were identified as understanding the underlying mechanism of virulent inactivation, how economic each solution is, and how efficient each material is [14]. Therefore, as it stands, further research into the various materials and scalable, cost-efficient designs is advisable. The strength of the photo-catalytic procedures lies in their ability to be used in various ways, from sterilizing sewers, to surfaces, to masks.

Researchers in [16] also looked at nanoparticle-engineered photo-catalytic paints as a way of creating long-term, self-sterilizing surfaces. TiO2 is reported as the most widely used semiconductor, born from several reasons: low cost, low toxicity, long-term photo-stability, abundance, chemical stability, and ease of preparation. Self-sterilizing materials like copper nanoparticles, antiviral polymers, polypropylene, or metal oxide nanoparticles like Ag, Au, Cu2O, TiO2, Fe3O4, and graphene are used to coat surfaces. Surfaces coated by these materials act as continuously self-sterilizing agents with a long shelf life, eliminating the need for frequent cleaning, lowering the risk of infection, and being cost-effective. It was found that WOx for paint performed better compared to daily chlorine disinfection in reducing microbial activity on the surface. A paint called RAZE is proposed as a contender for situations where low microbial activity is desired, but more research is proposed to meet stricter disinfection requirements. Furthermore, it was reported that current technologies used in cleaning hospitals are not suitable, viable, or economical for cleaning public spaces. As such, photo-catalytic paints may be a contender for breaking this barrier. Reports on photo-catalytic paints are compared by the authors and future suggestions for research are listed. Namely, these pointed to an increased need for researching how these paints may be applied to public spaces, and how economical they would be. It is stated that the application of such paints is still at a conceptual level and needs further thought before implementation on a large scale. Another meta-analysis [19] determined nanoscale materials as potential tools against coronaviruses in animal models, and because of their similarities with coronaviruses, probably against COVID-19. As such, there was reported a need for research against COVID-19 specifically, and a lack of consistent findings in vitro and in animal models.

In [17] graphene and its derivatives were considered in how they could be used against SARS-CoV-2. It was found that it could be used in making biosensors, personal protective equipment (i.e., PPE), graphene and graphene-based masks, coatings, and nanofoam, as well as 3D printing various components for PPE, ventilator parts, and viral swabs. These materials were preferred because while poisonous to bacteria, they are not so damaging to us, or other mammals. Limitations and challenges were found to be the impossibility of large-scale and high-quality graphene-based nanomaterial production, and the fact that it was environmentally damaging, requiring proper disposal, complicating its usage.

A scientific paper focused on the usage of robotics and AI during the COVID-19 pandemic [18] for disinfection. Several robotic solutions that exist were presented. One was the usage of disinfecting a certain area with the usage of UV-C light or hydrogen vapor, facilitated by a robot. An example of this by the company UVD Robots was given, with a robot capable of carrying out UV-C disinfection in patient rooms, corridors, and other units within a hospital. However, disinfection need not be conducted only using UV light: a robot named “Nimbus” was developed that uses hypochlorous acid to disinfect surfaces. Another robot was reported, Xenex, disinfecting using high-intensity pulse germicidal UV, being the most effective form of UV with its higher intensity and wide spectrum. In general, robotics was reported as being promising mainly for sanitization, automatization, and safely monitoring temperatures, mostly limited within clinical settings. However, another research paper in 2022 [41], despite this promising nature, reported on the lack of readiness in applicability, especially concerning the pandemic. Perhaps this lack of readiness can also be seen in the wide number of privacy and security problems that robots must deal with [42]. Furthermore, a review paper [43] considering robotics in laboratory settings during the COVID-19 pandemic reports on the existence of mass-testing robots and their usefulness for conducting Polymerase Chain Reaction (PCR) tests at rapid rates. These large robots are usually highly specialized, and most likely not suitable for lower-income areas. The development of drive-in sampling robots is also reported but awaits clinical validation. Similarly, various automated in-clinic swabbing robots have been developed, but their widespread application awaits further developments.

A similar method to the self-sterilizing coating has been reported by the researchers in [20] utilized in masks. Self-sterilizing materials are applicable to masks and, while this also contributes to air quality, mainly this would potentially prevent infections born from touching a mask saturated by the virus. Similar masks (named “Hazel” and “Guardian G-Volt” masks) are reported by [21] using UV technology and a power source (one uses an external battery, the other charges wirelessly). If perfected, these solutions could deal with many of the wasteful and problematic aspects of disposable masks.

6) AIR SANITIZATION

Aerosol and droplet transmission is a major risk and primary concern in contracting the SARS-CoV-2 virus. Air sanitization, in many cases, works via the usage of masks that limit the presence of the virus in the air. In many cases, it is common practice to use AC units and simply open the windows to facilitate air circulation, lowering the viral load in the air. These factors further interact with air-borne fine particles of pollutants that have negative effects on human health, and the respiratory system [20]. As such, especially concerning critical cases of COVID-19, air salubrity, in general, becomes important as well. In any case, in the literature screened, the focus was mainly on technologies that improved masks [20] [14].

Reported results showed that the SARS-CoV-2 virus can stay up to 3 hours in the air [40] [14]. Similarly, to object sanitization techniques, most self-sterilizing materials can be used [14], or approximated to masks [20], consequently providing us with cleaner air.

A comprehensive review of the similar technologies in face masks is presented by [20]. Air sanitization, while not quite possible in the way that surface sterilization is, is still made up of any factors that lessen not only the stressful load on the respiratory system but also prevent the infection. Therefore, an acknowledgment that the deterioration of air quality can be attributed to industrialization, and lately, frequent occurrence of epidemics and pandemics, ranging from SARS to Ebola, to now COVID-19, must be made [20]. In combatting these stressors, masks have been in common use, especially in already polluted areas, even before the pandemic. Now, in the pandemic-to-post-pandemic era, we have seen its natural resurgence in blocking the SARS-CoV-2 virus. And in this era, various types of masks have been utilized, mainly categorized by the researchers as cloth masks, surgical masks, and respirator masks, in rising order of success in blocking the virus. Important design problems were identified and pointed out as breathability, fit, thermo-physiological comfort, reusability, and biodegradability. Many companies and research institutes have tried to improve on these points and made various designs. For a more in-depth consideration of these masks, it is advised that the paper [20] is consulted. It was observed in the same paper that a poorly fitted surgical mask only stopped a fraction of infectious particles, both coming in, and out. Perhaps more importantly, considering not only surgical masks, but also respirator masks, it has been found that they were functioning below their expected or presumed performance, and efficiency levels are currently under dispute. Despite this, the importance of the usage of masks is nonetheless stressed, as it is still much better than not having one at all. This gives us much motivation to improve the masks to match the expected levels of performance. This was reported to be in the form of an impetus for discovering ways of inactivating viruses and pathogens on the mask while ensuring maximum longevity. Popular mask disinfection techniques were presented as short wavelength UV germicidal radiation, hydrogen peroxide vapours, ethylene oxide vapours steam, heat, disinfectant solutions, autoclaving, disinfectant wipes, and any other technique that may be applicable. Various materials were tested for the inactivation of the virus. An example of this was the proposed Fosshield™ fibers, utilizing a type of fiber embedded with a blend of copper zeolites and organic silver during spinning. On top of material sciences, a variety of research is also discussed on improving comfort, facial fit, and sustainability.

Future research directions were identified [20]. Pragmatic aspects like the loss of effectivity due to design failure were stressed, for example, a cracked nose strip, or loss of elasticity after exposure to sunlight. Enhancing filtering capacity, better ergonomic design, higher durability, and comfort features such as thermoregulation were reported to be decently well-researched. A late push for making economically affordable and reusable masks has been observed. Indeed, this is one of the problematic areas that needs addressing, as in order to achieve an effective preventative system against pandemics, we need a very high percentage of people to use masks. Such amenities can be hard to come by in low-income areas, adding to creating potentially consistent reserves for viruses, prolonging especially transmissible pandemics. There was also a great lack of technology focusing on solutions such as AC technologies in the withdrawn literature, or solutions that actively disinfected air. This should be another area for further research.

7) IoT INTEGRATED SOLUTIONS

We have seen so far that in terms of monitoring and sanitization, many interventions exist. We have not only the technologies for monitoring in a very detailed way the conditions of viruses and pathologies, but also affect, and at times effectively cut off their transmissibility. IoT devices are important for ensuring a real-time flow of relevant data. It enables various people from various areas to cooperate on issues. As a result, in conjunction with the technologies in use, the proper tracing and management of COVID-19 cases can be ensured. Such preventative power exists and has been utilized in most countries, but at differing, possibly insufficient levels ([11], [24], [42], [18], [25]), a perhaps most effective example being China. The simultaneous usage of IoT technologies is therefore necessary for effectively combatting any pandemic as, by itself, no intervention can stop such a transmissible virus. In fact, even indirect applications of IoT systems can help to keep people from taking risks by going to hospitals. An example of this can be seen in home-therapies mad available via IoT systems [38]. The importance of such clinical applications can even double, as people who require home therapy may have comorbidities, or be comprised of older people with weaker health, posing a higher threat when in contact with the virus. The impetus for a collation of implementations under IoT systems can also be seen in the research literature advocating for smart cities and IoT systems ([23], [24], [36], [44], [21], [38]). We now present the extracted research literature on IoT systems against pandemics.

In the research paper by [23], a brief discussion and a list of technologies that can be integrated into IoT systems are presented. The basic sensors have been touched on in the Monitoring section, and moreover, an IoT system is very variable in its nature. According to the goals and scope of an IoT system not only can the utilized sensors change, but also the way the whole system is set up. Therefore it has been observed that many IoT systems can be defined more so by the technologies (i.e., AI, edge and fog computing, blockchain, or 5G) that hold them together [45] [46], and their goals rather than a specific, rigid design or description. An IoT design has a set of sensors through which it collects information. A layer connecting these sensors to a central computing platform may or may not exist. It is usually at this centralized level that big data strategies are utilized, and technologies like AI can become truly critical in data management, and decision-making. In other cases, where fog-cloud computing is utilized, a more horizontal architecture can also be found. These may still require the processing of large amounts of data, however, possess less computing power. AI proposals to solve these problems exist [23], and in any case, AI's application to big data situations is not new [28]. Indeed, it can also be used for COVID-19 risk assessment [18]. As an example, this already makes an IoT system that takes inputs from various biosensors within a hospital, and outputs risk assessments dedicated to patients conceptually plausible. Furthermore, it is reported that several IoT-based systems have already been tried and tested for Zika, chikungunya and Ebola viruses, all relatively modern diseases [23]. In other, usual cases, while many proposals were present, rigid testing was lacking, especially concerning real-life environments.

It was reported in an assessment of the case of Iran [24] that IoT technologies should be included in diagnosis, management & planning, and protection endeavours. A comprehensive framework for COVID-19 management was constructed, including 22 technologies that could be used to combat COVID-19 Yet, in summary and practice it was found that IoT, alongside AI and even other technological interventions were either ignored, or underutilized. On the other end of the spectrum the significance of the full integration of these technologies was stressed by a research paper on China by [47].

In yet another study, mapping the role of digital health technologies in the prevention of the pandemic from the Yearbook of Medical Informatics, IoT, alongside other technologies, contributed to the lessening of transmissions [27]. IoT was found to be one of the most used digital health technologies in the studies limited to Europe and Australia. In this scoping review, methodological quality was not undertaken.

The literature review by [28] touches on an important challenge faced by IoT systems: the collation of information. When gathering information from many biosensors, many different types of data will be collected that need to be consolidated for further data processing (i.e., heterogeneous data). Moreover, data will at times be incomplete. More intelligent integration of systems and subsystems that make up an IoT is discussed. For example, AI could be used for data mining for the purpose of guiding or designing an IoT system. Understanding and reaching a sufficient level of intelligence in lower-level systems of an IoT device is also stated as being important for developing a proper IoT system.

5G technologies, discussed in [46] were proposed as a possible candidates for IoT integration, because of the unique use cases such as enhanced Mobile Broadband (i.e., eMBB), Ultra-Reliable and Low Latency Communication (i.e., URLLC), and massive Machine Type Communication (i.e., mMTC) it aims to fulfil. mMTC is the use case for meeting the demands of connecting many devices. IoT, falling under the mMTC category, could be helped by 5G. According to research, 5G can enable heterogeneous IoT devices to be directly integrated. It was also reported that 5G sported 10 times the longer battery life, and 10 to 100 times the number of devices. The main limitation is that such implementations require 5G connectivity anytime and anywhere, which currently seems infeasible with the minimal commercial dispersal of 5G networks.

In the review paper [48] IoT applications were reviewed, and a comprehensive discussion of the issue is held. It was found that in usual use cases, IoT systems took biometric inputs from various sensors (like glucose level, heartbeat, and blood pressure) on the infected person's body, and dealt with the data in a virtual management system. Some smartphone-based applications were touched on that prioritized "needy ones". This was one of the few mentions of an application aimed at underprivileged populations. A larger list of applications can be found in the paper. Several problems of IoT systems were identified under the headings "Safety, Security and Privacy of Data" and "Challenges in Network Integration". Safety, Security and Privacy of Data concerns were 1) potential misuse of patient data, and 2) cyber-crime.

Lastly, we propose that stakeholder integration should take centre stage in developing any integrated IoT system, like the work done by ([49],[50]). This is motivated by the multidimensional nature of IoT systems unavoidably requiring people from many different backgrounds, as well as stakeholders. Moreover, the full capabilities of technologies must be acknowledged and integrated [24], which may require expert informants.

8) AI-BASED SOLUTIONS

In the research literature, AI-Based solutions are relatively abundant and have the potential to handle many aspects of monitoring systems (e.g., CTAs) [31], [32], as well as IoT systems. These are usually considered for COVID-19 detection, prediction, screening, monitoring data and information, and several more, presented in [28], or even robotics [18]. It was seen that currently, the most common AI applications were for health response and that DNN (i.e., Deep Neural Network) models dominated the landscape for COVID-19 applications [51]. The largest body of research was found to be on the usage of AI in the detection of COVID-19 using CT scans. Some exciting research areas are identified under COVID-19 Modelling and Simulation, as AI systems hold the potential to make predictions on not only the transmission rates [52], but also severity and mortality rates, and even future mutations of the virus [28]. AI's potential as a decision-making tool was found to be inconclusive based on a lack of research.

In fact, deep learning algorithms have been used for understanding and predicting COVID-19 patterns [52]. Many popular algorithm structures were observed, such as

Recurrent Neural Networks (i.e., RNN), Long Short-Term Memory (i.e., LSTM), etc. Many other AI techniques were also used for surveillance tools [52], a possible example being computer vision. Some have proposed systems that incorporated many of these tools (for example using travel data, location tracking, epidemiological and behavioural patterns [53] but were faced with criticisms concerning privacy infringements. In real life, the usage of AI has been for monitoring endeavors in many countries. Usage with CCTV cameras, GPS signals, and a variety of other data was seen in various countries, like China and India.

[30] found a need for trust-building in AI solutions aimed at Extractive Industries (i.e., EI). These industries can make up a significant portion of economic forces and provide baseline materials for many industries. A disruption to the workers could have further negative economic repercussions. There was also found the need for effective procedures for qualifying such AI. Similarly, in tourism, [54] located a lack of research focused on the industry demands. This is potentially another very important area for research, as tourism plays a crucial role in the transmission of COVID-19. An AI solution that optimizes healthy travel and stays would be a very important tool in curbing spread via travel. Similarly, AI can be implemented in CTA methods [31], [32].

In line with prior papers, an in-depth report on the AI literature [32] reported that AI can help in slowing transmission via contact tracing, social distancing, trends analysis, symptom analyses, disease spread modeling, etc. The positive impacts were reported by many countries in curbing transmission rates. An important AI application was the identification of transmission routes. Furthermore, the application of AI as a "resource manager" was a unique technique. This led to forecasting of those who needed special help, and a reallocation of resources to meet this predicted demand, leading to the prevention of mortality and Intensive Care Unit (ICU) admission rates. Four pillars of biomedical ethics were proposed by the authors: beneficence, non-maleficence, autonomy, and justice. Moving further, AI was reported to have the potential to be used in data collection for IoT systems. A variety of fields are also presented that can benefit from AI in the new normal, such as making automated decisions, or boosting peoples' moods via show and music recommendations. It is also pointed out that AI experiences are highly applicable between epidemics to battle more effectively. The usage of AI is discussed in depth from six different points of view.

Several challenges were pointed out in the application of AI in the COVID-19 era [32]. These were: data heterogeneity issues, data manipulation and misuse, data volume, lack of data knowledge, data convergence issues, the inadequacy of metrics, lack of truthful data, mishandling in contact tracing, and fine-grained data collection. Altogether, the imperfection of such data stands as one of the biggest problems in AI applications. Further research areas were presented as incomplete security of the data lifecycle in AI, data fusion problems with heterogeneous data, and designing low-cost models and measures of AI. Moreover, integration into IoT and explainable AI that lessen the "blackbox" nature of AI are also exciting areas for research.

Lastly, two papers were found that touched on AI applications in a smart city system [36], [44]. While the idea of a smart city currently lacks definition, it is characterized by an increasingly integrated urban life. In such systems, the analysis of big data would be a requirement. This would be perfectly in line with prior usages of AI as prediction tools. This could lead to higher levels of monitoring and prediction, limited only by the number and variety of sensors we have in a city environment, and computing power. Prevention and precaution within smart cities could be achieved with facial recognition using various sensors, helping patients get information with AI-based chatbots, and using data from smartphones to monitor citizen health, supporting other decisions and decision-makers [44]. In total, AI could potentially facilitate the real-time tracking and management of complete cities.

9) PRIVACY ISSUES AND CONCERNS

Because of the sensitive nature of the data handled by IoTs, privacy is a large concern. To deal with these problems, various propositions such as the usage of blockchains exist. Currently, these propositions include mainly either 1) the usage of blockchain technologies for ensuring privacy [45],[55], or 2) coming to an in-depth understanding of the design principles behind technologies such as CTA. Indeed, it was found that the design of many CTAs required a trade-off between privacy, security, and the types of data and data structure utilized [31]. As an example, decentralized structures were deemed safer, as they did not have single points of failure, and could not be misused by hosting companies, unlike centralized structures, where these were the main concerns [31]. Indeed, the need for a health surveillance app that also considers personnel privacy in extractive industries was expressed [30]. For most cases, however, a decentralized or hybrid structure will most likely be preferred to strike a balance between privacy, security, and efficiency.

In [45] blockchain was assessed as a solution to privacy issues. It had some positives such as pseudo-anonymity, removal of third-party intermediaries and potentially facilitating sharing of data across hospitals and medical contexts. However, unique challenges remain such as legal ownership and consequent liability of data, privacy issues unique to the blockchain structure, throughput, and hyper resource intensity. In accordance with these findings, blockchains were also expressed as not being a “panacea” for conducting contact tracing safely [26].

In [32] confidential computing and zero-knowledge proofs were reported as solutions that are widely accepted in dealing with the privacy problems of data distribution. Blockchain technology was reported as having been “rigorously used... ...for transparency and verifiability” purposes.

Lastly, in [42] a comprehensive list of the types of attacks on robots is discussed, alongside security issues, vulnerabilities, threats, and risks. Especially in the medical field. Robotics were found to be vulnerable to a plethora of sources, born from a “lack of security by design of robotic systems, and reliance on open wireless communication channels”. Various recommendations such as Cyber Threat Intelligence, and identification, verification, and authentication strategies are discussed. Generally speaking, firmware, applications, and hardware protections were proposed as the three main protections necessary for robotic systems.

10) CONCLUSION

With this paper, an initial overall picture of the research literature on non-pharmaceutical technologies against COVID-19 was attempted. While it should be stated that such a feat is perhaps impossible owing to the multidisciplinary and ever-shifting nature of the literature, this paper should still give a good starting point for further research in various technological areas in combatting the SARS-CoV-2 virus and pandemic. Six different technologies areas involved in fighting pandemics were considered: Monitoring (Basic Sensors and CTA & Social Distancing), Object Sanitization, Air Sanitization, IoT, AI-Based Solutions, and Privacy Issues and Concerns. Many areas for further research specific to each technology were found, as the sheer number of technologies and aspects required an exponentially increasing number of areas to be considered.

There were several important limitations with this review. Perhaps the most important limitation was that the number of papers included was limited, as, despite attempts at focusing on the relevant high-quality literature, the multidisciplinary nature of the topic suggests an ever-increasing number of papers that could potentially hold relevance, but were missed. The delegation of quality assessment to IF systems was another limitation. Many of the reviews included methods at various stages of research and were not necessarily at a level of applicability. Yet another aspect was the fact that various review papers used different ways of categorizing their approaches. This made a complete and linear classification structure very difficult.

It was seen that a plethora of technologies exists to battle pandemics: masks, self-sanitizing materials and coatings, sanitization robots, sensors for gaining valuable information, and various advanced ways of monitoring contact and social distancing. This should show us that not only do we have the potential to truly curb transmission rates, but also prepare ourselves for later pandemics long before they develop. As the world tries to move on from the “COVID-19 era” to a “post-covid era” it is hoped that more complete attention is given to all possible preventive technologies. As time moves on, we will only be taking further virulent risks not only with various mutations of the current SARS-CoV-2 virus but also through the emergence of newer viruses. With complete and conscientious implementation, we can graduate from being a society that frequently deals with these viruses, to a society that is not only ready to deal with such crises but perhaps even prevents them.

To this end, various shortcomings within the literature were observed. Perhaps the biggest shortcoming was the lack of research concerning integrated systems beyond ideation. In more than one area (such as Monitoring, or AI), the testing of singular or very few technologies [39] together was prominent. Similarly, there was found a lack of Air Sanitization techniques that directly affected the air, such as AC systems or windows, hinting at a potential blind-spot in general scientific literature on the issue. Moreover, only a few systems where numerous technologies came together were attempted (i.e., CREW system, the extensive one-use biosensor made by LifeSignals Co., or the Safe Place Project [50], [21]). Meanwhile, furthering research on individual technologies was another area of potential research, especially in real-world environments, as there were found many technologies that currently did not make the cut for being realistically applicable in the real world. Distinctly, the field of robotics especially was seen to require further research on how to secure robotic systems. However, overall, the state of the literature currently seems to be that of an unmade puzzle, with various pieces such as biosensors, AI technologies, and tracking apps present, requiring putting together. IoT technologies, therefore, were seen as holding great potential, but currently lacking in research. Lastly, research in technologies and NPIs aimed at LIC was severely lacking. Research that utilizes present technological resources in areas where vaccines could not be procured should be seen as a critical area of research, as this situation not only goes unaddressed but also may create reserves for viruses, further prolonging our struggle with epidemics. As such, it is hoped that further research focuses on researching various integrated IoT systems and leveraging already existent technologies for underprivileged environments.

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