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Swarm Robotics in Healthcare: Coordinated Tasks in Hospitals

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ABSTRACT

Swarm robotics, inspired by the behavior of social insects, has emerged as a promising innovation in healthcare settings. In hospital environments, swarm robotic systems are utilized to streamline logistics, assist with repetitive tasks, and enhance operational efficiency while improving patient care. These robots work in collaboration with healthcare professionals, with semi-autonomous capabilities that allow them to perform tasks such as patient transport, medication delivery, and hospital disinfection. This paper examines the applications, challenges, and solutions associated with swarm robotics in hospitals, drawing from case studies and future research directions. The integration of swarm robotics promises to reduce hospital costs, improve workflow efficiency, and enhance both patient and staff experience, though careful consideration of technical, ethical, and regulatory issues is required for successful implementation.

Keywords: Swarm Robotics, Healthcare Robotics, Hospital Automation, Collaborative Robots, Patient Care, Disinfection Robots, Medical Logistics.

INTRODUCTION

Swarm robotics is a relatively new area of robotics that has evolved out of the principles governing the interactions between social insects. Although still in relative infancy, swarm robotics has shown promise for use in healthcare, especially within the clinical setting. The term 'healthcare swarm robotics' takes the principles discussed in regular swarm robotics but applies them to the healthcare or clinical domain. However, one main difference between regular swarm robotics and healthcare swarm robotics is that healthcare or clinical stakeholders only have so much tolerance for autonomy, so such systems are semi-autonomous intelligent systems. As such, for healthcare applications, swarm robotics is used mainly at the team level. This means that a surgeon, midwife, or medical doctor is fully in control of each robot inside the patient. Healthcare swarm robotics is the coordination of individual assistive robots offering support to a healthcare professional [1, 2]. In a hospital, there is a growing trend towards collaborative robots that work in collaboration with human staff to improve efficiency and patient care. Collaborative robots share the same workspace as human staff, are often flexible and mobile, and can adapt to new tasks. This makes them very well suited for working in unpredictable and dynamic hospital environments. A swarm robotic system is a team of very cheap, easy-to-replace, and easy-to-communicate robots. A system made of many such robots creates a pool of help, available on demand, anywhere on the hospital floor where the patients are. Thus, these systems are both resilient and adaptable, two important features in a hectic and unpredictable hospital environment. Another advantage of using swarm robotics is that they are very small. They can travel inside the veins, esophagus, or other parts of the human body to deliver drugs or perform operations. Moreover, these robots have short processing and reordering times. This is good because healthcare professionals in a hospital might not have a lot of time to ask for assistance [3, 1, 4].

Applications of Swarm Robotics in Hospital Environments

Swarm robotic systems for robots acting in coordination will have a significant impact on healthcare environments based on the application selected. Hospitals host a large number of patients and staff, which are interconnected through a logistics system. This logistics network could potentially be improved using a small robotic system sharing information with the hospital system in a privacy-preserving way. For example, a swarm robotic system can help streamline the processes of a hospital and make the process of delivering care to patients more efficient. The tasks that can be automated through these systems include patient transport, delivering medications to the wards, and even cleaning the hospital. This will not only reduce the workload of the hospital staff but also reduce the waiting time of patients and improve their comfort as a clean environment is maintained in the hospital [5, 6, 7]. All of these examples of swarm robotic systems applied to healthcare environments highlight how improved logistic processes have a social impact that is not necessarily directly linked to healthcare. We can reduce the number of staff necessary to run the hospital, which is a direct decrease in hospital expenditure. Hospital funds can be rerouted to patient care or hospital upgrades. Since the automated swarm robotic systems can operate for an extended time, we can improve staff and patient experience or create a safer space. This will have a positive impact on patient outcomes and the staff's professional growth. One thing to be aware of is when a swarm is useful in a hospital setting. The tasks that robots can do at the moment are mostly repetitive. Therefore, the system would work best if the swarm is managing the repeatability aspect of the workflow with as much human interaction as needed. Additionally, the logistics of the hospital would be the most useful task. There are situations where swarms have been introduced, so hospitals are an environment that swarms are capable of doing. These environments are mostly within the cleaning category. The best way to integrate hospital communication within the swarms is to communicate with the hospital systems; however, the level of authority needs to be predetermined. The level of participation in the ward process is to be determined. In one example above, the swarms are confined to the corridors, while in the other examples, they are allowed into the wards. This is what is considered by the health facility. Open spaces where patients and family are present are always up for inspection, even if they might not be occupied all the time. This is a measure to increase the security of the swarm and internal participants [8, 9, 10].

Challenges and Solutions in Implementing Swarm Robotics in Hospitals

Several technical and non-technical challenges need to be overcome before swarm robotics is used in a hospital environment. For the technical challenges, first and foremost, the communication and navigation of the swarm within the hospital must be robust and reliable. The localization of robotic units needs to be accurate, as each hospital has a different infrastructure and layout. Multiple technologies could be used as suitable communication devices and for accurate localization of the robots. The development of an interoperability mechanism between robotic units is another challenge since the use of multiple robotic units is more beneficial when chosen based on complementary abilities. The possible interest in floor-cleaning robots is a solution to be investigated. As for social interaction, hospital staff resistance is probably the most pertinent human consideration to be addressed for the employment of swarm robots in a hospital. The two categories of staff (experienced and beginner staff) must be studied. Consideration should be taken for those staff in favor of robotics. A representative sample of healthcare staff with work experience in a hospital producing medical waste would be suitable for a relevant and easily applicable study. The technological design should be robust to overcome human problems and advantages. Some design solutions that can be taken into account for these problems are: the robot should be able to continue acting at a functional level even if several robots refuse to act; the robot itself should also have an appealing design; the robot must act in a safe and user-friendly way. The iterative development of the system using feedback from practical experience is important for solving practical issues and should continue until the system is properly completed. The suitable technology must also incline towards overall balance as the diversity of users will mean multiple operation requirements. As for the financial side of things, detailed cost-benefit studies could be created. Robust design solutions can be achieved by considering that the actual robot employed for infection control will be working in close contact with people. A user-centered approach must be considered in terms of the physical design of the robotic units since operators will interact with the robots physically while unattended. The robots will physically contact patients when a bedpan is being exchanged or a room is being disinfected. Policymakers and other stakeholders must appreciate these barriers to the adoption of swarm robotics and take them into account to facilitate the successful transfer of these research results from academia into the marketplace, maintaining further research in this innovative area [11, 12, 13].

Case Studies and Success Stories of Swarm Robotics in Healthcare

This paper summarized several case studies describing the successes of swarm robotics in healthcare settings, together with lessons learned from each of these success stories. In brief, we look at automated disinfection, inventory management, and patient assistance use cases. Automated disinfection ring lasers with a wavelength of 266 nm, folded with mirrors for multi-angle irradiation, were chosen as illumination sources because they not only illuminate the operating room but also reflect strongly from walls, floor, ceiling, and surgical lamps. Our autonomous mobile robot is capable of driving between wards on any floor of a hospital while performing UV disinfection even during surgery. It cooperates with multiple mobile robots working on the same floor, following the same 2D path. A track is used with hot redundancy so that one or more lanes can continue to operate in the event of a track breakdown [14, 15, 16]. On the top deck are two LiDARs rotating 360 degrees to scan a total 14.25 m diameter UV disinfection range area with a horizontal field of view of 360 degrees, spaced 19.27 cm apart. A separate LiDAR scanner looks down towards the floor and is used for distance measurements and obstacle avoidance. The MRI and robot teams have not received negative feedback from other hospital staff members or patients about the presence or use of the autonomous UV disinfection robot during its partly pilot operation. No obstacles beyond the 5 cm atrium threshold have been experienced with the UV disinfection platform mobile robot. The UV disinfection platform robot has been operational inwards for an average of 5 to 6 hours every weekday and 3.5 hours at the weekend. The time the robot can be used is limited because it has to be controlled to not enter a room while a patient is under a surgical drape or being transported on the robot's adjustable top deck. Operating the UVD platform robot reduces the manual work of the assistants who go to the disinfected area sooner than if it would only be done manually. For a patient in a closed room, there is, on average, also a reduction of 15 minutes. In addition, it appears to be greatly appreciated by patients who like to perceive the hospital's approach as modern and innovative. The autonomous Navigating Indigo UVD robot creates a 6-log reduction if the robot stays in a space for a few minutes at a height of 2 meters with the UV unit elevated. This does not need to be in the same place for a long time, as the UV-C light directly disinfects the robot's own shadow, partially diffusing the light and surfaces. It has not been allowed to operate at a height lower than 2 meters, but there is no reason to assume that it would perform any differently. The faster-moving QSC unit at 1.5 meters high is expected to perform less well if the robot stops at an unfolded height of 1.5 m. This will generate educated guesses around the 3-log (99.9%) level, based on field evaluations performed at other sites [17, 18, 19].

Future Directions and Potential Impact of Swarm Robotics in Hospital Settings

The potential future work and direction will focus on using innovative technologies, such as machine learning and artificial intelligence methods, thus giving rise to super swarm robotics that can cope with more complex scenarios within a hospital and other various environments related to patient care and well-being. The current research in swarm robotics for terminal patients has shown that the results have the potential to provide welfare in a healthcare setting. Developing systems and proof of concepts that use advanced swarm features for prioritizing healthcare is still ongoing work. The results and ongoing research have demonstrated that there is a strong possibility for integrating adaptive technologies into healthcare infrastructures and existing policies for the benefit of organizations and patient health. The network of robots can expand patient care and efficiency in operations inside a hospital and has the potential to decrease stress and anxiety for patients, visitors, and staff. Predictions are that in the next couple of years, swarm robotics will have large integral systems for healthcare, providing multiple interconnected tasks for aiding in patient care, operational efficiencies, and staff support, to mention a few, in hospital settings. As adapted from other industries, the root management of an autonomous multi-robot network executing tasks in healthcare is instrumental as it is the core mechanism to maximize their potential and minimize threats. It will allow a balance between human interaction in the management of the robotic environment and creating a situation where practitioners can take more comfort in the safe execution of the multi-robotic interactivity, leading to the adaptation of the robots as systems to support patient care within a tertiary care setting, while being the first of its kind to involve the operational side of their interactions from a hospital informant point of view. Although swarm robotics have the potential to provide numerous benefits, it is imperative to hold the attitude of cautious optimism. Thus, even though swarm robotics pose great promise in the future healthcare landscape, they will need to succeed in the real-world environment and will certainly require further iterative trials. The e-readiness of both implementations can be benchmarked through the development and recital of empirically designed trials, which engage and learn from operational and public collaboration. At the same time, there is increasing attention towards critically attending to the ethical, security, governance, and regulatory dimensions of developing, implementing, and evaluating multimodal social robotics and advanced technologies in healthcare. Furthermore, the fine line between patient welfare and the dehumanization of care becomes foreseeable. A collaborative approach through a practice park and several stakeholders, from service designers to those who shape and manage robotic information systems, will need to be the focus for the design and implementation if it is to foster a contextual approach to technology development in healthcare. With the evolution of healthcare robotics connectivity to the main hospital network, guidelines and frameworks are called for to have a stronger data focus through consent-driven models and a revisit of the regulations, as robotics in healthcare settings has yet to manifest in this day and age [20, 14, 21].

CONCLUSION

Swarm robotics has the potential to revolutionize healthcare environments by automating tasks and improving hospital operations. Through applications such as patient transport, medication delivery, and disinfection, these robotic systems enhance efficiency, reduce staff workload, and improve the overall patient experience. However, challenges in communication, navigation, and social acceptance need to be addressed for broader adoption. Future advancements in swarm robotics, particularly with the integration of machine learning and artificial intelligence, could enable more complex healthcare tasks and provide comprehensive support to hospital staff. Despite the promising outlook, successful implementation requires overcoming technical, ethical, and regulatory hurdles, emphasizing the need for ongoing research and collaborative efforts among stakeholders to ensure safe and effective integration of swarm robotics into healthcare systems.

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