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Abstract

Drones have gained increasing attention in the healthcare industry for mobility and accessibility to remote areas. This perspective-based study proposes a drone-based sample collection system whereby COVID-19 self-testing kits are delivered and collected from potential patients. This is achieved using the drone as a service (DaaS). A mobile application is also proposed to depict drone navigation and destination location to help ease the process. Through this app, the patient could contact the hospital and give details about their medical condition and the type of emergency. A hypothetical case study for Geelong, Australia, is carried out, and the drone path is optimized using the Artificial Bee Colony (ABC) algorithm. The proposed method aims to reduce person-to-person contact, aid the patient at their home, and deliver any medicine, including first aid kits, to support the patients until further assistance is provided. Artificial intelligence and machine learning-based algorithms coupled with drones will provide state-of-the-art healthcare systems technology.

Keywords: Drone as a Service (DaaS), Artificial Bee Colony algorithm, Path planning, Drone delivery, Smart healthcare, COVID-19

1. Introduction

With the increasing number of COVID-19 cases in Victoria (VIC) and being the state with the longest recorded lockdown in the world, the Government of VIC must take stringent actions to minimize the spread of the disease and prevent such events from occurring in the future [1]. Drones may provide a solution to many of our everyday challenges and enhance contactless medical health services faster with minimum risk of disease transfer. This innovative technology involving drones as a service (DaaS) will save the lives of doctors and first-line responders, as they are in direct contact with the patients [2]. The self-testing kits will allow the patients to provide and test their samples and get accurate results within time. A simple color change will provide a positive or negative result. This can be the commonly used rapid antigen test (RAT) or other forms of rapid tests. The online paramedic will advise accordingly to use the medical supplies sent along with the drone. This will limit human contact and provide medical assistance to people at a distance.

The current study aims to provide a holistic mechanism for delivering COVID-19 self-testing kits to patients in Geelong, VIC, Australia. The drone path planning is carried out using Artificial Bee Colony (ABC) algorithms to optimize the distance and minimize the flight time to the target location. The drone path planning in this study uses Modified Artificial Bee Colony (MABC) algorithms to optimize the distance to the target location and minimize the flight time. Secondly, a mobile application that the consumers can download to facilitate the people to connect with the nearest hospital facility and inform them about the medical emergency is also proposed. The mobile application will provide tracking of the drone and estimated time to de-

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livery just like the food delivery apps commonly used in Australia, such as uber eats, menu log, etc. Hence, the study aims to optimize distance to the location, delivery time, and delivery cost with minimum environmental impacts. Further, reducing the number of resources required to deliver the kits lessens the economic burden on the health care system and lowers the carbon footprints.

The paper follows a standard format. In Section 2, the related work is reviewed based on existing technologies, and the associated challenges are identified. The methodology for drone optimization through the ABC algorithm is elaborated in Section 3. The results are summarized in Section 4, and Section 5 concludes the findings and provides future research direction for smart health care system applications.

2. Related Work

Healthcare sectors in countries across the globe experimented and tried to fight and manage the trajectory of this raging virus by using different techniques such as Artificial Intelligence (AI), Internet of things (IoT), Industry technologies 4.0, machine learning, and many more [3]. Putting AI-powered drones to use for fighting coronavirus to deliver self-testing kits is new, and this technique needs to be explored. The current study is focused on addressing this research gap. Drones are catering and responding to disasters and miscellaneous needs across the world. Virtual and augmented reality, Big9technologies, robotics, Artificial intelligence, drones, and many others are disruptive digital technologies whose initiation and application led to the amplified exploration of drones and other aerial vehicles for appropriate application in the world [4]. China, the first country to face COVID-19, implemented drone technology to overcome the spread of the virus. Since then, many countries have invested in research and development to explore ways to enhance the uptake of this technology [5]. To manage COVID-19 different technologies such as the Internet of Things (IoT) and 5G/6G communications have been implemented to reduce health, financial and political implications. The IoT provides an ideal network for monitoring patients remotely, drone delivery, managing health care, monitoring vaccines, and preventing the spread of COVID-19 [6].

Previous studies have proposed delivering health care assistance to patients in remote areas using drones. Different researchers have investigated daaS. However, delivering COVID-19 self-testing kits in the Australian context has not been explored. Various research and studies in different healthcare applications have suggested the implementation of mixed AI-powered drones and 5G, which could become the source of transforming this industry into a smart healthcare sector. The testing and exploration of drones for self-testing COVID-19 kit's shipment and collection to probably infected patients have not been done yet. This unexplored area addresses the uniqueness of this study. The study most closely related to the idea of using drones for care services distribution was carried out by Euchiber-attack [7]. Euchi suggested using drones for healthcare systems delivery to patients. In the study by Ullah et al. [8] a similar idea focused on a delivery system based on drones used for advertisements and delivery to clientele. However, the idea or implementation of an AI-powered sophisticated system designed to distribute COVID-19 testing kits to patients and then their collection from them and back to the clinics are yet to be explored.

The targeted region of this study is Geelong VIC, Australia. The primary goal of this novel study is to address the research gap and formulate a well-rounded mechanism for self-testing COVID-19 kit delivery to possible patients in the targeted region. The whole system of kit delivery and collection of COVID-19 samples from the patient to testing clinics will be an affordable and cost-effective solution which is another unique and important aspect of this study.

3. Methodology

There is a need for an alternative approach for safe sample collection and delivery to the laboratories. Unmanned aerial vehicles (UAVs) can be utilized in this scenario as they can contribute by visiting the house of suspected individuals and delivering the COVID-19 self-testing kits. Patients can use these self-testing kits, collect their samples, and return them to the labs or healthcare facilities by coupling them with AI-powered drones. As this method limits human-to-human contact, it is speculated that incidences of contracting CoronavirusCoronavirus at any point in the sample collection procedure can be minimized. St. John of God Geelong Hospital is the main base point with its helipad to launch and safely land drones. After safely delivering samples to the base point after completing the trip, the samples can be taken for further processing at COVID-19 labs in St. John of God Geelong Hospital. Figure 2 represents the scheme in a pictorial format. Three distinct routes start from the same base point or depot, with three different nodes where samples are collected and then back to the same depot. All the edges represent the distance covered by drones in their mission. St. John of God

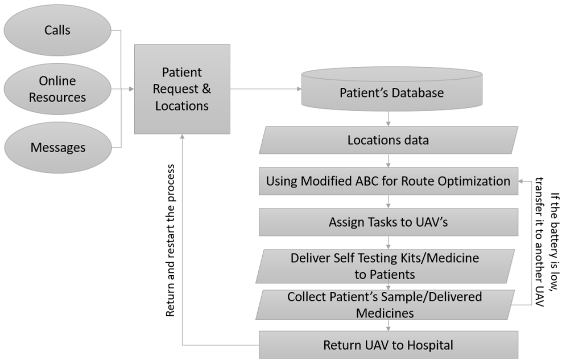

Figure 1. Holistic framework for delivery of payload using drones.

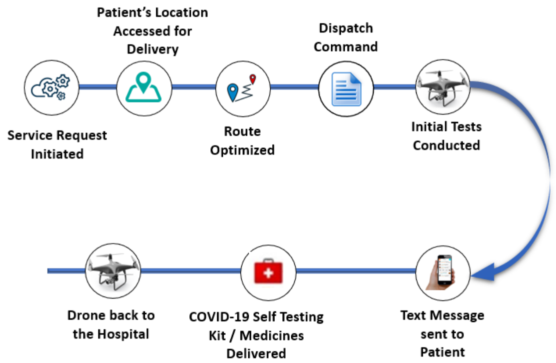

Figure 2. Flow of Kits/medicines delivery

Geelong Hospital is the base point or depot in this study. Nodes are the houses visited by drones for sample collection, and edges represent the distance covered.

However, a few shortcomings are linked to using drones for sample collection. As drones are made operational with batteries, they have a limited range of operation. There are different energy consumption factors that affect drone energy, such as drone design, its dynamics, environment, and delivery operations. Therefore, it must be considered that the battery stays operational during flight time. Flight time usually varies from 45 mins to 2 hours in many commercially available drones. Drones are in an operational state only for a short duration until the battery lasts. Therefore, these drones must complete the operation and return carrying the sample within the battery life. Because time is a limiting factor in this scenario, these drones must operate via the shortest route to deliver the testing kits and bring the samples back to the base point. This highlights the need to sort out the Vehicle Routing Problem (VRP), and as the drone can carry limited weight, the solution should focus on the Vehicle Routing Problem with payload weights constraints. VRP is a combinatorial optimization and integer programming problem which aims to find optimal routes for multiple vehicles. It focuses on minimizing the length of the longest single route among all the drones and completing all deliveries in the minimum possible time. Two objective functions were considered for the delivery and collection of kits for the patients.

1. Minimum total distance traveled by drones.

2. Minimum time required to deliver and collect kits.

3.1. Proposed Drone-based COVID-19 Kit Distribution and Collection System

Figure 2 describes the on-demand drone-based system design for the most optimal routing of drones for promptly distributing and gathering the COVID-19 kits to the patients. This system ensures a step towards a better and smarter health care system. The system has five steps, as shown in Figure 1, starting with a request from patients, drone routing, and finally collecting and flying the sample back to the collection center. Figure 3 shows the interface of the proposed app. The system steps are explained below:

1. Initiation of a request from the patient via video call to medical staff self-testing kit/medicines.

2. Patient's location and finding the most optimized route to dispatch the kit.

3. SMS is sent to the patients that the drone will be flying to their address for dispatching the Kit/medicines.

4. The drone lands on the target location with the kit and instruction manual. The drone has a camera, sensors, and microphone to facilitate interaction with the patient and safe delivery.

5. Drone can be re-routed to a new location depending on its battery time and weight constraints or will route back to the hospital

3.2. Proposed Path Planning Approach

The study aims to optimize drone routing and path planning by implementing the Artificial Bee Colony (ABC) algorithm. The ABC algorithm mimics the

Figure 3. Mobile interface for "Your online doctor" application

searching behavior of honeybees and is a global optimization algorithm. The ABC algorithm was proposed by Karaboga [9] for numerical optimization, and combinatorial optimization problems by Pan et al. [10]. The ABC algorithm has been utilized for unconstrained and constrained optimization problems [11]. The algorithm is based on three main parameters, i.e., population size, maximum cycle repeats, and limits that the user can adjust.

The model consists of three components: employed foraging bees, unemployed foraging bees, and food sources. In ABC, the agents (a colony of artificial forager bees) search for the optimum solution for a given problem (i.e., rich artificial food source). For the application of ABC, the optimization problem is converted into a problem of searching for an optimum parameter vector, thus minimizing an objective function. Algorithm 1 gives an overview of the proposed approach.

3.2.1. Global Optimization Problem

For global optimization problem the parameter vector is defined as $\overrightarrow{x}$ that minimizes an objective function $f(\overrightarrow{x})$ defined as:

$$\min f(\vec{x}), \quad \vec{x} = (x_1, x_2, \ldots, x_i, \ldots, x_n) \in \mathbb{R}^n, \tag{1}$$

following the following constraints:

$$l_i \leq x_i \leq u_i, i = \{1, \ldots, n\}, \tag{2}$$

$$g_j(\vec{x}) \leq 0, j = \{1, \ldots, p\}, \tag{3}$$

Algorithm 1 ABC algorithm for drone path planning

Initialization:
Initialize the population and Evaluating the fitness function
Calculate the value for initial cost function
Set best solution: $Solbest \leftarrow Sol$
Set the maximum number of iterations;
Set population size = PS
$PS = Onlookerbee = EmployedBee$
$Iteration \leftarrow 0$
Improvement:
while $Iteration < NumOflte$ **do**
  for $i = 1 : EmployedBee$ **do**
    Select a random solution and apply random neighborhood structure
    Sort solutions in ascending order based on penalty
    Determine probability for each solution using: $P_i = \frac{\Sigma[\frac{1}{fit_i}]^{-1}}{fit_i}$
  end for
  for $i = 1 : OnlookerBee$ **do**
    $Sol^* \leftarrow$ Select the solution who has the higher probability
    $Sol^{**} \leftarrow$ Apply random number on Sol^*
    if $Sol^{**} < Solbest$ **then**
      $Solbest = Sol^{**}$
    end if
  end for
  $ScoutBee$ determines the abandoned patient's location and replace it with the new patient's location
  $Iteration++$
end while

$$h_j(\vec{x}) = 0, j = \{p+1, \ldots, q\}. \tag{4}$$

Here, $f(\overrightarrow{x})$ is defined within search space, S (a n-dimensional rectangle in $R^n|(S \subseteq R^n)$. The lower and upper bounds limits the variable domains (2), known as a constrained optimization problem. While both $p = 0$ and $q = 0$ for unconstrained problem. Where l_i and u_i are the lower and upper bound of the parameter $x_m i$, respectively.

3.2.2. Initialization Phase

During the initialization phase, food sources for each employed bee are generated. Food source generation depends on the type of problem under consideration. The following definition can be used for initialization:

$$x_{mi} = l_i + rand(0,1) \times (u_i - l_i), \tag{5}$$

Table 1
Simulation parameters and values Parameter Value

Parameter	Value
No of bees(NB)	20
Food Sources (FS)	NB/2
Employed bees (n_e)	50 % of total bees
Onlooker bees	50 % of total bees
Scout	1
Limit	(n_e * D)

where l_i and u_i are the lower and upper bound of the parameter x_{mi}, respectively.

3.2.3. Employed Bees Phase

In this phase employed bees search for new food sources in the neighborhood. The food source is replaced with better food source having more nectar. For example, they can determine a neighbour food source $\vec{\upsilon_m}$ using the formula given by equation (6) and then evaluate its profitability (fitness):

$$\upsilon_{mi} = x_{mi} + \phi_{mi}(x_{mi} - x_{ki}). \tag{6}$$

All these parameters are randomly selected where $\vec{x_k}$ is a food source, i is a parameter index and $\vec{\upsilon_m}$ is a number within the range $[-a, a]$. The fitness of the new food source $\vec{\upsilon_m}$, is calculated with a greedy selection applied between $\vec{\upsilon_m}$ and $\vec{x_m}$.

For the minimization problem, the fitness value of the solution, $fit_m(\vec{x_m})$, may be calculated as given by the following:

$$fit_m(\vec{x_m}) = \begin{cases} \frac{1}{1+f_m(\vec{x_m})}, & \text{if } f_m(\vec{x_m}) \geq 0, \\ 1 + |f_m(\vec{x_m}))|, & \text{if } f_m(\vec{x_m}) < 0, \end{cases} \tag{7}$$

where $f_m(\vec{x_m})$ is the objective function value of solution $\vec{x_m}$.

To handle the constraints dynamic penalty method was used. A logistic map was applied along with the Levy flight in the employed bee phase. For the onlooker, bees were adopted based on selection probability and search mechanism learned from the best solution and neighboring food sources. Furthermore, the boundary handling mechanism inspired by the best solution was applied to repair the invalid solutions.

3.2.4. Onlooker Bees Phase

The onlooker bee perceives information from the employed bee based on which it select its food source. The probability value pm with which $\vec{x_m}$ is chosen by an onlooker bee is given as:

$$p_m = \frac{fit_m(\vec{x_m})}{\sum_{m=1}^{SN} fit_m(\vec{x_m})}. \tag{8}$$

3.2.5. Scout Bees Phase

When the neighborhood food sources are explored to their maximum, they are abandoned. Then the scout bees start looking for random food sources, just like in the initialization phase. For instance, if food source/solution $\vec{x_m}$ has been abandoned, the scout being the employed bee of $\vec{x_m}$ provides a new solution given by equation (5).

4. Results

We have benchmarked our proposed modified version of the ABC algorithm against Augerat et al. [12]. All benchmarks were implemented using python on a core i7 processor with 16 GB RAM. An equal number of employed bees and onlookers are assigned to the number of food sources (in this case, houses to be visited). Karaboga and Basturk [11] are the sources for this evaluation.

To simplify the number of factors, the number of employed bees equaled the number of onlookers. An optimum search convergence speed was found with a colony size of 50 bees (as per algorithm initialization). We have taken a case study of Geelong city to evaluate our approach. A novel path planning approach is required to deliver medicines and vaccines to patients at multiple locations. We have performed multiple experiments to evaluate ABC for optimal vaccine/medicine delivery in COVID-19-affected areas. For one of the experiments (as shown in Figure 4), we have considered 34 patients' locations and 5 drones, which can carry a 400 grams payload (weight of kit/medicines). Figure 6 shows the paths of the 5 delivery drones used for vaccine/medicine delivery in Geelong. Figure 5 depicts fitness function converging to the minimum overall cost over increasing epochs. The main aim is to minimize the distance covered by the vehicles with a constraint on payload weight, which is restricted to 400 grams per drone.

Table 1 shows the complete evaluation of our proposed ABC algorithm for the payload weight constrained drone path planning problem for the delivery of vaccine/medicine. It summarizes different experiments with varying numbers of drones and delivery locations. With the payload limit of 400, a fleet of 10 drones could visit a maximum of 64 houses with an optimal cost of

Table 2
Overall evaluation of modified ABC for drone path planning

Case	No. of Houses	No. of Drones	Payload Limit	ABC Cost	Time (s)	Optimal Cost	Error
1	34	5	400	899.86	40.56	789	0.140507
2	36	5	400	812.56	43.01	698	0.164126
3	38	6	400	1019.33	44.69	813	0.253788
4	43	6	400	997.33	53.99	973	0.025005
5	44	7	400	1259.36	60.46	1113	0.1315
6	45	7	400	1021.47	74.65	998	0.023517
7	56	9	400	1147.89	97.12	1079	0.063846
8	61	9	400	1489.67	121.03	1360	0.095346
9	63	8	400	1498.42	117.56	1232	0.21625
10	64	10	400	1496.34	124.98	1354	0.105126

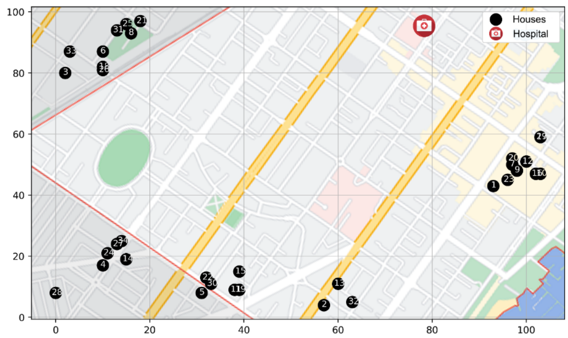

Figure 4. Houses and St. John of God Hospital Location in Geelong – Victoria.

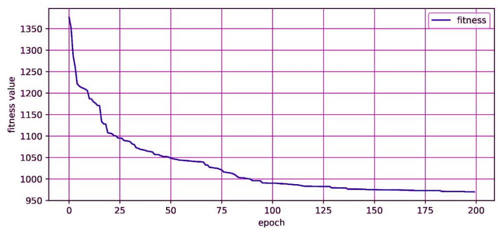

Figure 5. Fitness function of Artificial Bee Colony for drone path planning.

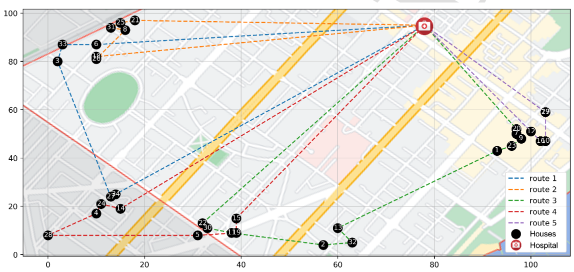

Figure 6. Drones route optimization using modified ABC Algorithm to deliver payload across Geelong - Victoria.

1354 and an ABC cost of 1496.34. Whereas with a minimum fleet of 5 drones, the total number of houses covered by the drone was 36, with an optimal cost of 698 and ABC cost of 812.56.

The optimal solutions are calculated using the work in [12]. This is the best-known approach for the most optimal solutions. The problem with such linear approaches is that the computations increase exponentially with the increase in the number of drones. With 6 drones, the simulations take hours, which is not tolerable for real-time solutions. Metaheuristics like ABC provide us with near-optimal solutions in seconds, as shown in Table 1. The error is very little, considering the time consumption. Error is calculated as:

$$error = \frac{ABC\ Cost - Optimal\ Cost}{Optimal\ Cost}. \quad (9)$$

5. Conclusion

This study proposed a holistic mechanism for delivering kits to patients in Geelong, VIC, Australia. The study aimed to optimize distance to the location, delivery time, and delivery cost with minimum environmental impact using the ABC algorithm. Keeping the payload constant, the fitness function converged to the minimum overall cost over increasing epochs and minimizing the distance the vehicles covered. The drones will cut the pollution caused by the vehicles and reduce greenhouse gas emissions into the environment. Applying metaheuristics like ABC provided near-optimal solutions in seconds with reduced error.

Thus, the study brings AI-powered drones to deliver self-testing kits, inference of tests, and online assistance from the paramedic. This study will have social, environmental, economic, and commercial prospects in the future. The delivery through smokeless vehicles will reduce the carbon footprint. This cutting-edge technology can be easily implemented in different countries and may foster future international collaboration and prospects for business opportunities. The proposed method is a dynamic addition to the rules and regulations taken for curbing the spread of a pandemic and a step towards improved smart health care systems. For future studies, the proposed method will be practically implemented in remote areas to facilitate the delivery of supplies.

Acknowledgment

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Conflict of interest

The authors declare that there is no conflict of interest in this paper.

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June 30, 2022

Editor-in-Chief
ICT Express

Dear Professor,

With humble submission, I would like to present the following revised manuscript for possible evaluation and publication in your prestigious journal. I believe we have carefully addressed all comments from the reviewers and sufficiently improved the overall quality of the manuscript.

Also, I affirm that the manuscript has been prepared in accordance with the Instructions for Authors provided by your journal. The manuscript has been double-checked by the main author and the co-authors, and we hereby affirm that the contents of this manuscript have not been published in a refereed journal, and it is not being submitted for publication elsewhere.

Yours Sincerely,

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Declaration of interests

☒ The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

☐The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: