UNIVERSIDADE TECNOLÓGICA FEDERAL DO PARANÁ
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MOBILE SYSTEM FOR OPTIMIZED PLANNING TO DRONE FLIGHT APPLIED TO THE PRECISION AGRICULTURE

TRABALHO DE CONCLUSÃO DE CURSO

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Trabalho de Conclusão de Curso, apresentado ao Curso de Especialização Java, da Universidade Tecnológica Federal do Paraná, *Campus* Pato Branco, como requisito parcial para obtenção do título de Especialista.

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TERMO DE APROVAÇÃO

MOBILE SYSTEM FOR OPTIMIZED PLANNING TO DRONE FLIGHT APPLIED TO THE PRECISION AGRICULTURE

por

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A avaliação deste trabalho de conclusão de curso foi realizada em 02 de março de 2020, como requisito parcial para a obtenção do título de especialista em Tecnologia Java. Após a apresentação o candidato foi arguido pela banca examinadora composta pelos professores Fábio Favarim (orientador), Andreia Scariot Beulke e Vinicius Pegorini, membros de banca. Em seguida foi realizada a deliberação pela banca examinadora que considerou o trabalho aprovado.

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RESUMO

Este artigo apresenta o desenvolvido de um aplicativo móvel para otimizar o voo de *drone* em um cenário de agricultura de precisão. A plataforma Android foi escolhida, pois possui ferramentas gratuitas para o desenvolvimento e existem muitas *APIs* diferentes que podem ser usadas para resolver esse problema. Para a apresentação do mapa, bem como a manipulação de geocodificação, foram utilizadas as ferramentas da Google. Para a otimização, foi utilizado um algoritmo baseado em leilões recursivos, que possui a característica de encontrar soluções viáveis, mesmo em cenários complexos. O aplicativo foi testado e alcançou resultados exequíveis para grandes cenários com mais de mil pontos de referência em apenas alguns instantes, mesmo rodando em um dispositivo móvel. Destaca-se o aplicativo e o algoritmo de leilão recursivo, é uma solução importante para a otimização de voos com *drones* em áreas rurais, onde geralmente não há possibilidade de executar o aplicativo em computadores tradicionais, pois geralmente não há acesso à Internet.

Palavra-chave: *Android*, *Drone*, Veículo aéreo não tripulado, Otimização de voo, Agricultura de precisão, Leilão recursivo

ABSTRACT

This paper presents a mobile app developed to optimize the drone flight in a precision agriculture scenario. The Android platform was chosen, once it have free tools for development and there are many different API that could be used to solve this problem. For map presentation, as well as geocoding manipulation, Google tools were used. For the optimization, an algorithm based on recursive auctions was used, which has the characteristic of finding feasible solutions even in complex scenarios. The app has been tested and achieved feasible results for large scenarios with over a thousand waypoints in just few minutes, even running on a mobile device. It highlights the mobile app, and the recursive auction algorithm, it is an important solution for drone flight optimization in rural areas, where thereis usually no possibility to run the application on traditional computers, as usually there is no access to the Internet.

Keywords: Drone, Android, Flight Optimization, Precision Agriculture, Recursive Auction

LISTA DE FIGURAS

LISTA DE SIGLAS

API	*Application Programming Interface*
SDK	*Software Develpment Kit*
OS	*Operating System*
UAV	*Unmanned Aerial Vehicle*
UTFPR	Universidade Tecnologia Federal do Paraná

SUMÁRIO

1. INTRODUCTION

In recent decades, Unmanned Aircraft Systems (UASs) have been used in a growing number in military and civilian applications. These are characterized as Unmanned Aerial Vehicles and can be controlled by a remote control, embedded computer or even via a terminal. In an UAS, two types of Unmanned Aerial Vehicles (UAV) are commonly used, which can be vehicles known as fixed wings, similar to small aircrafts, the other one is named rotary wings, which have pairs of propellers. The last one is popularly known as Drones. According BASTIANELLO (2012), highlights that there is a very high demand for the use of Drones, in the military field for reconnaissance and missions, as well as in the civilian field, in applications such as environmental monitoring, mapping and precision agriculture. According to NETO (2005), the concept of precision agriculture is usually associated with the use of high-tech equipment to evaluate or monitor conditions on a given part of land, and based on these data resources are applied to the land according to its real needs for it.. These resources can be seeds, fertilizer, water, among others. Drones have been highlighted in the agriculture scenario, according George (2013), having reported that they are the best platforms for evaluating production, presenting efficiency and speed above the techniques already in use today, allowing the reading of data in any kind of environment or ground surface. But there are some limitations in the drone handling, such as control accuracy, ability to adapt to faults, safety and flight range. It should also be considered the fact that must be carefully handled, which has, for many years, making it difficult to be approved for commercial use in many countries, such as Brazil FAB (2015), where this research was conducted. Considering these limitations, it is important to have ways for a good management of the flight and supervising how it is working to get the best results, as well as capturing this data for further processing and analysis, obtaining relevant results in order to achieve the optimization goals regarding results in the agricultural environment. The application of fixed wing UAVs in the precision agriculture is already common, however, authors as Avellar (2015) report that this type of vehicle has a high setup cost, and need an exclusive human operator per aircraft, in operations such as taking-off and landing, which take place horizontally and can hardly occur autonomously given the characteristics of the terrain in the scenarios where precision agriculture applies. On the other hand, Drones have vertical take-off/landing operations, making it easier for these operations to be autonomous (LEE, 2014), as the process of autonomous recharging of its battery (LOUREIRO, 2019). Another advantage in using drones in precision farming is that your flight can take place at slow speeds, and it can stop in the air, going up or down, allowing reading more detailed or more generics, depending on the needs. The advantages of Drones over fixed wing vehicles are varied and are highlighted in (BRITO, 2019). However, probably the biggest advantage when using drones over fixer-wing is in the possibility of using multiple drones, all flying simultaneously, with little to none human interaction. In order for this to happen in an optimized way, there is a need of a flight optimization platform for groups of drones, which must be fast in order to recover from adverse events, and light, so it can be executed in smartphones this being the best computing platform for executing the software at the rural area, even without the processing power of some personal computers, and it has an user-friendly interface along with bluetooth or wifi connectivity, which allows sending data to external devices such as robots and drones.

Thus, the present work presents a platform developed for smartphone, which runs to optimize the flight for a Drone in a precision agriculture scenario. The focus of this work is present an Android Application that is able to run a optimization algorithm and show on feasible plan of flight for Drone. The focus is not on its usability, but on the algorithms used for it. The application allows to inform the area of land that will be monitored by Drone, as well as the accuracy of the readings, which is used to create the ways-points that will be overflown for drones. This path plan is done using a based recursive auction algorithm for the optimization. This path plan could be sent to the Drone through WIFI or Bluetooth connection.

2. RELATED WORKS

In the literature there are many works that use autonomous vehicles, cooperating one with each other to develop a mutual activity, working together and exchanging information about the mission. It can be highlighted the systematic mapping developed in (BRITO, 2017), which informs that 70% of the researched works that use vehicle cooperation are using Drones or other air vehicles for cooperation. Some of these works, in particular, are focusing on the cooperation algorithm,, but no one presents the use of a mobile device, such as a smartphone, to perform the processing and optimization for the system.

One of the most significant researches was developed by [5]. This author worked with the cooperation of two Fixed Wing UAVs applied in precision agriculture. The author divides the problem into two parts: first, he uses the principle of particle flow to make Fixed Wings attracted to points they need to pass - waypoints. It then uses an optimization algorithm developed in Mixed Integer Linear Programming (PLIM) to perform the flight optimization of the two UAVs, since the waypoints and the landing and takeoff locations are known. Among the limitations of the work is the fact that it is developed for only two Fixed Wings, besides being a static model, so, before the flight, is executed a PLIM algorithm that generates the flight plans, which will later be executed by the UAVs, so, the processing is done in the computer, with no graphic interface, using only programing language, and after the processing, the result are programmed in the UAV. According to the author, the number of two fixed wings is ideal for cooperative flights in precision agriculture, because the higher the number of fixed wings, the greater the complexity and the total cost of the system. Fixed Wing Flights have a high cost to setup the aircraft, as well as the need for takeoff and landing intervention. Increasing the number of Fixed Wing increases the number of system operators. According to the author himself, in a research conducted for the development of his work, the justification for using Fixed Wings on cooperative flights is because most of the scientific work developed between 2005 and 2015 used this type of vehicle. Although the author uses Fixed Wings, he highlights its limitations, such as restrictions related to the minimum speed of the aircraft that cannot be below a certain limit to avoid the risk of falling and the non-detailed reading of data by high flight speed. In general, it is possible to observe that few scientific papers deal with rotative wing flight optimization, either, all of this works show presents the algorithm for optimization, but, not how this optimization could be done in a rural environment, with no computers or networks. Also, it is possible to verify that no article studied deals with the dynamics of the environment, a very common problem faced in real flight environments. It is believed to be because most works deal with pre-optimization rather than optimization during system execution.

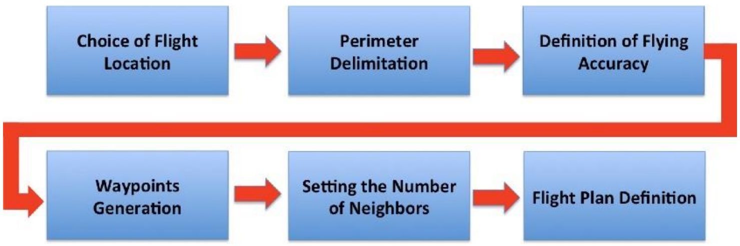
3. SYSTEM DESCRIPTION

According to (PIETERSE; OLIVIER, 2012), smartphones are classified through the operating system installed on the device, being the most popular Apple iOS, Google's Android OS, Blackberry's RIM OS and Microsoft's Windows Mobile OS. Android is prevalent in the market, and projections point out that for many years this will remain the leader, due to its openness and ease of customization, putting it ahead of other operating systems (LIU; TSENG, 2012). Thus, for the development of the app, we used the Android platform, because it has free tools for development and has numerous libraries for use and manipulation of geographic data. The main objective of this mobile application is develop an app like a Wizard, that allow the user inform data about the area that will be overflown, as the feature about the how will be this optimization. For this reason, we opted for the development of several screens, however, each one requesting few information from the user, and at the end of the process, a flight plan will be generated for the Drone, which can be sent over a wireless connection, most often the ad hoc WIFI network created between the Drones and the Android Device.

A. App Development Methodology

The blocks for generate the flight plans are presented in Figure 1.

Figure 1. Flow Diagram among--Screens



Source: Authored by the author.

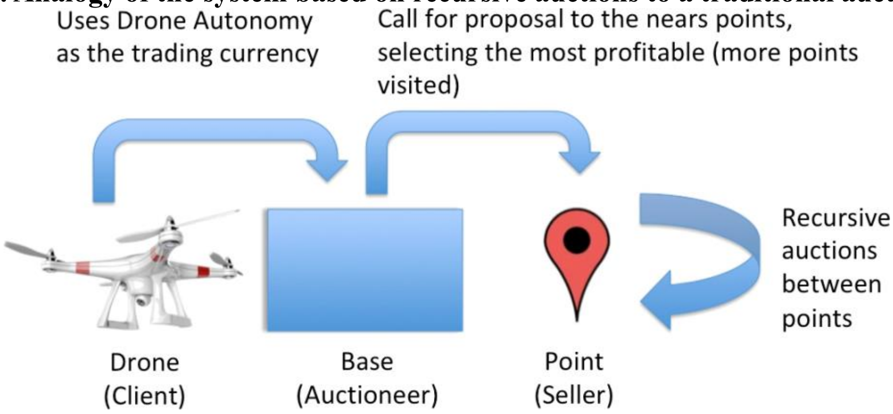
How presented in the Figure, to define an optimal flight plan are required six steps on the mobile app. To improve the Graphic User Interface for this app, map features as Google Maps version 16.0.0 were used. The first step of the wizard is define the location where the monitoring will be performed. The user can enter a specific address, or enter the name of a city or town. For map manipulation we use geocodes, which represent any position of the globe using latitude and longitude.

To transform textual data, such as an address, into geocode, we used in the app an API called Google Location and Activity Recognition, After, the map is displayed on the app with the position entered in the first screen on the center. The user also can navigate on the map, using features of the Google Maps API itself, such as zoom and navigation. Next step will be inform the perimeter of the location that will be overflown. For it, the user will click on the vertices of the area to be mapped, forming a geometric figure on the map. To visual mark of these vertices on the map, a non-dragging marker feature of Google Mapswas used, and for the perimeter line drawing, the library's Polyline feature was used. After we define the perimeter, the user have to click at the button located in the lower right, after that, the mobile application calculates the internal points for the selected area. This points is called waypoints. To calculate the waypoints the mobile application needs to respect the distance among the points, for it, we using the Android class Location . At the ende, this points are displayed on the screen and it is validated through the Maps Utils API. These points are drawn on the screen from a pivot point, which consists of the lowest longitude and lowest latitude added to a coefficient between the user-entered distance and the radius of the Earth, where the next point will be the previous longitude, plus this coefficient. This process is repeated until the longest edge is reached. At this point, the coefficient is added to latitude and the process is repeated from the shortest to the largest, always adding the coefficient to longitude, performing the process to the value generated. be larger than the highest latitude edge. After completing the point calculation step, the user have to click the right aligned button in the application Toolbar which will present a dialog box asking to the user how many nearby points (k) should be calculated by the application. After informed the k value, the application persists all of this data: the points and its neighbors. To persist, we used SQLiteDatabase feature, that initially save the information on the smartphone, and after, share this information using wireless with the Drone. The user can see the mapping again, or another old one, through the SideMenuBar¿ Mappings, which presents the list of mappings already made and stored in the local database. To choose the k nearest neighbors, one of the most costly parts of the processing, we needed to calculate the distance between points using the mathematical formula:

*acos (sin (lat / 180.0 * PI) * sin (lat / 180.0 * PI) + cos (lat / 180.0 * PI) * cos (lat / 180.0 * PI) * cos ((lat - lat) / 180.0 * PI)) / 180.0 / PI * 60 * 1.1515 * 1.609344.*

This formula will return the distance in meters between the points. Having calculate the distance between one point with all of the other points in the scenario, it necessary to do a simple sort on the list to identify the closest points. Finally, based on this information, the recursive auction algorithm will be applyed, which will run until its found a optimal result or until a timeout is reached. This timout can be informed by the user on the mobile app. This algorithm will return a path, similar to the Hamiltonian Circuit, which basically consists of passing through all points in the map only once and return to the starting point. Algorithms for finding optimal solutions for a Hamiltonian circuit usually are very slow, incompatible for mobile processing in a smartphone, and do not consider dynamics in the environment, such changing the value of the Hamiltonian circuit edges, that we have in the scenario of Drone flight in the Precision Agriculture. This edge values could be wind speed and direction, which is often dynamic.

Figure 2. Analogy of the system based on recursive auctions to a traditional auction.



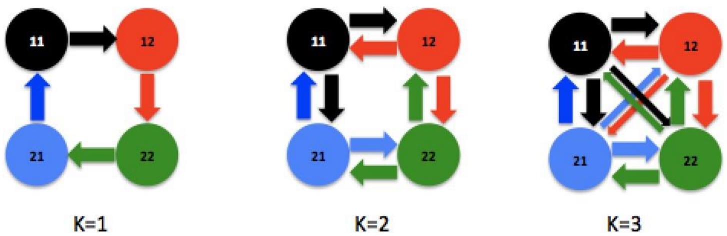
Source: Authored by the author.

The recursive auction algorithm adopted by this scenario works independently of the number of points to be visited, and works even when have changing in the scenario, once it is a dynamic algorithm. With the recursive auction algorithm, it is possible, for example, to increase or decrease the number of waypoints, as well as the costs of moving from one point to another.

B. Methodology for Optimization Algorithm Development

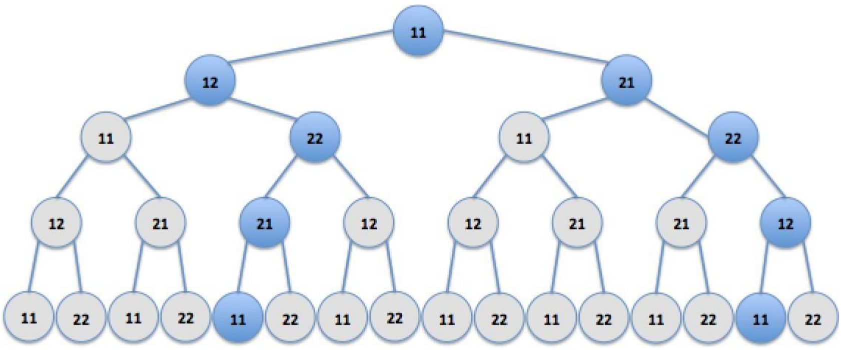
To be possible for such optimization in a dynamic environment in which UAV group flight is applied to precision agriculture, it is necessary to choose and test a fast, dynamic optimization algorithm that can be easily distributed on different processors. The proposed algorithm for this work is the recursive auction based optimization algorithm, presented in detail in this section and evaluated in the following session. This algorithm is relatively simple to apply in distributed computational systems from the FIPA Contract-Net protocol and allows the communicate within the system regardless of the amount of elements that may vary over time. According to (PIPPIN; CHRISTENSEN, 2012), auction-based trading methods are often used to perform the distribution of tasks assigned to teams with dynamic elements. Analyzing the problem in which the proposed system applies, it is possible to observe an analogy to a traditional auction - Figure 4, in which the UAV would be the consumers, and have as their trading currency their autonomy. They share this information with the bases of refills, which have the role of auctioneer that offer these resources to those interested by the auction, which in this analogy are the points that wish to be visited. Each point receives the proposal for the Drone's visit, and the applicant responds to the cost to be visited, as well as how many unique points will be visited on the same flight. The best proposal is chosen based on the desired objective function. In the proposed system, the objective function is to maximize the number of visit points in a single flight. If we run the auctions exhaustively, testing all possible possibilities, we can find the best result for the scenario, but in this situation we have the same problem as the classic algorithms proposed to find solutions to the TPS problem, for example: time Processing is disproportional, so in a scenario with a few dozen points, a normal computer cannot find results in a feasible time. To decrease computational complexity, heuristics can be used to decrease processing time without significantly compromising the result found, as well as meta-heuristics can also be applied to heuristics, allowing to considerably improve results without significantly compromising processing time.

Figure 3. 4 point scenario, with k ranging from 1 to 3.



Source: Authored by the author.

Figure 4. Graph with the possibilities of displacement of a drone considering



Source: Authored by the author.

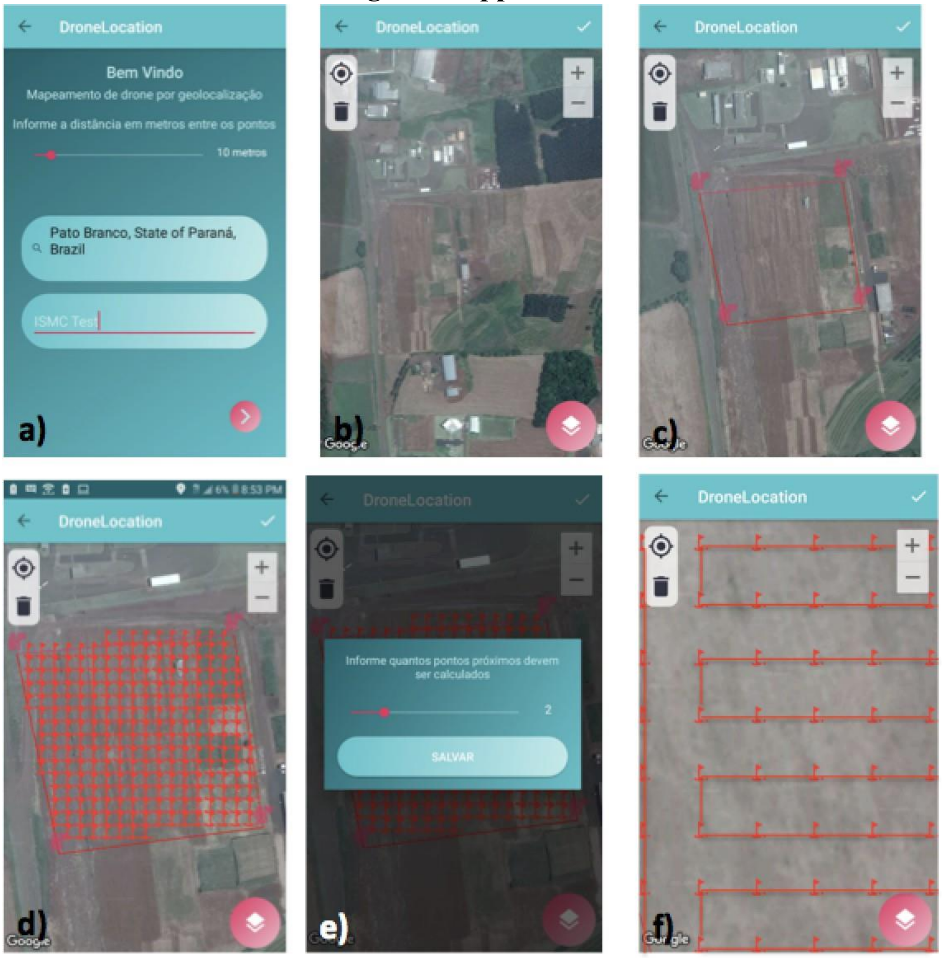
The problem presented where a UAV should visit a known number of points only once and return to base is similar to the resolution of the Hamiltonian circuit, where we have a graph in which the vertices are the points to be visited. Edges are the paths between one point and another, and the UAV, in turn, has to make the decision as to which points it can visit, optimizing flight time, and consequently the use of its battery. The Drone has to go through all points only once and return to the recharge base.

A system constant that directly influences response quality as well as processing time is the *k* constant, which represents the number of neighboring points that a given point can visit and, consequently, the number of auctions that the point will make. If we use *k* with small values, results are found at a shorter processing time, but if we use *k* larger, better results tend to be found, but with longer processing time. Figure 3 presents examples using k = 1, k = 2 and k = 3 for a 4-point scenario. Considering this same scenario with four points to be visited, and with a value of *k* equal to two, and considering that the base of the UAV is in point 11 of the figure, we will have a graph representing the possible visits of the UAV according to Figure 4. Note that the height of the tree is the autonomy of the drone, that is, the amount of points it can visit. The opening factor of this is 2, which is the constant *k*. For a scenario with 4 points to be visited: 11, 12, 21 and 22, 30 auctions (graph edges) were required, in which case 2 global optimal solutions (darker points) were found, which ensure that the UAV passes through all points and return to the starting point. For the recursive auction of the presented graph, it is considered that the base is at point 11, just like the UAV, thus, it requests the two nearest neighboring points proposals for the UAV visit. These points respond with the Drone's travel cost to them, as well as the Drone's return cost to base. Drone being left autonomous, each of these neighboring points start a new round of auctions, asking their neighbors for new proposals for Drone's visit, with the most lucrative bid being chosen (lowest cost with the largest number of unique points visited) and returned to the point you requested. This sequence of auctions happens exhaustively as long as there is autonomy in the Drone, which ensures that the optimal solution is found. This process is done by considering the starting point of each base point of the scenario, finding the best solution for each point, as well as the best position from point to base. Regarding the number of auctions executed, for the scenario presented, 30 auctions are held for each point chosen as the starting point of the Drone, as there are 4 points, in total there will be 120 auctions for this scenario. Thus, one of the heuristics adopted to decrease the number of auctions is to choose, by another algorithm or technique, a point to be the starting point of the Drone, and there is no need to test all possible possibilities, for this purpose. In the 4-point scenario, for example, there is a 75 % decrease in the number of auctions, and this decrease difference is even greater for larger scenarios. Since the goal is to make an optimization in which the UAV must visit each point once, another time-optimizing heuristic can be adopted: to make each visited point not receive new requests for visits, that is, a great pruning using this one heuristic happens. Initially, before the heuristic that prevents a point from being visited twice there were 30 auctions, after the application of this heuristic, the number of auctions fell to 8, a reduction of 73.33 %, and for larger scenarios, the reduction in number of auctions is even higher. The next session will present the result of applying the auction-based optimization algorithm features for some preestablished scenarios, with performance testing.

4. RESULTS

As a result of this work, we have an Android mobile app that is able, through a simple and interactive interface, to request data for a rural area that needs to be overflown by a Drone, and then generates a feasible flight plan, not necessarily optimal, that allow the drone flight above all the waypoints, returning to base at the end of the mission. The application consists in a sequence of screen, these shown in Figure 5. As we can see, the Screen a) requests a textual identification of where the Drone mapping will be performed. This can be the name of a city or an address. A name for the location is also requested, which will be used for persistence in the cell phone database. In the first screen is requested the accuracy of reading data in meters. On the next step - screen b) the map with the location entered on the screen a) is shown. In this screen, the user can navigate and use the zoom. In c) the perimeter of the area where it will be overflown is defined, and in d) the waypoints are presented considering the reading accuracy informed on the screen a). In e) is requested the number of neighbors that will be considered in the processing of the recursive auction optimization algorithm, and at finally, in f) is presented part of the screen with the flight plan, showing the points where the Drone should pass in the area that will be monitored.

Figure 5. App Screen



Source: Authored by the author.

Due to the small size of the mobile screen, it is not possible to see the flight route for the example presented above, which is a 340x340m, ie it has 34x34 waypoints, totalizing 1.156 point at all. We used a program to delimit this area and put all the point with 10 meters of precision. Considering these 1,156 points, and using 4 neighboor for each point, we used the optimization algorithm based in recursive auction to return the best way to pass in all of this 1,156 point only one time. After 176 seconds of processing the algorithm found the first optimal situation. The be easy to see the way, we put in a simulation environment, without background map, all the points and was traced the UAV path. How we have a lot of point in the map, probably we have a lot of option of way to the drone pass in all points, and probably the algorithm will spend a lot of time to returns all of the results, but, for our problem, we need quicker answer, because it, we use only the first best result. After the processing, this flight planning could be send to Drone using some specific SDK. For example, and DJI Phantom allow exchange information with other devices, like Smartphone Android, using DJI Developer SDK through WIFI.

5. CONCLUSION

This paper presented the development of a mobile application to aid the optimized planning of a drone's flight plan, applied to precision agriculture. It was only used to develop free tools, that allow the app to run on Androids devices. The application's graphical user interface allowed the user to inform the required information using screens with few graphics, in order to make the application easier to use. Additional tools and API, such as Google Maps, Google Places, and Geocoding API were used for the project development, allowing a better usability as well as greater accuracy in the generated data. The result of the processing was the optimized flight plan, which can be sent to Drone through specific communication APIs. Even when ran on a cheaper Android Device, the result of a solution happened in minutes, even for a scenario of more than 1,000 points. For the development of the heuristic used in the recursive auction algorithm, it was used features that allow the algorithm to find faster results in quadratic areas, but even in complex figures, formed by several vertices, such algorithm also allows to find feasible solutions, but in this case, the processing time could be longer. As future work, we suggest improving the application as well as the algorithm to handle the optimization of multiple drone flight.

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