Chapter

Path Planning Optimization with Flexible Remote Sensing Application

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Abstract

The purpose of the path planning optimization is to find the most favorable route between starting and arrival points based on defined criteria and target functions. The change in the characteristics of each route becomes complicated when there is an increase in the number of intermediate points. This study predominately analyses the monitoring of a limited area. The author demonstrates how the path of the autonomous systems will change in different conditions and further introduces the possibility of using mobile remote sensing systems. The test is performed firstly in 2D flat area, then 3D spaces, and then—taking a forest fire as an example—the ideal conditions changed to reality. The study reveals findings on efficiency, based both on professional and economic considerations. The utilization of remote sensing technologies was found to optimize the observation of the given area generating new problems, such as what is the size of the monitored area at a given moment and how can we increase it for the higher effectiveness. An increase in the size of the monitored area results into an efficient and functional autonomous system albeit generating a shorter and modified path. Mobile autonomous systems therefore can be replaced by stable systems; simultaneously under real conditions, they can be more efficient than stable ones.

Keywords: path planning optimization, remote sensing, professional and economic analysis, 2D and 3D analysis, test in ideal and real conditions

1. Introduction

The purpose of path planning is to be able to get from point of A to B in the most efficient way. Most often we look at criteria such as the speed of travel, the shortest possible distance, the comfort, or the economy, but sometimes there are special aspects such as the minimum time for a particular route to go, the exact date of arrival, or the cost-effectiveness of the travel. The method of acquiring the most efficient solution in a given criteria is called as the optimization process. There is an abundance of literature and studies dealing with this problem, such as a common problem [1], a special problem for ground [2] or aerial vehicles [3], and a problem of industrial robots [4] or public service [5], even the author's team [6] tried to analyze the problem, that results are basically used for this study.

Path planning between two or more points may have even other goals than just doing the route. For example, during the travel we can observe the immediate surroundings of the route. If we take into account the possibility of remote sensing, the observed field can be wider and wider when passing the route. Following this logic, we can conclude that choosing a route is not merely premised on getting from one point to another one but rather on supervising and monitoring an area of responsibility. The purpose of the area monitoring is typical for safety reason, prevention and protection against criminals, swift forest fire detection, or offering first aid to victims in case of disaster.

Following the path or monitoring, the area can be done by the traditional way meaning that the trained staff uses a vehicle; conversely it can be done in advanced way meaning that the presence of staff on board of the vehicle is no longer required. The latter can be interpreted as using the autonomous system. One of the advantages of autonomous systems is that we can eliminate human error by applying it.

The effectiveness of the autonomous system should be examined under different conditions. For easier understanding, the best method is if we start with the simplest condition that means the least distracting circumstances. This can also be called as an ideal case.

The purpose of observing an area is to detect the unrequired event or incident as soon as possible. In general, the faster the autonomous system detects the event, the more effective it is to apply. We need to look at how to optimize the path planning of the autonomous system with flexible remote sensing methods.

2. Basics of path planning

2.1 Path planning problems between two points

The purpose of path planning is to find the best route according to the desired target function between two points. The target function may have different expectations, such as making the route as short as possible or as fast as possible (1). Assuming a two-dimensional plane area and ignoring any kind of disturbing circumstance, ideally shown in **Figure 1** (left) and assuming constant speed, it means in both cases the same path and the same time spent:

$$A \to B(s \Rightarrow \min; t \Rightarrow \min) \tag{1}$$

The simplest assumption in reality is very rarely found. In most cases the natural conditions make the simplest approach impossible, which means longer paths as shown in **Figure 1** (right) and longer access times. If the ideal path between the two points is not available, you have to choose from the other options available. The number of available options may vary between zero and infinity, but both lower and upper extremes should be excluded. At the theoretical starting point, the zero option means that there is no point in the task, and with the infinite possibility, we can only count on the theory. By excluding the two extremes, we find that the number of solutions varies from 1 to a large number. The only possible path, of course, does not give a choice. The first choice appears in case of two different paths

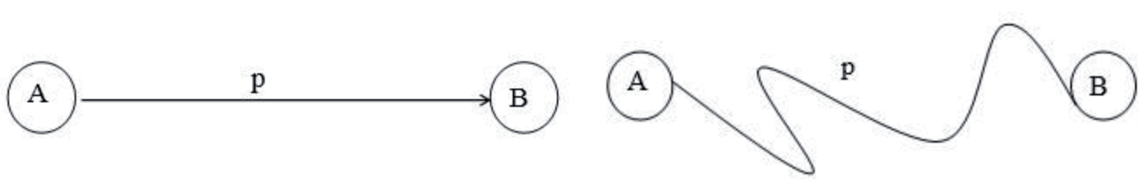

Figure 1.
Path planning between points of "A" and "B" in ideal (left) and in natural (right) circumstances with only one option.

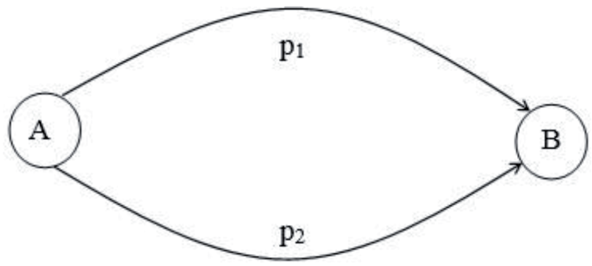

Figure 2.
Path planning options between points of "A and "B" with two different possible routes.

as shown in **Figure 2**. The quality of the different routes may be the same or different, but it is natural the better road quality allows faster progress, which means that it takes less time to do the same route length.

However, in case of different routes, choice is useless if there is no difference between them according to the target functions. The following options are available for two routes based on their length and quality:

1. The length and the quality of the two paths are the same ($s1 = s2$; $q1 = q2$).

2. The length of the two routes is different, but the quality is the same ($s1 \neq s2$; $q1 = q2$).

3. The length of the two routes is the same, but the quality is different ($s1 = s2$; $q1 \neq q2$).

4. The length and quality of the routes are different ($s1 \neq s2$; $q1 \neq q2$).

In general, the last one can be assumed. This gives new more opportunities, so the quality of the longer road can be better or worse than the shorter one and vice versa. In the latter case, when a longer road is combined with a poorer quality, it is clear this is not a choice. In the first case, when the quality of the longer road is better than the shorter one, you can get the following solutions:

1. The quality of the road is better, but not so much as to compensate the choice with time gains.

2. The quality of the road is better; however, its quality is able to compensate only for the loss of time resulting from the longer distance.

3. The quality of the road is so good that, despite the longer distance, we can achieve time gains.

The above is a mere combination of two different routes. It is easy to notice that changing the conditions makes the above more complicated. Example, if we increase the optional routes or the possibility of road quality per each new route but even with changing the quality along one route, the solutions increase exponentially. It is easy to notice that the above assumptions provide an ever-increasing choice, which is in the direction of infinity. However, a large part of the choices can be excluded, so all of those are certainly in a less favorable direction than the one that has already been examined before. As an example, all new routes with the same or worse route quality compared to a route of a given length can be excluded if they are longer than the examined one.

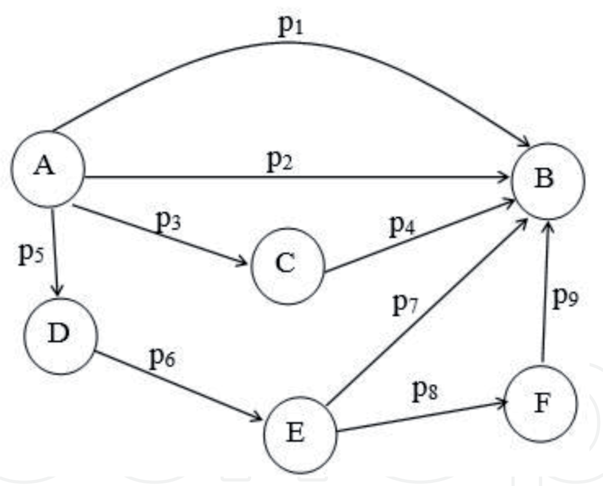

Figure 3.
An example for path planning between points of "A" and "B" in case of more options with pathway and with intermediate points.

Based on the above, it can be observed that in natural conditions there can be a significant number of solutions even between two points.

2.2 Path planning problems between several points

If we assume more than two points to be touched in the course of the route, we find that the number of options increases dramatically again as shown in **Figure 3**. Optimizing a multipoint path planning in a given plane area raises the travelling salesman problem (TSP) that has already been examined by many studies. At elementary level this question is raised hundreds years ago together with the trade development; however, as a classic scientific problem, it was mentioned firstly by Held and Karp [7] and Bellman [8]. They used dynamic programming approaches to find the solution.

Later other researchers followed these methods [9, 10], and others developed new ones offering other algorithms as well as time-dependent TSP [11] or TSP with time window and precedence constraints [12].

As new technologies appear in autonomous systems, like unmanned aerial vehicles (UAV) or drone applications, researchers found new problems and tried to give new approaches finding the best or optimized solution. Some of these studies focus only on the drone applications; others tried to combine drone application with the traditional delivery system [13, 14]. In these studies authors used different examining methods, as well as exact methods [15], heuristic methods [16–18], or approximation algorithm [14]. Bouman et al. cites a detailed summary about the above researches and results [19].

Based on the above, TSP is a very complex therefore not just natural condition, but also some idealistic assumption can generate a significant number of solutions.

3. The problem of path planning developed for area monitoring

3.1 Differences between effectiveness and efficiency

The overall goal of planning and optimizing routes is to solve practical problems in order to achieve the intended goal. This can focus only on one problem like transportation, e.g. the traveling salesman problem (TSP), in which the previous abovementioned logic can be continued, but the purpose can also be to select the path to optimize the observation of a particular area. Author calls it as the effective patrolling path problem (E3P), where the selected area is under observation by the staff who make its supervision by continuous patrol. In this assumption the staff of the patrol can also be replaced by an autonomous system.

Obviously, the purpose of observing an area is to detect a particular event or phenomenon as early as possible. Early detection prevents the escalation of many unwanted events, for example, CCTV camera used for criminal prevention [20], aerial surveillance for forest fire detection [21, 22], or disaster escalation [23, 24]. The effectiveness of the prevention correlates to the early detection. The problem is that the patrol can see only a limited part of the supervised area, so the entire area can be divided in time into observed and not observed parts. However, the event or phenomenon can be noticed not only by the patrol but also by any other person in the area. Therefore, it is questionable who will be the first to detect the event, the patrol in duty or any other person spontaneously. This question focuses not only on the effectiveness of the applications but also on the efficiency of the autonomous systems. Patrol is costly, while spontaneous detection has virtually no cost. From the above, efficiency can be approached from several sides:

1. Performing the patrol, the average detection time is shorter than without patrol. In this case the autonomous system used for patrol is professionally effective; however, we do not take its costs in account.

2. Performing the patrol, the average detection time is shorter than without patrol; moreover, the costs of patrol will return. The latter means that the faster the detection of the event, the faster the response of the dedicated service to the event or phenomenon, which can raise the amount of the saved value or reduce the loss of the damage. In this case the saved value or the reduced damage balances or overtakes the total costs of patrolling. At this point, the application is effective not just professionally but even economically, meaning that using autonomous system is efficient.

3. The costs of patrolling can be reduced significantly while its benefit remains. In this case we are looking for different methods to further increase efficiency within a given budget, to make the use of limited resources more efficient.

Each of the above approaches requires different analyses to understand how to optimize autonomous systems with remote sensing application. Since the optimization in the reality means not only the mathematical solution but also the economical point of view, the latest author takes it in account too.

3.2 Path planning is effective in professional point of view

Previously it has been clarified that the purpose of patrol is to detect an incident or phenomenon earlier than it would be performing by other sources. Professional efficiency does not count with anything else, just to make the signal faster with a new system than without it. If the average signals performed by autonomous system are faster than without it, then the autonomous system is efficient from a professional point of view.

It is logical that, with increasing number of people present in a given area, the frequency and quickness of the report will increase statistically. The dispersion of signals from the larger population over time is broader; however, only one of the extreme values of the scatter is required, which is manifested by faster detection. Recognizing this, it can be concluded that the quickness of the report depends both on the number of people present and the population density of the area; moreover, both of them increase proportionally.

It is easy to see that in case of random but large number of event or phenomena, the average detection time of the autonomous system is equal to half of the patrolling cycle time (2). It is logical that with the increase in the density of the potential observers in the observed area, the advantage of patrol decreases. It happens because the standard deviation of the reports given by external persons decreases the amount of efficiency (3). This statement can be accepted as a logical conclusion:

$$\overline{t}_{Autonomous\_report} = \frac{1}{2} t_{Autonomous\_patrol} \tag{2}$$

$$\overline{t}_{Autonomous\_report} < \overline{t}_{Civil\_report} \tag{3}$$

- $t_{Autonomous\_patrol}$: full time of the patrol, made by autonomous system
- $t_{Autonomous\_report}$: average time of the report given by the autonomous system
- t_{Civil_report}: average time of reports, given by civilians

Based on the above, it can be concluded that, in the event of the occurrence of random but regular phenomena, the effectiveness of patrol in densely populated areas decreases, while in less populated areas, it increases. The rarer the population density of an area, the higher the effectiveness of patrol and vice versa: the more densely populated the area, the lower the effectiveness of patrol.

It can be concluded that patrolling can be advantageous or not advantageous, depending on the attendance and the population density of the area. Similarly, it means also the professional effectiveness or ineffectiveness. Till the average deviation of the signals given by external persons is higher than the average detection time of the autonomous systems during observations, the method is professionally effective, but no longer.

3.3 Path planning is effective in economic point of view

Economic effectiveness can be proven by counting the costs of patrolling and comparing the expected benefits of the application. In this case it is natural that the professional aspects—discussed in the previous point—are fulfilled. As a result, it is required to fulfill the professional efficiency, but this is not a sufficient condition to achieve economic effectiveness.

In case of forest fires, the response with and without patrolling had to be demonstrable in the difference of the damage caused by fire and the saved value. As a result of the previous indication, the damage is reduced to such an extent (4), which at least reaches but rather exceeds all costs of autonomous system patrol. We can approach this statement even from the opposite site that is saved value: it should expand to such an extent, which at least reaches, but rather exceeds, all costs of autonomous systems used for patrol (5). In this case, the advantageous of patrol exists not only in professional but even in economic view. The economically advantageous response also means fulfilling the condition of the national economy in broader interpretation:

$$\Delta K_{damage} > \Sigma C_{patrol} \tag{4}$$

$$\Delta M_{saved\_value} > \Sigma C_{patrol} \tag{5}$$

- ΔK_{damage}: damage difference between patrolling response and non-patrolling response
- ΣC_{patrol}: total cost of patrolling
- ΔM_{saved_value}: the difference of the rescued value between patrolling and non-patrolling

The operating costs of autonomous systems can only be paying back from an economic point of view if significant reductions in damage are detected by perceptions. Therefore, the total number of the perceptions during patrolling reaches or exceeds a certain level. This rate is due to the frequency of observations. The result is that a quicker detection also makes a quicker response; thus, the damage decreases, or the saved value increases, because of the escalation of the event. The total loss of damage must reach or exceed the total cost of the patrolling. The use of limited resources is efficient.

3.4 Description of the example area

The criterion of the efficiency is to get information about the change we want to detect as quickly as possible. On the one hand, this can prevent the occurrence of unwanted change (e.g. surveillance of the security area for crime prevention), and on the other hand, it can reduce the extent of change, such as the amount of resources needed for liquidation (e.g. flood management).

The negative effect caused by the phenomenon is minimal if it is detected immediately. In some cases, this may mean immediate detection (e.g. crime), while in others it is more time-consuming (e.g. forest fire detection). In this latter mentioned case, e.g. the author's experience and other sources [25–27] accept that detection within 15 min of the occurrence of a fire can be called effective. Apart from the extreme fire spread possibilities, the extent of the fire still allows for safe firefighting by using minimal power and tools.

For the purpose of path planning, we can create a large number of routes on the responsible area which should be followed by the staff during the patrol. Optimization requires the shortest route during the patrol with the same rate of observation time per a pixel of the given area. It can be observed that in ideal case pathway cannot cross itself during a cycle. Depending on the scale of the responsible area and the size of the observed pixel at the same time made by the autonomous systems, we can create many path configurations with the equivalent value as shown in **Figure 4**.

When judging the effectiveness of patrolling, the basic question is how fast the autonomous system can do a report on the detection of a problem at any location. Patrolling can be divided into a period of one cycle for a specific area of under "observation" and "non-observation". The "blind area" can also be used for the non-observed area.

In the following, a sample area will be presented. Its parameters can be changed, so it can be adapted for other tasks as well. The area is a regular quadrilateral whose terrain condition does not limit the effectiveness of observation from the side. So it can be considered as a flat surface for the examination. The size of the examined area is 24 km × 24 km, making the whole area of 576 km^2.

According to the assumption, the autonomous system, which makes the patrolling, can run at different speeds on any route because of the nature of the area. It means the detection is done in two dimensions. An additional assumption is that the device installed on board of the autonomous system provides an angle of view that allows the simultaneous viewing of a 3 km × 3 km area at a given time.

Based on the above, we have the following data:

- $A = 576\ km^2$: total observation area.
- $A_{EA} = 3\ km \times 3\ km = 9\ km^2$ is the size of the pixel.
- α = focus angel of the camera.
- H_p = altitude of the patrol.
- v_p = patrol speed of the autonomous systems.
- A_o = size of the observed area in the given case.
- l = side length of a pixel.
- t_p = total cycle time of the patrol.
- L_p = total length of the patrol.
- t_o = observation time per a pixel.
- t_{blind} = non-observation time per a pixel (blind time).
- R_o = rate of observation and non-observation time per a pixel.

During the assumption the camera on board has an angle of view that allows a simultaneous viewing of a 3 km × 3 km area at a given moment. In this test, we increase the speed of patrolling within reasonable limits, and next we increase the angle of view of the camera. Our aim is to determine how the observed and the blind area changes to an arbitrary point and what further conclusions can be drawn from the trend of change.

4. Path planning: taking into account remote sensing applications

4.1 Path planning in two dimensions with patrolling speed modification

During the examination a route which ensures that each territorial unit, the so-called pixel, was chosen and only detected once during the cycle time of the patrol. Paths can be displayed in several forms as shown in **Figure 4**, but the equivalent is essential in the case of the fulfillment of the previous condition. The initial speed of the patrolling of the autonomous system is taken to be 60 km/h, and then it increased by 30 km/h up to 180 km/h. To examine the differences, the author takes the values of **Table 1**.

Defining the values of the basic case, "A" means that the area $A = 576\ km^2$ divided into $9\ km^2$; taking AA = 64 units of floor area, we got the so-called pixels, which look like a chessboard. When an AA area unit has been flown at 60 km/h, the observation time is $t_o = l/v_{pA} = 3\ km/60\ km/h = 0.05\ h$, so that is 3 min. The length of the total route $L_p = 64 \times 3\ km = 192\ km$ long, which takes the next $t_p = L_{pA}/v_p = 192\ km/60\ km/h = 3.2\ h$, that is, 192 min.

It can be seen from the values in the table that, by increasing the speed, the ratio of the observation time to the complete route is not changed ($R_o = 1/64$).

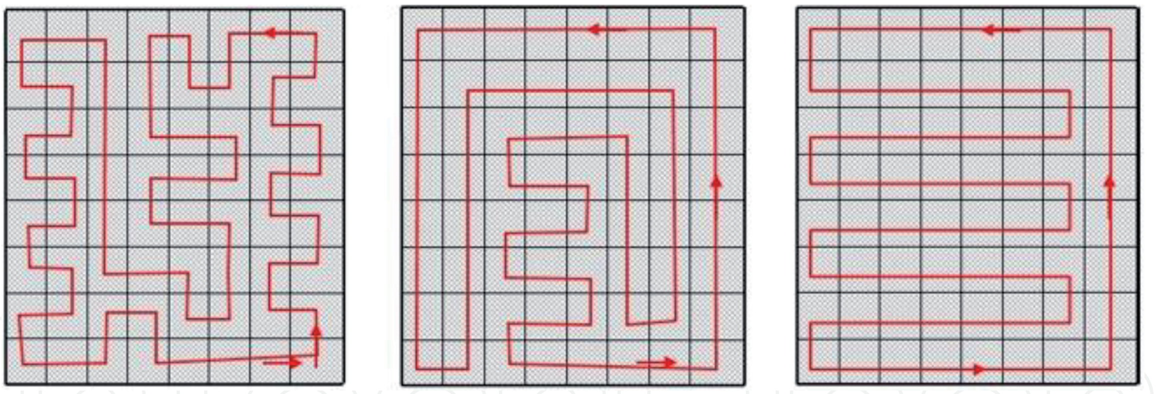

Figure 4.
Examples of path planning with different pathway configurations for patrol. With constant patrol speed, the time of observation is equivalent in each pixel as well as equivalent to the length of total patrol route in each configuration.

Value event	v_p (km/h)	H_p (m)	α (°)	A_o (km^2)	l (km)	L_p (km)	t_p (min)	t_o (min)	t_{blind} (min)	R_o (−)
A	60	0	180	9	3	192	192	3	189	1/64
B	90	0	180	9	3	192	128	2	126	1/64
C	120	0	180	9	3	192	96	1.5	94.5	1/64
D	150	0	180	9	3	192	78	1.3	76.7	1/64
E	180	0	180	9	3	192	64	1	63	1/64

Table 1.
Effects of changing speed of patrol for the observation time per a pixel and for the rate of observation and non-observation time.

The non-observation time frequency changes exponentially, the exponent is negative. In security checks, this result could be acceptable, but not in case of other examples like fire detection. The reason for this is that the fire increases constantly from the ignition time, so the burnt area changes exponentially. In the case of wildfires, it can be stated that the detection must be done within 15 min [25–27]. Continuing with the logic of the table, it can be calculated that it can only be provided at extremely high speed (v_p > 720 km/h). Based on the information above, it can be determined that by increasing the speed of the patrol, the efficiency of the detection cannot be increased (**Figure 5**).

The purpose of patrolling is to provide faster detection than the signals of the citizens. This allows police officers to investigate hot trail or firefighters to begin the intervention earlier. The result of it is a faster response and more saved values. If the patrolling can result faster signal, it can be considered as an effective method. Professionally, this approach is obviously true; however, the higher efficiency in the point of national economy view is not proven by this method. It is effective at national economy level only in that case if the increase of the saved values reaches or exceeds the all cost of the patrolling.

4.2 Using remote sensing: increasing the camera's angle of view

To optimize the autonomous system's path planning, we should examine what happens if the camera's angle view is changed. For it we have to take the values from **Table 2**. We suppose the speed of patrolling, the maximum value of the patrolling speed based on **Table 1**, so the value is 180 km/h. We should also take other special

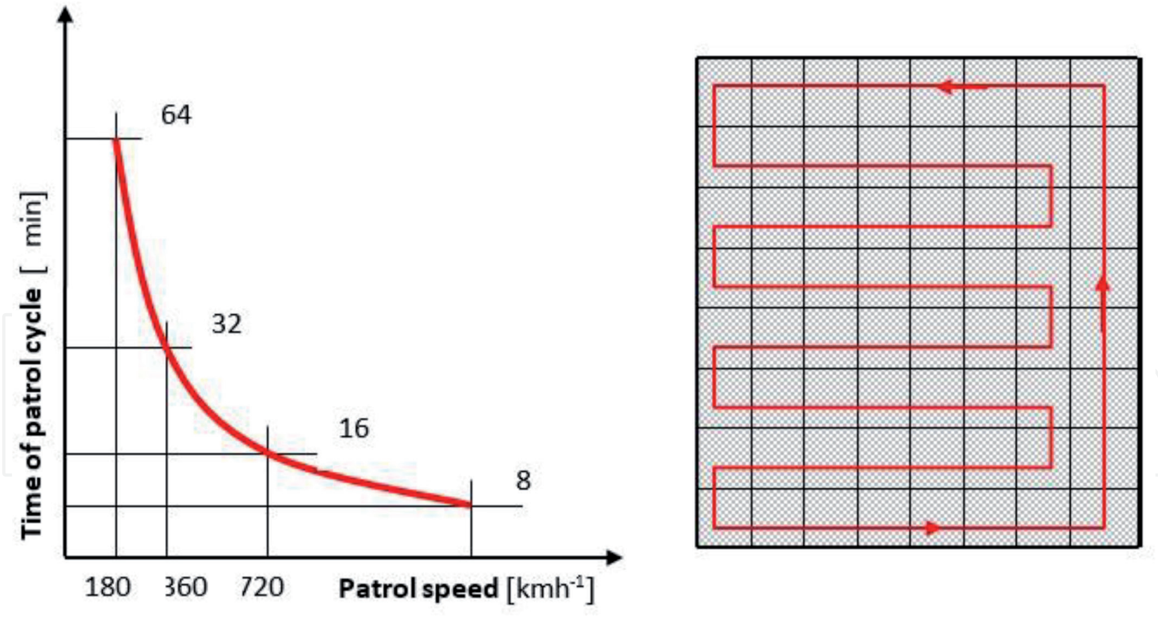

Figure 5.
Correlation of patrol speed and time of patrol cycle (left) and a variation of patrol route planned for autonomous systems (right).

Value event	v_p (km/h)	H_p (m)	α_D (^{0})	A_o (km^2)	l (km)	L_p (km)	t_p (min)	t_o (min)	t_{blind} (min)	R_o (−)
A	180	1500	90	9	3	192	64	1	63	1/64
B	180	1500	126	36	6	96	32	2	30	4/64
C	180	1500	151	144	12	48	16	4	12	16/64
D	—	1500	165	576	24	—	—	Cont.	—	64/64

Table 2.
The effect of changing camera angle for the observed part of the area, demonstrating the theory with 1500 m path altitude.

circumstances regarding the camera's view angle to understand the process better. Even if the patrol example in the previous subchapter was worked out at ground level, in **Table 2** the author counted with 1500 m altitude. It is performed to demonstrate with good visibility how the camera angle should change to be able to observe more than only one pixel at the same time.

The easiest way to change observation parameters is that to double the side length of the pixels, which means the territory becomes four times bigger than before. This process shows the development direction of the method. With this step we jump from the two-dimensional flat area to the three-dimensional space area that can be seen in the next subchapter even if in this moment this assumption serves only the more demonstrative understand.

It can be seen that by increasing the angle of view, the ratio of the time under observation increases exponentially comparing to the total flight time. Non-observation time reduces in the same way as well as the non-observed area but with the opposite direction as shown in **Figure 6**.

The 15 min criteria as the tipping point of the effectiveness can be satisfied at the case of line "C" in **Table 2** with $\alpha = 151^0$ camera angle. In this case the value of the rate of observed area and non-observed area is ¼. By increasing the observation angle, the observed area unit increased as shown in **Figure 7**.

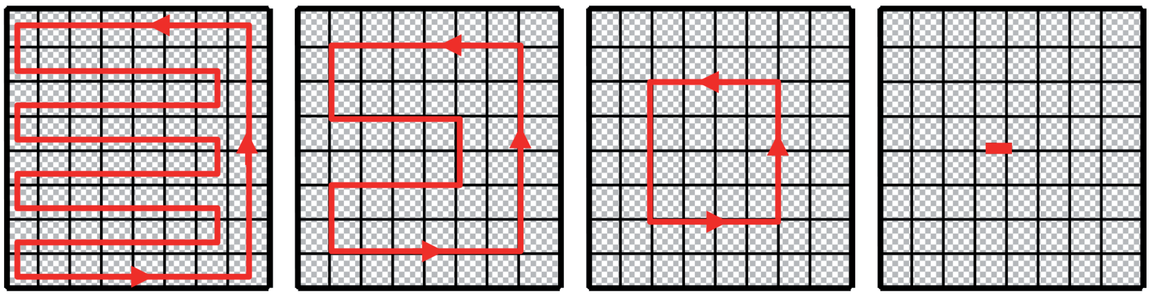

Figure 6.
The effect of changing camera angle for the flight path.

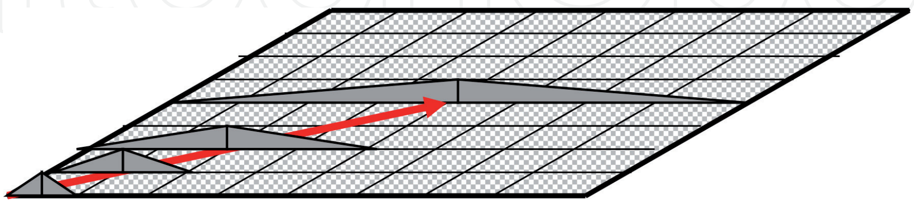

Figure 7.
Changing camera angle moves the flight path in to the centre of the observed area.

Since the sample area is delimited, the centre of the larger area unit—4 pixels, than 16 pixels—as well as the trend of the path change moves also toward to the centre of the area. In the "D" case of **Table 2**, we can see that, under certain conditions, by increasing the angle of view, the area can be monitored continuously. In conclusion, by increasing the camera's angle of view, the efficiency of the detection can increase significantly.

Even if we used 1500 m altitude to better understand the process, it is easy to accept that the method works at non-zero but minimal altitude too. We can assume a 2–3 m high installed camera on autonomous systems like an unmanned ground vehicles (UGV), but in this case the change of camera angel is very minimal. Since the assumed speed is 180 km/h, it is much easier to take an aerial autonomous system like unmanned aerial vehicle (UAV) for this example. This assumption signs also the direction of the next examination.

4.3 Extending the possibility of patrolling by remote sensing to the third dimension

As a next step, we can unlock the criteria for monitoring in two-dimensional area or standard but relatively at low-altitude (1500 m) observation. Based on it we can examine how the results change if we extend the possibility of patrolling to the third dimension. In this case we use the aerial autonomous systems like UAVs or drones as it was explained in the previous subchapter where 1500 m altitude was used. In this example we assume the same observation area that is 576 km^2, the same maximum patrol speed that is 180 km/h, and the standard camera angle view that is 90°. However, we modify now the altitude of the flight path using 1500 m basic level—as it was in the previous subchapter—and raise it with double steps as well as 1500, 3000, 6000, and 12,000 m. Based on these conditions, the results are shown in **Table 3**.

It can be seen that by increasing the flight altitude, the ratio of the time under observation increases exponentially comparing to the total flight time. Non-observation time reduces in the same way but with the opposite direction as shown in **Table 3**.

Value event	V_p (km/h)	H_p (m)	α_D (^{0})	A_o (km^2)	l (km)	L_p (km)	t_p (min)	t_o (min)	t_{blind} (min)	R_o (−)
A	180	1500	90	9	3	192	64	1	63	1/64
B	180	3000	90	36	6	96	32	2	30	4/64
C	180	6000	90	144	12	48	16	4	12	16/64
D	—	12,000	90	576	24	—	—	Cont.	—	64/64

Table 3.
The effect of flight altitude of autonomous system for flight path.

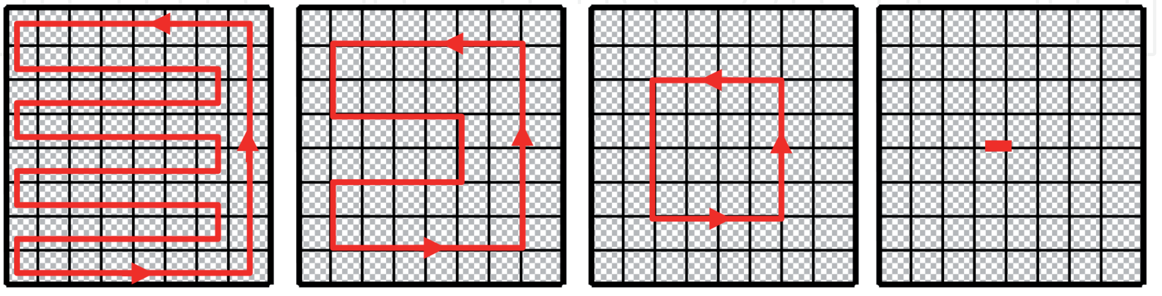

Figure 8.
Changing flight altitude moves the flight path in to the centre of the observed area.

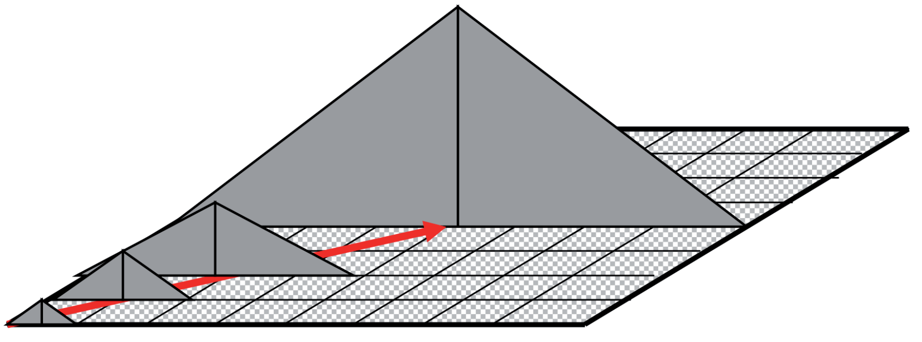

Figure 9.
Higher observation altitude means that the flight path will move to the centre of the given area.

Taking the forest fire detection as an example, the efficiency criterion is 15 min. This overflying time above the same point (pixel) can be assured at 6000 m flight altitude, ignoring the fact that the observation time ratio in this case is ¼. Increasing the observation altitude, the size of the observed area unit also increases. As the sample area is delimited, the centre of the larger area unit and the route of the patrol are moved toward the centre of the area as shown in **Figures 8** and **9**. In the “D” case of **Table 3**, we can see that by increasing the altitude, there is a point where the whole area can be monitored continuously.

Practically, the results are the same as we could see at the process of raising the camera angle view at the previous subchapter. Obvious changes of the flight paths are also the same in both cases as it can be seen in **Figures 6** and **8** as well as in **Figures 7** and **9**. Both in raising the flight altitude and the camera's angle view the efficiency of the detection increases significantly.

According to the example, the continuous monitoring was materialized quite high, that is, at 12,000 m. The possibility of it can be carried out by a medium-altitude long-endurance (MALE) or high-altitude long-endurance (HALE) unmanned aerial vehicle (UAV) or system (UAS). Moreover, it can be served even by satellite-based monitoring systems.

The effect of raising the camera angle of the autonomous system or the flight altitude of the aerial autonomous systems, like drone, UAV, or UAS results in the same effect meaning that the path will move to the centre of the responsible area.

4.4 Comparing the mobile and stabile remote sensing applications

The results from the increase of the flight altitude and of the camera angle, logically, will lead to further ascertainment. In both cases, the entire area can be observed simultaneously. This point locates in the centre of the area. From the data we can see that the speed value belonging to the centre point is zero. This is a very special situation: The camera of the autonomous system, as a monitoring device, does not require any movement, i.e. patrolling. The values in line "D" of **Table 2** and **Figure 7** show the increase of the camera's angle view—which justifies the full observation of the area—can be ensured if the observation is not only from the same point but also from the same height! This statement proves that the application of the mobile autonomous system with the help of a stable or fixed installed autonomous system—in case of a flat area—can be theoretically triggered.

The characteristics of the function between the monitored pixels and flight altitude (left) or camera's angle view (right) can be seen at **Figure 10**. In both cases we can see that there is a value where all pixels—which means the whole area—are under observation in the same time.

The comparison analysis based on economic base of the abovementioned ascertainment gives results as follows:

1. The camera, as a remote sensing device, would be present in both test lines, with approximately the same values in its technical parameters. Technically this would not cause a significant difference.

2. According to **Table 2**, the fixed-system monitoring rate is apparently full, so the comparison with the use of a mobile device is definitely a disadvantage of the latter.

3. While using a fixed installation system, we should choose the solution, when the camera does not see the whole area at the same time but detects it moving

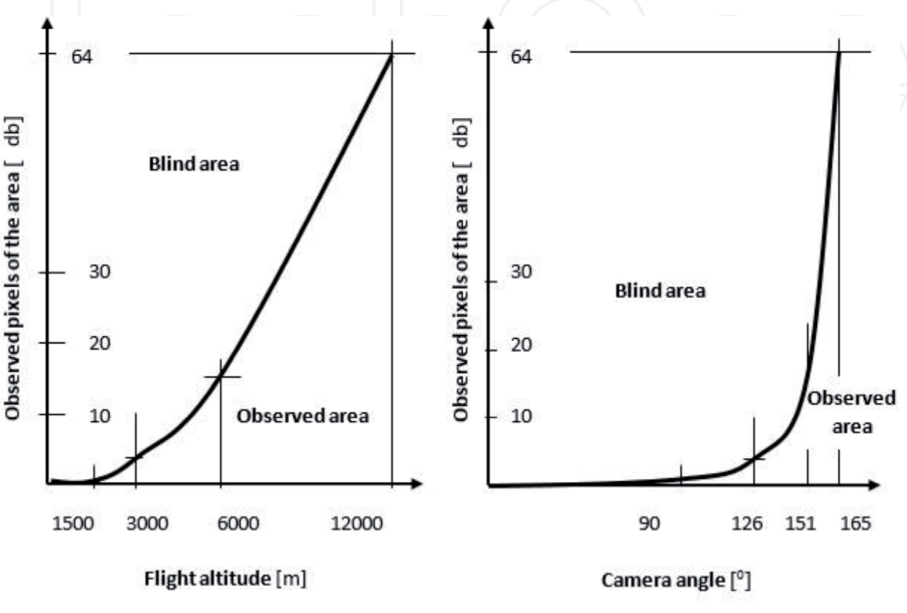

Figure 10.
Rate of blind and observation area depending on raising the flight altitude (left) and the camera angle (right).

around. The advantage of this is that in its parameters, almost the same efficiency can be achieved with less power.

4. In the abovementioned case, the degree of efficiency can be calculated from the speed of rotation and the ratio of the angle of view, similar to the method used for speed testing.

5. The purchasing, operating, and personal costs of the autonomous system are very high. The investment costs of the fixed system are low. The continuous operation of the system is also low, practically free, because it does not require human intervention.

Of course, the abovementioned data are the extreme values of the mobile autonomous system's route planning. This can sometimes be an objective function, but that does not mean that it is always the only way to go, but this is the direction of increasing the efficiency by using remote sensing technology.

4.5 Examples with real circumstances

The result of the examinations above is a flat or an area which is almost flat. Aside from examining the advantages of using a fixed installed camera system and the possibilities of using an autonomous system, it is also important to examine their limitations.

4.5.1 Considering the articulation of the monitored area

The sample area allowed, for example, the detection of fire or its accompanying smoke, from the side. The latter is strongly influenced by the terrain. If there is only indirect fire detection, which is really a smoke detection (e.g. in a valley, a hill, or a fire behind a hill) in this case, the possibility of the detection is the rise of the smoke column above the mountain ridge and its visibility.

If the distribution of the terrain and the level differences are significant, the detection of smoke by a fixed monitoring system is also significant, but it may be delayed, which has an influence on the effectiveness. In this case, the efficiency of using a mobile autonomous system may again exceed the efficiency of fixed systems. [28]

The absolute criterion of the efficiency for the above mentioned case can be defined as the following: the non-observation time of using aerial patrolling is less than the average deviation of the appearance of smoke rising above the ridge due to fire development and reaching the detection threshold.

4.5.2 Considering extreme weather condition of the year

Examining the possibility of the fire detection in some periods, especially in dry seasons, the conditions of fire propagation become significantly more favorable. As a result of it, the burned area increases per unit of time. The damage will increase, the amount of power and tools for firefighting should be increased, and a higher alert state should be ordered. The time of the intervention will be longer, and costs will also increase. The firefighting units which are located far away from the fire department take a long time, the potential protection of the original location decreases, and the vulnerability of people and material goods increases. These factors also increase the risk of danger; the risks however can be reduced, if the fire department commences promptly with fire suppression efforts preferably in the early stages of the development of fire.

As a condition of this, in areas where stable fire monitoring stations are not required due to the low average risk level, it is advisable to shorten the average time of fire detection by using aerial or ground patrolling. To do this, we need to develop objective indicators which on the basis of the cost of patrolling can be recovered from an economic point of view. In this case, the interpretation of the return results from the quick firefighting of fires and the loss values.

In highly flammable periods, air reconnaissance may be more effective from an economic point of view than a stable observer station. The reason for this is that the probability of detecting air surveillance during these periods increases, so its unit costs are decreasing in relation to the number of "matches" meaning the number of detections. Due to the higher fire propagation, the unit costs are also reduced to the damages per unit time. Although it is difficult to measure, it has added benefit because people who are responsible for the fire take into consideration the air patrolling which also serves as a kind of deterrent.

5. Summarizing

This chapter examined a specific form of path planning. It has been stated that by increasing the number of the intermediate points and changing some characteristics of each path, the number of the possible options increases exponentially. It has already been confirmed by multiple literature sources, and it is part of the traveling salesman problem. The two-dimensional approach to the problem of the path planning to different points is abandoned. The chapter focused mainly on the problem of path planning in case of area observation. It further revealed that the optimization of path planning enables detection and observation of unexpected event during patrolling. If this activity is regular and targeted, we can call it patrolling and get to the effective path patrol problem (E3F). The author aimed to make an effective detection by using patrolling in a particular area.

E3P has been tested in several ways. The author assessed the effectiveness of the phenomena and the event of the detection from a professional and an economical point of view. An investigation on how to make use of the available limited resources more efficient was conducted. It has been determined that when we want to increase the speed, it is not practical to increase the efficiency, because of some objective reasons. However, by increasing the angle of view of the remote sensing system and introducing the possibility of aerial patrolling in different altitudes, the same results were achieved. Ideally, to monitor a two-dimensional particular area, the moving autonomous system can be replaced by a stable set of devices. However, apart from ideal conditions and taking three-dimensional area, we can conclude that mobile autonomous systems may be more efficient than stable systems. The optimization is entirely dependent on the on the target function we achieved and also on a particular condition system. This can usually be determined individually.

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