A Preliminary Report on a Computer Model to Simulate Searching for a Missing Person Using a Drone, With Some Early Results

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Synopsis

This paper looks at the early stages in the development of a digital simulation model to investigate searching for a missing person by using a drone, and reviews progress to date. This thread of work began in 2011 with the construction of a digital simulation model to investigate the performance of a ground searcher; the drone model has been developed from that. It will help the reader to understand this paper if they are familiar with the report on the ground searcher model [1].

The ground searcher model provided useful results about Effective Sweep Width and Probability of Detection that were of practical benefit to searchers and search managers. It was hoped that the drone model would do the same and perhaps suggest directions for further investigation.

This work marks the starting point of a project involving the Department of Computing at Newcastle University.

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[1] Perkins, D. (2011), *Some Consequences of a Computer Model to Simulate the Performance of a Land SAR Searcher*, The Centre for Search Research, available from https://tcsr.org.uk/media/2l1lgrzs/2011-some-consequences-of-a-computer-model-to-simulate-the-performance-of-a-land-sar-searcher.pdf

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Background

Our interest in the use of drones in missing person searches was an outcome of Exercise Northumberland [2]. Among its recommendations was the suggestion that further research should be done to assess the role and performance of the drone as a search asset. The work described in this paper is part of that process.

The Three Step approach to drone modelling

It is convenient when modelling searching using a drone to break the process down into three steps. Each of these steps contributes in its own way to the success of the overall process.

Step 1
In Step 1 an image of that part of the search area that is within the visual field of the camera lens is formed within the camera. This image will contain any targets that are not obscured by obstacles. It is this part of the process that is the subject of the model described in this paper. Steps 2 and 3 are beyond the scope of this model. The paper ignores the possibility of the drone camera containing image recognition software.

Step 2
In Step 2 the image formed within the camera is transmitted by some means to the spotter(s) on the ground. This part of the process may involve image degradation, so that the image arriving with the spotters does not contain the same degree of detail as the original image in the camera.

Step 3
In Step 3 the image received from the camera is displayed on a screen and scrutinised by the spotter(s). The problems associated with human observers interpreting a moving image on a screen have been well researched by others.

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[2] Hamilton, C., Perkins, D., Roberts, P. and Hughes, S., (2017), *Exercise Northumberland Research Report,* The Centre for Search Research and Newcastle University Business School, https://tcsr.org.uk/media/vlxkc4fo/2017-exercise-northumberland-research-report.pdf

It is possible that within each of Steps 2 and 3 the image generated in Step 1 will be degraded, and therefore targets that were correctly identified in Step 1 will be missed in Step 3.

Outline

The two-dimension ground searcher model and the three-dimension drone model both work by randomly placing identical search targets in a virtual search area. The search area also contains randomly placed obstacles. These may or may not hide the target from the searcher or drone camera.

The ground searcher model represents a virtual world that exists in two dimensions. The searcher, targets and obstacles are all in the same plane. The searcher moves in a straight line through this virtual world and will detect a target if there are no obstacles between the position of the searcher and the position of that target.

In the two-dimension model the ground searcher's view of a target will always be obstructed by an obstacle that lies directly between the searcher and that target, whereas in the three-dimension model, as well as seeing between obstacles the drone camera can also see over them and detect a target beyond.

There is only one variable in the ground searcher model and that is the obstacle density, which represents, for example, the amount of vegetation in the terrain through which the searcher is moving. The three-dimension drone model involves four variables. Two of these describe the terrain in which the search is taking place (obstacle density and height) and are therefore beyond the control of the drone operator. These allow the model to simulate the drone searching in a wide variety of terrain types. The other two variables describe the disposition of the drone (its height and the angular field of view of its camera lens) and are set by the model operator.

There are other factors in a search that can be thought of as variables, for example the variations in obstacle distribution and height, and target detectability. The first two of these will be discussed later.

The three-dimension drone model eventually ran up against capacity limitations on the original host computer but was nevertheless able to produce some useful results and indicate directions for further work.

The structure of the models

The two-dimension and the three-dimension models have the same basic structure and method of operation.

The virtual search area

The area being searched is represented by a rectangular grid of rows and columns in two dimensions. The grid represents the ground surface where the objects being searched for are located. In the two-dimension model the ground searcher is located on this grid along with the targets and obstacles. In the three-dimension model the drone flies above it.

Each square of the search area grid either contains a target or an obstacle or is empty.

Targets

A target is the name given to the objects for which the ground searcher or drone is searching. A target has zero height. Each target occupies one square of the search area grid. In both models one target is placed on each row of the grid in a randomly chosen location.

Obstacles

Obstacles are objects that each occupy one square of the search area grid and can obstruct the view from the searcher or drone camera of grid squares beyond that obstacle. Obstacles are randomly placed in the search area. There can be any number of obstacles on each row of the search area grid limited only by the size of the search area and the obstacle density. An obstacle and a target cannot both occupy the same grid square.

Variables in the models

Obstacle density

This is the only variable in the two-dimension ground searcher model. Obstacle density is a measure of the density of the vegetation and in terms of the model means the percentage of grid squares in the search area that are occupied by obstacles; an obstacle density of 20%, for example, means that one in five of the grid squares in the search area, selected at random, contains an obstacle.

Obstacle height

Obstacles in the drone model have height, targets do not. Obstacle height can be thought of as vegetation height. In the early stages of model development, all the obstacles were given the same height. Later the model looked at the effect of the obstacles having different heights.

Drone height

The ground searcher in the two-dimension model is of zero height. In the three-dimension model the height of the drone above the search area is specified by the user.

Drone camera lens angular field of view

In the three-dimension model the angular field of view, measured in degrees, is used to calculate the size of the area of ground that is contained in the image from the drone camera.

How the models work

The size of the search area

The search area was originally 250,000 units long and 500 units wide. While this worked satisfactorily for the less complex two-dimension ground searcher model, this size of search area became unworkable on the original host computer for the three-dimension drone model, with its additional memory requirements. Most of the runs of the drone model were done with a reduced search area length of 50,000 units, which appeared to have little effect on the results. The width of the search area remained at 500 units throughout.

To the author the grid square units are metres, making each grid square 1 metre by 1 metre; this is personal preference and suggests that the height of obstacles and the drone are also measured in metres, as are any subsequent results, for example Effective Sweep Width (ESW). The drone model therefore contains a search area that is 50 kilometres long and half a kilometre wide, which is searched as one continuous area.

Targets and obstacles

One target is placed in a random position on each row of the search area grid. There are therefore as many targets as there are rows. The size of the search area for both models allowed for 250,000 targets (later 50,000 for the drone), giving 250,000 (or 50,000) detection opportunities, which is good from a statistical point of view. After the targets are placed in the search area, obstacles are placed in random locations in empty grid squares. The number of obstacles is determined by the obstacle density.

Hidden areas

This applies to the three-dimension model only. Imagine a drone flying past an obstacle at a height that is greater than that of the obstacle. Even though the drone camera can see over and beyond the obstacle, it cannot see the ground immediately behind it. There is an area of ground behind the obstacle such that any target within this area will not be detected. The size of this hidden area is a function of drone height, obstacle height and the horizontal distance from the drone to the obstacle. The drone will detect a target that is beyond the hidden area.

When two obstacles are close together and in line with the drone it is possible that the hidden area due to the obstacle nearest to the drone will reach beyond the second obstacle and into its hidden area, giving a continuous hidden area that extends from the first to beyond the second obstacle.

How the ground searcher and the drone search in the models

In the two-dimension model the ground searcher moves up column zero of the virtual search area and scans along one row at a time. The searcher will detect a target if there is no obstacle between the searcher's position and the target position. In the three-dimension model, the drone is also considered to travel up column zero of the virtual search area, and to detect a target if there is no obstacle between the position on the ground directly below the drone and the target, or if the drone camera can see over the top of an obstacle and detect a target beyond the obstacle's hidden area.

Sensitivity analysis: the effects of variations in the four main variables in the drone model

There are three values that are output by the drone model that can be used to measure how sensitive it is to variations in the four main variables. These three are the percentage of targets that the drone camera detects, the ESW calculated from the Lateral Range Curve, and the Probability of Detection (PoD). These values are linked in that the number of targets detected by the drone is part of the process for constructing the Lateral Range Curve, which gives the ESW, which in turn is used to calculate coverage, which in turn is used to give PoD.

For PoD we need to decide which coverage / PoD relationship to use. For the moment we will use the inverse cube curve; this was developed for searching for a target from an aircraft, although there are reasons why this might not be the most suitable relationship to use for searching by drone.

To carry out a sensitivity analysis for the four main variables (obstacle density, obstacle height, drone height and camera lens angular field of view) we need to select a set of fixed values for them and then in turn vary one of them through a range of values while the other three remain fixed and observe the effect on the three output variables. The fixed values around which this analysis was done were obstacle density 10%, obstacle height 5m, drone height 50m and camera lens angular field of view 65 degrees.

The values obtained from this are shown in tables 1 to 4 and figures 1 to 4.

% obstacle density	% targets detected	ESW	PoD %
2	97	31.0	79
3.5	95	30.4	78
5	93	29.8	77
6.5	90	28.8	75
8.5	87	27.7	73
10	84	26.9	72
11.5	83	26.7	71
13.5	81	25.8	70
15	78	25.0	69
16.5	78	24.9	68
18.5	74	23.8	67
20	73	23.4	65

Table 1: effects of varying obstacle density

Table 1 shows that as the obstacle density increases then the percentage of targets detected decreases. This is because as obstacle density increases targets become more difficult to detect between or over obstacles and so fewer are detected. This means that the area under the lateral range curve (i.e. the ESW) is reduced and this in turn means that the coverage and hence the PoD are reduced also.

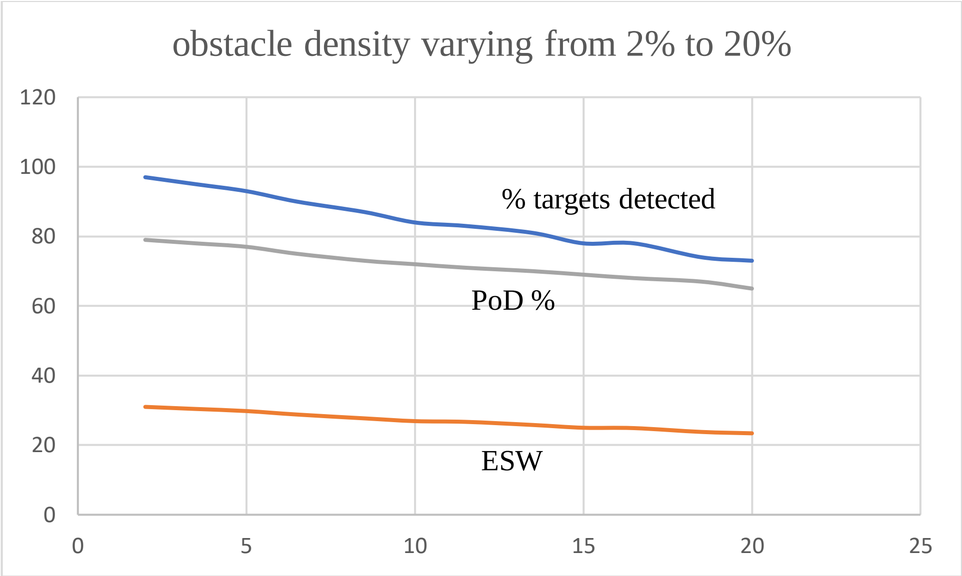

Figure 1: effects of varying obstacle density

Figure 1 is a graph of the values in table 1. It is interesting to recall the hyperbolic relationship between ESW and obstacle density identified in the paper on the two-dimension ground searcher model; clearly no such relationship exists for the drone.

Table 2 shows the results for varying the obstacle height.

obstacle height (m)	% targets detected	ESW	PoD %
1	98	31.4	80
2	94	30.0	77
3	92	29.3	76
4	89	28.4	75
5	85	27.1	73
6	84	26.8	71
7.5	81	25.8	70
8.5	78	25.0	69
10	73	23.4	66

Table 2: effects of varying obstacle height

The results shown in table 2 and figure 2 follow the same pattern as those shown in table 1 and figure 1. As obstacle heights increase then fewer targets are detected over them and consequently ESW and PoD will be reduced. Figure 2 is a graph of the values in table 2.

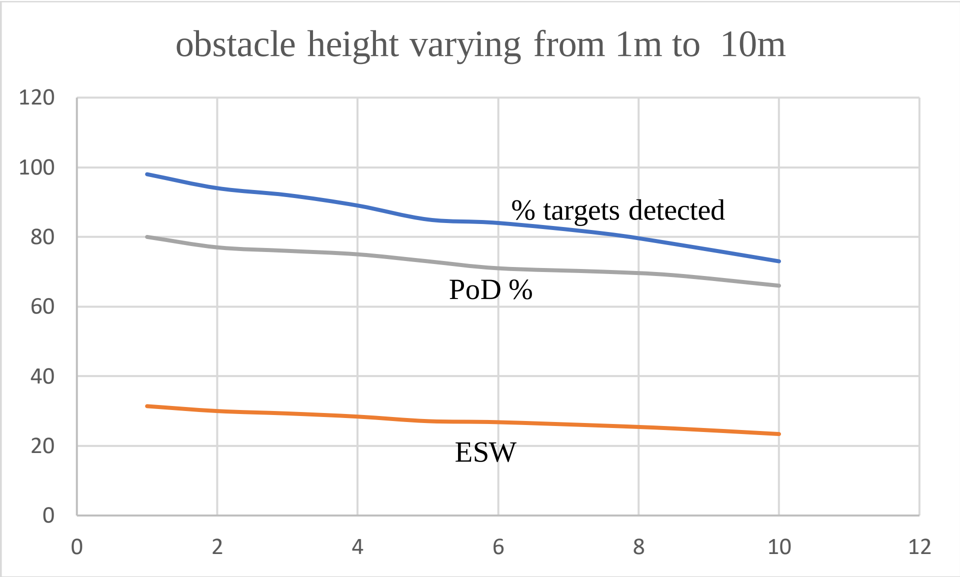

Figure 2: effects of varying obstacle height

Table 3 shows the results obtained when the height of the drone varies. Varying the drone height makes little difference to the percentage of targets detected or PoD; this is clearly shown in figure 3.

drone height (m)	% targets detected	ESW	PoD %
30	86	17.2	74
35	85	19.5	73
40	86	22.3	73
45	85	24.6	73
50	85	27.3	73
55	85	30.6	73
60	85	33.3	73
65	85	36.0	73
70	85	38.5	72

Table 3: effects of varying drone height

Table 3 shows that ESW increases as drone height increases. This is because the increase in the actual number of targets detected brings about an expansion of the Lateral Range Curve and an increase in the area under it. As drone height increases the width of the field the camera is observing increases also and hence coverage (ESW / number of columns being searched) remains about the same. And therefore, so does PoD.

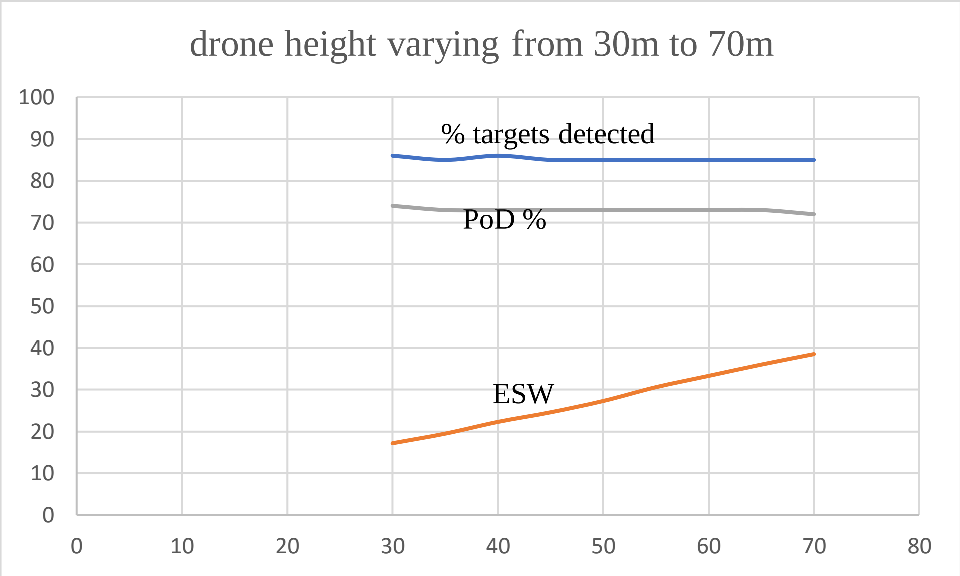

Figure 3: effects of varying drone height

Angular field of view degrees	% targets detected	ESW	PoD %
45	90	18.9	76
50	89	21.4	75
55	88	23.7	74
60	87	25.1	74
65	86	27.6	73
70	84	30.1	71
75	81	31.7	70
80	81	34.0	70
85	79	36.4	69

Table 4: effects of varying drone camera lens angular field of view

Table 4 and figure 4 show the effects of varying the focal length of the camera lens. As the camera lens zooms in from a wide angle towards more of a telephoto effect the field of view is reduced but within that reduced field of view a higher percentage of targets is detected. The reduction in the field of view, however, brings about a reduction in ESW and an increase in PoD.

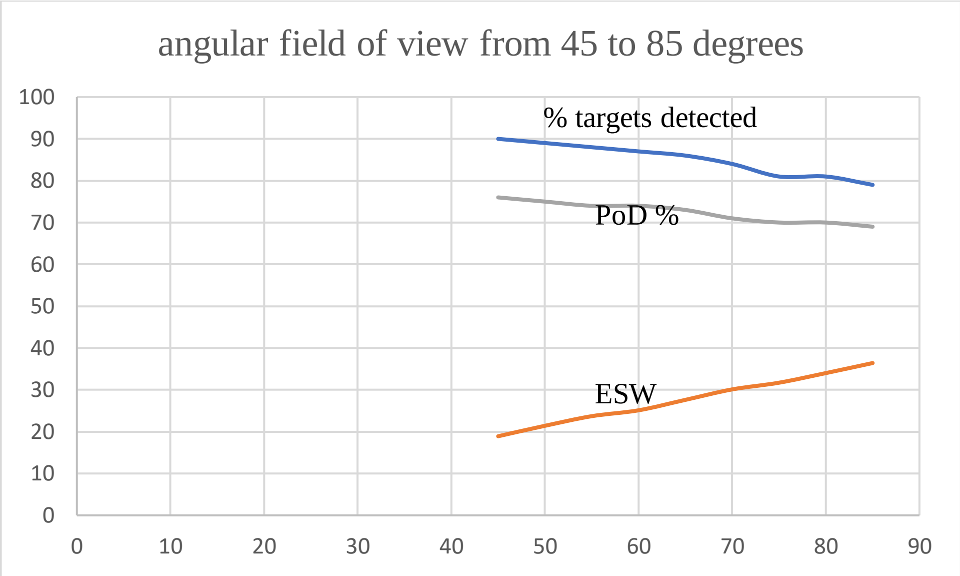

Figure 4: effects of varying drone camera lens angular field of view

Obstacles of different heights

In the version of the model discussed so far, the user provides a single value for obstacle height at the start of each run. This value is then applied to all the obstacles in the search area. Later the model was modified to accept as input a range of obstacle heights, defined by a minimum and a maximum together with a value for the increment by which the height increases from minimum to maximum. Using these, the model can assign a height to each individual obstacle as it is placed in the search area.

A number of runs of the model were carried out with this modification in place. For each of them an obstacle height range was chosen so that it was centred about an obstacle height value that had been used previously and for which the ESW was already known. The result from one of these runs is given below; the obstacle density was 10% and the drone height 30 metres.

- Original run: a constant obstacle height of 5 metres gave an ESW of 56.3 metres
- Using variable heights: varying the obstacle height uniformly between 3 and 7 metres in intervals of 1 metre gave an ESW of 57.5 metres

These results are typical; the value of ESW for varying obstacle height is consistently close to the value obtained for obstacles of constant height. It was also noticed that the detection percentage for the varying obstacle height is between 50% and 60% of the value for obstacles of constant height.

The reason for this is not known at the time of writing. It would appear to be a significant result and worth further investigation. However, it was at this point that capacity and speed limitations of the original host computer brought further investigation to a halt.

Non-uniform distribution of obstacles

In real life, obstacles in the search area not only have a range of heights but also are not likely to be randomly distributed. For example, in nature we can imagine that vegetation occurs in clumps with each element within the clump having a different height. This was not explored in this study but deserves investigation.

Field estimate of Effective Sweep Width

The earlier study that used a simulation model for a ground searcher showed that the value obtained for Critical Distance (cd) was close to the value obtained from the model for ESW and provided therefore a suitable parameter for the field measurement of ground searcher ESW. It was therefore reasonable to investigate to see if a similar relationship existed tor the drone model.

Critical Distance in the ground searcher model is calculated as the mean distance of detected targets from the searcher. Using a similar method for the drone model gave the following result:

ESW = 1.9 x mean horizontal distance from drone to detected targets, or

ESW = 2 x mean horizontal distance approximately

This is certainly close enough to be used for a field estimate.

Field values in general

The two values used in the model that are properties of the terrain being searched (obstacle density and obstacle height) are not directly measurable but are nevertheless important factors for the drone operator to understand, bearing in mind earlier comments made about the effect that they have on detection percentage. This is another aspect of this study that deserves further investigation.

Suggested further work

Suggested topics for further research include:

- A more refined sensitivity analysis
- A closer look at the effect of variable obstacle heights.
- The effect of obstacle clumping.
- Assessing obstacle height and obstacle density in the field.
- Determining the coverage / PoD curve for a single drone

There are many other aspects of using a drone to search for a missing person that require thorough research that have not been touched on during this work, for example the ergonomic issues of a group of people whose duties include flying the drone and scanning the screen looking for the missing person, the use of different cameras and the use of two or more drones working together.

Conclusions

- This paper has shown that a simple digital model to simulate a drone searching for a missing person can prove to be a useful research tool and can provide results that are worthy of note.
- The demonstration that there is a field method that gives an approximate value of ESW like the one identified for a ground searcher is encouraging.
- The sensitivity analysis showed that there is a consistency in the results, suggesting an underlying strength to the model.
- As was the case with the ground searcher simulation, these results and the construction of the model itself provide a better understanding of the search process.
- This work has shown that there is much that could be learned from developing this approach.