Efficient design of UAVs system for utilization at tourism industry

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Abstract. At present, Unmanned Aerial Vehicles (UAVs) are applied in various kinds of fields with several purposes such as military, rescue, monitoring, transportation, recreation and so on. Tourism industry is an emerging field of UAV application and one of the important roles of UAV is to provide safety and security in tourism industry. Usually, tour attractions are crowded with people. Also many attractions such as canyon, coastal area, national park have possibility of dangerous accidents and tourists are exposed to those accidents. To prevent the accidents and provide quick responses to the accidents, UAVs system can be constructed and operated. UAVs conduct monitoring and patrolling tasks. After serving a task, it returns to the depot for refueling and maintenance. After that, UAV moves to perform a task persistently. In this study, the economic UAVs system design and efficient operation are investigated by developing the mixed-integer programming model. Proposed mathematical model is tested via numerical example.

Keywords: Unmanned Aerial Vehicle (UAV), UAVs system design, safety and security, tourism industry, persistent UAV operation.

1. INTRODUCTION

Many advantages of Unmanned Aerial Vehicle (UAV) such as flexibility, easy access and low cost make the UAV popular in these days. Therefore, UAV is extending its application fields from military industry to various commercial industries. Nowadays, UAVs are used for many civil purposes such as traffic monitoring, agricultural operations, aerial photography, search and rescue, environmental monitoring, firefighting, communication relay, etc. Among the emerging UAV application fields, one of the interesting fields is tourism industry. Many UAVs have built-in camera, so, people can enjoy controlling

Figure 1: UAV refueling (recharging) station

UAVs and watching live video from the sky. Also people can see the poor access points using UAVs. Therefore, some tour attractions use UAVs and provide new experiences to the tourists. This is interesting use of UAVs for fun. However, there is more important role of UAVs in tourism industry. In usual, tour attractions are crowded with people. Also many attractions such as canyon, coastal area, national park have possibility of dangerous accidents. In above attractions, tourists are exposed to the dangerous accidents. To prevent the accidents and provide quick response to the accidents, UAVs can be used. Set of UAVs will monitor congestion areas and patrol dangerous areas. After serving missions, they will return to the depot, refuel its energy source and take maintenance work. And then, it will move to conduct missions persistently. As a result, with the use of UAVs system, tour attractions can be kept safe and provide quick response to the accidents. Figure 1 shows an example of depot to refuel (recharge) energy source of UAV.

We can find the real application of UAVs system in tour attraction. Kaziranga National Park in India uses UAVs for patrolling missions. According to the Sydney Morning Herald (2013), UAVs patrol the national park and safeguard the rare one-horned rhino from poachers. UAVs give patrols with a new strategic advantage by providing a view from the sky. Also it can access into previously unreachable areas and can observe illegal activities of the ground. Also Korea Forest Service is developing UAVs system to monitor and extinguish forest fire. Figure 2 shows the use of UAVs in Kaziranga National Park.

Figure 2: UAVs of UAV in Kaziranga National Park

When we consider the installation of UAVs system, we should consider system design issue. It should be designed in economic and efficient manner. Economic issue is related with the investment cost for purchasing depots and UAVs. Efficient issue is about the operation schedule of UAVs to conduct missions. For the short and long term of UAVs system operation, both issues are needed to be considered simultaneously. In this study, we will pursue economic and efficient UAVs system design for safety and security missions in tourism industry. Mathematical model is developed to achieve the goal. Through the model, an optimal UAV system configuration which includes required number of depots and UAVs will be derived and help to construct economic UAVs system. Also schedule of each UAV will be derived simultaneously to use the UAVs in efficient way.

2. LITERATURE REVIEW

In this literature review, we will introduce the use of UAVs in civil purposes. As discussed previously, UAVs are used in various missions with civil purpose. To successfully conduct those missions, researches developed methodologies to efficiently use UAVs system. Xiao-feng et al. (2012) developed mathematical model with multiple objectives for UAV cruise route planning. The role of UAVs is to collect traffic information. In the study, authors tried to design the system in economic manner by minimizing the total number of required UAVs and its cruise distance. Use of UAVs in communication relay can be found in Cetin et al. (2013). Authors constructed airborne communication relay chain using UAVs. To provide stable service, collision avoidance between UAVs and other obstacles is considered. UAVs are also applied in agriculture. Zhang and Kovacs (2012) summarized the researches on the application of small unmanned aerial systems for precision agriculture. Unmanned aerial system uses geospatial techniques and sensors such as GPS, GIS and remote sensors to identify variations in the field instead of satellite image to achieve low investment cost. In addition, UAVs conduct dangerous missions in harmful area instead of human operator. Goodrich et al. (2008) uses camera-equipped mini UAVs for search and rescue missions of large wilderness regions. Qi et al. (2015) developed the use of rotary-wing UAVs in the search and rescue mission of earthquake area. Han et al. (2013) developed low cost multi-UAV technologies for contour mapping in nuclear radiation field. Coordination of multi-UAVs and wireless sensor networks for disaster management and civil security applications was addressed by Maza et al. (2011). Task of tethered UAVs for detecting oil pollution on the sea was investigated by Muttin (2011).

3. MATHEMATICAL MODEL

In this section, we will describe the developed mathematical model.

3.1 Notation

System parameters

c_{uav}	:	Unit purchasing cost of UAV
c_{depot}	:	Unit purchasing cost of depot
$c_{service}$	:	Unit cost to perform task
d_{ij}	:	Euclidean distance between depot(task) *i* to task (depot) *j*
t_j^a	:	Start time of task *j*
t_j^b	:	End time of task *j*
t_{max}	:	Maximum operation time per day
t_d		Maximum utilization time of depot per day
td^o	:	Required time for UAV refueling and maintenance at depot
TS	:	Travelling speed of UAV
M	:	Large positive number

Influence variables

n_{uav}	:	Influenced variable, number of purchasing UAV
n_{depot}	:	Influenced variable, number of purchasing depot
n_r	:	Influenced variable, maximum allowed number of flights for UAVs

Decision variable

$task_j^{ir}$	:	Binary decision variable. it is equal to 1 if task *j* is served by the r^{th} flight of UAV *i*, otherwise, 0.

3.2 Mathematical model

$$Maximize \ n_{uav} \cdot c_{uav} + n_{dep} \cdot c_{dep} + \sum_{j}^{n_j} \sum_{i=1}^{n_{uav}} \sum_{r=1}^{n_r} task_j^{ir} \cdot c_{service} \quad (1)$$

$$Subject\ to \ \sum_{i=1}^{n_{uav}} \sum_{r=1}^{n_r} task_j^{ir} = 1, \quad \forall j = 1, \ldots, n_j \quad (2)$$

$$d_{j0} / TS + \sum_{i=1}^{n_{uav}} \sum_{r=1}^{n_r} task_j^{ir} \cdot t_j^b \le t_{\max}, \quad \forall j = 1, \ldots, n_j \quad (3)$$

$$\sum_{i=1}^{n_{uav}} \sum_{r=1}^{n_r} task_j^{ir} \cdot t_j^a \ge d_{0j} / TS, \ \ \forall j = 1, \ldots, n_j \quad (4)$$

$$td^o + \sum_{j=1}^{n_j} task_j^{ir} \cdot (t_j^b + d_{j0}/TS) \le \sum_{j=1}^{n_j} task_j^{ir+1} \cdot (t_j^a - d_{0j}/TS) + M(1- \sum_{j=1}^{n_j} task_j^{ir+1}), \quad i = 1, \ldots, n_{uav}, \ r = 1, \ldots, n_r - 1 \quad (5)$$

$$\sum_{j=1}^{n_j} task_j^{ir} \cdot t_j^a \ \le \ \sum_{j=1}^{n_j} task_j^{ir+1} \cdot t_j^a, \quad \forall i = 1, \ldots, n_{uav}, \ r = 1, \ldots, n_r - 1 \quad (6)$$

$$\sum_{j=1}^{n_a} task_j^{ir} = 1, \quad \forall i = 1, \ldots, n_{uav}, \ r = 1, \ldots, n_r \quad (7)$$

$$n_{depot} \cdot t_d - td^o \cdot | J | \ge 0 \quad (8)$$

$$task_j^{ir} \in \{0,1\}, \quad \forall j = 1, \ldots, n_a, \ i = 1, \ldots, n_{uav}, r = 1, \ldots, n_r \quad (9)$$

$$n_{uav}, n_{dep}, n_r \ge 0 \quad (10)$$

Before we explain developed model, we will discuss the relationship between mission and task. Sometimes, a mission requires long duration of service time that is not servable using a single UAV. In this case, a mission can be divided into a set of tasks and UAVs will cooperate to serve the entire mission. As a result, a mission can be represented as a single task or a set of tasks depends on the duration of the mission.

Equation (1) describes the objective function of proposed model. It includes the total task service cost and total purchasing cost of UAVs and depots. The goal of this model is to provide safety and security in tourism attraction by performing monitoring and patrolling missions. Therefore, every monitoring and patrolling task has to be served by the UAVs by Equation (2). Equation (3) means that maximum operation time per day and task start time should be obeyed. Equation (4) and (5) are used to obey task start time. Equation (4) guarantees UAV moving time from depot to task *j* when it serves task *j*. Equation (5) is developed to guarantee the UAV – task availability between each flight. Equation (6) ensures the precedence relationship between assigned tasks for connected flights of each UAV. Using equation (7), every UAV is assigned to a task or depot in every flight. Required number of depots can be calculated with equation (8). Equation (9) and (10) show our decision variable and influenced variables.

4. NUMERICAL EXAMPLE

In this section, proposed mathematical model is tested with the hypothetic data of monitoring and patrolling missions in tour attraction. Seorak Mountain National Park is located in Gangwon Province of Korea and one of the promising candidates to construct and operate UAVs system. Annually more than 3 million people visit Seorak Mountain National Park. However, there are frequent climbing accidents and forest fires. For example, a forest fire has been outbroken and it burned 3,500 m^2 of forest in

Seorak Mountain in June, 2015. Use of UAVs system in Seorak Mountain National Park may prevent above accidents and provide quick responses. Therefore in this study, we will consider the installation and operation of UAVs systemin Seorak Mountain National Park.

Figure 3 shows a part of Seorak Mountain National Park. The green, orange, purple and black lines show the trail and its steepness. Green is the easiest trail and black is the most difficult trail. To monitor intersections and patrol steepest trail, UAVs can be applied. UAVs will monitor two intersections (task 1 and 2). Also it will patrol steepest trail. Patrol path of UAV is divided into two tasks, task 3 and 4. UAVs will refuel its energy source and get maintenance at depots which will be located at gray rectangle point. With the hypothetic data, we will investigate the economic way to construct UAVs system by deriving the optimal number of UAVs and depots to be purchased. Figure 3 shows the trail, task and depot information.

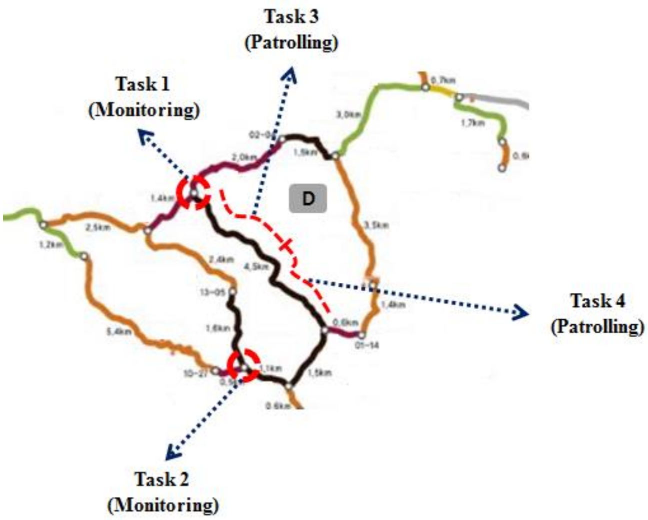

Figure 3: Geographical information of numerical example

Specific task information is described in table 1. To provide uninterrupted patrol service, end point and end time of task 3 is equal to the start point and start time of task 4. Depots will be located at (240, 257, 255). UAV travelling speed is set to 180. t_{max}, t_d and t_{d0} are set to 17:00, 150 and 10. c_{uav}, c_{dep} and $c_{service}$ are set to \$1,000, \$3,000 and \$20 respectively. With the above hypothetic data, mathematical model is tested with various system configurations of n_{uav}, n_{dep} and n_r. CPLEX version 12.4 is used for this test.

Table 1: Location and time information of each task.

Task	Start point	End point	Start time	End time
1	(150, 262, 220)	(150, 262, 220)	13:40	14:00
2	(189, 125, 233)	(189, 125, 233)	14:40	15:00
3	(172, 263, 225)	(222, 221, 313)	15:40	16:00
4	(222, 221, 313)	(256, 167, 232)	16:00	16:20

Table 2 summarizes the results of numerical test. If there is only one UAV purchased, every task cannot be served and problem becomes infeasible. This result comes from the patrol task 3 and 4. A single UAV cannot serve task 3 and 4 continuously because it has to move to the depot for refueling and maintenance after serving task 3. Therefore, one extra UAV should arrive at the end point of task 3 (start point of task 4) before task 4 starts. A replacement UAV will relieve the patrol mission by performing task 4.

Optimal configurations can be found when (n_{uav}, n_{dep}, n_r) = (2, 1, 2) or (2, 1, 4) with the total cost of \$5,080. 2 UAVs and 1 depot are purchased. In the optimal UAV schedules, UAV 1 performs task 1. After refueling and maintenance, it moves to serve task 3. UAV 2 serves task 2 during its first flight. After refueling and maintenance, it moves to replace the UAV 1 and performs task 4.

Table 2: Results summarization of numerical example

System Configuration	n_{uav}	n_{dep}	n_r	Total cost	CPU Time (sec)
1	1	1	2	Infeasible	-
2	1	1	4	Infeasible	-
3	1	2	2	Infeasible	-
4	1	2	4	Infeasible	-
5	2	1	2	\$5,080	0.88
6	2	1	4	\$5,080	0.96
7	2	2	2	\$8,080	1.53
8	2	2	4	\$8,080	0.88

5. CONCLUDING REMAKRS

Due to the development of technology about Unmanned Aerial Vehicles (UAVs), it is using in various kinds of fields. In this study, use of UAVs in tourism industry is investigated. In the tourism industry, one of the important issues is safety and security. Due to the advantages of flexibility, easy access to the unreachable point and low cost, UAVs can provide monitoring and patrolling missions instead of human force. Therefore, the methodology to construct and operate UAVs system was developed in economic and efficient manner. Mixed integer programming model was developed to derive a solution for optimal system configuration and UAV operation schedules. Proposed mathematical model was tested with commercial optimization software, CPLEX 12.4. Through the numerical test, proposed mathematical model derive optimal number of UAVs and depot to be purchased and the optimal UAVs schedules.

Using proposed mathematical model, a system manager can easily figure out the optimal configuration and UAV schedules due to the fast computation times around a second for 4 cases. As a result, we hope that proposed model can be successfully applied in tourism industry to provide safety and security to tourists. For further research, the model needs to be extended to serve several tasks during a flight. UAV serves a set of small tasks in a flight and move to depot for refueling and maintenance. Also non-constant refueling and maintenance time at depot can be considered in the future.

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