

Economic Evaluation of Unmanned Aerial Vehicle for Forest Pest Monitoring

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산림 병해충의 모니터링을 위한 무인 항공기의 경제성 평가

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Abstract Pine wilt disease occurred for the first time in Busan in 1988 and the damage has since been increasing. In 2005, a special law was enacted for pine wilt disease by Korea Forest Service. Incidences relating to the forest pest had been frequent and chemical control as well as physical control techniques had been applied to control it. Therefore, there is a need to reduce the damage caused by the pine wilt disease through intensive management such as continuous monitoring, control, and monitoring based on active control as well as management measures. In this study, the UAV-based monitoring method was proposed as an economical way of monitoring the forest pest. The efficiency of the existing method and UAV method had been analyzed, and as a result the study suggested that UAV can be used for forest pest monitoring and indeed improve efficiency. The UAV-based forest pest monitoring method has a cost reduction of about 50% compared with the conventional method and will also help to reduce the area where the survey was omitted.

요 약 우리나라는 1988년 부산에서 처음 소나무 재선충병이 발생하였으며, 산림청은 국내 소나무림의 보호 및 산림자원의 확보를 위해 2005년에 소나무 재선충병에 대한 특별법을 제정하였다. 현재 소나무 재선충병의 발생 빈도는 증가추세를 보이고 있으며, 발생지역 확대를 막기 위해 화학적 통제 및 물리적 통제 기술이 적용되고 있다. 소나무 재선충병의 방제를 위해서는 먼저 피해 상황을 파악하고 주변 환경 및 특성을 고려한 최적의 방제 계획 수립이 필요하며, 넓은 지역에 대한 모니터링 방안으로 최근 UAV(Unmanned Aerial Vehicle)에 대한 관심이 증가하고 있다. 이에 본 연구에서는 UAV 기반 산림 모니터링 방법에 대한 경제성을 평가하고자 하였다. 기존 인력에 의한 모니터링 방법과 UAV를 적용한 방법의 효율성을 분석 한 결과, UAV 기반 산림 병해충 감시 방법은 기존 방법에 비해 약 50%의 비용 절감 효과가 있으며, 산림 조사의 누락 지역을 줄이는 데도 도움이 될 것이며, 향후 추가적인 연구를 통해 UAV 기반의 산림 모니터링 방안의 검증이 이루어진다면 산림 조사 관련 업무의 효율성이 크게 증가할 것이다.

Keywords : Economic Evaluation, Forest, Pine Wilt Disease, Monitoring, UAV

1. Introduction

In order to control forest pests, it is necessary to

first identify the damage situation and to establish an optimal control plan considering the surrounding conditions and characteristics [1-3]. Also, there is a

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need to prevent the secondary damage and spread through continuous monitoring by completing the primary control through faithful control according to the planned pest control method [4-6]. Fig. 1 shows damage status of pine wilt disease [7].

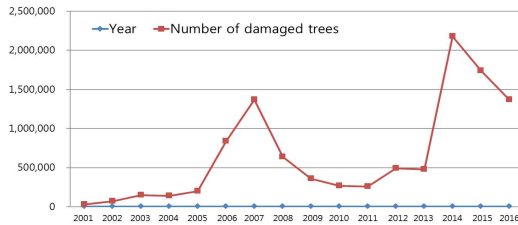


Fig. 1. Damage Status of Pine Wilt Disease

Since monitoring is carried out throughout the year, it is necessary to concentrate on a large area in a short period of time considering the time when the damage had intensively occurred and the time when the control can be carried out [8-10]. Therefore, effective monitoring methods are needed to overcome these difficulties. In this study, the economic analysis of forest pest monitoring using UAV was conducted, and thus an effective pest monitoring method was proposed. Fig. 2 shows study flow.

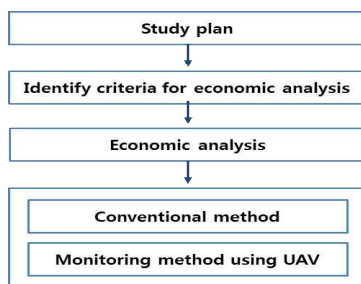


Fig. 2. Study Flow

2. Analysis of existing pine wilt disease monitoring method

Monitoring of pine wilt disease by existing manpower is very inefficient in terms of manpower

composition, time, and area of trail, because manpower with basic knowledge of forest pests needs to be trained for a large area over a short period of time [11-14]. This process largely consists of preparation and planning, field surveys, as well as summary of results. Table. 1 shows the contents of each step by conventional method [15].

Table 1. The Contents of Each Step by Conventional Method

| Step | Description |
|--------------------|---|
| Plan | <ul style="list-style-type: none"> - The route to the survey site is determined - Supplementary surveys may be conducted because there may be gaps in field surveys |
| Field Surveys | <ul style="list-style-type: none"> - The process of monitoring the area covered by walking |
| Summary of Results | <ul style="list-style-type: none"> - Mapping of GPS coordinates and 1:1 matching process of local questionnaire |

The grades of manpower in each process are divided into "advanced" and "beginner". In Korea, the grade of manpower is defined in the "National Technical Qualifications Act" and the main contents are shown in Table 2[16].

Table 2. Grade of Manpower in 「National Technical Qualifications Act」

| Grade | Description |
|--------------|--|
| Advanced | Those who have obtained an engineering certificate and have at least 7 years of experience in related fields |
| Intermediate | Those who have obtained an engineering certificate and have at least 4 years of experience in related fields |
| Beginner | The person who obtained the engineering certificate |

At the plan process, the method using GPS is prepared by arranging two persons. Since it is necessary to carefully prepare so that there are no missing parts, one advanced technician will organize the zone which will take about 8 hours to set up the route.

The Field Survey is a two-person process (1

Table 3. Monitoring of Pine Wilt Disease by Conventional Methods

| Item | Process | Manpower | Qty | Day | Unit price (won) | Price (won) |
|-----------------------------|--------------|----------|---------------------------------|-----|---------------------|----------------|
| Labor cost | Plan | Advanced | 1 | 1 | 173,417 | 173,417 |
| | Field Survey | Advanced | 2 | 10 | 173,417 | 3,468,340 |
| | | Beginner | 2 | 10 | 104,129 | 2,082,580 |
| | Summary | Advanced | 1 | 1 | 173,417 | 173,417 |
| | Sub Total | | | | | |
| material cost | Roll Tape | | 3 | | 40,000 | 120,000 |
| | Sub Total | | | | | 120,000 |
| Total | | | | | | 6,017,754 |
| Discount · Surcharge Factor | | | | | | |
| Factor | | | Condition | | | % |
| Slope | | | High | | | 0 |
| | | | Middle | | | 5 |
| | | | Low | | | 10 |
| Obstacle | | | Below knee height | | | -10 |
| | | | Less than breast height | | | 0 |
| | | | Above chest height | | | 10 |
| Time | | | October, November, March, April | | | -10 |
| | | | December ~ February | | | 0 |
| | | | May ~ September | | | 10 |

advanced and 1 beginner) that identifies trees that have pine wilt disease in the forest area through walking. It took about 10 days for two teams consisting of two people to investigate an area of about 235ha. In the Summary of Results, mapping of the surveyed GPS coordinates for each team and 1:1 matching process of local survey charts were performed. Each of them was transformed into an excel form and the surveyed contents were entered. In this process, one advance technician took 8 hours. Table 3 shows the Monitoring of the pine wilt disease by conventional methods.

A total of 42 people (22 advanced, 20 beginners) are required for 245ha on the forest monitoring by manpower, and 6,017,745 won is needed when the material cost is included. When converted into unit price per hectare, it takes 25,607 won.

3. Analysis of monitoring method using UAV

The UAV monitoring method can greatly reduce the

time of the field survey process in the conventional work process. In this study, the amount was calculated by dividing the area under investigation by 300 hectares or less, considering the very high rate of data acquisition of UAV. Forest monitoring using UAV consists of plan, data capture, survey, data processing and image classification. Table 4 shows the contents of each step using UAV and Table 5 shows the comparison between the conventional method and UAV method.

Table 4. The Contents of Each Step using UAV

| Step | Description |
|----------------------|---|
| Plan | Select the target area and establish the UAV flight plan |
| Data capture | The image of the target area is acquired using the UAV |
| Survey | Perform GCP (Ground Control Point) survey to increase the accuracy of the results |
| Data processing | Process the data acquired by UAV to produce an ortho image |
| Image classification | Select the affected trees using the ortho image |

Table 5. Comparison between the Conventional Method and UAV Method

| Step | |
|---------------------|----------------------|
| Conventional method | UAV method |
| Plan | Plan |
| Field Survey | Data capture |
| | Survey |
| | Data processing |
| Summary | Image classification |

In order to apply UAV in forest monitoring, one set of UAV (including related software), a workstation for image processing, one set of GNSS surveying equipment and UX5 consumables (fuselage) are needed. To calculate the cost, equipment, consumables, labor cost, etc. are considered and the durability period of the hardware is 5 years. Table 6 show hardware rental costs.

Considering Korea's weather, the day of UAV operation was calculated as 148 days, which was selected as the average day wind speed of less than 1.5m/s. Workstations and GNSS are estimated to have

an annual utilization rate of 220 days, which is 22,499 won and 25,667 won, respectively. In other words, the total rental cost for one day flight of UAV is calculated as 292,067 won.

To operate the UAV, work process of the plan, data capture, survey, data processing and image classification were needed, which requires advanced engineers. The cost of surveying, UAV operating was applied to the cost of surveying engineer. Table 7 shows labor cost by UAV (305ha).

For the images taken one time, it was calculated that 2 persons in the plan, 3 persons in data capturing, 1 person in the survey, and 2 persons in the image production and classification. Also, the cost of monitoring projects using UAV was calculated as 3,818,265 won, considering 110% of labor cost, 10% profit, and 10% of value added tax. Table 8 shows monitoring of pine wilt disease by UAV (305ha).

The costs of the shooting, image production, and classification of the damaged area smaller than 200ha are the same as those of the equipment renting over 300ha. However, when 305ha is used as the reference

Table 6. Hardware Rental Costs

| Item | Cost Option | Cost | Depreciation rate | Durability | Number of annual days | One time cost |
|--------------|---|-------------|-------------------|------------|-----------------------|---------------|
| UAV | Depreciation | 100,000,000 | 0.9 | 5 | 148 | 121,621 |
| | Maintenance | 100,000,000 | 0.9 | 5 | 148 | 121,621 |
| | Sub Total | | | | | 243,242 |
| | - 1 year rental: 243,242 won × 148 days = 35,999,816 won | | | | | |
| | - 1 month rental: 35,999,816 won / 12 month = 2,999,985 won | | | | | |
| Work Station | - 1 time rental: 2,999,985 won / 12.3 / month = 243,901 won (A) | | | | | |
| | Depreciation | 15,000,000 | 0.9 | 5 | 220 | 12,272 |
| | Maintenance | 15,000,000 | 0.9 | 5 | 220 | 12,272 |
| | Sub Total | | | | | 24,544 |
| | - 1 year rental: 24,544 won × 220 days = 5,399,680 won | | | | | |
| GNSS | - 1 month rental: 5,399,680 won / 12 month = 449,973 won | | | | | |
| | - 1 time rental: 449,973 won / 20 / month = 24,499 won (B) | | | | | |
| | Depreciation | 22,000,000 | 0.9 | 5 | 220 | 18,000 |
| | Maintenance | 22,000,000 | 0.5 | 5 | 220 | 10,000 |
| | Sub Total | | | | | 28,000 |
| | - 1 year rental: 28,000 won × 220 days = 6,160,000 won | | | | | |
| | - 1 month rental: 6,160,000 won / 12 month = 513,333 won | | | | | |
| | - 1 time rental: 513,333 won / 20 / month = 25,667 won (C) | | | | | |
| Total | | | | | | 292,067 |

area, the unnecessary cost is applied to the small area. Therefore, the required cost is calculated at the area ratio of 200 ha to the reference area (305ha). Since the area of the site was reduced, the area ratio was calculated by applying 0.65 time for field survey, surveying, image production and classification. Table 9 shows labor cost by UAV (200ha).

Table 7. Labor Cost by UAV (305ha)

| Item | Process | Manpower | Qty | Day | Unit price (won) | Price (won) |
|------------|----------------------|----------|-----|-----|------------------|-------------|
| Labor cost | Plan | Advanced | 2 | 1 | 152,855 | 305,710 |
| | Data capture | Advanced | 3 | 1 | 152,855 | 458,565 |
| | Survey | Advanced | 1 | 1 | 152,855 | 152,855 |
| | Data processing | Advanced | 1 | 1 | 176,043 | 176,043 |
| | Image classification | Advanced | 1 | 1 | 176,043 | 176,043 |
| Total | | | 8 | 5 | - | 1,222,840 |

Table 8. Total UAV Monitoring Cost (305ha)

| Item | Unit Price | Rate | Price (won) |
|---------------------------------|------------|------|-------------|
| Rent, material cost, labor cost | - | - | 1,759,453 |
| 110% of direct labor costs | 1,269,216 | 110% | 1,396,138 |
| Profit | 3,155,591 | 10% | 315,559 |
| Value added tax | 3,471,150 | 10% | 347,115 |
| Total | | | 3,818,265 |

Table 9. Labor Cost by UAV (200ha)

| Item | Process | Manpower | Qty | Day | Unit price (won) | Price (won) |
|------------|----------------------|----------|-----|------|------------------|-------------|
| Labor cost | Plan | Advanced | 2 | 0.65 | 152,855 | 198,712 |
| | Data capture | Advanced | 3 | 0.65 | 152,855 | 298,067 |
| | Survey | Advanced | 1 | 0.65 | 152,855 | 99,356 |
| | Data processing | Advanced | 1 | 0.65 | 176,043 | 114,428 |
| | Image classification | Advanced | 1 | 0.65 | 176,043 | 114,428 |
| Total | | | 8 | 3.25 | - | 824,990 |

Therefore, the total cost of implementation, profit, and VAT based on rent, material, and labor is calculated as 2,689,488 won. If two consecutive shots are taken in the same area, it is possible to shoot up to 610ha, which must be included in two ranges of each reference grid (2km × 2km). In such cases, the rent portion may be excluded. In this case, it is possible to exclude the rental portion. Therefore, the cost of consumables is exempted except for the rental fee, and the workload of field trip, shooting, and surveying is increased by 0.5 days respectively. Therefore, the total cost is 7,012,566 won, which is about 8.2% of the total cost. The total cost is 3,818,265 won and the additional cost is 3,194,301 won. In this study, the cost of forest monitoring using UAV was calculated based on 305ha, 200ha, and 600ha or more. Based on the results of the study, the project cost per area was calculated. Table 10 shows comparing the total cost of target area according to the data acquisition area.

Table 10. Labor Cost by UAV (200ha)

| Area (ha) | Based on 305ha | Based on 200ha | | |
|-----------|----------------|----------------|---------------------|----------------------|
| | | Cost (won) | Surcharge area (ha) | Surcharge cost (won) |
| 200 | 3,818,265 | 2,689,488 | 0 | - |
| 210 | 3,818,265 | 2,814,058 | 10 | 124,570 |
| 220 | 3,818,265 | 2,938,628 | 20 | 249,140 |
| 230 | 3,818,265 | 3,063,198 | 30 | 373,710 |
| 240 | 3,818,265 | 3,187,768 | 40 | 498,280 |
| 250 | 3,818,265 | 3,312,338 | 50 | 622,850 |
| 260 | 3,818,265 | 3,436,908 | 60 | 747,420 |
| 270 | 3,818,265 | 3,561,478 | 70 | 871,990 |
| 280 | 3,818,265 | 3,686,048 | 80 | 996,560 |
| 290 | 3,818,265 | 3,810,618 | 90 | 1,121,130 |
| 300 | 3,818,265 | 3,935,188 | 100 | 1,245,700 |

When the area is small, 200ha is applied as the reference value, and when the area is 290ha or more, it is preferable to apply the standard of 305ha as the unit area. In addition, if takeoff and landing in one place, the agency performing the business will save money on areas over 600 hectares. Table 11 shows an example of cost by area.

Table 11. Example of Cost by Area

| Area (ha) | Cost (1,000 won) | | | | Remark |
|--------------|------------------|-------------|-------------|--------|---|
| | 1 flight | 2 flight | 3 flight | Total | |
| 200 | 200 | - | - | 2,689 | Small area |
| 300 | 300 | - | - | 3,818 | Standard area |
| 400 | 300 | 100 | - | 5,058 | Same location (takeoff and landings) |
| 500 | 300 | 200 | - | 6,507 | |
| 600 | 300 | 300 | - | 7,012 | |
| 800 | 300 | 300 | 200 | 9,701 | |
| 900 | 300 | 300 | 300 | 10,206 | |

The cost of forest investigation by existing manpower cost 25,607 (won) per ha, and the method using UAV cost 12,488 (won). The UAV method showed a cost reduction of about 50% over the conventional method. As the monitoring area increases, the cost difference between conventional methods and UAVs becomes greater. Fig. 3 shows the comparison of costs due to increased monitoring of the area.

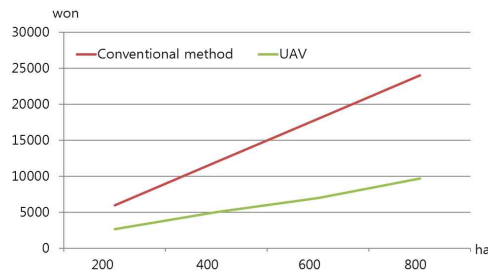


Fig. 3. Comparison of Costs Due to Increased Monitoring Area

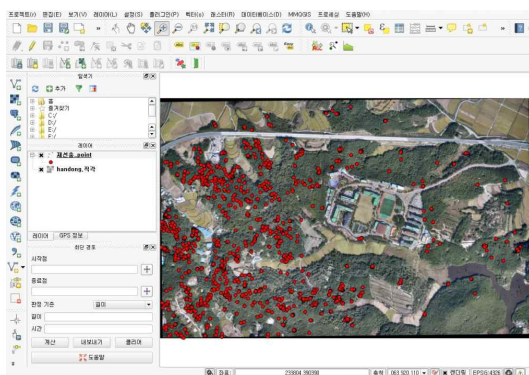


Fig. 4. Example of a Forest Monitoring Using UAV

In addition, the UAV method is expected to prevent the omission of the survey area in the field survey by manpower. Fig. 4 shows an example of a forest monitoring using UAV.

4. Conclusions

In this study, economic feasibility of forest monitoring method using UAV was analyzed. The results of the study are as follows.

1. The forest monitoring method using UAV can greatly reduce manpower and time for field survey in the existing process.
2. The UAV-based forest monitoring method has a cost reduction of about 50% compared with the conventional method and will also help to reduce the area where the survey is omitted.
3. As the area of the field survey increases, the difference in costs between conventional method and the methods using UAV will be greater.
4. If the UAV-based forest monitoring method is verified through various studies in the future, the efficiency of forest monitoring will be greatly improved.

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