Wildfire Management Supported by UAV Based Air Reconnaissance: Experiments and Results at the Szendro Fire Department, Hungary

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Abstract

Szendro Fire Department has recently carried out several real fire experiments using Unmanned Aerial Vehicles (UAV) for fire monitoring. The first experiment took place in August 2004, and the most comprehensive one occurred in September 2005. The aims of the first experiment were to demonstrate the tactical efficiency of using UAVs and to test control, data transmission and capacity. The objectives of the subsequent experiments were to analyse the effect of changing parameters, to predict spread of fires and to test the infrared camera system. This experiment was also a demonstration of using UAVs for fighting against wildfire to end-users. The test flights continue in the spring of 2006 too. From 14th August 2006 as operational UAV will be in service at the Szendro Fire Department, supporting fighting against wildfires. As we know it will be 1st of the World!

Keywords: *Unmanned Aerial Vehicles (UAVs), real fire experiments, fire monitoring, operational UAV 1st of the world.*

I. INTRODUCTION

The proportion of forested areas in the district of Szendrő is well in excess of the national average, Hungary and also includes about 90 percent of the Aggtelek National Park, parts of which feature on the UNESCO World Heritage list. Therefore, for us, improving preventive measures against forest fires and efficiency in extinguishing them is not only an option but also an obligation.

In Hungary alone, the damage caused by vegetation fires amounts to some million Euros every year. The production value of one hectare of forest is around 4 thousand Euros. The intangible value destroyed is generally estimated at around ten times the production value. Accordingly, forests as living environments have an intangible value that certainly justifies measures to protect them from fire. The extent of the damage is increased further at the level of national economy by the cost of extinguishing those fires.

We may state that global warming is increasing the frequency of extreme weather conditions. This results in an increase of protracted periods without precipitation.

Consequently, we may expect increases in the number of, and the level of destruction caused by forest fires, which generally occur during dry periods.

II. ADVANTAGES OF AIR RECONNAISSANCE

In general, the development of a fire can be characterised by the so-called damage-time function. The vertical axis shows the amount of the damage, the horizontal one shows the passage of time. In the ideal case of a forest fire the damage-time function gives an exponential curve that diverges to infinity. The rise of the curve is determined by two factors. One of them is derived from the area of the circle already covered by the fire and is proportional to the square of the radius of the circle. The other is derived from the velocity of spread of the fire over a unit of time. The faster the fire spreads, the larger the area that is burnt. It is easy to see that if for any period ***Δt*** is reduced, the area burnt and thereby the damage caused is reduced exponentially.

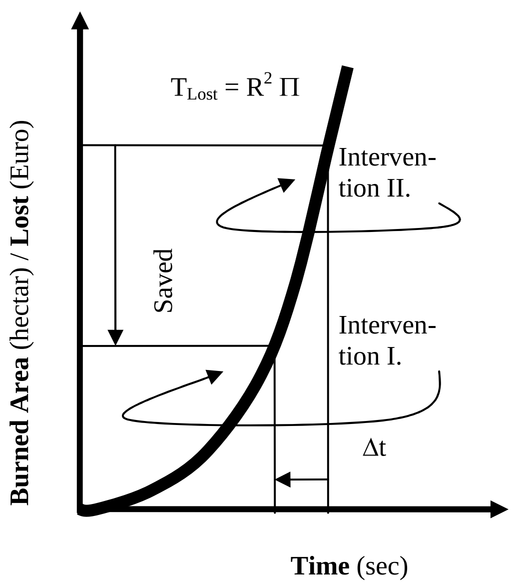

Fig. 1. Damage – Time Function

When assessing efficiency, it is usually the return on investment and the period of time required for such returns to be realised that we take into account. The concept of efficiency is applicable to fire-fighting, but the way it is applied differs from the traditional interpretation. In the case of fire-fighting and other interventions, efficiency is measured either by the quantity of value saved or by the actual damage, which, of course, should be as small as possible. The smaller the area affected by a fire the smaller the quantity of resources and equipment that are required to extinguish it. Therefore, the application of any method that allows fire-fighting to begin earlier will result in an increase in the relative productivity or efficiency of fire-fighting.

Once fire fighters on the scene, the first important task is reconnaissance. Reconnaissance comprises of data collection and orientation required for defining the tasks associated with the saving of lives and the extinguishing of the fire, along with their safe implementation; it extends from the fire report until supplementary work is concluded. The following problems are frequently associated with the reconnaissance of forest fires:

1) The fire may cover such a large area that reconnaissance requires touring around the entire affected area. Natural conditions may mean this cannot be done in a motor vehicle. Walking around it may also be hindered by terrain topology and vegetation. It should be taken into account that circumambulating an area with a radius of 300 m involves a distance of almost 2 km!
2) If the commander of fire-fighting operations is at the scene, he is too close to the fire to be able to manage it along with its environment. Quite literally, he cannot see the forest for the trees! As the extinction of forest fires is a protracted process in time, and since during that time the fire will continue to spread, the ability to manage a fire together with its environment is an indispensable precondition for the efficient extinguishing of a fire.

The above problems can be solved using a tool that can rapidly provide accurate information about the entire fire zone. The use of personal reconnaissance from the air is a logical solution.

Air reconnaissance is efficient because obtaining an overview of several hundred or even thousand hectares of forest allows intervention measures to be co-ordinated. Without air reconnaissance, co-ordination of measures can only be based on the information circulated between the commanders of individual units at various locations. But the assessment of the gravity of their individual situations by commanders located at various sites may be completely subjective and not made in relation to the other sites. Air reconnaissance helps to eliminate subjectivity in such judgements and to rank the individual sites in relation to the others. Air reconnaissance may also eliminate the effects of terrain topology that otherwise hinder or prevent visual access to the area concerned. Our task is to find a solution that allows us to take advantage of the benefits of air reconnaissance in the case of smaller fires as well.

We can retain the benefits of air reconnaissance at a relatively low cost if visual inspection by staff is replaced by the acquisition of image data. The replacement of inspection by staff by machine data acquisition does not reduce the efficiency of reconnaissance or prevent the facilitation of more efficient fire-fighting. In short, machine reconnaissance can support the achievement of criteria required for greater efficiency to a similar degree. And it does not require manned aircraft!

Machine data acquisition meeting the above criteria can be performed by an UAV, I mean a model aircraft that is controlled from the ground by personnel. There are several examples of such systems already in operation. Today, cameras attached to model aircraft controlled from the ground can transmit photos and live images of excellent quality. Trained personnel control them. Their application can have great benefits in natural disaster situations that develop or occur slowly. Typical examples are the reconnaissance of floods and the assessment of dykes. In those situations, there is time to transport the model aircraft to the site, to find an area that is suitable for the launching of the machine and for providing support, etc. Those aircraft are usually flown by dedicated personnel or may be located at specific bases. Staff fly them for sport, as a hobby, but on a regular basis in order to maintain precise navigation and flying skills.

Given the above advantages, a question suggests itself: if that UAVs are so efficient, and if it has proven its efficiency in the case of floods, why is it not being used for the reconnaissance of forest fires whose dimensions do not warrant the deployment of manned reconnaissance aircraft? The answer comes mainly in the time factor. As it was mentioned such UAVs are generally flown by specific personnel and are located at specific stations. The extinction of a medium size forest fire takes from a couple of hours to at most half or a whole day. The use of model aircraft flown by specific personnel would take too long relative to the total timescale of the intervention. Alerting the model plane unit would only be justified after land reconnaissance on foot, but as a result, the model plane would be too late to perform early reconnaissance.

Maximum efficiency is best supported by making the corresponding efforts as early as possible. That problem could be solved by an UAV being operated by the fire service! The relatively low flight performance requirement reflects the preference for a really small UAV that can provide efficient support for the reconnaissance activities of even the smallest fire-fighting unit rather than an UAV with excess capacity. Excess capacity is unnecessary as the requirements of efficient reconnaissance can even be met by a single image from a suitable perspective! As the fire spreads relatively slowly, a second flight can furnish precise information to the fire-fighting commander.

If we can find a UAV that can be used by even the smallest fire brigades, a number of incidental benefits will also accrue that would not be furnished by larger UAVs. They include the fact that once the UAV is used in the field, the everyday practice of the smallest units would provide support for the viability of the UAV in a very short time. Without any risk the populated area! The frequent calls that fire brigades receive in dry periods would allow a tremendous quantity of experience to be collected. UAV with large flight potential are only deployed in emergencies of a magnitude that is relatively rare. As a result, the experience of application would be of an inferential nature rather than one of statistical certainties. On the other hand, the use by small UAVs of limited capabilities would provide a quantity of data sufficient for statistical analysis in a single year.

III. THE PROCESS OF USEING UAV

After the fire brigade receives the fire report, a single section set off for the scene of the forest fire. In terrain of medium articulation, topological conditions do not allow the area to be viewed as a whole, but, based on the smoke, the fire-fighting commander believes that thorough reconnaissance is in order. Therefore the commander defines the point of control and the small UAV is prepared for flight. In effect, preparation for flight takes less than 10 minutes.

Based on the visible smoke, the commander of fire-fighting (CF) can give a rough estimation of the extent of the fire. In our example, the fire is assessed as being of medium severity. Due to terrain conditions, the direction of spread and the extent of the fire cannot be assessed with any accuracy. The laptop transported on the vehicle is used to display a digital map of the area. A special pencil is used to draw a curve starting from and returning to the point of control. Alternatively, some points may be defined, which would be connected to obtain the flight path, this time as straight sections connecting the turning points. The UAV, which would be connected to the laptop, would convert the flight path to the digital map that it stores in its own memory.

Experience indicates that it is not difficult to draw a curve that is certainly significantly larger than the actual extent of the fire. This will ensure that the UAV flies around the fire in the way that the CF would have to walk around it. Using its built-in GPS unit, the UAV flies along the specified flight path, transmitting images from its digital and thermal cameras to the screen of the laptop. As a result, the fire-fighting commander can see perspective images of the area affected by the fire in real time. If possible, the precise image and thermal data transmitted by the UAV would be mapped onto the digital map displayed on the screen of the laptop.

From the moment of launch, the UAV supply data continuously, therefore within in the first few minutes it provide information of a quantity and quality that provide effective support for the decisions of the commander of fire-fighting. One such element of decision support is that even before the UAV returns, it possible to establish the extent of the burning area and to request the assistance of further units. This save a significant amount of time. Also, as it was already mentioned, the amount of damage prevented is proportional to the square of any amount of time saved.

Another example of decision support: if we are able to manage the entire area in a complex manner, it may well be the case that protecting the area where the fire is currently most intense is the most important task. It is possible that our forces need to be concentrated in a location other than that furnished by the initial assessment. While fire fighting is in progress, the fire continues to spread in the areas where no countermeasures are taken, and indeed it may meet natural obstacles or barriers. A river, a wider road or glade may stop the fire as a natural barrier, so beginning fire-fighting measures at a distance of 100 or 200 metres from such a natural barrier can only be considered efficient if we have plenty of resources and equipment not needed elsewhere. On the other hand, it is also possible that in a direction which currently has low parameters for spread and is thus assessed as lower priority, there lies a much more valuable area, such as a highly protected plant community, a habitat of protected animals, or perhaps an area of vegetation with higher parameters for spread. The proximity of a pine forest is an example of the latter scenario. [1]

The above examples show that the most efficient intervention is not necessarily the same as intervention at the point where the fire is the most intense. In order to make the best decision, the area of the fire must be managed in a complex manner, together with its environment. The above considerations lead to the conclusion that we should always attempt to extinguish forest fires so as to consume the smallest possible quantity of resources.

IV. ECONOMICAL ANALYSIS

It is very important to evidence the advantages of using UAVs by economical analysis. Szendro Fire Department made three different ways. First was the Air Reconnaissance Matrix. Comparison the advantages and disadvantages of the three different type of air reconnaissance may give us a matrix. Using staff aircraft, model plane and UAV developed specially to fire fighters was comparised by 4 different factors, which is wanted, very important for beginning intervention. These are: the time starting supply information, the quality and quantity of information, the demanded background support, and naturally the cost. Giving the mark from one to three we get the matrix. The classification is maybe a little bit subjective, but the aim is the cost effective support of forest fire intervention. The results of UAV developed to fire fighters gained superior.

Table 1.
Air reconnaissance matrix

	STAFF AIRCRAFT	UAV	SPECIAL UAV
TIME	XXX	XX	XX
INFORMATION	XXX	XX	XX
SUPPORT	X	XX	XXX
COSTS	X	XX	XXX
SUM	8	8	10

Second was the Affected Area Analysis. In this case we have to take a forest. The fire affects a little part of the forest without starting any control. It means the lost is absolute. After starting the intervention the affected area by fire will further expand. If the UAV able to support the intervention at a requested level, the burned area reduce significantly. The question is the last extension of the affected area by the fire. It means the economical efficiency can be measured by the saved area of the forest. Unfortunately it can be very subjective to estimate it, but with any expertness the specialists can give us an acceptable value. The difference between the traditional controlled affected area and the affected area controlled by the robot reconnaissance aircraft will give us the economical efficiency.

Third was a real economical analysis, to understand the basic process. The conclusion is the next: if summarising the different cost between the affected area and the traditional intervention and subtract the cost of UAV give us a positive value, the use of the UAV is economical effective! [2]

V. 3- STEPS PROGRAM

Based on the above results the Szendro Fire Department plans a 3- steps program, in which the first 2 steps are developed by the Fire Department. The third one is only a logical consequence, which cannot be financed by Szendro Fire department. The essence of steps:

A. First Step

Aim: to create a UAV which is as cheap as possible, with limited capabilities, but in a useable form, so that fire fighters have a chance to use UAV without any fear of crashing or losing it. *Plane/equipment:* the material of UAV is not easy to broken (wing from latex or plastic) but easy to replace. The UAV carries a cheap camera, visible only. Ground control only. Flight capacity: 15 minutes flight time, within a circle of, 1 km radius and 500 m altitude. *Advantage:* no fear from using UAV. Fire fighters get lots of experience in a real fire situation (fire) and within a short time. *Disadvantage:* limited capabilities, providing moderate quality information. Ground control only. At least 2 users. *Time:* I plan to fly it in the second part of March or the first part of April 2006. (Because of the dry grass this period is the first fire season of Hungary.) *Costs:* 1 – 2.000 Euros/UAV, Szendro Fire Department to finance it.

B. Second Step

Aim: to create a UAV with autonomous flying ability specialized for supporting fighting against forest fire. *Plane/equipment:* Carried by jeep, measuring 40x40x150 cm. Have to stick or turn the wings to carry it easily (40x40x150 cm). Able to turn, good quality visible/thermal camera with zoom. Autonomous flights, limited ground control. Able to start within 2 minutes. Flight capacity: 30 minutes flight time, within a circle of 3 - 5 km radius and 800 – 1000 m altitude. *Advantage:* full intervention support. Providing high quality information. User friendly. *Disadvantage*: first UAV is expensive. *Time:* it depends on money and developer but I hope it will fly before the end of 2006. *Costs:* 10 – 20.000 Euros, haveing a promise from R&D Found getting it in 2006.

C. Third Step:

Aim: to create a mobile and integrated UAV base. It can be used in any type of intervention (not only forest fire). *Plane/equipment*: about 5 – 7 planes. 2 Zeppelins (1 little and 1 bigger one), (1 Helicopter), 1 little UAV (as the 1. step), 1 moderate UAV (as the 2. step) and 1 high capacity UAV (have to develop it). Compact system to be carried it in a little truck. *Advantage:* ability to support any intervention from little accidents to disaster management, not only fighting against forest fire (e.g. at chemical accidents attached a special sensors, floods, Before - Fire Patrol, After - Fire Damage Estimation). *Disadvantage:* expensive. Several hours needed to start the planes. Use it only at long time intervention. Extensive background support needed. *Time:* development 2006 – 2008. *Costs:* 100 – 200.000 Euros. Need to apply for R&D Found.

VI. EXPERIMENTS AND RESULTS

Szendro Fire Department made 2 real fire experiments using UAVs for fire monitoring last years. [3] The first was in 10th August 2004 and the second was in 23rd September 2005. At the first experiment aims were to evidence the tactical efficiency of using UAVs for fire monitoring and to test the flying control, data transmission and flying capacity.

At the second experiment aim were to analyse the effect of changing flying parameters, to predict spreading of fires based an on-line data transmission, and to test the infrared camera system. This experiment was a demonstration too. It was held in Szendro at the same time of Regional UAVNET Meeting aiming to close using UAVs for fighting against forest fires to end users.

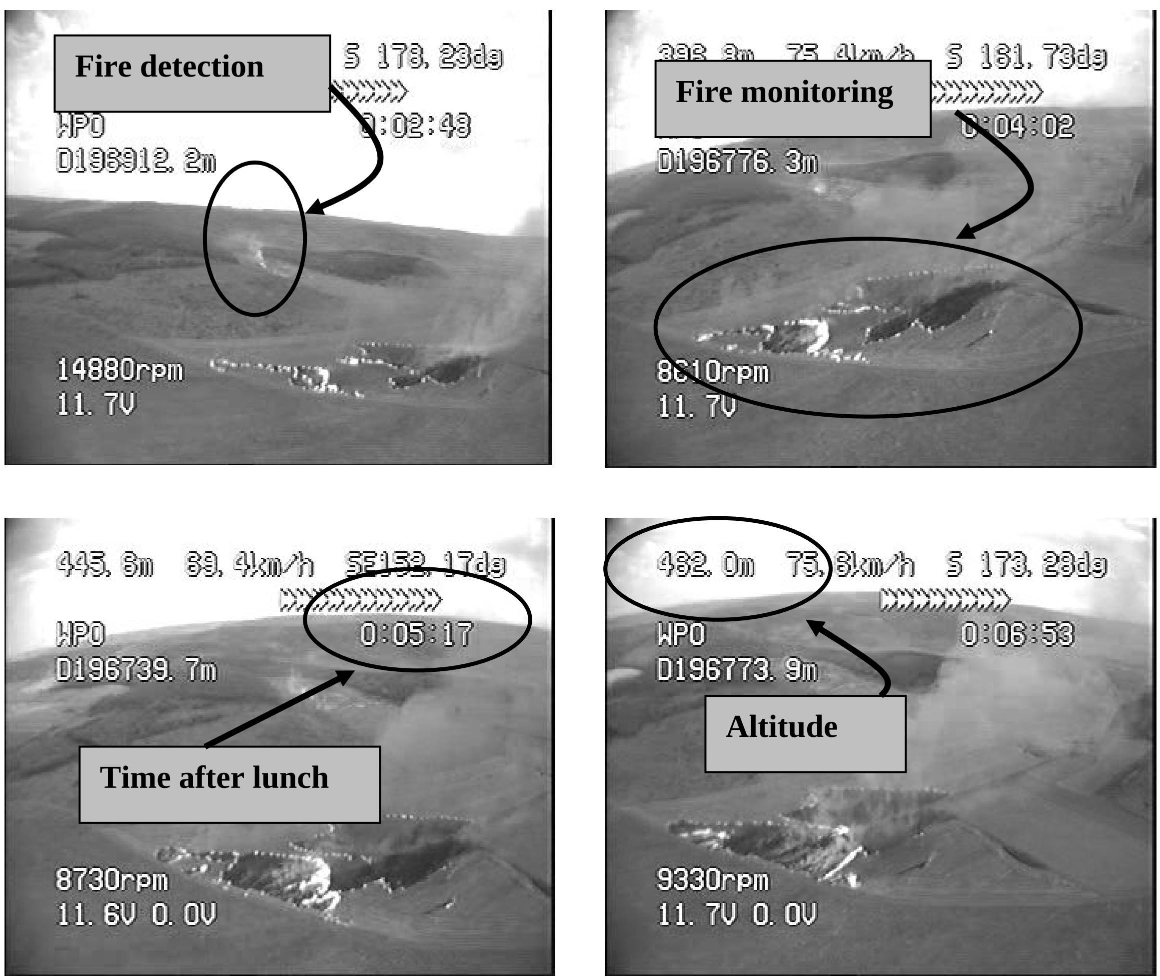

Fig. 1. On line picture data supported by UAV

Some results of the experiments [4]:

1. For a minimum efficiency do not necessary coloured camera. Naturally the infra red camera is much more better but the black and white camera able to give fire fighters enough information. The coloured pictures very nice but too much information for mind.
2. Not necessary the high technologies. Much more important giving a user-friendly technologies for fire fighters.
3. After lunch below 2 - 3 minutes we have enough information to choose a good solution managing the fire.
4. Not necessary fly more than 500 meters altitude above the fire. It assumes not very articulated territories. This altitude is fit to Szendro Fire Department area including Aggtelek National Park. Maximum altitude can be 1000 meters depending others air traffic.
5. Analysing the different time made pictures fire fighters are able to predict the spread of fire and see that how changing the characteristic of the fire. The Fig 1. show that a little bit more than 2 minutes after lunch we have a global information about the fire. The time between the pictures is about one and quarter minutes and we can see that how changing the fire line. At the background can be seen a smoke column, which is not belongs to the experience. It means that was the first real fire detection by UAV in Hungary!
6. We are evidence that the UAV is very useful tool supporting fighting against forest fire but even if it is used at the scene of fires as soon as possible. It means UAV have to be managed by fire fighters not by any other persons.
7. We evidence the efficiency of UAV at fire monitoring but we were unable to evidence the same at fire detection doing UAV patrols.
8. If we have as big affected area as not possible to managed by our small UAV means we have to ask for help. In this case we have a chance to support the fire management by any staff aircraft.

From 14th August 2006. the Szendro Fire Department use an own UAV for air reconnaissance supporting fighting against forest fire as a regulation UAV. As we know it will be the first regulated UAV at fire service all of the world! [5]

VII. CONCLUSIONS

The tool of air reconnaissance, which has proven effective, can be made available to even the smallest fire brigades through the use of UAVs. Traditional reconnaissance no longer provides information of a quality and quantity sufficient for today's applications. I believe that the introduction of UAVs suited to the needs of even the smallest fire departments would make a great contribution to the solution of that problem.

Increasing the efficiency of reconnaissance will result in increasingly efficient interventional measures. This will increase the area of forests saved while reducing the areas destroyed. It can be demonstrated that at the level of the national economy, the costs of development and implementation would be returned in a short period of time.

The workload of fire-fighters may be reduced, in many instances there may be no need to mount a response at all. The elimination of unnecessary responses will reduce the level of risk to citizens, resulting in a higher level of fire safety.

VIII. REFERENCES

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