https://orcid.org/0000-0002-5080-1856

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D.V. VERHULIESOV*

THE NEW METHOD OF FORESTATION AUTOMATION WITH UAV AND THROUGH-THE-AIR SEEDLING DELIVERY TECHNIQUE BASED ON THE LIDAR GENERATED LAND SURFACE MODEL OPTIMIZATION

*Institute of Mathematical Machines and Systems Problems of the National Academy of Sciences of Ukraine, Kyiv, Ukraine

Анотація. *Знеліснення – одна з найбільших екологічних проблем сучасності. За період 1993–2020 рр. людство втратило 154 мільйони гектарів лісів, що призвело до таких негативних наслідків, як збільшення виділення парникових газів, порушення водних циклів, пришвидшення ерозії ґрунтів, порушення природних ареалів перебування тощо. Вчені погоджуються, що єдиним способом боротьби із знелісненням в його теперішніх масштабах є штучне насадження лісів – заліснення. Класичними методами заліснення є ручне та автоматизоване, наприклад, за допомогою використання комбайнів, що, попри відносну простоту імплементації, мають ряд недоліків, які заважають використовувати їх для ефективного вирішення проблеми, зокрема, низьку здатність до масштабування. Використання БПЛА – новий перспективний підхід до автоматизації заліснення, який було розроблено протягом останніх десятиліть. У даній статті розглядаються його основні практичні імплементації у порівнянні до класичних методів заліснення задля пропозиції нового, більш ефективного методу на основі їх синтезу. У процесі аналізу наявного досвіду імплементації заліснення за допомогою БПЛА декомпонується на три основні етапи: сканування поверхні, обробку даних та висаджування дерев. Дослідження показало, що на додачу до використання методів та алгоритмів моделювання й оптимізації на перших двох етапах підвищення ефективності висаджування шляхом використання підготовлених саджанців аналогічно до класичних методів, може забезпечити значно вищу ефективність. У даній роботі пропонується здійснювати автоматичне висаджування з повітря у точки, знайдені на основі побудови й оптимізації моделі розташування саджанців на поверхні Землі, змодельованої за допомогою ЛІДАР сканування. Стаття описує основні етапи нового методу заліснення та закладає теоретичну й практичну основи для продовження дослідження і практичної реалізації.*

Ключові слова: *знеліснення, заліснення, лісонасадження, лісовідновлення, БПЛА, ЛІДАР.*

Abstract. *Deforestation is one of the biggest ecological challenges faced globally nowadays. From 1993 to 2020 the world lost almost 154 Mha of forests which brought about various negative consequences, such as an increase in greenhouse gas emissions, disruption of water cycles, increased soil erosion, disrupted livelihoods, etc. Scientists agree that artificial forestation is the only way to solve the problem on its present scale. Classic methods of artificial forestation include manual and automated ones or their combination. Despite its simplicity and comparably easier improvement, classic methods also have some disadvantages that do not allow them to solve the problem, i.e., bad scalability. Automated forestation that utilizes UAVs is a new promising approach that was developed in the last decades. The current paper addresses its common implementations compared to classic forestation methods from the perspective of its improvement possibility based on their synthesis. Analysis of the existing experience of UAV-based forestation consists of three stages: surface scanning, data processing and planting itself. The research showed that in addition to the usage of modelling and optimization algorithms at the first two stages, analogically to classic methods higher efficiency can be achieved by planting seedlings instead of seeds. The present paper suggests performing planting from the air to the defined points based on the creation and optimization of a tree situation model. Such approach requires the usage of advanced LIDAR generated land surface modelling techniques and methods of trajectory calculation. The article describes a step-by-step new method of tree planting automation, suggesting theoretical and practical perspectives and directions for future research.*

Keywords: *deforestation, forestation, afforestation, reforestation, UAV, LIDAR.*

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1. Introduction

Deforestation is an ongoing process of losing forests caused by either human activity such as farming and construction, or by various natural hazards, for example, wildfires. The catastrophic scale of the problem can be proved statistically. According to the FAOSTAT[1] from 1993 to 2020, the world lost almost 154 Mha[2] of forests [1]. In other words, the area of lost forests during the last three decades is almost equal to Ukrainian land area times 2.5 or French land area times 3. As a result, deforestation has brought about various negative consequences, such as an increase in greenhouse gas emissions, disruption of water cycles, increased soil erosion, disrupted livelihoods, etc. [2].

Lots of scientists, researchers, politicians and other concerned people around the world carry out numerous research, establish organizations, create policies and regulations every day with the single aim – to stop deforestation. All in all, practically these efforts are made to stimulate forestation both artificially and naturally. Despite ongoing debates around artificial versus natural forestation, it is argued that artificial invasion is required [3, 4].

There are two main approaches to artificial forest recreation. The first one is reforestation – planting new trees on the areas previously covered with forests, and the second one is afforestation – planting completely new forests [5].

The aim of this article is to analyze automatic forestation improvement through the development of a new tree planting method based on the fusion of classical methods with UAV-based forestation.

2. Analysis of existing methods, models and applications for artificial forestation

2.1. Classic methods

Reviewing some artificial reforestation methods made it possible to conclude that they all can be divided into the following two main categories: manual and automated [6, 7].

Manual methods imply the usage of human labour. Among the advantages of this method there are its simplicity and high rate of seedling adoption achieved by 1–2 years of pre-planting preparation; on the other hand, its main disadvantage consists in low efficiency due to the lack of ability to scale.

Automated tree planting methods use machinery to provide better scalability. A typical example of such automation is the use of heavy agricultural planting combines [8]. This approach is much more efficient than the manual one, but it is still limited in terms of the applicable area since the type of land surface in some places almost eliminates the possibility of using there machinery. Moreover, combines can be utilized only on lands which are also suitable for agriculture. Therefore reforestation of such territories will create a ground for future deforestation.

2.2. UAV-based forestation

During the last decades, a lot of different discoveries and improvements were made in the field UAVs[3] depend on. These efforts caused general technology costs reduction what resulted in drawing attention to its application. In addition, booming development of mobile LIDAR[4] sensors during recent years made UAVs one of the best platforms for the use in real-life applications [9].

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[1] The Food and Agriculture Organization Corporate Statistical Database (FAOSTAT) is statistical data collected and maintained by the Food and Agriculture Organization (FAO) of the United Nations (UN).
[2] Million hectares.
[3] Unmanned Aerial Vehicle.
[4] Light Detection and Ranging sensors.

The mentioned above factors led to more and more wide utilization of UAV-based applications in agriculture. Its main purposes are remote sensing, pesticide spreading, seed planting, etc. [10]. Moreover, the mobility of such systems together with the existing agriculture experience could be a solution to challenges faced in forestation automation with combines.

Nowadays, around the idea of planting trees with UAVs, for example, Drone Seeds, FlashForest, Dendra systems, etc., there have been established multiple organisations [11, 12, 13]. Despite its practical popularity, there is still the lack of knowledge from the scientific point of view that should be filled up to achieve synergy and develop the most efficient UAV-based tree planting method.

Analysing existing experience of the mentioned above companies, the process of UAV-based tree planting can be decomposed into 3 stages:

1. Surface scanning.
2. Data processing.
3. Planting.

Some other existing stages such as planting material preparation or existing forests biome analysis, which is important for achieving success in forestation, will not be mentioned below. The main reason for such a decision is that they all are indifferent to the planting method. Moreover, they constitute an independent field for research out of the current paper.

The purpose of the first stage called «Surface scanning» is to collect required information about the surface of the target area or other environmental conditions, such as relative altitude and exact GPS location. The main goal of this stage is to collect enough information to build a precise model of the environment. To achieve this goal two common techniques are used: photogrammetry and LIDAR scanning [14]. Formally, this step can be rewritten as some function $surfaceScanning$ with a list of target area frontier GPS coordinates[5] as a parameter and raw data dictionary output:

$$CONST\ FRONTIER\_GPS = [\{x_1^1, y_1^1\}, \{x_2^1, y_2^1\}, ..., \{x_k^1, y_k^1\}], \tag{1}$$

$$\begin{aligned} sur\ face_{raw_{data}} &= sur\ faceScanning(FRONTIER_{GPS}) = \\ &= [\{x_1^2, y_1^2, L_1, P_1\}, ..., \{x_n^2, y_n^2, L_n, P_n\}], \end{aligned} \tag{2}$$

where $\{x_i^1, y_i^1\},\ i = \overline{1,k}$ – latitude and longitude of i frontier GPS coordinate, $x_j^2, y_j^2,\ j = \overline{1,n}$ – GPS coordinates of points equally distributed across the target surface area, L_j – LIDAR data, P_j – photogrammetry data.

Photogrammetry is a method of surface scanning based on combining multiple camera shots into a single 3D surface model. Lower equipment and post-processing costs are among the advantages of this method, while on the other hand it has a priori lower accuracy compared to the LIDAR scanning caused by its visual basis.

The main idea behind the LIDAR scanning is remote ground surface sensing by a laser. Its core principle is to measure the time required for a piece of light to travel from the laser, then reflect from the surface and return to the sensor. From a positive perspective, this method is known for its extreme accuracy, but at the same time such sensors are more expensive, hard to maintain and work with what is a downside. Moreover, the data come from the sensors as a cloud of points each representing a single reflected laser shot. Post-processing of such information can be much more difficult if compared to photogrammetry.

[5] Frontier GPS coordinates is a set of coordinates that represents the border of the planting target area.

Despite all the challenges related to these methods, the common practice is to use both to create colourized point clouds and then transform them into an extremely precise 3D surface model [15].

It is worth mentioning that such remote scanning can be done from the plane or satellite [16]. However, the precision losses due to the high altitude are the main obstacle for the advanced planting techniques.

The second stage of UAV-based tree planting is data post-processing. The main goal of this step is to provide planting mechanisms with a set of direct instructions based on data collected in the first stage. To put it another way, the data from the sensors should be translated into a set of commands for the planting machine.

To achieve such results, advanced calculation and optimization techniques are required. The first action performed in the current stage is raw sensor data processing by some function $createModel$ that leads to the creation of an environment model. Secondly, the model is being optimized by the function $optimizeModel$ to find the best possible places or areas for tree planting regarding the given set of restrictions by extracting the surface from the environment model and solving the planting tree count maximization problem on the extracted surface. In the last third step, the optimal planting points are converted to the GPS coordinates which are then transformed into a set of direct commands for the planting machine. Formally:

$$env = createModel(surface\_raw\_data), \tag{3}$$

$$\begin{gathered} optimal_{points} = optimizeModel(env,\ kwarg) = \\ = [\{x_1^3, y_1^3, z_1\}, ..., \{x_m^3, y_m^3, z_m\}], \end{gathered} \tag{4}$$

$$commands = Translate(optimal\_points), \tag{5}$$

where env – an environment model, $kwarg$ – a set of optimization parameters, $\{x_l^3, y_l^3, z_l\},\ l = \overline{1,m}$ – latitude, longitude and height above sea level of points selected for planting.

The complexity of calculations performed at the data processing stage requires both advanced optimization algorithms and powerful computational facilities. This stage is usually performed using ground or cloud computing stations outside the UAV.

Planting itself is the third stage of UAV-based methods. This action can be performed in various combinations of delivery methods and planting materials.

As a plant material, there can be used either fertilized seeds or specially prepared seedlings. However, the common practice in UAV planting is to use fertilized seeds instead of seedlings that have multiple pros such as lightweight of seedlings that enable its delivery to the ground right from the UAV and lower requirements to the precision of step two generated 3D surface model. On the other hand, the price reflected in cons is a much lower than the seed adoption rate. As it was mentioned before for the classic planting techniques, the usage of prepared for 1–2-years seedling is a common practice to achieve a great adoption rate. The neglect of such proven practice is in the author’s opinion one of the biggest blockers for efficient autonomous UAV tree planting.

The decision to use seeds instead of seedlings was caused by the capabilities of common planting techniques. There are two widely used approaches. The first one consists in simple spreading of seeds from the air. This approach is easy to implement and it requires simpler calculations. Such simplicity results in limited ability to control exact planting location that in addition to demerits caused by the usage of seeds leads to low overall efficiency.

The second approach implies performing pneumatic seed shooting from the UAV. Unlike the simple spreading method, it allows controlling exact planting location based on advanced surface modelling. As a result, this technique has higher overall efficiency. On the contrary, its higher relative efficiency can still be improved tremendously through the use of prepared seedlings instead of seeds. But its weight prevents the utilization of seedlings with this technique. Such problem can be handled only with huge UAVs that cannot be efficiently scaled to real-life applications.

Concluding the methods review, the development of a new through-the-air automated seedlings planting mechanism is required to provide a better autonomous forestation method.

3. A new method of forestation automation

One of the prospective solutions to through-the-air seedling planting was proposed by Lockheed Martin company. The idea was to use «Aerial Forestation» that consists in dropping small eco-friendly darts with offspring from the plane [17]. Supporting this theoretical approach, scientists from the University of Glasgow have studied an optimal design for darts [18].

On the one hand, such an approach can ensure high adoption rate of planted trees; on the other hand, it loses precision and ability to control the location of trees. Moreover, using planes is much more expensive. All the pitfalls resulted in the freezing of the program by Lockheed.

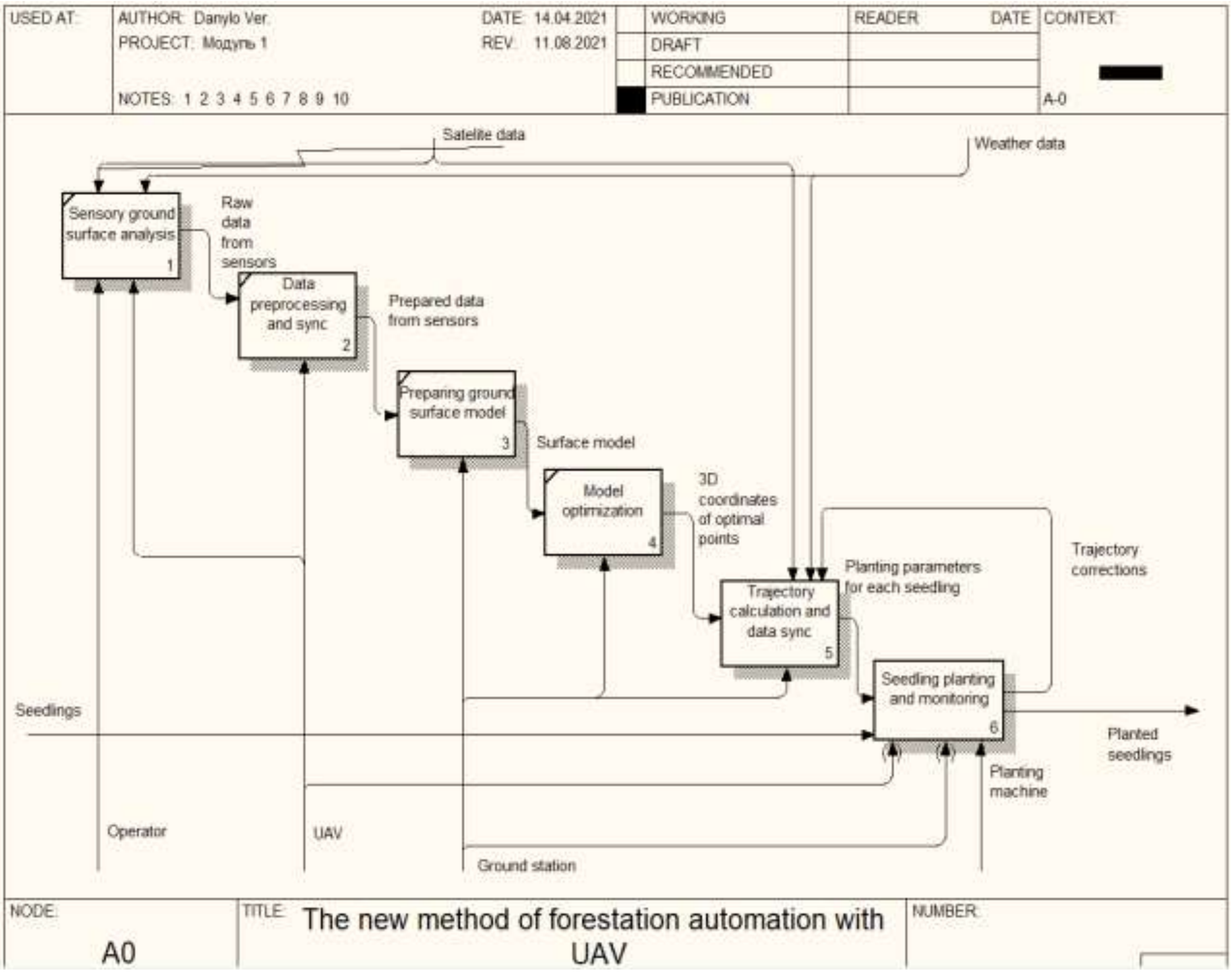

Figure 1 – The generalized model of automated forestation application using UAV and land launched darts

The foundation of the proposed method is to combine existing UAV planting methods with a Lockheed vision of the utilization of darts by their launching from the ground using pneumatic mechanisms. This approach will provide flexibility in launch mechanisms capacity, weight, number of seedlings, etc. without planes or heavy UAVs. On the contrary, it requires more complex computer models with the ability to calculate a trajectory of each dart. This challenge is stipulated by the novelty of the approach.

The overall application based on the new method is shown in Fig. 1. The application takes seedlings as inputs; configs, satellite and weather data as given restrictions; UAV, pneumatic seedlings dart launcher, ground station and operator as part of mechanisms. The output of the model is planted trees.

The proposed method consists of three stages. At the first stage (blocks 1 and 2 of Fig. 1) the surface data should be collected with the most precise available technique to ensure high dart accuracy, for these reasons there should be used LIDAR combined with photogrammetry.

At the second stage (blocks 3-5), a 3D surface model will be optimized to satisfy the given restrictions such as minimum cross tree length to plant the maximum possible number of trees. Then the model will be post-processed to calculate parabolic dart trajectories. The calculations will be performed by the ground station.

The third stage includes dart launching and planting. The feedback regarding the precision of the strike performed should be used to correct trajectories of the subsequent launches. An efficient approach that can be used is the application of ANN to build a trajectory forecasting mechanism and train it before planting. To find the best ANN configuration, a genetic algorithm will be used.

It is worth mentioning that in further research an emphasis will be made on software and optimization rather than on hardware configuration, an octocopter will be chosen as a UAV component. The main drivers of such choice were its falling protection, potential trust value and ability to safely carry massive electronic sensors with huge power consumption.

For the dart launching purpose land-based short-range pneumatic systems will be used. This decision is stipulated by higher safety requirements.

4. Conclusions

After conducting an analysis of the existing experience, there was proposed a new method of UAV-based dart-seedling planting and automated forestation. In case of success, it may have enough efficiency/cost ratio to be used for real-life scale applications to stop deforestation. It is also worth mentioning that a pneumatic launcher was chosen because of its higher affordability and lower usage complexity. At the same time as a seedling delivery mechanism there can be used another robotic system, for example, advanced ground drones that still require the same precision level of situation coordinates.

The expected result of further research is to build software and hardware solution running on ground and air stations that will automatically plant trees in the target areas based on advanced optimization techniques. Another approach of such methodology can imply terraforming of such large areas as deserts or planets, in defence areas – delivery of supplies or other small parcels, etc.

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