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Evaluation of the operational performance of an agricultural unmanned aerial vehicle

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Summary

Increasing demand for sustainable agricultural food production and mitigating the changing weather conditions require more continuous crop monitoring and field data management. Unmanned aerial vehicles (UAVs) provide versatile methods for aerial imaging of different crop fields to extract plant and crop characteristics. There is a need to investigate operational performance of UAVs especially when larger field areas are desired to be covered, and more frequent flight mission are planned. Agricultural drones rely on lithium based electrical batteries that offer adequate performance but add substantially weight to the drone. Therefore, weight-optimal design and energy-optimal flight planning are desired features for agricultural drones. This research evaluates the operational performance of a custom-built agricultural drone focusing on the flight conditions, energy consumption, drone design and mission planning. The research results indicate that the custom-built drone shows robust operation during the measurements in 2020 and 2021. The energy analysis clearly shows that the drone operation is energy intensive, and the flight time is quite limited. It can be concluded that the drone weight and battery performance are the key elements for increasing the operation performance of agricultural drones.

Keywords: agricultural drone; operational performance; lithium battery, energy consumption; UAV

1 Introduction

Unmanned aerial vehicles (UAVs) are increasingly being used for different tasks in agriculture [1]. Small-sized UAVs are typically used for taking aerial images from field crops for different types of analyses of agricultural crops [2]. Drone images are used for input data for detecting invasive alien plants [3] or weeds among field crops [4]. Large-sized drones can be used for crop spraying and other heavier tasks [5]. Aerial imagery can be also used to identify and monitor plant and animal diversity and conservation as well as facilitating the detection of quality habitats [6]. Another application for UAVs is the 3D mapping of harsh environments and buildings [7]. The operation of small unmanned aerial vehicles can be cost effective with custom-built drones and low-cost cameras [8-10]. For all agricultural drones, one of the technical challenges is the limited on-board energy that limits the operating time and productivity. UAVs usually rely on electrical batteries as their primary energy source. Despite of the significant technical development of lithium-ion batteries, the operating time for agricultural drones remains often less than 30 minutes. Lithium-ion batteries can be charged relatively fast, but it is not always desired due to the battery aging [11]. Because of the limited on-board energy, the operation and energy efficiency should be evaluated in order to optimize the drone operation for maximum efficiency [12, 13].

Although agricultural drones have been under rapid technological development, there is a need to evaluate their operational performance for more efficient use of on-board energy thus longer fight missions. This research presents the development and operational performance for a custom-built agricultural drone, which was built in a research project for aerial imaging of different types of field crops. The objective is to evaluate the influence of the drone design, flight conditions and mission planning on the energy consumption and operational performance.

2 Description of the drone

The first version of the custom-built drone was built for the summer 2019 and the second for the summer 2020. The newest drone has six rotor blades (18-inch propellers) that are powered by electric motors having continuous power about 800 W. The drone is powered by one lithium-ion battery pack (weight: 1775 g, size: 192x78x58mm), which has six cells in series and capacity of 14000 mAh. The battery can provide about 280 Wh of energy when 90% of the state of charge is used. There were six different battery packs which were used during the flights and some of them were already been used for couple of years and showed some effects of aging in 2021. The battery energy is enough for less than 10 minutes of aerial imaging from 50 meters of altitude and with carrying three different cameras. The operating power for the cameras and other auxiliary systems is taken from another small battery pack. Figure 1 presents the drone, which has weight little over 10kg.

Figure 1: The custom-built hexacopter.

3 Flight operations

3.1 Field measurements

The flight missions were carried out with multispectral and thermal cameras. The cameras added weight about 2 kg. The purpose of the flights was to evaluate the influence of the field conditions on the camera images. For that reason, the flight missions were done in the morning, at noon, in the afternoon, and in the evening. The flights were done in five different days and in two different fields in 2020 and 13 different days and in three different fields in 2021. The imaging data is also used for evaluating the crop development during growing season by calculating suitable vegetation indices from the multispectral reflectance data. The evaluated data in this research included 4 x (5+13) = 72 flight missions, thus 144 flights because one flight mission included two flights. The measured fields (Koirasuo, Mölylä and Patoniitty) are presented in Figure 2 with typical trajectories of the flight missions. The target altitude was 50 meters and operation speed 6 m/s.

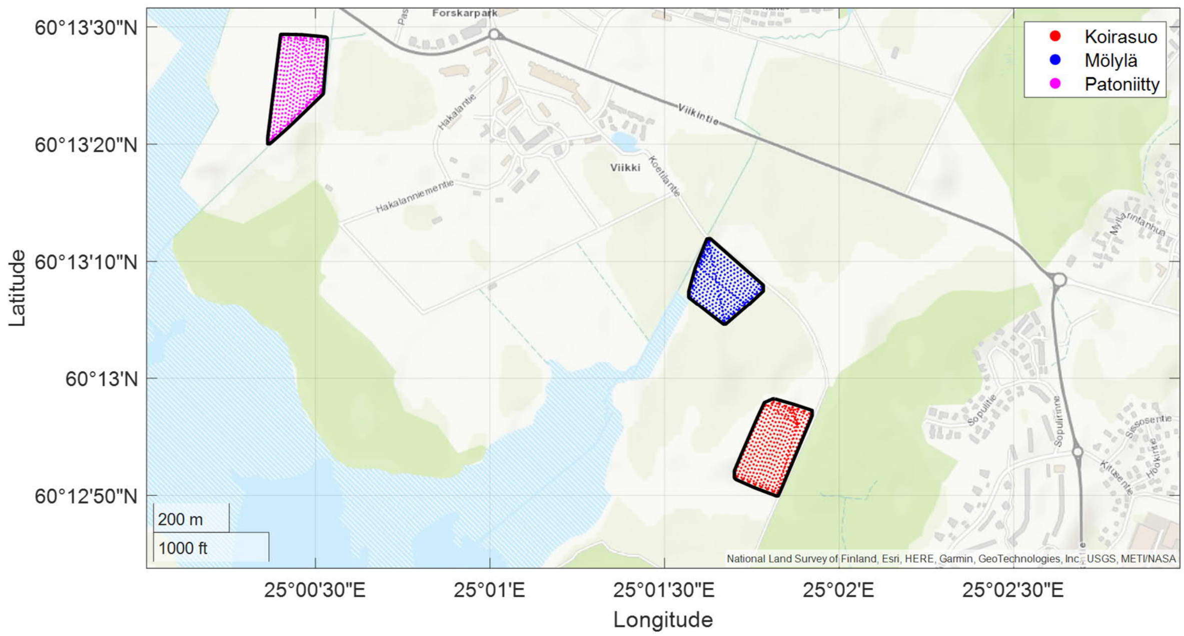

Figure 2: Measured fields with flight mission trajectories.

The flight data was recorded by the flight controller of the drone. There are numerous data recorded from the sensors, controllers, and components. The interesting data in terms of drone performance is the flight operation and battery data. The data was processed and organized in MATLAB where the values for key performance indicators were calculated. The Tables 1 and 2 present summary tables for the flight data from the fields Koirasuo and Mölylä. All the presented values are average values calculated from daily flights. Overall, all the flights were very similar in terms of the flight and measurement time as well as ground speed. The major difference between the flights in 2020 and 2021 was the accuracy improvement of the altitude, which is illustrated by the standard deviation (STD) of the altitude in the Tables 1 and 2. The average ground speed is calculated from the measurement time, which corresponds the flight without the take-off and landing periods.

Table 1. Summary of the flight data from the Koirasuo field in 2020 and 2021.

Date (day-month-year)	28-06-2020	15-07-2020	01-08-2020	04-06-2021	17-06-2021	01-07-2021	13-07-2021	26-07-2021
Flight duration (min)	8.2	8.1	8.2	8.1	8.1	8.1	8.1	8.1
Meas. duration (min)	6.5	6.5	6.4	6.5	6.5	6.5	6.5	6.5
Altitude (m)	54.1	52.9	53.4	52.2	52.0	54.0	54.7	55.1
STD Altitude (m)	1.2	1.2	1.5	0.7	1.0	1.1	1.0	0.8
Ground speed (m/s)	4.9	4.9	4.9	4.9	4.9	4.9	4.9	4.9
Covered area (ha)	1.58	1.56	1.56	1.57	1.57	1.56	1.57	1.56

Table 2. Summary of the flight data from the Mölylä field in 2020 and 2021.

Date (day-month-year)	12-07-2020	26-07-2020	19-06-2021	07-07-2021	23-07-2021	05-08-2021
Flight duration (min)	7.1	7.1	7.1	7.2	7.1	7.2
Meas. duration (min)	5.4	5.4	5.4	5.5	5.5	5.5
Altitude (m)	50.6	50.4	51.5	51.5	50.4	49.6
STD Altitude (m)	1.3	1.4	1.0	1.0	1.0	1.4
Ground speed (m/s)	4.7	4.7	4.7	4.6	4.6	4.6
Covered area (ha)	1.25	1.24	1.26	1.27	1.26	1.27

In relation to the target speed, the average speed is reduced due to the turns at the end of the field where the speed is lower as presented in Figure 3. There were basically no differences in the ground speed between the flights in different fields and measurements years. Figure 3 shows the ground speed for flights in Mölylä field in 2020 and 2021. The target speed is almost reached during the direct part of the flight but the speed drops under 2 m/s when making the turn. More area would then be covered when the flight trajectories are along the long side of the field and that is how the flight trajectory is usually planned.

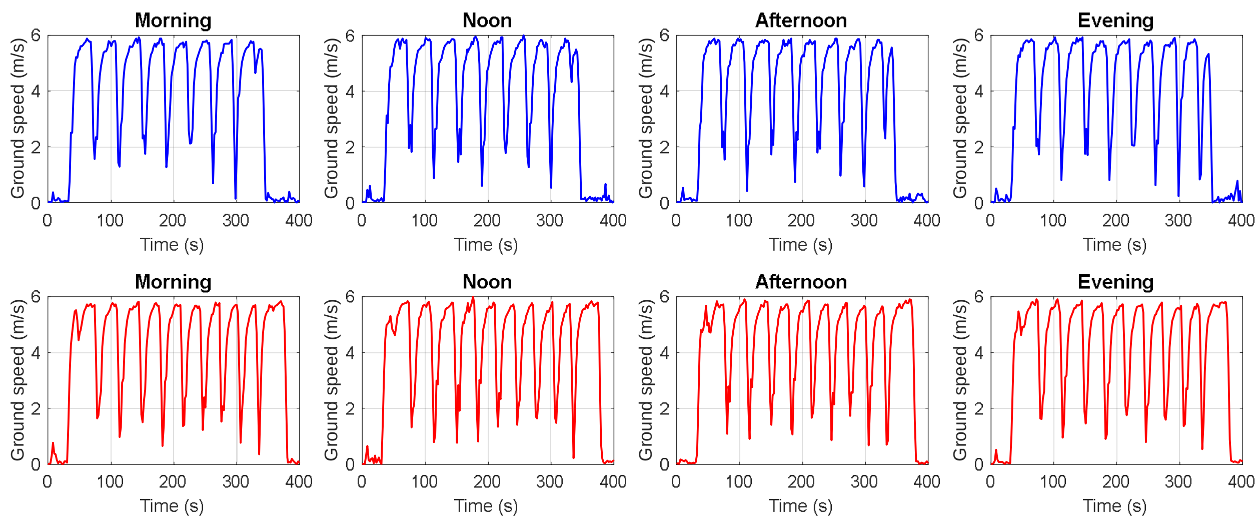

Figure 3: Ground speed comparison between 12th of July 2020 (blue) and 7th of July 2021 (red) in the Mölylä field.

3.2 Flight trajectories and altitude

Figures 4 and 5 illustrates the flight mission trajectories for one day of measurements in 2020 and 2021. Typically, the flight trajectory planned in the mission planner has been well followed in each separate flight missions as can be seen in Figure 5 in which the horizontal position (latitude and longitude) is practically the same between flight missions. The more accurate satellite positioning system installed in 2021, improved the horizontal accuracy and especially the vertical (altitude) accuracy. This can be seen by comparing the Figures 4 and 5 as well as the variation in the average altitude, which is included in the legend of the Figures.

Figure 6 presents the flight altitude in Koirasuo and Mölylä in 2020 and 2021. There is obviously quite a lot of variation in the altitude due to the flight direction or wind direction. Somehow the average altitude was constantly higher in the Koirasuo field and there was no clear explanation in the flight data for that.

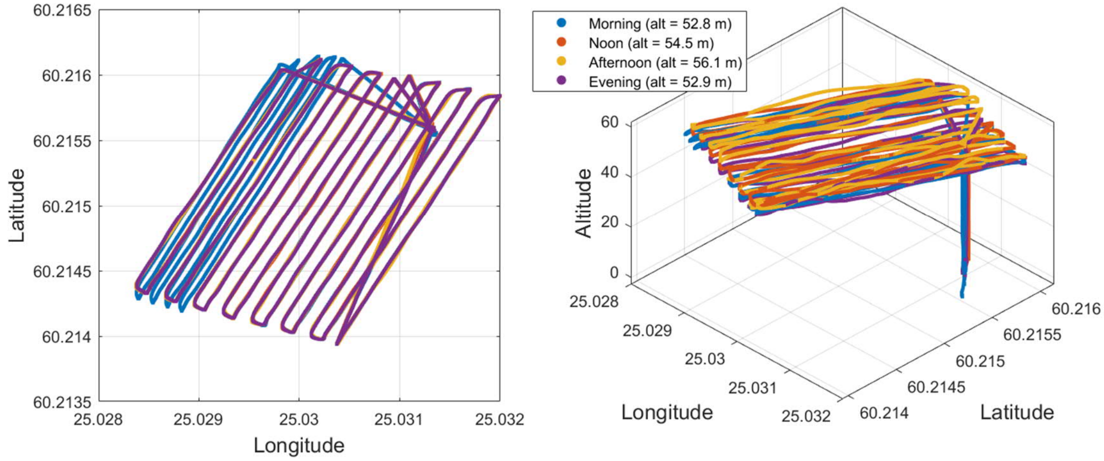

Figure 4: Flight mission trajectories for one day (28th of June 2020) in the Koirasuo field.

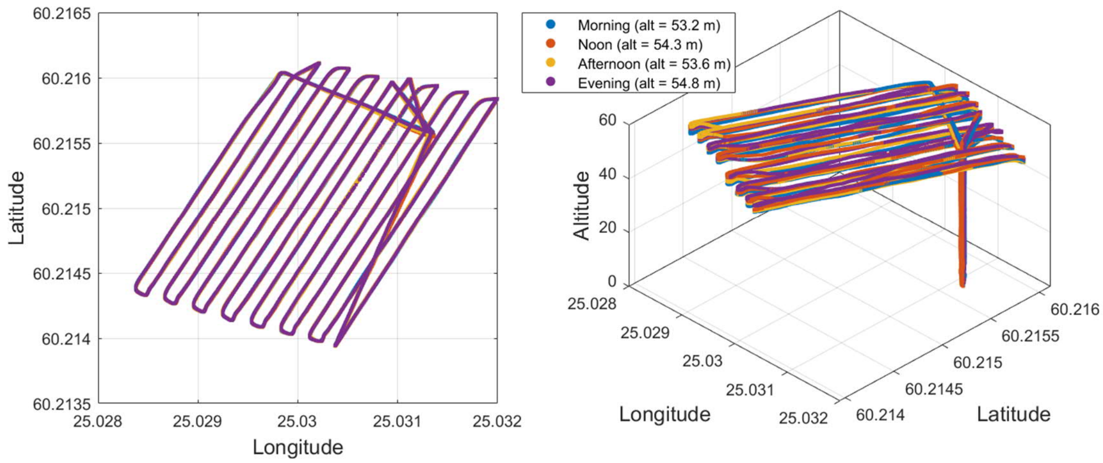

Figure 5: Flight mission trajectories for one day (1st of July 2021) in the Koirasuo field.

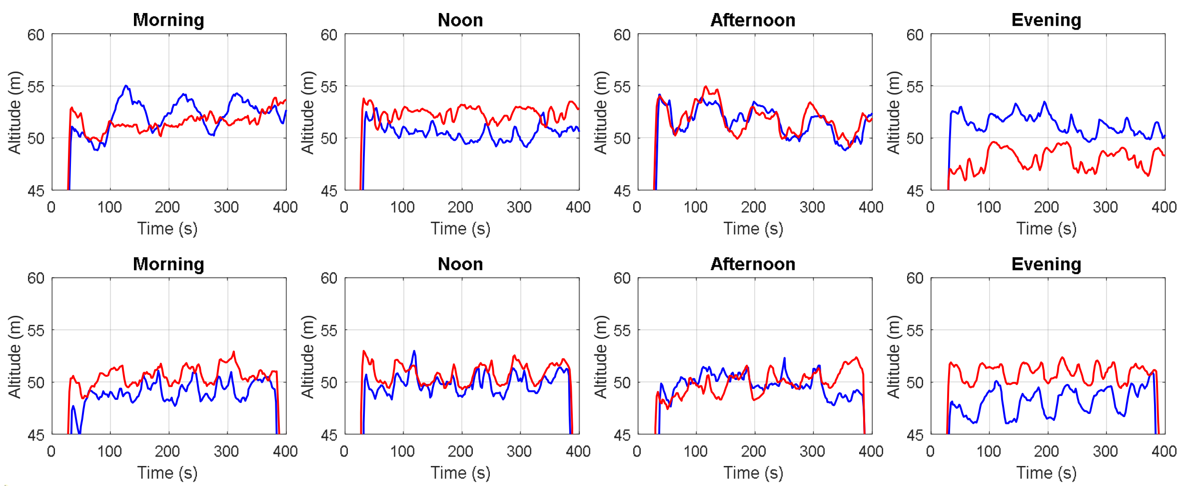

Figure 6: First row: altitude comparison between 15th of July 2020 (blue) and 17th of June 2021 (red) in the Koirasuo field. Second row: altitude comparison between 12th of July 2020 (blue) and 26th of July 2021 (red) in the Mölylä field.

4 Battery operation

4.1 Battery data

The battery pack was observed by the flight controller during the flight and the voltage and current were measured for each flight. There was no measurements of the current of the motors therefore it was not possible to estimate the energy losses of the propulsion system. The battery data was processed and analyzed in MATLAB similarly as the flight data. Tables 3 and 4 present the daily average values of the recorded battery data. It was observed from the flight operational data (Tables 1 and 2) that there were basically no differences in the operational values except from some deviation in the flight altitude. Due to the weather conditions, mainly wind conditions, there are variations in power requirements as well as energy consumption.

Overall, the average and maximum current drawn from the battery was higher in all flights in 2021 in comparison the flights in 2020. As there was no significant weight increase of the drone by the updates done during the winter, it was concluded that the battery current measurements were somehow too low in 2020. Most probably the reason was the parameterization of the current sensor. Furthermore, the energy consumption in the flights of 2021 corresponded to the estimated consumed battery energy quite well. Also, battery aging might have a small influence by increasing the internal resistance of the battery packs. Tables 3 and 4 present the battery data from the flights done in the Koirasuo and Mölylä fields. The difference in the battery current is quite clear between the flights in 2020 and 2021.

Table 3. Summary of the battery data from the field Koirasuo in 2020 and 2021.

Date (day-month-year)	28-06-2020	15-07-2020	01-08-2020	04-06-2021	17-06-2021	02-07-2021	13-07-2021	26-07-2021
Start voltage (V)	25.2	25.2	25.2	25.2	25.2	25.3	25.2	25.2
Final voltage (V)	22.4	22.4	22.3	22.3	22.4	22.3	22.3	22.3
Average current (A)	56.9	56.7	60.0	67.7	66.2	67.5	67.4	67.9
Max current (A)	90.9	77.2	84.8	97.2	93.9	102.3	94.5	93.4
Energy (Wh)	171.5	170.3	179.0	201.8	199.5	203.2	201.6	203.7

Table 4. Summary of the battery data from the field Mölylä in 2020 and 2021.

Date (day-month-year)	12-07-2020	26-07-2020	19-06-2021	07-07-2021	23-07-2021	05-08-2021
Start voltage (V)	25.1	25.2	25.2	25.2	25.2	25.2
Final voltage (V)	22.6	22.5	22.5	22.5	22.5	22.4
Average current (A)	56.0	60.6	68.4	68.9	66.1	68.6
Max current (A)	80.7	84.0	97.1	98.7	96.9	110.5
Energy (Wh)	146.5	158.8	180.1	183.5	174.0	181.3

The battery operation is illustrated more in detail in Figures 7 and 8 which show the battery current, voltage, and cumulative energy. During the flights in 2020 (Figure 7), the battery voltage was steadily decreasing, and the operation was generally quite smooth. The variation in current is caused by the motor control which in turn is driven by the changing flight conditions such as wind speed and trajectory changes. Same batteries were used during the flights in 2021 and some aging can be recognized in some of the oldest batteries. This was clearly detectable in the battery operation characteristics and also in Figure 8 in which the flights at noon and in the evening were carried out with the older batteries. The voltage level of the battery drops rapidly after the take-off and remains in a lower level during the flight. However, there is no notable difference in the energy consumption even if the voltage is lower. This could be because the power demand changes from the flight conditions are much more important than influence of the battery aging.

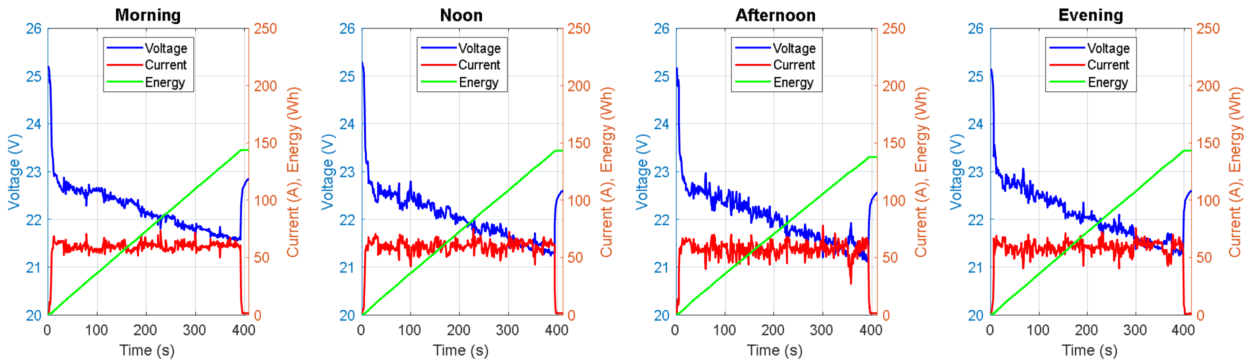

Figure 7: Battery operation during flights on 28th of June 2020 on Koirasuo field.

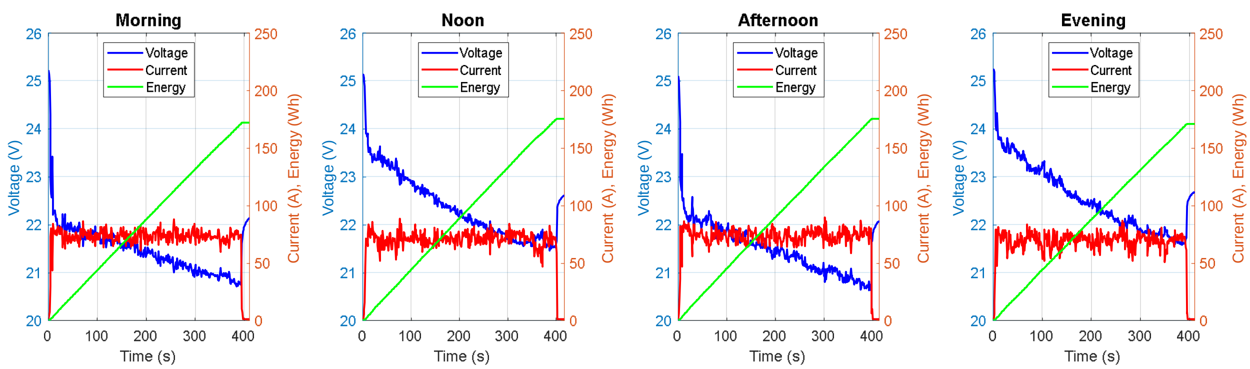

Figure 8: Battery operation during flights on 4th of June 2021 on Koirasuo field.

4.2 Battery data

The operation of drones is highly dependent on the energy consumption therefore it is important to evaluate the energy efficiency in flight operations. Figure 9 illustrates the variation of the energy consumption between the different flight days and measured fields in 2021. In the Mölylä field, there is much more variation in the energy consumption than in the other fields. The variation in the energy consumption is most likely caused by the weather conditions such as wind. The flight trajectories have different directions and were shown in Figure 1. Most of the flights were carried out in good weather conditions because the main objective was to evaluate the influence of lightness conditions on the reflectance values of multispectral camera.

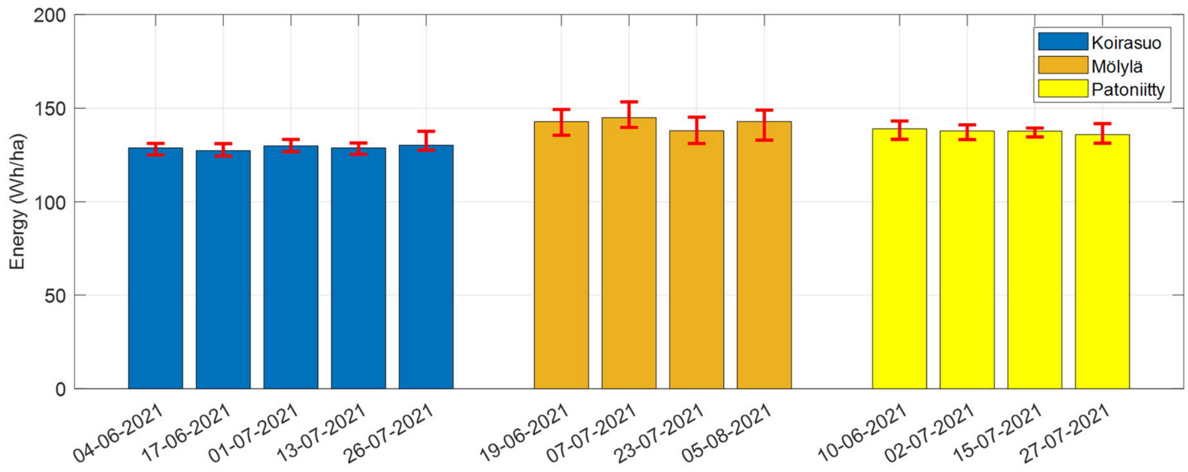

Figure 9: Daily average energy consumption and the variation within the day.

Depending on the flight conditions, the power demand of the motors might have quite a lot of variation. This was analyzed by processing the battery data and selecting only the measurement section of the flight so that the take-off and landing of the drone were excluded. The Figure 10 presents the standard deviation of the average battery output power for the three measured fields in 2021. Overall, there are not much difference between the flights done in the different times of the day or between different measurement days.

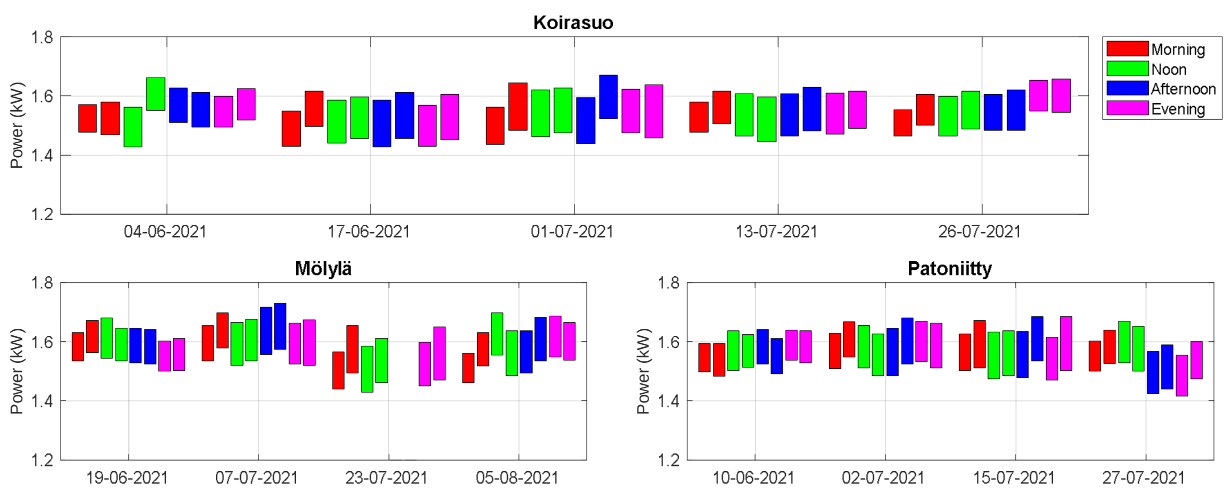

Figure 10: Battery output power variation in the three fields in 2021.

5 Discussion and conclusions

The operational performance and energy consumption were evaluated for a custom-built agricultural drone. The drone was built for aerial imaging flight missions in which it can carry multiple cameras and other sensors. The drone has primarily been used for research purposes including the evaluation of the performance of the drone and different camera technologies. The imaging data has been also further analyzed for agronomical purposes e.g. biomass estimation of the crops. The custom-built drone can be considered as midsize scale among the agricultural drones. The large drones are built for carrying much more payload typically liquid for spraying. These types of drones are preferable powered by energy sources that are higher in energy density than electrical batteries.

The research results showed that a midsize agricultural drone powered by a 22-volt lithium battery with less than 300 Wh of usable energy has a quite limited operational performance especially in terms of flight time and covered area. The analysis of the flight missions illustrates that the drone was carrying out the planned flights successfully and showed robust operation in different times of the day and also during the whole summer seasons. It was clearly observed that the altitude positioning performance was increased after the system upgrade was done by purchasing a more accurate GNSS system after the summer 2020. For some unexplainable reason, the altitude was higher in one field in both measurement years. There was no clear explanation what was the reason for this difference.

The small and medium size drones are highly dependent on the lithium battery technology, and they provide an adequate performance for agricultural drones. As the usability of aerial imaging is steadily growing, in the future, larger areas are desired to be covered during one flight mission. Practically, there are two ways of increasing the operating time; reducing the drone weight and increasing the energy efficiency. The drone frame can be quite heavy depending on the material but using e.g. carbon fiber could reduce the weight. The main components of propulsion system include electric motors and batteries. Even if there have been tremendous technological developments in increasing the energy density of electrical batteries, they tend to be quite heavy especially for drones. However, the energy efficiency could be improved by increasing the battery voltage because the average current can be quite high during the flight missions and consequently generating power losses.

Based on the experiences of this research, we have built a new drone with a target of 30 minutes of operation time. The quadrocopter is operated in 22-volt lithium-ion battery with 10 Ah of capacity and much lighter frame than the midsize drone. The new drone can carry one camera but that will be enough when doing more focused aerial imaging e.g. weed detection and environmental mapping.

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