

Article

3D-Printed, Remote-Controlled Soil Sample Collector for UAS

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Abstract

Remote-controlled UAS-based soil sampling offers great potential for scientific research and practical applications in various fields, including agriculture, environmental monitoring, hazardous waste, radiation measurements, chemical plants, snow sampling and glaciology. The added value of automated sampling using a UAS (unmanned aircraft system) compared to manual sampling lies primarily in improved accessibility to hazardous or remote locations, increased operational safety, and the potential to improve efficiency in applications requiring repeated or difficult-to-access sampling. This article introduces two different 3D-printed constructions (grab arm and screw pipe) for UAS-based, remote-controlled sample collection of different soil types. The grab arm construction is based on an adapted version of an open-source CAD from GrabCAD. The screw pipe construction is a new design. During an expedition to Greenland in August 2025, the two constructions were manually evaluated during several days of field work near the Danish and Austrian research stations at the Sermilik Fjord to assess their mechanical sampling performance on challenging Arctic surface materials, including dry and wet sand, gravel, glacial sediment, snow, and glacier surfaces. Because flight testing was not possible during the expedition due to unavailable UAS batteries, these experiments were limited to manual ground evaluation of the constructions. Independent flight tests were subsequently conducted in Austria using a DJI Matrice 300 to evaluate the integration of both the grab arm and the screw pipe with the UAS platform and their operational handling during flight. In Greenland the performance of manual sampling was documented precisely. Further the coordinates of each sampling point were recorded by using GPS, sample images were taken on site, and the collected material was weighed. The results show that UAS in combination with 3D printed constructions is a flexible and location-independent solution for obtaining soil samples of varying composition. In addition to the design, materials, and electronics of the systems, the article also describes the connection to the UAS and the field work results.

Keywords: Arctic; UAS; 3D-printing; soil sampling; constructions



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1. Introduction

The development and testing of the two UAS-based soil sample constructions, a screw pipe and a grab arm, is particularly relevant for the following areas of application:

- Agriculture: UAS-based soil sampling may support precision agriculture by enabling targeted sampling in large agricultural fields, reducing travel time between sampling locations, and facilitating repeated sampling campaigns. Rather than replacing conventional manual sampling, UAS-assisted sampling is particularly advantageous where large areas, difficult accessibility, or frequent monitoring make conventional approaches inefficient [1].
- Environmental monitoring: UAS-based soil sampling can be used to detect heavy metal contamination in soil materials. For example, the Campania region in southern Italy is facing unintentional contamination of agricultural soils. The high concentration of heavy metals in the soil is due to natural phenomena (volcanic activity and hot springs) as well as intentional or accidental industrial activities [2].
- Hazardous waste: This would involve taking soil samples from disused or uncontrolled landfills in order to analyze pollutant levels, as exceeding the maximum permitted pollutant level poses a significant risk to the population [3].
- Radiation measurements: Samples can be taken to measure radiation levels in soil [4].
- Chemical plant: Soil and sediment samples can be taken from sewers near chemical plants to measure the impact on public health and the environment [5].
- Industrial areas: UAS-based soil sampling can be used to detect contamination in the proximity of industrial plants [6].
- Snow sampling: Snow samples can be taken to determine crystal forms and measure density, which can then be used to determine the specific surface area (SSA) of the sample [7].
- Glaciology: Sampling using UAS in glaciology can be used to collect surface material from the glacier in a defined area and thus determine the aerosol content of mineral and soot particles, as these components lead to a dark surface. Increased accumulation of dark mineral and soot particles on the glacier surface leads to a lower albedo. This means that less solar radiation is reflected and instead absorbed and converted into heat [8].

Traditional manual sampling requires direct physical access. In remote areas such as Greenland's glaciers, this involves considerable efforts in terms of cost and time, slows down research, and often comes with a very large environmental footprint (e.g., helicopter-based sample collection). Using special sample collector constructions in combination with drones, also known as UASs, samples can be taken even at hard-to-reach or dangerous sampling points with varying soil conditions without having to be physically present at the same location.

The term UAS describes the interface between humans and machines and thus the entire infrastructure required for the system to operate. Aircraft was first used in industrial settings as early as the 19th century, when balloons were used for photography for remote sensing purposes [9]. The importance of and demand for UASs have increased enormously in recent decades. The areas of application for UASs are no longer limited to military applications as today UASs are used in a wide variety of industries [10]. Thanks to the continuous development of UAS technology over recent decades, it has been possible not only to reduce the price but also to expand the range of functions while making them more user-friendly [1].

UASs have become increasingly important tools for environmental monitoring because they enable flexible, cost-effective, and high-resolution data acquisition in areas that are difficult or hazardous to access. Consequently, numerous UAS-based systems have

been developed for environmental sampling and monitoring, including applications for soil characterization, air-quality monitoring, and environmental surveying [11–13]. While these studies demonstrate the growing potential of UAS technology, most existing systems either focus on remote sensing or on highly application-specific sampling solutions. Comparative investigations of lightweight sampling mechanisms that can be integrated into commercially available multirotor platforms for collecting solid environmental samples remain limited.

In recent years, UASs have evolved from purely remote sensing platforms towards systems capable of interacting physically with their environment. Initially, research focused primarily on monitoring applications, such as environmental and atmospheric sensing, where UASs offer advantages including high spatial flexibility, low operational costs, and rapid data acquisition. For example, Zhou et al. developed a fixed-wing UAS for three-dimensional urban air-quality profiling based on optimized coverage path planning. Their work demonstrated the potential of UASs for efficient environmental monitoring but was limited to sensor-based data acquisition without physical interaction with the ground [11].

In recent years, considerable research has focused on automating soil sampling using ground-based robotic platforms. Early developments primarily targeted precision agriculture, where unmanned ground vehicles (UGVs) equipped with automated sampling mechanisms were designed to increase sampling efficiency, reduce manual labor, and enable higher spatial sampling densities compared with conventional manual approaches [14]. More recently, autonomous robotic systems have been developed for environmental monitoring and contaminated-site characterization. These systems integrate sensing, sampling, mobility, and autonomous navigation to collect soil samples and perform measurements while operating in hazardous or difficult-to-access environments [15]. Although ground-based robotic platforms demonstrate significant potential for automated soil sampling, their mobility remains constrained in inaccessible terrain, creating opportunities for aerial platforms capable of reaching locations that are difficult or unsafe for terrestrial robots.

More recently, research has expanded towards UAS-assisted soil sampling. Klopfenstein and Lussier Desbiens introduced the Terra-22 system, which is considered the first airborne platform capable of collecting soil samples from densely compacted agricultural fields. Their approach combines a lightweight drilling mechanism, an anchoring system, and an adaptive penetration controller to overcome the limited payload capacity and reaction forces of multirotor UASs. Field experiments demonstrated reliable sampling in soils with compaction levels between 0.8 and 2 MPa while maintaining a lightweight system suitable for UAS deployment [13]. Despite these promising developments, existing UAS-based soil sampling systems are typically optimized for specific agricultural applications and rely on comparatively complex drilling and anchoring mechanisms. Furthermore, only a limited number of studies have investigated lightweight, modular, and easily manufacturable sampling mechanisms that can be integrated into commercially available UAS platforms and directly compared under identical operating conditions. Consequently, there remains a need for compact and versatile UAS-compatible soil sampling concepts that simplify the mechanical design while enabling systematic evaluation of different sampling principles. This research addresses this gap by developing and experimentally evaluating two lightweight UAS-based soil sampling mechanisms based on different operating principles, with a particular focus on mechanical simplicity, manufacturability using additive manufacturing techniques, and applicability for environmental soil sampling.

However, environmental monitoring applications often require standardized sampling procedures with defined sampling depth, sample quantity, and sample representativeness. Therefore, the present study focuses on the mechanical feasibility and practical implementa-

tion of lightweight UAS-compatible sampling mechanisms, while a quantitative evaluation of sampling representativeness remains part of future work.

This work presents and experimentally evaluates two 3D-printed sampling concepts—a grab arm and a screw pipe—for remote-controlled sampling under Arctic field conditions. Furthermore, all CAD files are provided as Supplementary Material to facilitate reproducibility and future developments.

However, despite the increasingly rapid development of UASs, no performance tests have yet been carried out for the attachment of special structures for collecting samples of different soil types. During an expedition to Greenland in August 2025, the two sampling constructions “grab arm” and “screw pipe” were tested near the Sermilik research station by using dry and wet sand, gravel, sediment from the glacier river, and snow and surface material collected from the glacier. The following sections describe both designs in terms of their construction, materials, manufacturing process, and integrated electronics. Subsequently, the drone platform, its integration with the sampling systems, and the results of the field validations are presented. Finally, the key findings and limitations of the developed concepts are discussed.

2. CAD of the Designs

The grab arm and screw pipe were designed using Autodesk Fusion 360 v2602.0.71. Parametric CAD modeling enabled rapid design iterations, dimensional optimization, and assembly verification prior to manufacturing. The final CAD models were subsequently exported as STL files for additive manufacturing. To support reproducibility and further development, all CAD files are provided as Supplementary Material.

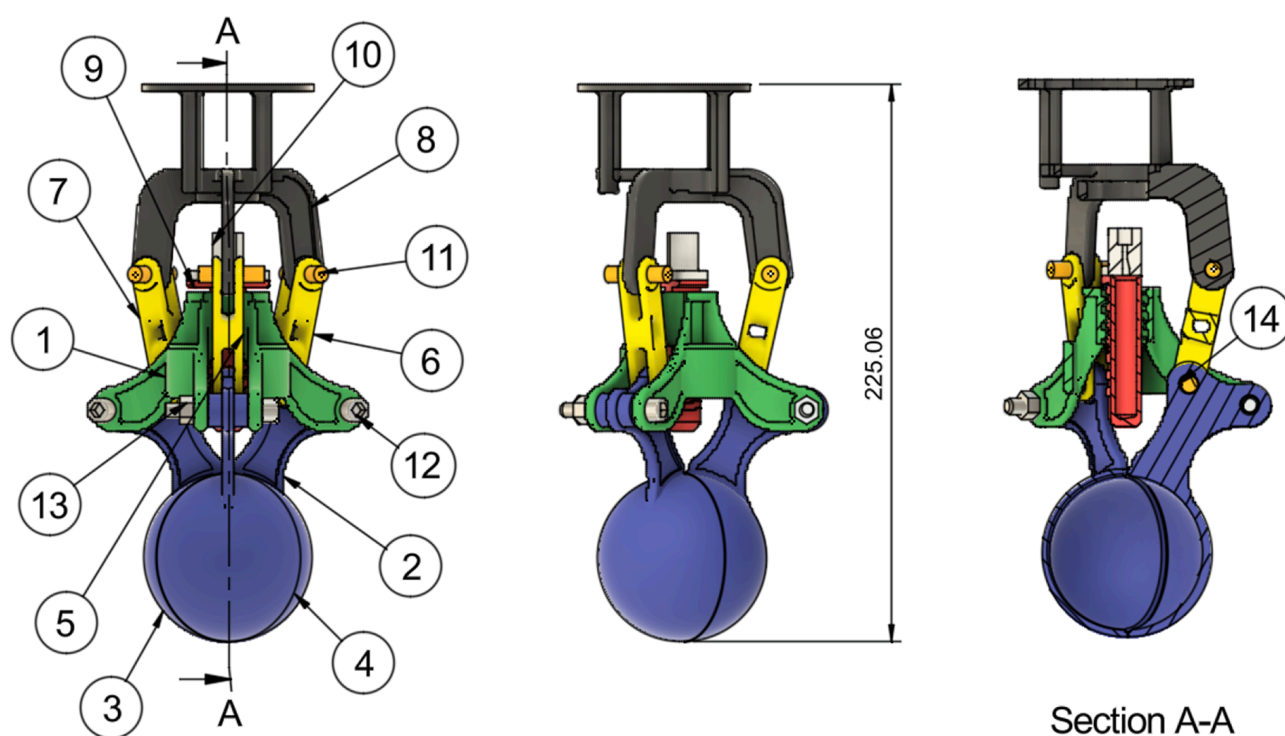
2.1. Grab Arm Design

The grab arm construction is based on an adapted version of an open-source CAD file (claw to soil analysis by Adriano Ordoz Barissa on <https://grabcad.com/library/claw-to-soil-analysis-by-adriano-ordoz-barissa-1>, accessed on 27 June 2026) from the website GrabCAD. Table 1 illustrates the bill of material for the grab arm. The grab arm was selected because it represents a mechanically robust and comparatively simple sampling solution that is well suited for UAS integration. In contrast to more complex sampling mechanisms, the articulated grab arm was expected to provide stable contact with the ground during the sampling process while minimizing dynamic disturbances to the UAS. This design was therefore considered advantageous for maintaining flight stability during touchdown and sample collection. Furthermore, the modular design offers the potential for future adaptation to different sampling tasks and environmental conditions.

The list is intended to provide an overview of the individual components which were subsequently 3D-printed. In addition, Figure 1 shows the assembly of the grab arm in the closed state, including a numbered representation of the individual parts and section A-A. All STL files downloaded from the GrabCAD website were scaled in size to 170% in Fusion 360 to increase the height of the grab arm to 225.06 mm. After scaling, the width of the grab arm was 113.89 mm. For elements 1 to 8 and elements 11 and 14, only the scaling was changed from 100% to 170%. Element 9—large screw—was provided with a flat spot on both sides to improve the thread’s mobility. Element 10—screw extension—was added to increase the distance between the servo motor and the thread to allow the grab arm to open further. Figure 2 shows the adapted, final version of the assembled grab arm in open position.

Table 1. Bill of materials for grab arm design.

Bill of Materials for Grab Arm Design		
Element	Number	Component Name
1	1	Threaded joint
2	1	Bucket 1
3	1	Bucket 2
4	1	Bucket 3
5	1	Connecting piece 1
6	1	Connecting piece 2
7	1	Connecting piece 3
8	1	Attachment for servo
9	1	Large screw
10	1	Extension screw
11	3	Long bolt
12	3	Cylinder head screw M6-40
13	3	M6 nut
14	3	Short bolt

**Figure 1.** Assembly of closed grab arm.

The following two Figures 1 and 2 show that element 1—threaded joint—connects the three blades (elements 2 to 4). This connection is held together by three M6 cylinder screws with a length of 40 mm (element 12) and three M6 hex nuts (element 13). Inside element 1 is a screw that has been joined to the thread in the joint. Element 10—screw extension—enables the servo to then transfer the rotational movements to the screw, allowing the three blades (elements 2–4) to be opened or closed by means of linear movement. Depending on

the direction of rotation of the screw, the blades open or close. Three additional connecting pieces (elements 2–4) are required to perform this movement. The connecting elements are connected on one side by element 14—short bolt—to the blades and on the other side by element 11—long bolt—to the attachment for the servo (element 8).

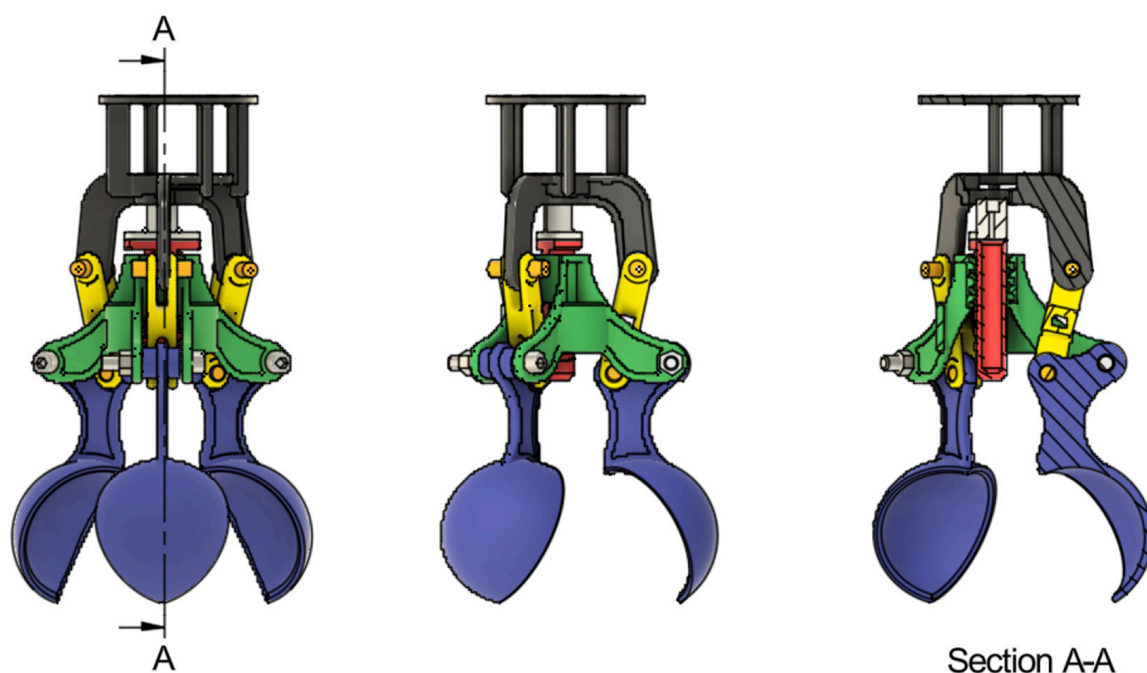


Figure 2. Assembly of open grab arm.

Unlike the design downloaded from the GrabCAD website, threaded M6 cylinder screws with nuts (elements 12 and 13) were used to connect the blades (elements 2–4) to element 1—joint—so that this connection could be quickly and easily loosened without tools if necessary. These are standard parts that were purchased separately. In the GrabCAD version, long bolts (element 11) were used for this purpose. Furthermore, in the tested grab arm, the connecting pieces (elements 5–7) were connected to the servo attachment (element 8) using the long bolts (element 11). The connections between elements 11 and 14 are press fits, which were assembled using a hammer.

Due to its operating principle, the grab arm is intended for collecting unconsolidated surface material rather than obtaining samples from a predefined soil depth. Therefore, the system is not designed to recover standardized soil cores.

2.2. Screw Pipe Design

The design for the screw pipe was created with Fusion 360. Table 2 shows the individual parts that make up the screw pipe, summarized in a parts list. The height of the screw pipe is 250 mm, and the width is 227.72 mm. Figure 3 shows the screw pipe including section A-A and numbered individual parts. Elements 19 (M4 cylinder screws with a length of 20 mm) and 20 (M4 nuts) are standard parts that were not printed but purchased. The uprights 1–4 (elements 2–5) were made from a 1000 mm round aluminum tube with an outer diameter of 12 mm and a bore diameter of 10 mm. To do this, the round tube was sawn into four equal pieces, filed, and then drilled with a 5 mm bore to a depth of 15 mm.

Table 2. Bill of materials for screw pipe construction.

Bill of Materials for Screw Pipe Construction		
Element	Number	Component Name
1	1	Plate
2	1	Upright 1
3	1	Upright 2
4	1	Upright 3
5	1	Upright 4
6	1	Trapezoidal base 1
7	1	Trapezoidal base 2
8	1	Trapezoidal base 3
9	1	Trapezoidal base 4
10	1	Ball bearing
11	1	Connecting shaft
12	1	Gear wheel Z200
13	1	Gear wheel Z20
14	1	Retaining pin 1
15	1	Retaining pin 2
16	1	Retaining pin 3
17	1	Retaining pin 4
18	1	Screw pipe
19	4	M4 cylinder screw 20 mm (DIN EN ISO 4762-10.9)
20	4	M4 nut

Figure 3 shows that element 1—plate—forms the base for the screw pipe. The four uprights (elements 2–5) are connected to the plate by a 13 mm hole in the corners of the plate. The uprights prevent the structure from tipping over when placed on the ground and form a guide so that the structure can be placed straight. The trapezoidal feet (elements 6–9) are located on the bottom of the uprights and are joined to the uprights. The trapezoidal feet are designed to give the structure more stability, thereby reducing the risk of tipping. The 5 mm holes were then screwed into the uprights to a depth of 15 mm using M4 cylinder head screws and M4 nuts (elements 19 and 20) to prevent the uprights from slipping. The ball bearing (element 10) is located in the center of the plate and is connected to element 11—the connecting shaft. On the other side of the stepped connecting shaft (element 11) is the large gear wheel with 200 teeth (element 12), which is driven by the small gear wheel with 20 teeth (element 13) via a servo. The large gear wheel (element 12) then transmits this rotary motion to element 18—screw pipe—via the connecting shaft. The screw pipe (element 18) and the large gear wheel (element 12) are secured not only by element 11—connecting shaft—but also by four retaining pins (elements 14 to 17) to prevent the connecting shaft from turning when assembled. The screw pipe has a chamfer from the flat surface to the inner area, which is connected to an internal screw as shown in Figure 3. The internal screw serves to pick up the soil material. In addition, the screw pipe has two screw threads on the outside of the screw pipe to make it easier to turn the structure into the soil material. The following components were connected to each other by means of press fits:

- Stand with trapezoidal feet;
- Ball bearing with plate;
- Connecting shaft with ball bearing;
- Connecting shaft with gear wheel (Z200);
- Adhesive pins with gear wheel (Z200) and screw pipe;
- Gear wheel (Z20) with servo.

The screw pipe was designed to penetrate into the ground before sample extraction. However, the effective penetration depth was not quantitatively evaluated in the present study. Consequently, the system cannot yet be considered suitable for standardized depth-specific soil sampling, which should be investigated in future work.

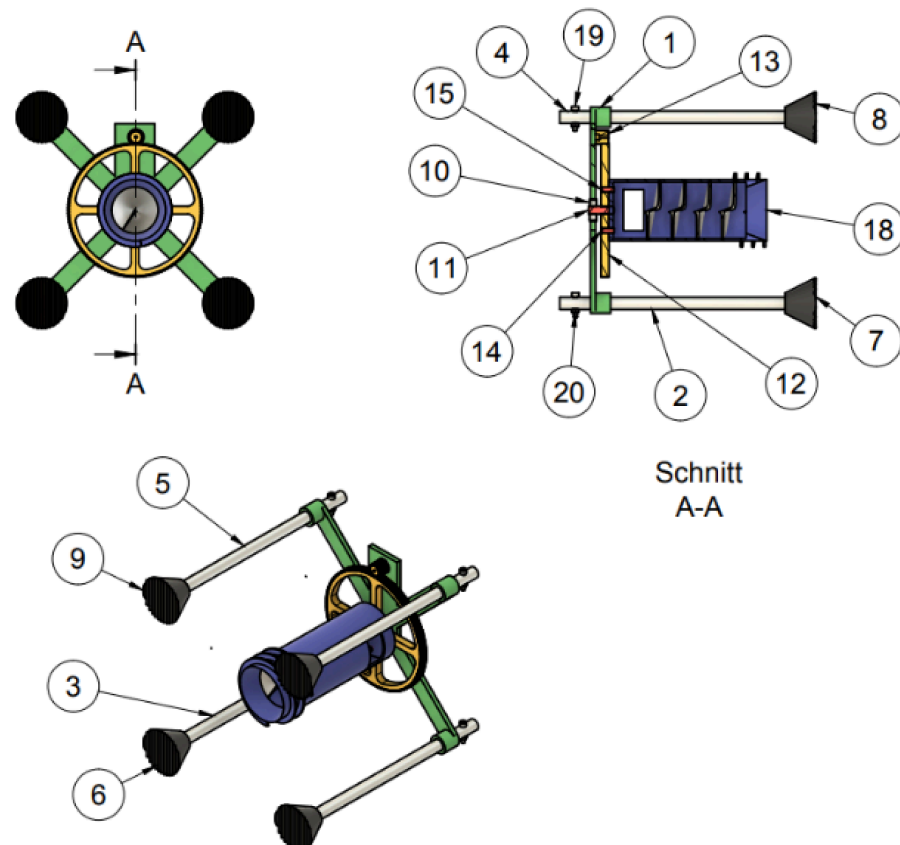


Figure 3. Assembly of screw pipe.

3. 3D Printing of the Two Constructions

The sample collector structures were mainly produced using 3D printing technology. The term additive manufacturing is often used as an umbrella term. 3D printing makes it possible to process many different materials. It was first used to manufacture sample parts and prototypes back in the 1980s, but it is still a relatively young technology that has already made great strides. In particular, its speed, reliability, quality, and accuracy have increased enormously in recent years. Additive manufacturing, or AM for short, is therefore particularly well suited to produce custom-shaped and inexpensive components. In 3D printing, layers are applied in three-dimensional space, i.e., in the X, Y, and Z directions, and the material is thus bonded together [16].

In this article, FDM (Fused Deposition Modeling), which is a type of melt layer process, was used to print the two constructions: the grab arm and the screw pipe. In this form of 3D printing, plastics in filament form are melted and processed into a defined shape [17]. The filament is printed (extruded) through a nozzle with a reduced diameter and applied

layer by layer to the heated print bed. The filament runs through the guide tube with a defined feed movement and is thus unwound from a spool. The distance between the nozzle and the print bed corresponds to the layer thickness that is applied. The axes of the FMD printer are controlled by CNC (computer numerical control) and executed by stepper motors [16]. FDM has the advantage of being inexpensive to purchase, very efficient in terms of printing speed, and low maintenance. The disadvantage is that high temperatures and supports are required for printing [18].

The process from design to printing involves the following four steps [16]:

Create a CAD model:

The CAD for the two designs, the screw pipe and the grab arm, were created by using Autodesk Fusion 360 for printing.

STL-File:

The conversion of a CAD model into an STL file (stereolithography file) serves as the base between digital design and physical implementation. The conversion enables 3D printers to interpret the individual steps of the build. The STL files for printing the two designs were created when saving in Fusion 360.

Slicing:

UltiMaker Cura V5.10.0 was used for slicing. This involves breaking the STL file down into many thin horizontal layers, which makes the file printable. During slicing, G-codes are created that give the printer instructions for its movements. This is referred to as CNC. The slicing software also offers the option of adjusting the speed, layer height, support structures, and much more. These adjustments can affect the quality, strength, and appearance of the printed component. In addition, many slicing programs offer the option of previewing the printing process in order to identify potential problems.

Preparations for printing:

Before printing can begin, the material is loaded into the printer. Next, it must be ensured that the print bed is free of residue and grease in order to achieve satisfactory adhesion. The distance between the extruder and the print bed must be even at all four corners so that the bed is straight and adhesion is satisfactory. Finally, the temperature for the print bed and extruder must be set to ensure material adhesion and thus overall quality.

The individual components for the screw pipe and grab arm were manufactured using the Anycubic Mega Zero 2.0 3D printer. The Mega Zero 2.0 has a positioning accuracy of 0.0125 mm in X and Y and 0.002 mm in Z. The Anycubic 3D printer has an extruder and a nozzle diameter of 0.4 mm. The spatial limitations of the Mega Zero 2.0 are 220 mm in length, 220 mm in width, and 250 mm in height. The maximum extruder temperature is 255 °C and the bed temperature is a maximum of 110 °C. In total, the Anycubic weighs in at a net weight of 7 kg [19].

PLA was used as the printing material for both constructions. 1.75 mm filament is available on Amazon starting at €12. PLA, or polylactide, consists of synthetic polymers made from renewable raw materials such as corn starch, which makes PLA compostable as well as inexpensive. Another advantage of printing with PLA is that it adheres very well to itself, allowing high printing speeds to be set. In addition, PLA is particularly dimensionally stable and available in many different colors. The disadvantages of PLA include its sensitivity to heat and moisture, which is why PLA is not suitable for use at high temperatures or in humid environments [18]. During printing, the extrusion temperature was 220 °C and the bed temperature was 60 °C. All components were manufactured using fused filament fabrication (FFF). To improve reproducibility, the principal printing parameters are reported here. Deeplee PLA filament was used for manufacturing all

components. A layer height of 0.3 mm, a wall thickness of 0.8 mm (two wall lines), a top and bottom thickness of 0.8 mm (three layers each), and an infill density of 20% were selected. The nozzle temperature was set to 200 °C, while the print speed was 60 mm s⁻¹. Print cooling was enabled with a fan speed of 100%, retraction and Z-hop were activated, and no support structures were required. A skirt was used as build plate adhesion. The print orientation of each component was individually selected to achieve the best possible layer formation and printing quality while minimizing potential defects during the manufacturing process.

Connection to the Drone

The DJI Matrice 300 was used for sampling. The drone has a diagonal axis distance of 895 mm and weighs 6.3 kg including batteries. The maximum permissible total weight of the Matrice 300 is 9 kg, which means that the structure attached to the drone, including the load of soil material, must not exceed a maximum weight of 2.7 kg. The model is suitable for use in a temperature range between −20 °C and 50 °C, making it particularly well suited to the cool temperatures in Greenland [20]. The grab arm was attached to the drone using a specially designed connection, as shown in Figure 4.

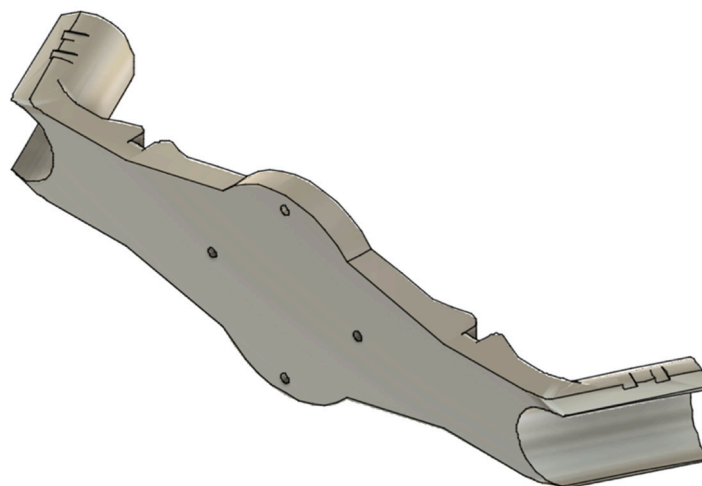


Figure 4. Connection for grab arm to drone.

To do this, element 8 from the grab arm in Table 1 was screwed to the connection using four M4 screws and nuts. The connection can then be attached to the drone's skids using cable ties. The advantage of the 3D-printed connection to the drone is that it is robust and precise during removal and stable against tipping over. The disadvantage is that this connection option is not very flexible.

The screw pipe was attached to the DJI Matrice 300 using a fishing line. To do this, the line was attached to all four ends of the plate (element 1) from Table 2 of the screw pipe. A length of 1 m was chosen for the fishing line, which can be maintained between the drone and the screw pipe. This has the advantage that a sufficient distance can be maintained between the drone and the soil sample collector but has the disadvantage that the attachment with the fishing line to the four outer positions of the plate (element 1) tends to knot easily.

4. Used Electronics

Both the screw pipe and the grab arm were equipped with identical electronics for remote control (RC) operation.

The following equipment was bought from Amazon, the equipment was used to control the two constructions:

1. Flysky FS-i6X transmitter;
2. Flysky FS-iA10B receiver;
3. RC servo with continuous rotation;
4. AA battery holder housing, plastic for 1.5 V batteries;
5. Four AA batteries for power supply.

The RC servo with continuous rotary motion was used on the grab arm to set the screw in motion via the attachment. On the screw pipe, the servo was connected directly to the small gear wheel, which then transmitted the rotary motion to the large gear wheel and the screw pipe. The direction and speed of movement were controlled by a remote control, using the FS-i6X transmitter from Flysky. To enable the servo to execute the direction and speed of rotation entered on the remote control, this input is transmitted to the Flysky FS-iA10B receiver in the 2.4 GHz frequency range. The receiver has ten different channels, but only one channel was used for the grab arm and the screw pipe to transmit the rotational movement to the servo. Four AA batteries were used to power the servo, and the battery compartment was connected directly to the receiver. Including the electronics used, the grab arm has a total weight of 425 g and the screw pipe has a weight of 473 g.

In the case of the screw pipe, the servo was permanently attached to the plate with superglue, as shown in Figure 5. The battery housing and the receiver were attached to the plate of the screw pipe with double-sided adhesive tape. In the case of the grab arm, the servo was installed in the designated component “attachment for servo.” The receiver and battery housing were also attached to the top of the grab arm’s connection to the drone with double-sided adhesive tape.

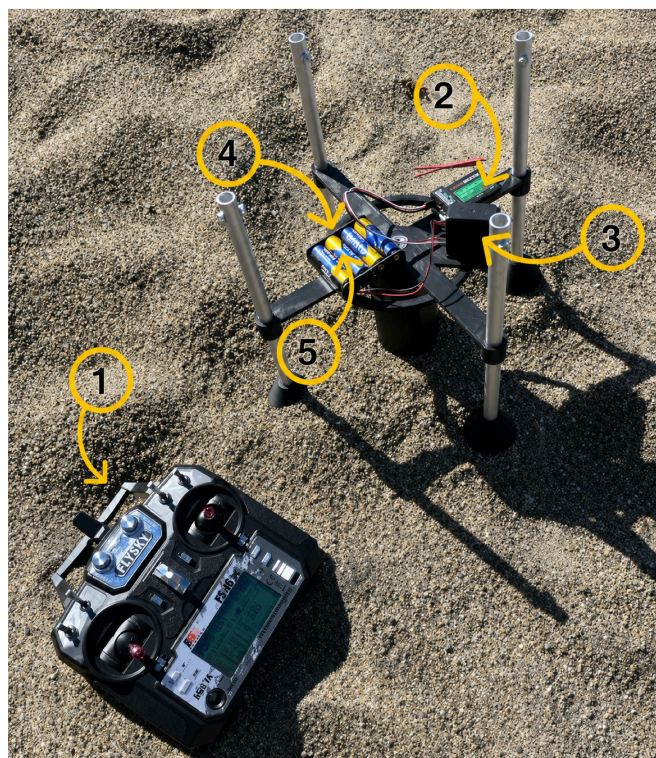


Figure 5. Screw pipe with electronic attachment.

5. Manual Performance Evaluation in Greenland

In Greenland, the mechanical performance of the two constructions was manually tested under representative Arctic field conditions. Owing to logistical, regulatory, and operational constraints, the collectors were operated manually rather than being deployed from the UAS. Consequently, the results presented in this section evaluate the sampling capability of the collection mechanisms themselves and should not be interpreted as a direct assessment of the complete UAS-based sampling system.

Unfortunately, the two TB60 batteries for the DJI M300 did not arrive in Greenland on time to test the sample collectors in a flight test during the expedition at the Sermilik Research Station in Greenland in August 2025. To test the construction in Greenland, the constructions were lifted and placed on the ground manually (partly with and without the DJI M300 attached). The two soil sample constructions were tested in Greenland at seven different locations, as shown in Figure 6.



Figure 6. Graphical representation of sample collection points.

The Danish and Austrian Sermilik Research Station is located at $65^{\circ}40'53''$ N and $37^{\circ}54'50''$ W. The geographically furthest sample was taken at SP7 (Sample Point) with coordinates $65^{\circ}41'17''$ N and $37^{\circ}52'32''$ W. The distance in kilometers between the research station and the furthest-distance sample point 7 was 1.75 km (calculated using the Haversine formula).

Each sampling attempt was evaluated individually. No composite samples were prepared by mixing material from multiple nearby sampling locations, as the objective of this study was to assess the performance of the proposed sampling mechanisms rather than to perform a standardized soil survey.

The samples shown in Table 3 were taken without a drone, but exclusively with the constructions. After collecting, the material samples were packed separately in labeled plastic bags and then weighed at the research station. All reported sample masses were measured approximately 3 h after collection. The samples were not subjected to any drying procedure before weighing; therefore, the reported values do not represent dry mass. The individual sampling points are described in more detail below regarding the application of the two constructions.

Table 3. Sampling with the two constructions in Greenland.

Sample Point	Coordinates	Sample Collection		
		Soil Conditions	Grab Arm	Screw Pipe
SP 1	65°40'45'' N 37°55'11'' W	Wet sand	210 g	61 g
SP 2	65°40'44'' N 37°55'10'' W	Dry sand	158 g	15 g
SP 3	65°40'44'' N 37°55'13'' W	Gravel	215 g	-
SP 4	65°40'38'' N 37°54'38'' W	Sediment	170 g	29 g
SP 5	65°41'4'' N 37°53'15'' W	Snow	59 g	-
SP 6	65°41'18'' N 37°52'36'' W	Glacier position 1	1 g	-
SP 7	65°41'17'' N 37°52'32'' W	Glacier position 2	1 g	-

- Sample point 1 (SP1)

Wet sand was taken at coordinates 65°40'45'' N 37°55'11'' W as shown in Figure 7. The use of both constructions was successful in this soil condition, with the grab arm taking a soil sample of 210 g and the screw pipe taking around 61 g.

**Figure 7.** Application of the screw pipe at SP1.

- Sample point 2 (SP2)

Sample point 2 was taken at coordinates 65°40'44'' N 37°55'10'' W in dry sand as shown in Figure 8. Both constructions were successfully used for this soil type. The grab arm collected 158 g of soil material and the screw pipe collected 15 g. Since the dry sand grains did not stick together as well as the wet sand, they slipped off each other more quickly, which meant that less soil material could be collected at SP2.



Figure 8. Application of screw pipe at SP2.

- Sample point 3 (SP3)

At sample point 3, gravel was collected at coordinates $65^{\circ}40'44''$ N $37^{\circ}55'13''$ W as shown in Figure 9. However, due to the nature of the soil, it was only possible to collect a 215 g sample using the grab arm.



Figure 9. Application of the grab arm on SP3.

- Sample point 4 (SP4)

The sample point was set at coordinates $65^{\circ}40'38''$ N $37^{\circ}54'38''$ W as shown in Figure 10. Sediment from the glacial river was successfully tested at this location. The grab arm was able to collect 170 g and the screw pipe 29 g of sediment at SP4, meaning that the operation was successful for both constructions at SP4.



Figure 10. Application of screw pipe with SP4.

- Sample point 5 (SP5)

At sample point 5, snow was collected near the glacier at $65^{\circ}41'4''$ N $37^{\circ}53'15''$ W as shown in Figure 11. The grab arm was successfully tested during this process. When collecting the sample, the interior of the three shovels was completely filled with snow. The snow sample taken with the grab arm is the only sample that was not taken to the research station. The calculation below shows the basis on which the 59 g defined in Table 3 was assumed. The first step is to calculate the maximum volume that the grab arm can hold:

$$V = \frac{4}{3} \cdot \pi \cdot 30.5^3 \quad (1)$$

$$V = 118,846.97 \text{ mm}^3 = 0.00011884697 \text{ m}^3$$

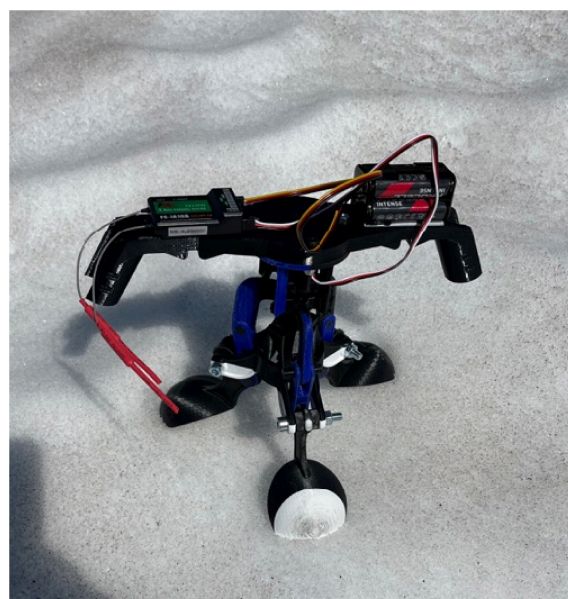


Figure 11. Application of the grab arm on SP5.

When closed, the three blades of the grab arm have a diameter of 68 mm, which corresponds to a radius of 34 mm. If we subtract the wall thickness of 3.5 mm from this 34 mm, we arrive at an actual radius of 30.5 mm. The calculated volume of $0.00011884697 \text{ m}^3$ is then used to calculate the mass. A density of 500 kg/mm^3 was assumed for the snow, as the sample taken was wet snow.

$$M = V \cdot \rho \quad (2)$$

$$M = 0.00011884697 \cdot 500$$

$$M = 0.0594 \text{ kg} = 59.4 \text{ g}$$

- Sample point 6 (SP6)

The sample was taken from the glacier using the grab arm at coordinates $65^\circ 41' 18'' \text{ N}$ $37^\circ 52' 36'' \text{ W}$. The grab arm was used to collect 1 g of surface rock material and soot particles from the glacier.

- Sample point 7 (SP7)

Sample point 7 was defined as the second position on the glacier with coordinates $65^\circ 41' 17'' \text{ N}$ $37^\circ 52' 32'' \text{ W}$. SP7 differs in that there is less rock material and soot particles on the glacier, as can be seen in Figures 12 and 13. A total of 1 g of material was also collected from this position using the grab arm.



Figure 12. Application of the grab arm on SP6.



Figure 13. Application of the grab arm on SP7.

6. Flight Test Sampling in Austria

Since flight tests were not possible during the expedition in Greenland, additional testing was performed in Austria on 30th of October 2025 at the airfield in Tannhausen (Styria), next to Weiz at 47°13'6" N 15°18'56" O, with the support of staff from AIRlabs Austria GmbH.

The flight tests performed in Austria had a different objective than the manual field tests in Greenland. On the one hand, the Greenland validations focused on evaluating the mechanical sampling capability of the collection mechanisms; on the other hand, Austrian validations investigated the airborne integration of the payload, flight stability, deployment procedure, and operational handling of the UAS system.

The test flights were planned as follows:

1. Flight with grab arm and gravel;
2. Flight with screw pipe and gravel;
3. Flight with screw pipe and sand;
4. Flight with grab arm and sand.

For the testing, 15 kg gravel with a size of 4–8 mm and 15 kg sand were used as soil samples. Since both structures were mounted underneath the drone, the drone had to land and take off on two small load carriers (SLCs) as shown in Figure 14 with a height of 20 cm and a distance of 30 cm between them.



Figure 14. Takeoff and landing position.

6.1. Sample Flights

During the flight tests, the obstacle perception sensors of the DJI Matrice 300 were temporarily disabled to allow low-altitude operation directly above the ground, as the default obstacle avoidance system would otherwise initiate automatic landing or avoidance maneuvers. This configuration was used exclusively for experimental testing in a controlled environment under continuous supervision by experienced operators. However, disabling the perception sensors reduced the available flight safety functions and therefore limited the operational safety and reliability of the conducted flight tests. Future system developments should aim to maintain active obstacle sensing while enabling low-altitude sampling operations.

6.1.1. Grab Arm and Gravel

For sampling, the grab arm was attached to the drone as shown in Figure 15 with the connection shown in Figure 4. After the M300 achieved its final position, the grab arm

was controlled by remote control to perform the rotary movement in order to close the shovels. After sampling, the drone landed back on the two SLCs. The collected material was then weighed. The grip arm worked successfully, so it was possible to collect 181 g gravel during the flight.



Figure 15. Sampling gravel with the grab arm.

6.1.2. Screw Pipe and Gravel

The fishing line attached to the screw pipe was secured to the drone by wrapping it around once and additionally secured with adhesive tape to prevent it from slipping as shown in Figure 16. After placing the screw pipe on the gravel, the rotational movement was triggered by the remote control. After 60 s, the rotational movement was stopped. During the experiment, no gravel was picked up by the screw pipe, so the soil collection was unsuccessful. Since the fishing line almost became caught in the propellers during landing, the planned sample flight with sand and screw pipe was not carried out as a precautionary measure to avoid damage to the drone.



Figure 16. Sampling gravel with the screw pipe.

6.1.3. Grab Arm and Sand

During takeoff, the antennas came very close to the propellers, which is why the drone was landed in order to reposition the receiver with the antennas. During landing, one side of the drone's skid slipped between the SLCs and four of the eight rotor blades collided with the SLC and broke off like shown in Figure 17.



Figure 17. Drone after collision.

6.2. Operational Safety Considerations

The collision during the flight tests highlighted several operational challenges associated with UAS-based soil sampling systems. In particular, the suspended payload increases the overall system dimensions and introduces additional dynamic behavior, such as pendulum motion, which may reduce flight stability during low-altitude maneuvers. Furthermore, the proximity of the suspended sampling device to the aircraft increases the risk of collisions between the payload, surrounding obstacles, and the UAS propellers, especially during takeoff and landing procedures.

During the presented flight tests, the obstacle perception sensors of the UAS were temporarily disabled to permit operation close to the ground. While this configuration enabled the experimental evaluation of the sampling devices, it reduced the available safety functions and therefore required operation in a controlled test environment by experienced personnel. Such a configuration should not be considered suitable for routine field operations.

Future developments should therefore focus on improving operational safety by integrating a rigid or actively stabilized deployment mechanism instead of the flexible suspension, maintaining obstacle sensing whenever possible, implementing dedicated flight procedures for payload deployment and recovery, and incorporating automatic emergency abort procedures in the event of unexpected payload oscillations or obstacle detection.

6.3. Sample Representativeness and Study Limitations

In the present study, the performance evaluation focused primarily on the mechanical functionality of the proposed sampling mechanisms and the collected sample mass. Additional performance indicators, such as sampling success rate, operation time, power consumption, effective penetration depth, and retained sample fraction, were not systematically recorded. Nevertheless, these parameters are important for assessing the operational

performance and practical applicability of UAS-based sampling systems. Future work should therefore include a comprehensive performance evaluation using standardized metrics to enable quantitative comparison between different sampling concepts and environmental conditions.

The representativeness of the collected samples should be interpreted in the context of the operating principles of the two sampling mechanisms. The grab arm was specifically designed to collect unconsolidated surface material and therefore primarily samples the exposed surface layer. In contrast, the screw pipe penetrates the material before sample extraction and is expected to recover material from below the immediate surface. However, the effective penetration depth, disturbed sampling volume, and sampling footprint were not systematically quantified in the present study. Consequently, the present work does not aim to evaluate the representativeness of the collected samples according to standardized soil sampling procedures, but rather to demonstrate and compare the mechanical feasibility of two lightweight UAS-compatible sampling concepts under different environmental conditions. Future investigations should therefore quantify the effective sampling depth, sample recovery, disturbed soil volume, and sampling footprint for different soil types to assess sample representativeness more comprehensively.

7. Conclusions and Outlook

This article introduces two different 3D-printed constructions (grab arm and screw pipe) for UAS-based, remote-controlled sample collection of different soil types. The two constructions were manually evaluated during several days of field work near the Sermilik research stations in Greenland to assess their mechanical sampling performance on different Arctic surface materials. Independent flight tests were subsequently conducted in Austria using a DJI Matrice 300 to evaluate the integration of the sampling mechanisms with the UAS platform and their operational handling during flight. The tested soil samples included sand (dry and wet), gravel, sediment from glacier runoff, snow, and glacier surfaces. The results demonstrate the mechanical functionality of both sampling mechanisms under representative Arctic field conditions and confirm the successful integration of the proposed devices with a commercially available UAS platform during separate flight tests. These findings demonstrate the potential of the presented concepts for future UAS-based soil sampling applications, while a complete validation under operational field conditions remains subject to future work.

The use of UAS in combination with soil sample collectors offers great potential for scientific research and practical applications in various fields including agriculture, environmental monitoring, hazardous waste, radiation measurements, industrial plants, snow sampling and glaciology. The added value of UAS-based sample collection compared to manual sampling lies in the significant increase in safety and efficiency, and reduction in costs and environmental impact (e.g., compared to manual helicopter-based sampling). UAS-based sample collection allows access to hard-to-reach or hazardous environments without putting the people involved at risk.

The field work tests demonstrate both potentials and limitations of the two presented 3D-printed construction designs (grab arm and screw pipe) for soil sample collection. A limitation of the screw pipe, as can be seen in Figure 3 for component 18, is that it has a very large chamfer of $10\text{ mm} \times 70^\circ$ on the opening side, i.e., the side through which the soil material is to be collected. The intended purpose of the chamfer was to enable more soil material to be picked up, but field work showed that this was not feasible. Due to the existing chamfer, the distance between the screw conveyor inside the screw pipe and the soil material was often too great, meaning that only small amounts of material could be picked up. Another limitation of the screw pipe is its own weight. The printed PLA is very

light, but the screw pipe should pull itself into the ground material via the connection to the drone using a fishing line through the screw inside and outside the screw pipe. This screwing process could be made easier by adding additional weight to the construction for ballasting. However, the maximum permissible total weight of the drone must be taken into account. With a drone weight of 6.3 kg plus 0.473 kg for the screw pipe and taking into account 0.5 kg of soil material, the additional weight attached must not exceed 1.727 kg. In addition, the fishing line selected was too long and almost caused a collision with the propellers. It is essential to use a more robust and shorter line to minimize the risk of it getting caught in the propellers. The drone was launched and landed on two SLCs, as the two structures were attached under the drone's feet and the M300 could therefore not land at $Z = 0$. This led to the challenge of having to perform the complex landing maneuver without the sensors switched on. There is potential here for automated lowering in the Z direction to extend the structures after takeoff and retract them again before landing.

There are also limitations regarding the used servo. A servo with a torque of 5.5 kg/cm was used to control the two constructions. When removing moist sand or snow, it became apparent during sampling that the servo was being used close to its maximum load.

Future work will not only focus on improving the sampling performance but also on enhancing the operational safety of the complete UAS system. Attention will be given to reducing payload oscillations, improving collision avoidance, enabling obstacle sensing during low-altitude operations, and increasing the robustness of the constructions. Further future work will include a more comprehensive quantitative performance assessment of the proposed sampling mechanisms, including sampling success rate, operation time, power consumption, penetration characteristics, retained sample fraction, and long-term operational reliability under fully integrated UAS missions.

In summary, it can be said that designs involving UASs for taking samples from different soil conditions represent a technological innovation that work well, but still have room for further optimization to improve their functionality in remote-controlled sampling. They also make a sustainable contribution to efficient, safe, and environmentally friendly data collection, thus offering direct added value for science, industry, and society.

Supplementary Materials: The following supporting information can be downloaded at: <https://www.mdpi.com/article/10.3390/geomatics6040090/s1>. Please see the documents attached.

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