Development of unmanned aerial vehicle (UAV) based high altitude balloon (HAB) platform for active aerosol sampling

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Abstract. The knowledge on the abundance and diversity of the minute particles or aerosols in the earth's stratosphere is still in its infancy as aerosol sampling at high-altitude still possess a lot of challenges. Thus far, high-altitude aerosol sampling has been conducted mostly using manned flights, which requires enormous financial and logistical resources. There had been researches for the utilisation of high altitude balloon (HAB) for active and passive aerosol samplings within the stratosphere. However, the gathered samples in the payload were either brought down by controlling the balloon air pressure or were just dropped with a parachute to slow the descend speed in order to reduce the impact upon landing. In most cases, the drop location of the sample are unfavorable such as in the middle of the sea, dense foliage, etc. Hence a system that can actively sample aerosols at high-altitude and improve the delivery method in terms of quality and reliability using unmanned aerial vehicle (UAV) is designed and tested in this study.

1. Introduction

Aerosol particles are found on the earth’s surface and are transported both vertically and horizontally in the atmosphere [1]. Generally, aerosol particles appear in almost any shape or size, and can either be solid particles or liquid droplets. These particles can be defined as fine and coarse particles, which are smaller and larger than 1 micrometer, respectively [2]. Alternatively, they can also be categorized into small and big particles. Big particles' size usually ranges between 2.5 and 10 micrometers (from about 25 to 100 times thinner than a human hair) [3]. These particles are called PM10 (stands for Particulate Matter up to 10 micrometers in size). In contrast, the small particles' size is smaller than 2.5 micrometers (100 times thinner than a human hair). These particles are also called PM2.5 (Particulate Matter up to 2.5 micrometers in size) [3].

Aerosol particles sampling at high altitude has contributed much to meteorological researches such as the study of atmospheric pollution, health effects, global warming and ozone loss. Apart from that, multiple studies on microbial aerosol samplings have also been conducted to understand the dispersal of microorganisms from one part of the earth to another. Studies regarding aerosol particle samplings at high altitude are typically conducted by either manned (aeroplane) or unmanned vehicle (HAB). Table 1 below shows the comparison between these two methods. Based on Table 1, balloon is more cost effective and feasible method for aerosol samplings at high-altitudes compared to manned flight. The researches on aerosol sampling using balloons include tethered or non-tethered methods [1]. A tethered balloon based sampler provides the advantage of longer duration of the sampling process. The drawback would be that it could only conduct sampling around a certain altitude due to the limitation posed by the tether length and weight. British Antarctic Survey from Natural Environment Research Council, Cambridge, United Kingdom used a tethered blimp and the sampling process was done at maximum altitude of 300 meters [4]. According to the requirement, a non-tethered balloon can be used so that the sampling process can be conducted at higher altitude. Without active control of the balloon altitude, the duration of the sampling would be much lesser as compared to the tethered-balloon based platform [5].

Table 1. Comparison between high altitude balloon and manned flight

Aspects	**High Altitude Balloon (Unmanned flight)**	**Aeroplane (Manned flight)**
Cost	Low	High
Effectiveness	Less Effective	Very effective
Range	Wide range (limited to vertical range only)	Wide range (unable to go much higher altitude)
Feasibility	Easy	Complicated

Aerosol sampling at higher altitudes using balloon have been conducted passively during ascend by Bryan *et al.* [1] and Harris *et al.* [6] from Louisiana State University (LSU). The LSU team developed a bioaerosol sampling payload, Life's Atmospheric Microbial Boundary (LAMB) to passively collect microbial aerosols from defined air mass volumes at different altitude ranges. LAMB was transported to high-altitude using latex sounding balloon, and was released and descended by parachute. Besides real-time tracking capability of the system provided by the embedded beacons on the payload, there is no way to ascertain a safe landing site for payload recovery. Meanwhile, Yang *et al.* [7] used a pump actively in the stratosphere above Pacific Ocean, adjacent to Honshu Island of Japan. In this research, which involved the Tokyo University of Pharmacy and Life Science (TUPLS) and Japan Aerospace Exploration Agency (JAXA) team, a payload was developed to actively sample bioaerosol at high-altitude from 12 km to 30 km in three phases. The payload was mounted on a gondola that hanged from a balloon. The balloon was eventually landed on the sea by exhausting the balloon gas.

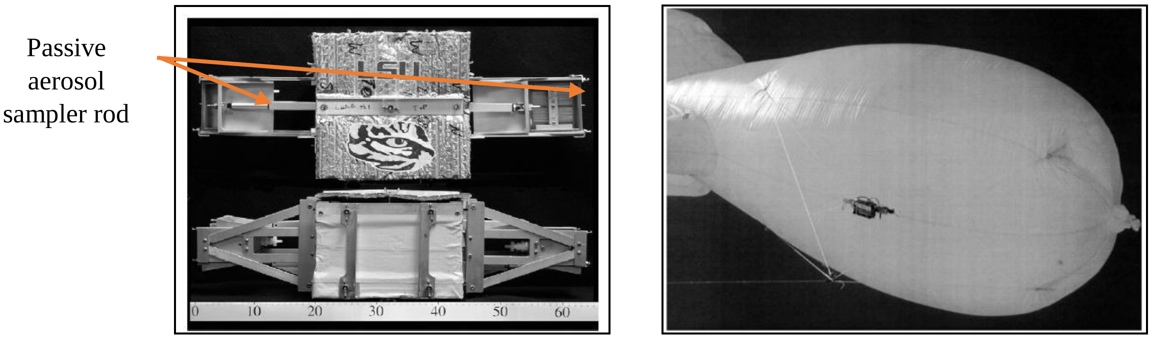


Figure 1. LAMB payload [1] (left) and the blimp [3] (right)

Manned flights for aerosol sampling may have higher reliability in terms of securing the sample from damages and lost. However, it would be too costly to perform in higher frequency. HAB-based sampling is of lower cost but there are risks sample contamination and lost during payload retrieval. Payload recovery mission such as the one conducted on the sea by Yang *et al.* [7] would require massive resources and complex logistical coordination. Given the current background of high-altitude aerosol sampling technology, where there is a gap between manned and unmanned methods in terms of cost and reliability, a UAV-based HAB platform for active aerosol sampling to reduce the risk and uncertainty of the landing site of the payload is developed and demonstrated. The development of such platform is essential to accelerate the high-altitude aerosol sampling based researches that would also contribute in the fields such as high-altitude microbiology, weather prediction, pollution studies, etc., where current approaches require large-scale financial and human resources.

2. Method of aerosol sampling

Aerosol sampling method can be further divided into active and passive. Passive air sampling such as inertial impactors and gravity sampling rely on the physical process such as diffusion or permeation [8]. Inertial impactor depends on particle motions and the sampling surface motions while gravity sampling method allows air particle to fall onto the collecting surface due to gravitational force [8]. LAMB payload applied inertial impactor in their sampling process by allowing bioaerosol particles to impact onto the rod surface as the balloon ascended. This method effectiveness relies on constant wind speed and direction. On the other hand, the active sampling method involves vacuum pump or fan in drawing air onto the impaction surface such as filter paper and it is independent of wind speed.

In this research work, the active sampling method with filtration sampling was applied. Filtration sampling that involves inertial impaction and diffusion can be more effective at collecting particles from air stream than the passive sampling method [8]. The design of sampling device was taken from Andersen cascade sampler. Cascade sampler or cascade impactor is a suction sampler that has two or more stages of air collection with the nozzle as shown in Figure 2. This sampler can sample various size of air particle depending on the number of stages of sampling such as Andersen cascade sampler that has six-stage of sampling that differs by their hole sizes [9]. Low speed and a larger hole in the first stage makes it possible to capture larger air particles (greater inertia) and the smaller the hole size becomes, the smaller the particle size that is able to collect in subsequent stages [9]. Furuchi *et al.* used the same concept to develop a nanosampler, which is capable of collecting particles from PM10 to PM0.5. This sampler consists of four stages, each stage contains a different type of filter paper [10].

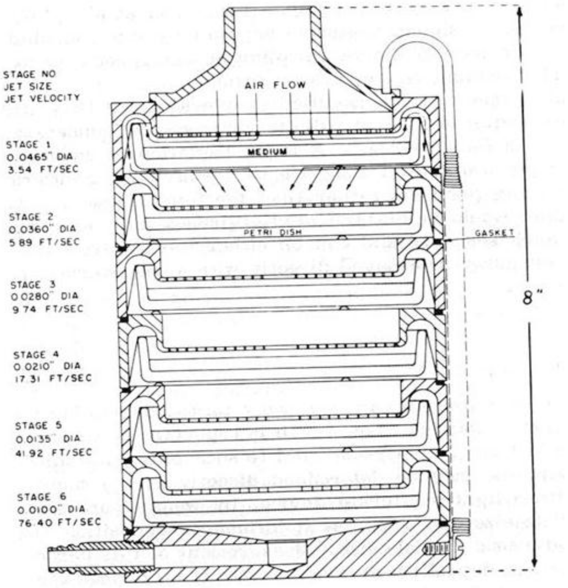


Figure 2. Andersen six-stage cascade sampler. Each stage contain a petri disc below the perforated plate that contain sticky surface to collect particles form air stream that flow through [9]

3. Materials and method

3.1. High altitude balloon vehicle

A 1600 g latex balloon filled with helium was used to bring the sampling device to the stratospheric altitudes, with a glider as the payload of the balloon. A parachute was used to slow down the free fall during descent. The total weight suspended below the balloon was about five kilograms. The balloon carried the payload up to its burst altitude. When the balloon burst, the parachute was deployed until the payload reached the parachute release altitude and the glider began to glide for recovery. The ratio of lift produced by the balloon was twice of the payload weight.

3.2. The fixed wing payload

The biggest concern of HAB mission is the landing site. To increase the chance to retrieve the payload and avoid water landing, a glider with a wing span of two meters was used as a payload to carry all experimental apparatus as shown in Figure 3. All electronics and sampling devices were placed inside the glider as illustrated in Figure 4. The internal compartment was covered with aluminium tape to prevent extreme internal temperature drop, which could cause failure of the electronics and power supply. This glider was pre-programmed to glide back to desired landing coordinate and would be then landed manually using RC controller.

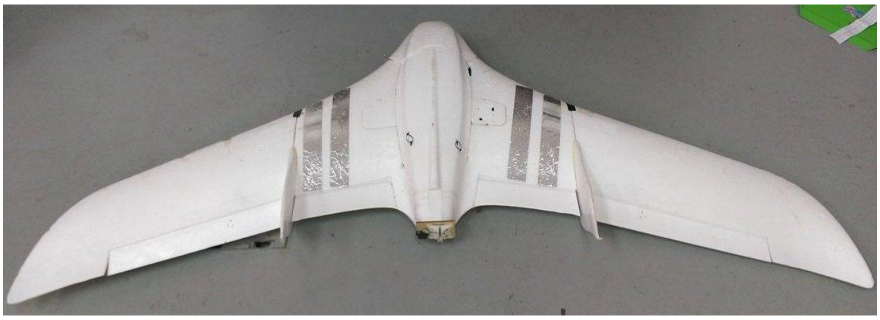


Figure 3. FX79 fixed wing with 2 m wingspan

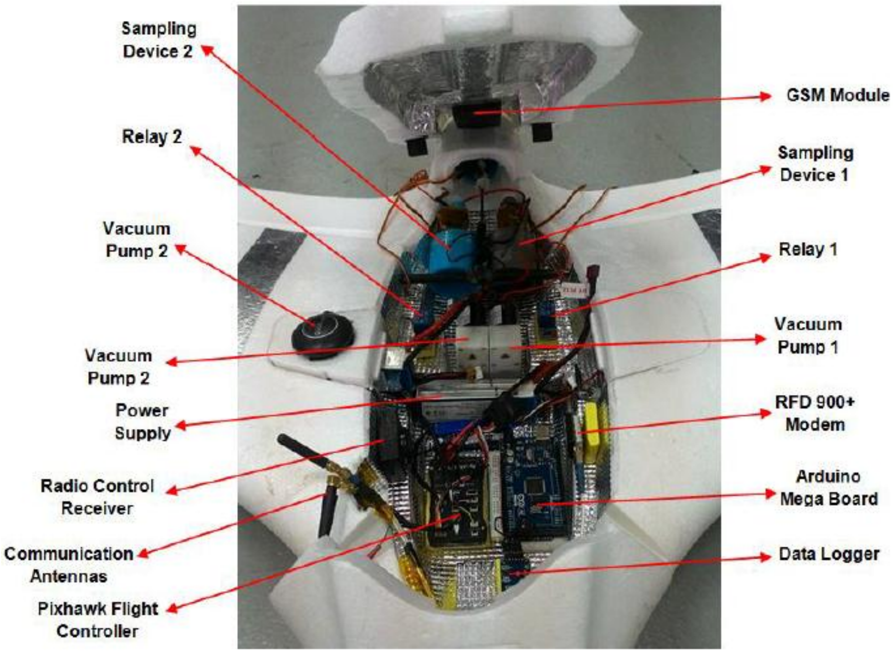


Figure 4. The payload setup

3.2.1. Sampling collector. The design of the sampling collector is shown in Figure 5. This sampling device was designed using CATIA software and printed using a 3D printer. The body was made of ABS (Acrylonitrile Butadiene Styrene). This sampling device used cellulose nitrate membrane filter with diameter of 47 mm and pore size of 0.45 µm. The collectors consisted of four stages: inlet stage, distribution stage, compression part, and outlet part. Nozzle shape of these collectors increased the speed of airflow. The small holes distribute the airflow evenly inside the nozzle. A 12 Volt pump was used to collect the aerosol particles.

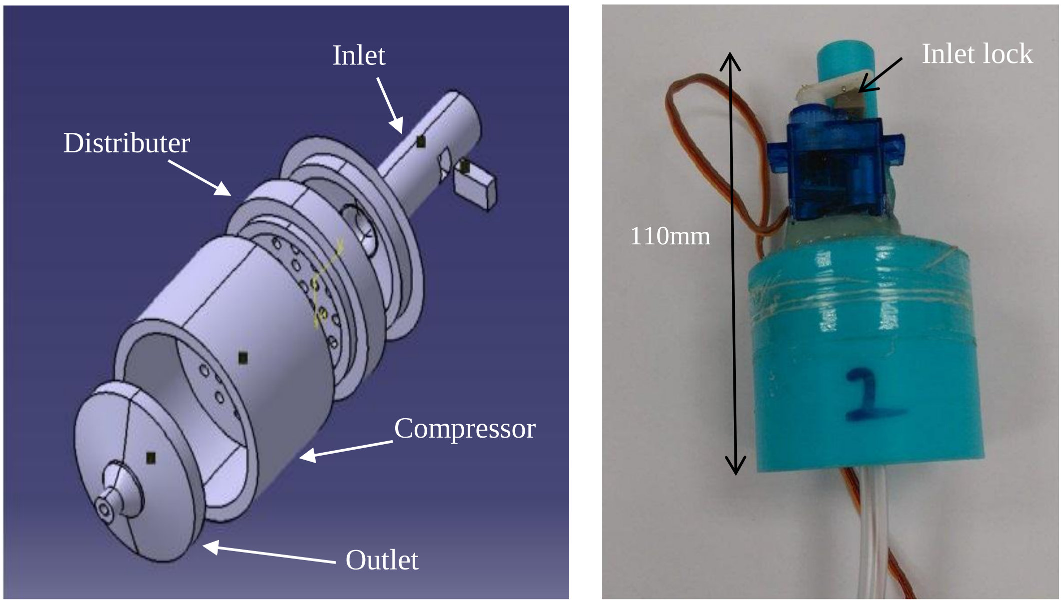


Figure 5. 3D view of sampling device (left) and sampling device after printed using 3D printer.

3.2.2. Electronic and power supply. The payload electronics consisted of power module and control system. The control system consisted of 3DR Pixhawk PX4 flight controller and Arduino Mega 2560 microcontroller. This system was responsible for monitoring the payload altitude and making decision of activation and deactivation of the pump. The flight controller was used to monitor the payload condition such as coordinate, altitude and attitude of the payload. During gliding mode, 3DR Pixhawk with GPS was used as a flight controller that control the glider and also responsible for parachute release mechanism. When the balloon burst at the maximum altitude, the glider began its free fall. Parachute was used to slow down the descent speed. Parachute release mechanism would be activated if the difference between current descent altitude and maximum altitude was 2 km, and the glider began gliding to desired landing coordinate autonomously. All important data from flight controller such as temperature inside the payload, speed, altitude and pressure was stored in data log inside the flight controller. The data was also transmitted to the ground station for backup when the onboard data log encountered errors.

For tracking and recovery, the payload used two tracking systems. The primary system used RFD 900+ modem radio transmitter to transmit GPS data to the ground station and secondary tracking system used GSM (Global System for Mobile Communication) network to send coordinate to ground station. Primary tracking system used 902-915 MHz frequency and broadcasted the data directly via Mavlink protocol to ground station. This system enabled the balloon to be continuously monitored from the ground station. The advantages of this tracking system include its independence of the other broadcasting method such as the Automatic Packet Reporting System (APRS) and cost savings for subscribing the broadcast system. The main reason of using two tracking system was to minimize the risk of payload lost. The primary system was used to report the real-time coordinate and altitude to the ground station while the secondary system functioned as backup tracking system when primary system failed or the glider encountered crash landing. The disadvantage of using secondary tracking system was its full dependence on the network coverage.

Located at the front of the glider was a Mobius wide-angle HD camera. This camera recorded the video of the surrounding (aerial view) throughout the flight. The payload was powered by three Lipo batteries. Two 11.4-V Lipo batteries were used to power the flight controller module and the pump respectively. Arduino Mega was powered by a 7.4-V Lipo battery.

3.3 Feedback control system design

Control system of this sampling device was done using Arduino Mega microcontroller by receiving the PWM (Pulse Width Modulation) signal from Pixhawk PX4 every 500 ms through serial port and triggered if the desired altitude obtained from GPS (Global Positioning System) was achieved. To preserve sample after sampling process, two 180 degree servos acted as lock and unlock mechanisms to open and close the inlet of the sampling device. The relay functioned as an on-and-off switch to control the vacuum pump. A pre-programmed Arduino Mega microcontroller was used to transmit digital signals to both relays and servo in order for activation. Pixhawk (with GPS) was used to give input (altitude reading) to the Arduino, which would then decide whether to send the PWM signal to activate the pump and servos for aerosol sampling, and the opening of the collector chambers. The schematic of the sampling device and the flow chart of the feedback control system are shown in Figure 6 and Figure 7, respectively. Figure 6 shows the schematic diagram of the platform system for aerosol sampling. The aerosol sampler contained two sampling chambers to collect aerosol particles with the help of vacuum pump.

The algorithm for sampling device is shown below. This algorithm was applied in Arduino Mega to make the decision to activate or terminate the sampling device using ch_6 (channel 6) and ch_7 (channel 7) from Pixhawk to Arduino digital pin.

```
//ch_6 and ch_7 connected to Pixhawk
If ch_6 ≧ 1800 or ch_7 ≧ 1800 (pump activation altitude reached)
    Then
        Turn on Relay
        Unlock inlet door
Else
        Turn off Relay
        Lock inlet door
```

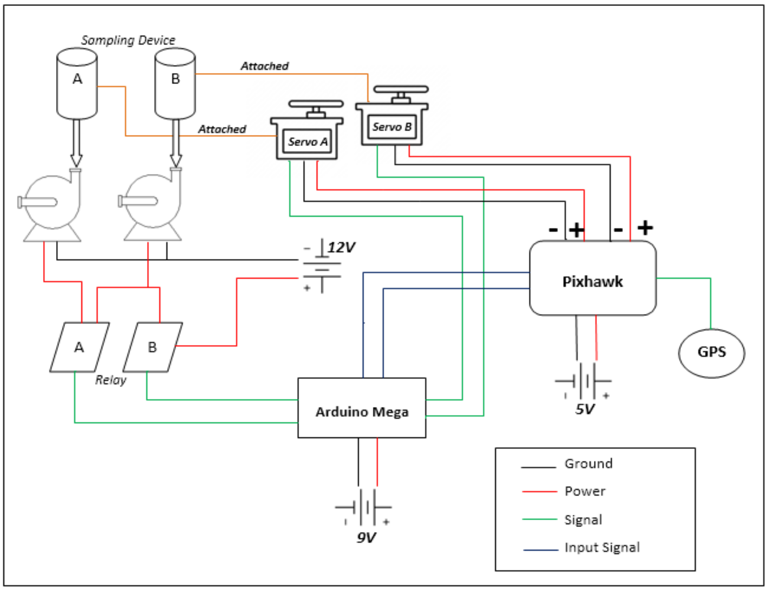


Figure 6. Schematic diagram of platform system for aerosol sampling

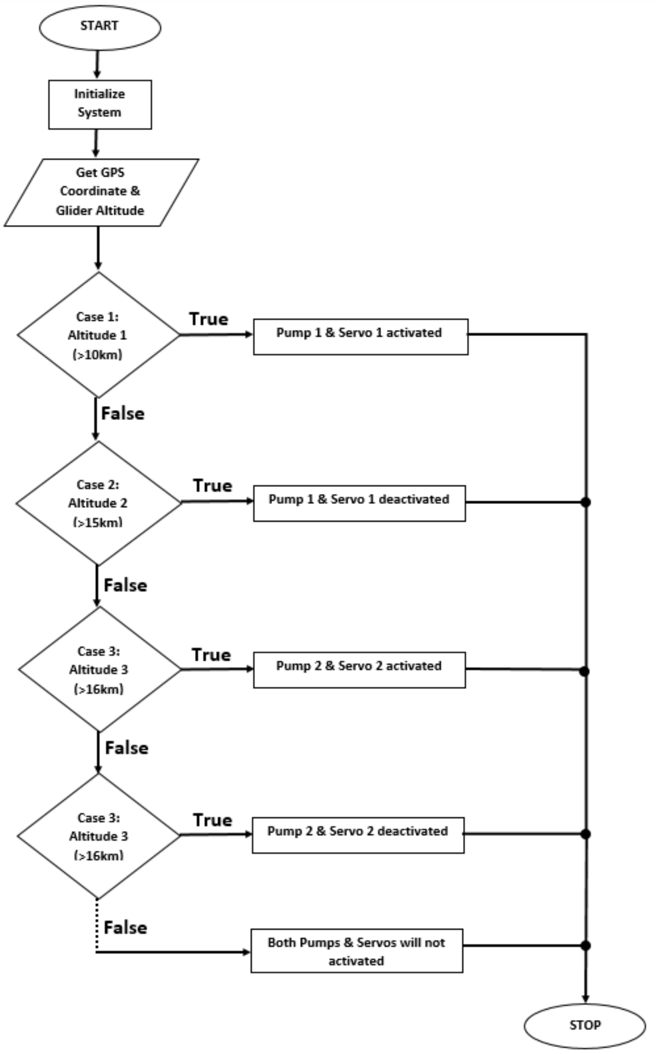


Figure 7. Switch case flowchart of platform system for aerosol sampling

Figure 7 shows the switch case flowchart of the platform system for aerosol sampling process. The flowchart of the system started with initialization of the on-board system, which included the Pixhawk, GPS and Arduino Mega. After the initialization process was completed, the balloon was released manually for ascend. During the ascending process through the atmosphere, the platform system was set with four conditions. These four conditions were used to activate and deactivate the vacuum pumps and servos for aerosol sampling process. For the sampling device number 1, as the balloon reached an altitude of 10 km, the system activated vacuum pump 1 and servo 1.This allowed the first sampling process to take place. This went the same to sampling device number 2. When the balloon reached an altitude of 16 km, the system activated vacuum pump 2 and servo 2, and both terminated at 20 km altitude. The classification of the samples is listed in Table 2.

In triggering process, if current ascent altitude more than activation altitude, Pixhawk would send 1800 PWM signal to Arduino mega. Arduino mega would switch on the 5-V relay by changing the relay state from low to high and unlock the sampling door chamber. The PWM value would stay constant at 1800 during sampling process until current altitude was more than deactivation altitude. Default PWM value that Pixhawk sent to Arduino Mega was 1100 and the inlet of sampling device was locked. For smooth and reliable data, Kalman filter was applied to filter all data including altitude data.

Table 2. Reference samples altitude

Sample	Altitude (m)
A	1000 – 15000
B	16000 – 20000
C	N/A (Reference)

3.4. Aerosol analysis

3.4.1. Analysis through weight of filter paper. Amount of aerosol particles collected was determined by using the initial weight and final weight of filter papers. In order to determine the weight of the filter paper, a highly sensitive weighing scale was used. In this experiment, the micro weighing scale was used to weigh the filter paper. The difference of weight between A and B filter papers with the reference filter paper (filter paper C) was used to determine the existence of other particles on the filter paper that made the weight of filter paper increased than the original weight.

3.4.2. SEM/DEX analysis method. Analysis of sample was done using scanning electron microscopy with energy dispersive X-ray spectroscopy (SEM/EDX) analysis, as shown in Figure 8. This method was used to determine the type of elements found on the filter paper. In this analysis, sample C was used as reference filter paper, which was compared to sample A and B. In SEM/DEX analysis, high-resolution images of surface topography with excellent depth of field were produced using a highly focused scanning electron beam. Besides, most elements in the periodic table (ranging from carbon to uranium) can be easily detected by using SEM/DEX analysis and a maximum sample size of 50 mm diameter (~20 mm thick) can be accommodated [11]. Additionally, SEM/EDX is also useful to capture images at 100 000 times magnification or greater, which is great advantage for the analysis of aerosol particles and some elemental information such as element weight percentage, element atom percentage and element compound percentage can also be obtained by using this analysis [11]. Lastly, SEM/EDX analysis is considered as a fast, cost-saving and non-destructive approach for surface analysis and it is often used to survey the surface analytical problems before proceeding to more specialized techniques. Since the filter paper used in this research work was 47 mm in diameter, it was compatible with the SEM/EDX.

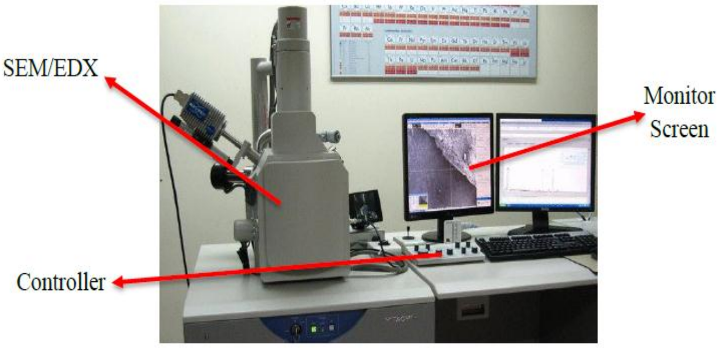


Figure 8. SEM/DEX machine used in sample analysis

4. Result and discussion

4.1. Flight test result

This subsection explains the results analysis of a flight test that was done, that includes analysis of mission profile, flight path, altitude profile, internal temperature, pressure and parachute release mechanism. On the 2nd of May 2016, the sampling device was flown with High Altitude Fixed Wing

Experimental Platform using 1600 g balloon and 2.5 kg payload. It was launched from the Paddy field of Kampung Chui Chak, Langkap Perak, Malaysia (4° 2'31.62"N 101°10'4.45"E) at 12:40 noon. The flight path of the flight is as shown in Figure 9. This flight was fully controlled by the flight controller system autonomously. After approximately four hours, the fixed wing (glider) was safely landed at a paddy field Felcra Seberang Perak, Perak, Malaysia (4° 3'31.51"N 100°51'54.00"E) that was about 50 m from the ground station. Mission profile and other important parameters were plotted against the Mission Elapsed Time in unit milliseconds (ms) as shown in Figure 10.

Figure 9. Flight path of May 2016 mission

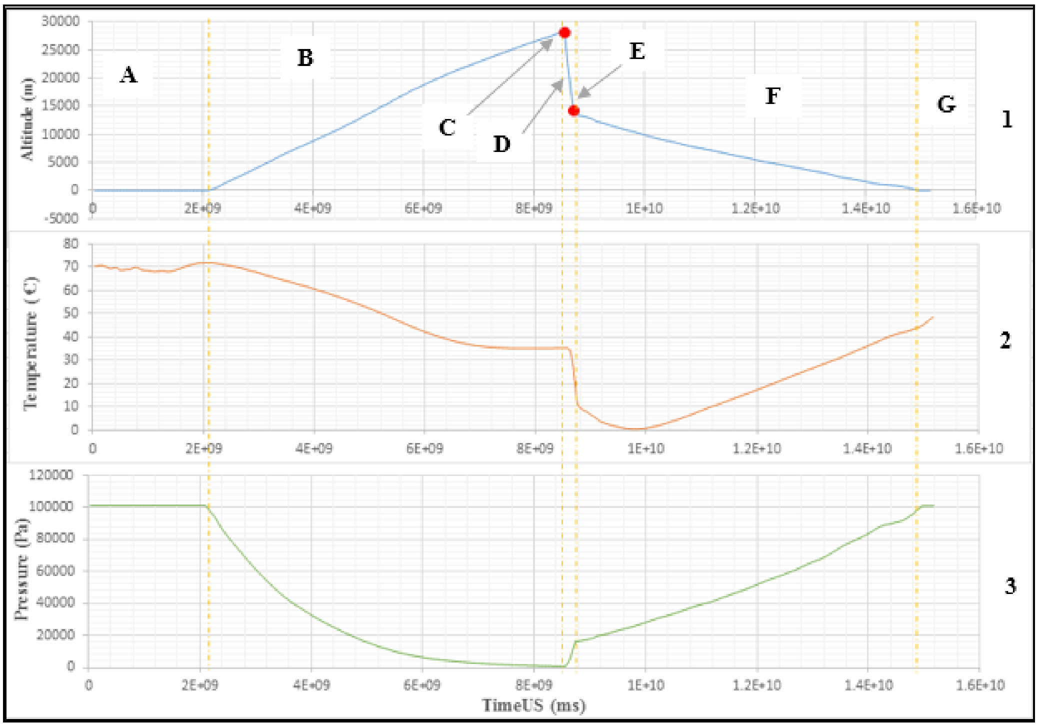


Figure 10. Mission Profile of 2nd May 2016 flight test. Region A indicated preparation time. Region B indicates launching and ascending period. Point C represents where the balloon burst (Maximum altitude). Region D indicates where the glider experience free fall. Point E indicates where the glider begins to glide. Region F represents loitering time and region G after the glider landed.

In Figure 10, graph 1 represents the whole mission profile that is presented as Altitude (m) against Time (ms), graph 2 represents Internal temperature (°C) against time (ms) while graph 3 represents Pressure (Pa) against time (ms) graph. Figure 10 is divided into 5 regions, which are preparation (A), ascending (B), free fall (D), loiter (F) and landing (G). The balloon took about 1 hour 40 minutes to reach the maximum altitude. As the balloon went up, helium gas expanded until the balloon reached its burst altitude (Point C) that was 28,000 m. At maximum altitude, the internal temperature was 32℃ and zero pressure. After balloon burst, the glider experienced free fall and slowed down by the help of a parachute. After approximately 26,000 m, the parachute was released. At approximately 14,000 m, glider began to gain lift (Point E) and began its autonomous mission to desired landing coordinate (4° 3'31.51"N 100°51'54.00"E). After arriving at landing coordinate, the glider began loitering and at approximately 100 m altitude, ground control took over the control surface and landed the glider manually using radio controller. The glider loitering was about 1 hour 45 minutes as it descent slowly in a circular path. During free fall, internal temperature dropped gradually from 32℃ to 10℃ and during loitering, it dropped until 0℃, which was the lowest internal temperature recorded. The temperature drop was due to high velocity during free fall and loiter that increased the humidity inside the payload and led to condensation process. After 10,000 m, the temperature and pressure increased constantly. The important mission parameters are summarized in Table 3.

Table 3. Simplification of important mission parameter

Parameter	Value
Maximum altitude	28,000 m
Minimum internal temperature	0 °C
Minimum pressure	0 Pa
Average ascent speed	5 m/s
Average loiter speed	11 m/s
Flight time	≈ 4 hours 20 minutes

Figure 11 shows the PWM value that was sent by Pixhawk to the servo in the parachute release mechanism. To lock the parachute, 1800 PWM value supplied to the servo to output an equivalent rotation angle. This PWM value supplied constantly until release parachute altitude reached. After approximately 1 hour 45 minutes, the parachute release mechanism was activated by changing the PWM value to 1100, which is represented by point B. The PWM value represented by point A is due to system testing during the preparation process.

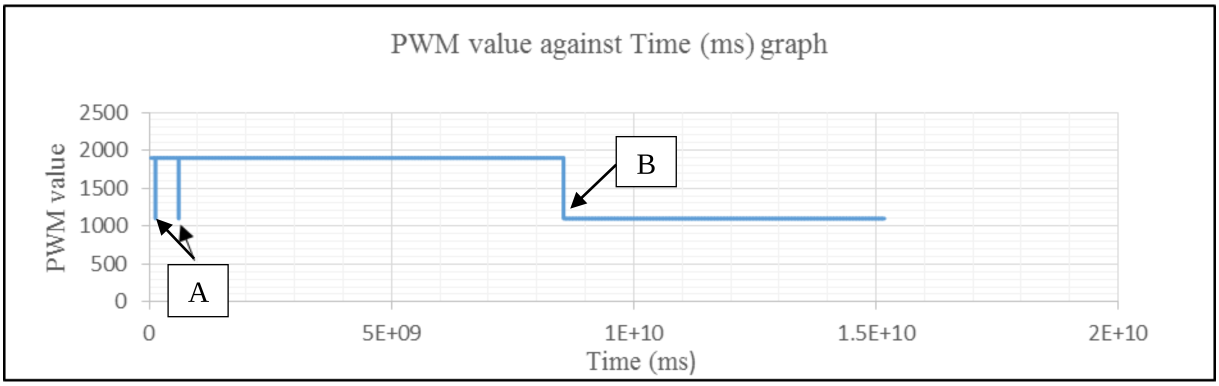


Figure 11. PWM value against Time (ms) graph of parachute release mechanism

4.2. Platform system

An analysis was done on the platform system by extracting the output data from the Pixhawk. One of the digital output data, PWM was extracted and analysed by plotting the data against pressure altitude. Figure 12 shows the graph of PWM against pressure altitude.

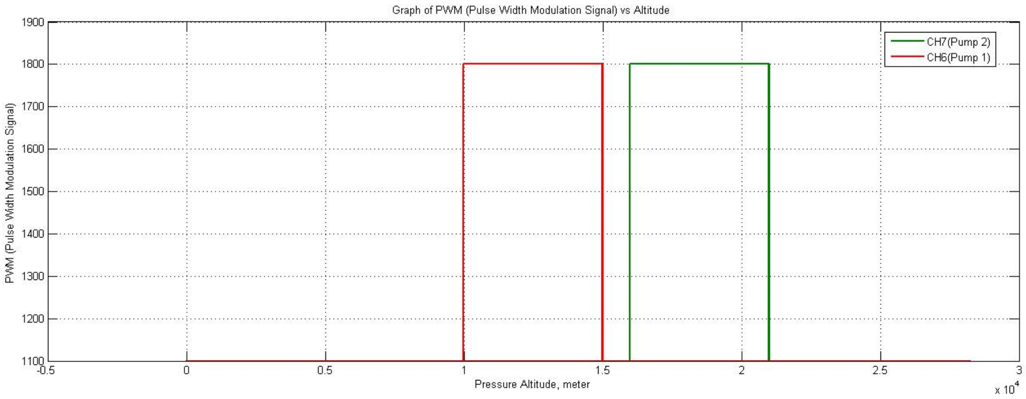


Figure 12. Graph of PWM versus Pressure

For the testing of platform system, a glider was used as a payload to carry the sampling device and all system onboard. Based on Figure 12, it shows the graph of pulse width modulation (PWM) versus pressure altitude. From this graph, it shows that both vacuum pumps were functioning properly according to the coding that has been designed. The red line of the graph represents vacuum pump number 1 and the green line of the graph represents vacuum pump number 2. From the graph, it shows that the vacuum pump number 1 was activated at an altitude of 10 km until 15 km and for vacuum pump number 2, it was activated at an altitude of 16 km until 21 km.

4.3. Weight analysis method

For aerosol sampling process, three filter papers were used where one of them was the reference filter paper and the other two were tested at different altitudes. Two sampling devices were used and both of them were run simultaneously. After sampling process was done, analysis and comparison between the two filter papers and the reference filter paper was conducted. For the analysis and comparison process, two methods were used. The first method was to determine the difference value between the initial and final weight of filter paper, and the second method was by SEM/EDX analysis.

In this experiment, cellulose nitrate membrane filter paper was used as the filter paper. This filter paper was 47 mm in diameter and had the pore size of 0.45-micron meter. For the sampling process, a vacuum pump with a flow rate of 45 L/min and negative pressure of 90kpa was used. A calculation for the duration of sampling process was determined by dividing the altitude range with ascending speed of the balloon (constant ascend speed of 5 m/s was used). Table 4 below shows comparison between the initial weight and final weight of the three filter papers with Petri dish.

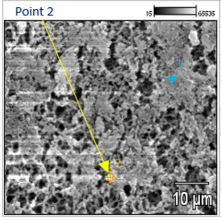
Table 4. Comparison of initial weight and final weight of different filter paper

Sampling Altitude (km)	**Sample**	**Readings**	
		Initial weight (g)	**Final weight (g)**
10-15	A	18.45	18.50
16-21	B	18.46	18.47
N/A	C (Raw)	18.47	N/A

The duration for both sampling process A and B was calculated to be 1000 seconds. From the table above, the amount of aerosol particles collected was determined by using the initial and final weight of the filter papers. As mentioned earlier, a high sensitivity weighing scale was used to determine the weight of the filter paper. In this experiment, the micro weighing scale was used to weight the filter paper. Based on Table 4, the difference in weight between initial and final of sample A and sample B was 0.05 g and 0.01 g, respectively. This was the exact weight of the air particles that was collected from the sampling process. Based on sample A and sample B, the result shows that sample A has the highest value in weight different between initial and final. From this observation, it was assumed that at an altitude of 16 km until 21 km, the size of the air particles is smaller than 0.45-micron meter while at an altitude of 10 km until 15 km, the size of the air particles is larger than 0.45-micron meter. Thus, sample A was able to collect more air particles than sample B. For sample C, it was set as a reference filter paper for further analysis.

4.4. SEM/DEX Analysis method

The collected particles on the filter paper were analysed using Scanning Electron Microscopy (SEM) with Energy Dispersive X-Ray (EDX) device, and the sample results are shown in Figure 13, Figure 14 and Figure 15 for first (Sample A), second (Sample B) and third (Sample C), respectively.

Test(1573)_pt2	*C-K*	*N-K*	*O-K*
	**Weight %**		
	23.10	26.59	50.30
	Atom %		
	27.61	27.25	45.13
	Formula		
	C	N	O
	Compound %		
	23.10	26.59	50.30

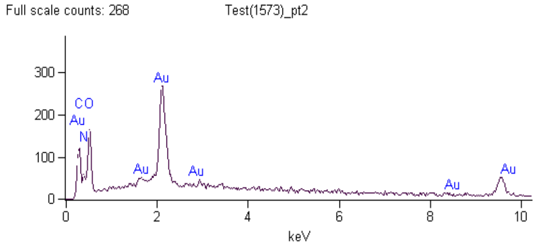
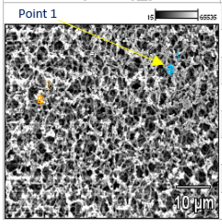


Figure 13. SEM/EDX result analysis of sample A

Test(1574)_pt1	*C-K*	*O-K*	*K-K*
	**Weight %**		
	97.64	0.40S	1.96
	Atom %		
	99.08	0.31	0.61
	Formula		
	C		K2O
	Compound %		
	97.64	0.00	2.36

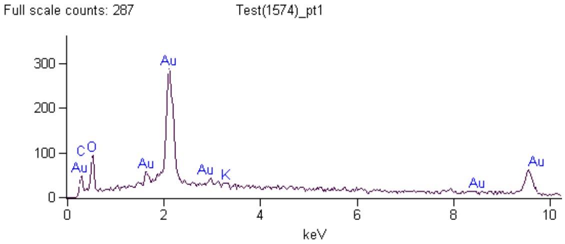
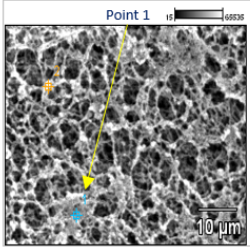


Figure 14. SEM/EDX result analysis of sample B

Test(1572)_pt1	*C-K*	*O-K*
	**Weight %**	
	38.17	61.83
	Atom %	
	45.12	54.88
	Formula	
	C	O
	Compound %	
	38.17	61.83

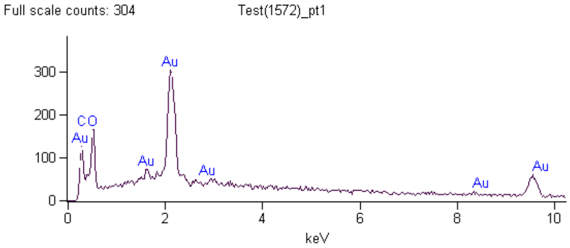


Figure 15. SEM/EDX result analysis of sample C

From the results of SEM/EDX analysis, it shows that all the samples have the same basic elements on the filter papers which were Carbon Monoxide (CO) and Gold (Au). Based on Figure 13, it shows the graph of elements (at Point 2) that was found on sample A. For sample A, which was sampled at an altitude of 10 km until 15 km, another element that is Nitrogen (N) was found. Based on Figure 14, it shows the graph of elements (at Point 1) that was found on sample B. For sample B, which was sampled at an altitude of 16 km until 21 km, another element that is Potassium (K) was found. In addition, from Figure 13, Figure 14 and Figure 15, they show all of the elements composition, which included the percentage of weight, percentage of the atom, percentage of compound and formula for elements that was found at both point 1 and point 2. Based on all the results, the platform system and the sampling device were verified to function properly. Even though the outcome was a success, it was only limited to particles with a size of 0.45-micron meter and above only. In order to collect aerosols particles that are smaller than 0.45-micron meter, an advanced sampling device or another method should be considered. Despite the limitation in the aerosol sampling process, the platform system successfully proved its reliability, feasibility and effectiveness in the sampling process. Hence, with a good consideration of sampling device and sampling method, a large range of aerosols particles size and various types of microbes can be obtained at high altitudes by using high altitude balloon (HAB) based platform system.

5. Conclusion and recommendations for future work

Unmanned Aerial Vehicle (UAV) based High Altitude Balloon for active aerosol sampling system was successfully developed and tested. It is also shown that automatic control works properly and the glider that carried the sample was retrieved safely at the desired landing coordinate autonomously. The system was able to collect aerosol particles (as in Figure 13 and 14 were Nitrogen (N) and Potassium (K) gas particles collected at different altitudes). It is hoped that the developed system can be utilised with different balloon settings, as well as with other filter types, to collect microbial and aerosols to characterise their distributions at the high-altitude atmosphere. Despite the positive results obtained through this research, several limitations to the system platform and sampling process existed. Thus further study is required before this platform system can be applied for aerosol sampling or other environmental/biological survey.

The following areas could benefit from further development of the system platform for aerosol sampling. Throughout this research, sampling process was only done for pore size of 0.45-micron meter. Any air particles that is larger than 0.45-micron meter was trapped on the filter papers but any air particle that is smaller than 0.45-micron meter was able to pass through. Furthermore, in this research, only one filtering chamber for one device, thus it limited the size of the particle that can be filtered. Hence for future work, for certain meteorological or bioaerosol research requirement, a suitable and precise sampler needs to be developed. More chambers are needed in the sampler to fit more filter papers of various sizes to increase efficiency. Other type of sampler that can be considered for application is the Rotorod Sampler. The Rotorod Sampler is commonly used to collect spores in the air by allergists [12,13]. The Rotorod Sampler consists of a U-shaped metal rod covered with sticky tapes, attached to a spindle to a battery-powered electric motor. Rotating the metal rod at high speed will trap spores and other air particles on the tapes. For analysis, the tapes are removed and examined microscopically to identify the spores and other particles such as pollen grains in the air. Modifications need to be made on the glider compartment to suit the sampler design and power requirements. Using such sampler with the current platform would accelerate studies on microbes or spores at high-altitude, which are abundant and diverse. A good communication and autopilot system must be developed and maintained throughout the mission profile of the HAB. The risk of payload lost could be lowered if lost of communications occurrence between the payload computer and ground station can be further reduced. During the test flight of the system, the signal between a ground station and HAB was sometimes lost due to some interference from other devices and dissipation of signal by clouds. Communications could also be cut off due to power issue, as batteries could not longer power devices in an unanticipated long flight or unexpected power consumption by other devices such as camera and sampler. Improvement in antenna design, introduction of satellite based communication system as well as installation of other redundant communication systems for backup such as low-powered beacons is needed in future platform to increase reliability during payload recovery. Studies on power management are required as merely increasing the number of batteries will lead to higher payload and may lead to undesirable glider flight performance.

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