# KiteCam – a novel approach to low-cost aerial surveillance

Abhinav Navnit, Deeksha Devendra, Anushka Tiwari, Aftab M. Hussain*
PATRIoT Lab, Center for VLSI and Embedded Systems Technology (CVEST), International Institute of Information Technology (IIIT) Hyderabad, India
*Email: aftab.hussain@iiit.ac.in

***Abstract*— The ever-growing need for surveillance over various geographical locations has necessitated the development of novel monitoring approaches. While drones are still considered the most suitable aerial surveillance equipment, new techniques based on use of kites such as kite aerial photography (KAP) are becoming popular. This paper deals with one such novel approach, termed as KiteCam, which provides a low-cost and versatile method of performing local aerial surveillance for a prolonged period. The camera, processor, battery and power management module have been designed and fabricated such that the total weight of the system is approximately 42 grams. Hence, the system is light enough to be carried by most kites under normal weather conditions, thus offering a wide variety of applications with minimal energy consumption and concealed surveillance options. The test flights have been successfully conducted and observed in terms of stability and duration. The images obtained from the flight tests have been analyzed and verified for consistency and clarity. Finally, some modifications have also been mentioned regarding the future generations of the device.**

***Keywords*— *KiteCam; aerial photography; surveillance; low-cost; light-weight system***

## I. INTRODUCTION

Information is the key to the development of any nation or organization [1]. Gathering specific and timely intelligence is of vital importance and can include surveillance over vastly different landscapes such as a reef, a mountain, a wildlife sanctuary, a disaster affected area, a refugee camp or the border area between two countries. Aerial photography is considered the most suitable method in such cases [2, 3]. Aerial surveillance is often implemented through unmanned aerial vehicles (UAV), commonly known as drones [4, 5]. Although drones have proved to be a good choice for aerial surveillance and are being widely used, they still face several shortcomings [6]. Among these issues, the major ones are related to high power consumption leading to low flight duration or restricted payloads [7], deviation from path under bad weather conditions [8], spoofing attacks [9] and various other cybersecurity issues [10]. Further, UAVs usually tend to generate privacy anxiety among the bystanders and have regulations governing their use which effectively renders them unusable on certain occasions [11]. Furthermore, drones are relatively easy to spot because of the noise created or their size. This can compromise fact finding missions and aerial surveillance missions in sensitive areas. To overcome these issues, some other models based on the concept of tethered platforms like kites and hot air blimps are being used for small-format aerial photography (SFAP) [12, 13]. Among these, one notable method is the kite aerial photography (KAP), which involves the use of a camera rigged to a kite [14, 15]. When compared to a drone, the implementation of kite in aerial surveillance is beneficial in terms of power requirement during flight, as well as in terms of security issues. Further, being directly controlled by the user through strings, the chances of path deviation or crash are relatively low. While KAP acts as a good alternative for drones in terms of the mentioned issues, it faces its own challenges which are camera instability [16] and requirement of specifically tailored kites [17, 18]. Even with advances in the present photogrammetry techniques and introduction of color infrared photography, RGB and near IR based image capturing, the mechanics of KAP still contribute to a bulky device structure [19-21]. Thus, it is evident that a kite is a good alternative for aerial surveillance but is only restricted because of the current KAP structure.

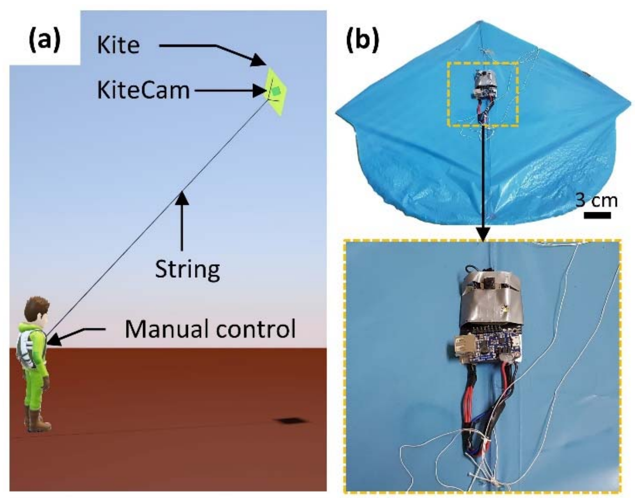


Fig. 1. (a) Illustration of the flight of KiteCam using manual control through an attached string. (b) Photograph of the fabricated system including the controller, camera, battery and power management module.

In this paper, we present KiteCam, a novel approach to the present KAP structure. KiteCam is a kite with a camera module attached to its spine which effectively nullifies the requirement of any specific kite shape or size (Figure 1). This is made possible because the complete module has been designed and fabricated such that the total weight of the system (including that of a 360 mAh battery module) is only around 42 grams. Attaching the system to the spine of the kite (close to the center of gravity) enhances the safety and stability of the system, and offers a better imaging opportunity. Depending on the size and

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type of kite used, KiteCam has a wide variety of use cases including wildlife monitoring, remote monitoring of unreachable terrains, concealed tracking of clandestine movements, and rescue missions. Based on the wind speed and camera settings, the current KiteCam design can perform surveillance for as long as six hours in a single flight. The requirement of minimum windspeed for the flight is easily met at almost all the geographical locations.

## II. KiteCam Design

### A. Flight Mechanism

Any kite depends on the wind dynamics for its flight and at higher altitudes, wind is generally plentiful and stable [22]. A stable kite can be managed in such conditions, however, with a camera mounted on it for imaging, the need for stability becomes of utmost importance in order to obtain proper surveillance data. Further, given the low weight carrying capacity of a kite, it is important to determine the maximum payload a kite can carry under particular weather conditions, to make sure that the total weight of the system (including that of the kite) does not exceed this limit. A kite uses energy from the wind to achieve lift and remain in flight, which gives rise to the forces of lift (L) and drag (D). The angle formed between the direction of wind and the orientation of kite is known as angle of attack (a). Other forces acting on the kite are the weight of the kite (W) and the tension from the string (T) as shown in Figure 2. The aerodynamic forces act through the center of pressure (P), while tension acts through bridle point (B) and the weight through center of gravity (G).

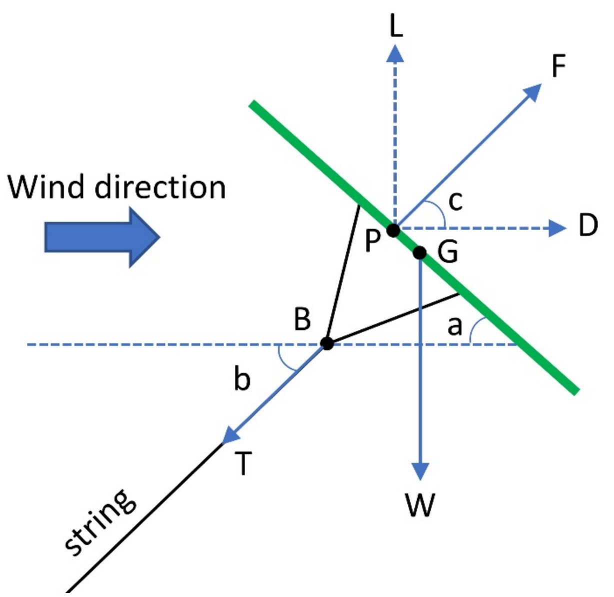


Fig. 2. Free body diagram of the forces acting on the kite during a stable flight.

For a smooth flight, all the forces need to be balanced linearly as well as in terms of torque. From the balance of force in the vertical direction, we get:

$$W + T\sin(b) - L = 0 \tag{1}$$

here 'b' refers to the bridle angle (angle between the string and horizontal plane). From the balance of force in the horizontal direction, we get:

$$T\cos(b) - D = 0 \tag{2}$$

The force generated by the wind (F) depends on the speed of the wind (v), density of the air at that location (ρ), area of the kite (A) and a constant (k) which varies based on the kite structure and angle of attack. The angle between the force generated and the horizontal plane is given by c.

$$F = k\rho v^2 A \tag{3}$$

$$L = F\sin(c) \tag{4}$$

$$D = F\cos(c) \tag{5}$$

The above equations are general equations for any force $F$ acting at an angle $c$ to the kite. Based on the assumption that the wind reflected from the kite is proportional to the bridle angle, the value of $k$ and $c$ can be found as,

$$k = 1 + \frac{4b^2}{\pi^2} - \frac{4b\sin(\mathrm{b})}{\pi} \tag{6}$$

$$c = \tan^{-1}\left(\frac{2b\cos(b)}{\pi - 2b\sin(b)}\right) \tag{7}$$

Thus, from these equations, we can calculate the maximum weight of the system for a given windspeed and area of the kite. The bridle angle is the independent variable, because weight, area of kite and the density of air are constant during flight. Thus, during flight, the balancing occurs between wind speed and the bridle angle. It should be noted that the wind speed is relative to the kite and thus can also be changed through string movements by manually moving the control point on the ground. From the given analysis, the variation of bridle angle with the payload is as shown in Figure 3, for a kite of area 0.114 $m^2$. Thus, for a wind speed of 5 km per hour, the theoretical maximum payload weight was found to be around 60 grams at an approximate value of 45 degree of angle of attack.

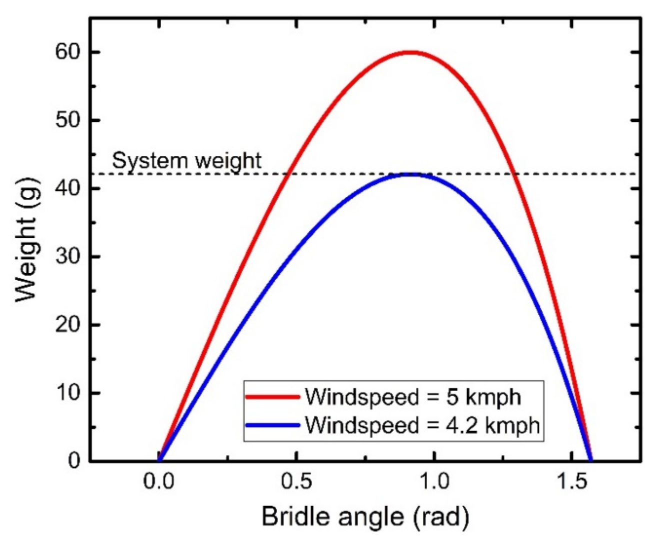


Fig. 3. The bridle angle of the kite changes with the payload weight. The maximum weight for a windspeed of 5 kmph is around 60 grams. The designed system can operate in windspeed of 4.2 kmph for a kite of area 0.114 $m^2$.

## B. KiteCam Fabrication

The KiteCam consists of a kite, a small camera module, lithium polymer batteries and a power management module. For the experiment, a simple diamond kite with a surface area of 0.114 $m^2$ and weight of 0.015 kg was used (Figure 1b). The kite was made of a thin plastic sheet with a wooden spine and cross par. The camera module and batteries were pasted on the spine of the kite. The camera module used was ESP32-CAM board with OV2640 camera. The power source used was two lithium polymer batteries of capacity 180 mAh, connected in parallel. We used ultra-light flexible lithium polymer batteries weighing only 4.65 grams each to make the system as light as possible. In addition to this, a power management module was used in order to provide the required voltage to the cam module and to facilitate charging of the batteries. The weight of each individual component was carefully chosen (Table I) such that the complete setup weighed below the theoretical maximum limit for average wind speeds of 5 kmph.

TABLE I. WEIGHT OF INDIVIDUAL COMPONENTS

| **Equipment no.** | **Equipment details** | | |
|---|---|---|---|
| | ***Equipment part*** | ***Quantity*** | ***Weight of single part (in g)*** |
| 1. | ESP-32 CAM module | 1 | 6.05 |
| 2. | OV2640 | 1 | 0.40 |
| 3. | SD card | 1 | 0.25 |
| 4. | Lithium polymer battery | 2 | 4.65 |
| 5. | Power boost chip | 1 | 5.93 |
| 6. | Switch | 1 | 0.20 |
| 7. | Kite | 1 | 15.00 |
| 8. | Wirings | - | 5.00 |
| | Total | | 42.13 |

# III. RESULTS AND DISCUSSION

The first test flight of KiteCam was conducted on 20$^{th}$ February 2020 at International Institute of Information Technology, Hyderabad. The average windspeed during flight was 5 kmph with an air density of 1.229 kg/$m^3$ (based on relative humidity and temperature). The weight of the system was 42.13 g. The camera module was set to take two pictures per second and save it to the SD card mounted on the module. The image resolution was chosen as SVGA (800x600 pixels) for optimum performance of camera and battery. The first flight was conducted at 16:04 IST for 35 minutes duration. During the flight, a total of 4365 images were taken without exhausting the total battery capacity of 360 mAh. In terms of energy consumption, the flight time of 35 minutes takes a total energy of approximately 2.6 kJ. In comparison, average energy consumption of a drone hovering in the sky at an altitude of 5 m and then flying horizontally at a speed of 1 m/s for a total duration of only 20 seconds is experimentally found to be 8.22 kJ [23]. Thus, it is evident that the KiteCam setup is vastly superior to drones in terms of energy consumption. The kite was stabilized at an altitude of around 150 m for most of the flight duration. As expected, some images got blurred due to abrupt changes in the wind during capture. However, there were many images that were usable for aerial surveillance (Figure 4).

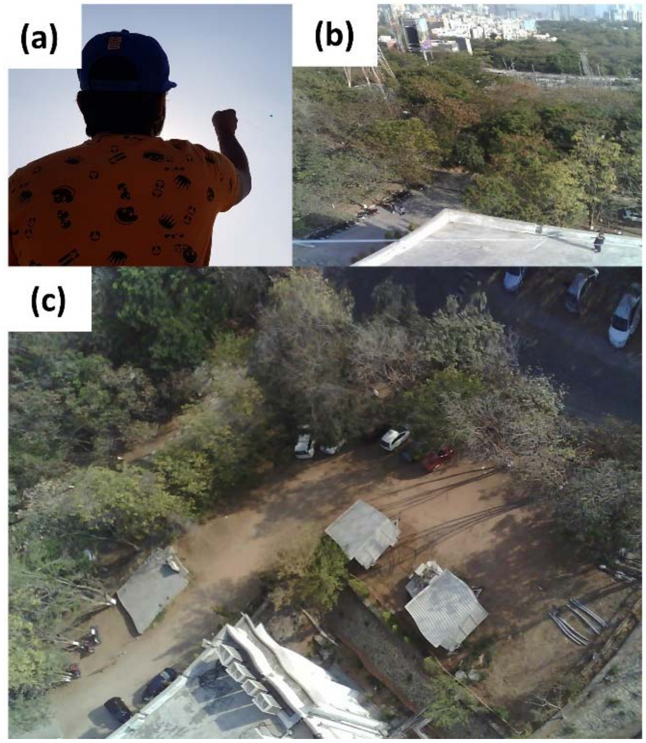


Fig. 4. (a) Manual ground operator; (b) and (c) Images from KiteCam with ground features such as trees, cars, roads and buildings clearly visible.

# IV. CONCLUSION AND FUTURE WORK

This paper introduces a novel approach to aerial surveillance in response to the various energy, cost, safety and flight duration related issues associated with drone surveillance as well as the kite-specificity issues of KAP. The KiteCam provides a solution as alternatives to both methods as a cost effective, energy compliant, safe and concealed approach. Several flight trials were successfully completed, and the performance was found to be acceptable in terms of stability and flight duration. The images were found to be satisfactory in terms of clarity and consistency given the cost of the setup used. The system design was made possible because of ultra-light flexible lithium polymer batteries. With the successful first run of the KiteCam setup, the future advances will be focused on obtaining better quality results even in adverse weather conditions. Some improvements in the design include optimizing the shutter speed for better image stability and reducing the frames captured per second in order to save battery capacity. Further, the camera is currently fastened directly on the spine of the kite, but next generation systems may have a lightweight hinge-based movement to control the camera angle relative to the kite. This can be remotely controlled or have automatic programming to keep the camera focused on a certain target. Other modifications include implementation of cameras capable of capturing images in the dark or for highlighting some specific motion or geometry, use of other sensors such as temperature, humidity, pollution and so on for aerial environmental monitoring.

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