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# Visual signature reduction of unmanned aerial vehicles

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## ABSTRACT

With the emergence of unmanned aerial vehicles (UAVs) in multiple tactical defence missions, there was a need for an efficient visual signature suppression system for a more efficient stealth operation. One of our studies experimentally investigated the visual signature reduction of UAVs achieved through an active camouflage system. A prototype was constructed with newly developed operating software, Cloak, to provide active camouflage to the UAV model. The reduction of visual signature was analysed. Tests of the devices mounted on UAVs were conducted in another study. A series of experiments involved testing of the concept as well as the prototype. The experiments were conducted both in the laboratory and under normal environmental conditions. Results showed certain degrees of blending with the sky to create a camouflage effect. A mini-UAV made mostly out of transparent plastic was also designed and fabricated. Because of the transparency of the plastic material, the visibility of this UAV in the air is very small, and therefore the UAV is difficult to be detected. After re-designs and tests, eventually a practical system to reduce the visibility of UAVs viewed by human observers from the ground was developed. The system was evaluated during various outdoor tests. The scene target-to-background lightness contrast and the scene target-to-background colour contrast of the adaptive control system prototype were smaller than 10% at a stand-off viewing distance of 20-50 m.

**Keywords:** Unmanned aerial vehicles, visual signature reduction, active camouflage, visibility, outdoor tests, lightness contrast, colour contrast, adaptive control

## 1. INTRODUCTION

UAVs (unmanned aerial vehicles) are extensively used in many civil and defence missions. Because human lives are not endangered, their use promotes safety. Because of their relatively smaller sizes and propulsion systems, they have the ability to achieve stealth more readily than manned aircraft. Thus, many of defence missions can be performed without detection from enemy units [1] [2].

Under some circumstances, UAVs are required to fly at a low altitude, which also can avoid heat-seeking missiles and radar guided missiles. Hence, for low altitude UAVs, the challenge is to prevent detection by human eyes [3]. Loss of an UAV could cause a commander inability to continue with a mission [4] [5]. The most efficient way to improve the survivability of a small and task specific UAV is to avoid detection. To achieve invisibility for an aircraft when it is viewed from below, brightness and hue are the main factors to be considered [6]. The lower surface of the aircraft should be rendered as closely in colour and brightness to the sky as possible to obtain the invisible effect. Luckiesh [6] stated that a method to lower visibility of aircraft, when viewed from below, is to increase the brightness of the lower surface of the plane to the observers, because an aircraft is always darker when viewed from the ground. A research [7] to predict the visibility of an aircraft uses the contrast threshold as a parameter. Contrast is obtained from brightness of the object expressed as a proportion of the background, and the contrast threshold is the smallest contrast in which the object is barely detectable reliably. Colour based techniques harness to determine whether an object of interest is detectable, but changes in the background colour can affect the visual detection of the object [8]. One visual response measurement method is the visual cross section test [9]. To quantify colours viewed by observers, we can employ CIELAB colour space to represent colours and use it for image analyses [10].

Predicting the visibility of an aircraft from a human observer includes various estimation, modelling, and prediction methods. The degree of visibility would depend on the size, shape, distance, brightness, contrast, and coloration of an object [11]. Barrett and Melkert developed a method of visual signature suppression by the usage of adaptive materials [12], which preselected one colour as a default colour and modified the illuminance against the sky background. One recent technology is optical camouflage [13]. Grippin has developed a technology of utilizing fibre optics for the visual camouflage purpose [14]. However, the configuration of fibre optics is heavy and expensive, and might not be applicable

in all UAV settings. Alu and Engheta suggested the use of plasmonic coating to reduce the total scattering [15]. Coordinate transformation techniques have been suggested by several researchers including Alitalo and Tratyakov [16] and Chen *et al* [17].

A nearly invisible UAV is a perfect weapon [18]. Stealth is applicable in many ways [19], and we would focus on reducing visibility of UAVs in the sky. This article reports UAV-related projects done by the students under the supervision of the first author, and an R&D project funded by MINDEF, Singapore.

Two of our studies involved retro-reflection and electrochromic materials. Retro-reflection is the case for some specific material which would reflect back the incident ray to the original source, regardless of the incident angle. Retro-reflectivity could be constructed by arranging two surfaces, one is reflective and the other one is refractive [20], by applying retro-reflective paint coating, or by modifying the grating of the surface [21]. The most common method of achieving retro-reflection is the use of retro-reflective paint on a surface [22]. The electrochromic material changes its optical properties when a different electrical potential is applied [23]. The electrochromic polymer is basically a conducting polymer which can control its colour by making use of its electrochromic properties. The work of Silva [24] indicated that polyaniline thin films can be electrochemically deposited on transparent indium tin oxide (ITO) plates. Feast [25] reported that polyaniline exists from colourless, green, light blue, dark blue in order of its oxidation state.

## 2. A CLOAK SYSTEM

An experiment prototype model was designed to investigate the visual signature reduction of UAVs by a method of active camouflage. A programming code “Cloak” was developed as the brain to operate the active camouflage system. To analyze the result for colour analyses, another program “LAB Analysis” was also developed.

The prototype has 5 main components: a video camera, a processor, a VGA–AV converter, a micro projector, and a model (a part of an UAV). The basic idea is to place an image recognition device mounted on the top of the model frame. It captures the image of the background, and the image data are forwarded to a processor which runs the program. The output of the program is an augmented image to be projected by the micro projector to the model frame.

A wing model was manufactured by using a foam composite laying method with additional retro reflective coating. The model was designed as a flying wing. A 3M Retroreflective Engineering Grade Sheet was used to coat the whole structure to give a reflecting surface for the purpose of projection. A hole was created at the top of the model, for mounting the camera.

The basic idea of the *Cloak* was to use the digital zooming and brightness control to transform the input image into needed output. The input image was the background captured by the camera, and the output image was the portion of the input blocked by the UAV model as viewed by an observer at a certain distance. The output image was then projected back to the UAV model to provide an active camouflage system. The algorithm had two main variables, the distance of the model to the observer, and the input brightness level. The distance would affect the digital zooming process, and the input brightness would affect optimum brightness. To quantify the result of the colour change method, one possible method is based on the colour difference principle in the colour scheme of CIE  $L^*a^*b^*$ . To do this analysis, program *Lab Analysis* was developed to extract colour information of an image.

Real time backgrounds were also used in the experiment. As shown in Figure 1, the system was able to predict the portion of the background blocked by the object as viewed by an observer camera at a specific distance, project the relevant area back to the object, and thus simulate the invisibility effect. Even though it was not fully invisible, this semi-transparent effect helped reducing the visibility of the object. As it was without brightness control, the colour tone profile of the output appeared too light and did not approximate the background closely.

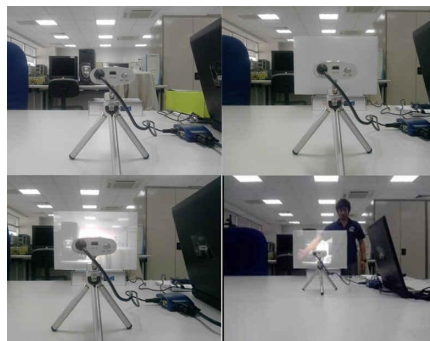


Figure 1. Photos of a background without an object (top left), the background with an object without (top right) and with (bottom left) the system turned on, and a human standing partially behind the object (bottom right).

The system maintained this semi-invisibility effect when a human was passing through the background. This indicated that the system could accept real time changes and give out a real time response.

In the second experiment, it was discovered that the system achieved higher performance with a bright background, as compared to a dark background. Several additional parameters have been identified to complement the colour difference method to achieve a more accurate result. A luminance difference method was chosen, as it gave indication on the brightness characteristic of the system. Root mean square contrast was also adopted as one of the parameters, as it gave the indication of luminance spread relative to average luminance.

It was also observed that the system had uneven distribution of luminance by default, where the centre part was much more luminous than the edge. The effect was caused by the nature of retro-reflective sheet which reflects more energy at a viewing angle near the line of projection. This effect was reduced by placing a different material at the centre of the model near the projection point, coupled with implementing a differential brightness effect in the program. The result of the enhancement was investigated in experiment three, and it was found out that the modification resulted in a more even distribution as compared to the previous result. The implementation of the additional parameter in analysing process also improved the accuracy of the analysis.

### 3. EC DEVICES FOR COLOUR CHANGING

An electrochromic (EC) polymer was fabricated in the lab. Thereafter, an electrochromic polymer device was fabricated and mounted on a UAV. A number of experiments using the polymer were conducted under laboratory and natural environmental conditions, to test how the electrochromic polymer on the UAV could vary its colour.

The first experiment coated the polyaniline onto ITO plates using electrolysis. ITO coated plates turned into light green when a potential difference of 2.5 V was applied.

The next experiment tested the electrochromic properties of the polymer (polyaniline coated ITO plate) that was obtained. The polyaniline coated ITO plate was immersed into a buffer test solution containing both positive and negative ions for oxidation/reduction purposes. An electrical potential was applied to observe the colour changing properties of the electrochromic polymer. The polyaniline coated ITO plate showed its electrochromic properties by undergoing a colour change after being subjected to different voltages. When there was no potential difference, the electrochromic polymer remained the same colour.

Next, a test was conducted using a prototype of the electrochromic polymer device that was mounted on a UAV. The test yielded positive results. When electrochromic polymer was mounted on the underside of the UAV wings, it was able to change to a light blue colour to blend with the sky. From the positive experimental results, the experimenter has established the feasibility of this concept. However, such a colour change takes time to be realized. The feasibility of mounting the electrochromic polymer device on the UAV needs to be further investigated.

#### 4. A TRANSPARENT PLASTIC MINI-UAV

A mini-UAV made mostly out of transparent plastic was designed and fabricated. The UAV has a wingspan of 1 m and flying weight of 1.4 kg, powered by an electric motor. Ground tests and flight tests were conducted to evaluate the performance of the UAV. Figure 2 is a photo obtained from a video taken during a flight test in this project. Because of the transparency of the plastic material, the visibility of this UAV in the air is very small, and therefore the UAV is difficult to be detected, as shown in Figure 2.

This project has also revealed other advantages and disadvantages of using acrylic as a material for UAV construction. For example, acrylic does provide relatively high strength. The UAV would be able to withstand greater loads, compared to similar UAVs made out of such materials as foam and plywood. Moreover, the surface hardness is relatively high as well. It can withstand accidental knocks and scratches, unlike foam which is deformed easily. Using a laser cutting machine, complex geometries can be simply and consistently fabricated through the use of computer-aided drawing software to design the parts.



Figure 2. A photo of the transparent plastic UAV obtained from a video taken during a flight test in this project.

#### 5. VISIBILITY REDUCTION OF LOW-ALTITUDE UAVS

This project aimed to develop and test a system prototype for adaptive visibility reduction of remote-control UAVs with reasonably low weight and costs. Microcontrollers with the programs developed, camera vision systems, and colour-changing actuators, actuator drivers, and their power supply sources were integrated with remote-control UAVs. Lab tests, rooftop tests and field flight tests were intensively conducted to evaluate and improve the performance of the systems developed. Figures 3 and 4 are photos taken during flight tests showing a flying model in the air with and without the system developed, respectively, while Figure 5 shows a photo taken during a rooftop test of the system developed.

Rooftop tests were performed, in which the developed system implemented on a mini UAV was held at a distance of about 20-50 m from the ground to the top of a six-story building. With the prototype held in the air, visual observations were performed and photos were taken at various angles. Such tests, in contrast to actual flight tests to be conducted in a small city-state with very high population density, are safe without risking any possible accidents of crash and damage to the UAVs, the electronics on-board, and most importantly humans and properties. At the same time, they enable quick evaluations of various changes/improvements made to the system components of the prototypes.



Figure 3. A photo taken during a flight test of the system developed.



Figure 4. A photo taken during a flight test without the system developed.



Figure 5. A photo taken during a rooftop test of the system developed.

The scene target-to-background lightness contrast and the scene target-to-background colour contrast were calculated based on the photos obtained from the rooftop tests and in-flight tests. The scene target-to-background lightness contrast and the scene target-to-background colour contrast of the adaptive control system prototypes developed were smaller than 10% at a stand-off viewing distance of 20-50 m. Tests indicated good results of the concept proposed and the system prototype developed.

## 6. CONCLUSIONS

Visual signature reduction of a UAV model using active camouflage by retro-reflective projection technology was investigated. A system prototype consisting of custom built UAV model, camera, laptop, video converter, and micro-projector was built and a program code to run the system, Cloak, was developed. The system was tested by series of experiments relating to visual signature. Tests of the colour-changing devices mounted on UAVs were conducted in another study. A series of experiments involved testing of the concept as well as the prototype. The experiments were conducted both in the laboratory and under normal environmental conditions. Results showed certain degrees of blending with the sky to create a camouflage effect.

A mini-UAV made mostly out of transparent plastic was also designed and fabricated. Because of the transparency of the plastic material, the visibility of this UAV in the air is very small, and therefore the UAV is difficult to be detected. A practical system to reduce the visibility of UAVs viewed by human observers from the ground was also developed. The system developed was evaluated during various outdoor rooftop tests and in-flight tests. The scene target-to-background lightness contrast and the scene target-to-background colour contrast of the adaptive control system prototype developed were smaller than 10% at a stand-off viewing distance of 20-50 m.

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