A Study on a Flight Display using Retro-reflective Projection Technology and a Propeller

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Abstract
The head up display (HUD) is becoming increasingly common in the aerospace field because it has many benefits such as enabling operations in poor visibility and improving flight safety. The HUD is a kind of augmented reality display that enables a pilot to observe the scene outside the cockpit while simultaneously viewing an artificial image of flight information. However, the HUD is too expensive and heavy for light airplanes. In this paper, we propose a new method to combine real and artificial images using Retro-reflective Projection Technology and rotating objects, and we apply the method to an airplane with a single propeller to compose a simple HUD. In this report, we also describe the developed system and preliminary experimental results.

Keywords
Retro-reflective Projection Technology, Head Up Display, Augmented Reality

ACM Classification Keywords
H5.m. Information interfaces and presentation.

Introduction

Recently, many researchers have been focusing on Augmented Reality (AR) technology, and many applications have been developed [1][2][3]. This has also been the case in the field of aerospace. For example, Sims, D. has developed a wire-guide system for aircraft maintenance [4], and Haritos, T. *et al.* have developed an AR maintenance training system [5]. In addition to these, the Head-Up-Display (HUD) [6] is a typical example of an aerospace AR system. The HUD is visual display which allows pilots to observe the scene outside the cockpit while at the same time viewing artificial visual information showing flight parameters. The HUD removes the need for the pilot to constantly switch focus between the outside scene and the instrument panel, reducing the amount of eye movement and consequently reducing workload. Also, the aerospace HUD presents the virtual image at infinity so that the pilot does not have to re-accommodate his eyes when switching attention between the outside scene and the displayed visual information, which further reduces workload. Furthermore, a well-designed display layout and information presentation improves the pilot's situation awareness and thereby improves flight safety[7].

Because of these benefits, the HUD is increasingly appearing in commercial passenger transport aircraft, but is unknown in light airplanes. The accident rate of light aircraft is higher than that of passenger transport aircraft[8], so a system that can improve flight safety for light aircraft is desired. The HUD may be a solution to this problem, but at the moment it is too expensive and heavy for light aircraft.

Generally, a HUD consists of a CRT display that generates an artificial image, an optical lens system that collimates (infinity focuses) the image and relays it from the CRT, and an image combiner in front of the pilot's eyes onto which the artificial image is projected. It is primarily the lens system that makes the collimated HUD heavy and expensive, and so many efforts have been made to develop simpler HUDs. Burch, D.P. *et al.* have developed a simple HUD using a conventional projector and a half mirror installed between the pilot and the cockpit window as the image combiner [9]. However, their display is not collimated, with the distance from the pilot's eye point to the combiner (approximately 1m) being roughly the same distance as the conventional instrument panel. The display reduces the eye movement required to switch attention between the outside scene and the image, but the accommodation workload changes little. It is better for the pilot if the artificial image is displayed closer to infinity.

In this paper, we develop a new flight information display system for light aircraft based on the premise that combining an artificial image with the outside view can reduce workload. We propose a new display system using Retro-reflective Projection Technology (RPT, [10]) and the aircraft's propeller to optically combine the real and artificial images.

Flight information display using RPT

RPT is a technology based on a screen made of retro-reflective material, a coaxial optical system and a projector. The user of a display based on this technology can perceive distortion-free images regardless of the shape of the screen. If we apply RPT to aircraft, we can make any object on the aircraft an information display.

It is easy to apply the video-see-through method [11] to combine real and artificial images. This method uses cameras to capture images of the real world which are then combined electronically with artificial visual information, and the synthesized total image is presented to the user. However, in aviation displays we must be careful about camera and image characteristics as these directly affect flight safety. The field of view of cameras is often narrower than that of the human eye, and imaging sensors have lower dynamic range than human vision. Technically speaking, it is not difficult to solve these problems by using multiple cameras, but these will increase the system's weight and complexity and reduce its reliability. While it would be better to combine the real and artificial images optically, allowing the cameras to be dispensed with, this is difficult because retro-reflective material is not optically transparent and so obscures the visual scene behind it. For instance, if we put a retro-reflective screen on the cockpit window, it would be hard to view the outside scene behind the screen unless we used cameras to capture the outside view and display it combined with the artificial image.

For a single-engine "tractor" propeller-driven aircraft (i.e. with a propeller installed on the nose in front of the cockpit), which is the most common type of light airplane, the solution is quite simple: We use the propeller. The propeller cannot be seen while the aircraft is flying because it rotates very fast. If we put the retro-reflective screen on the backside of the propeller blades, it would not obscure the view through the propeller in flight and would enable us to optically combine real and artificial images using RPT; in effect, this is an optical-see-through method [11] for RPT. Furthermore, using RPT would enable the pilot to perceive distortion-free images regardless of the curved shapes of the blades and their pitch angle (i.e. the angle of rotation of the blade around its vertical axis). With this method, the propeller could be used as a flight information display. While the displayed image would not be at infinity, it would be beyond the cockpit window. Furthermore, the pilot could observe the outside scene and the artificial flight information images simultaneously, so the display should reduce eye movement workload.

In the following section, we verify the image quality obtained by this method in a preliminary experiment.

Preliminary experiment using an electric fan

For the safety and convenience of the experiment, we first used an electric fan (Yamazen LT-CM300) to verify the image quality of the proposed method. The fan has five 30 cm-long blades, to each of which we affixed a 2.5x9 cm piece of retro-reflective material (Nihon REF-LITE Industry #8301) cut from sheet (figure.1)

figure.1 Electric fan with retro-reflective sheets

We then projected two static images (figure.2) onto the rotating blades using a projector (Seiko Epson EMP-

1810) with an output brightness of 3500 lm from a distance of about 2 m in a dark environment. To simplify the setup, a coaxial optical system was not used but was approximated using projection. This approximation was adequate since the aim of the experiment was simply to verify the image quality

figure.2 Projected images (left: a standard photograph, right: a tunnel-in-the-sky instrument image [12])

The images used were a standard image commonly used to evaluate image quality (figure.2 , left) and a "tunnel-in-the-sky" instrument image (figure.2 , right, [12]) to verify that the display could be used to show flight information.

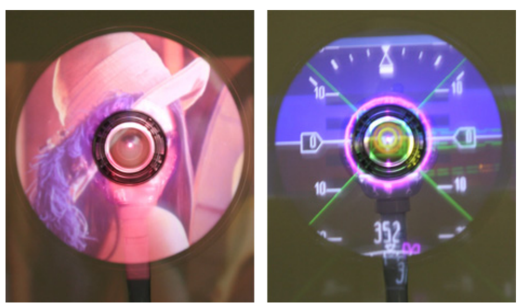

figure.3 Images projected onto the electric fan using RPT

The projected results are shown in figure.3 . The clear images obtained demonstrate the capability of rotating blades to be used as an RPT screen. The electric fan with affixed retro-reflective sheets ran normally with no unusual vibrations.

Having confirmed the method's principle, we then applied it to the propeller of real airplane, as described in the next section.

Experiments using a real airplane propeller

In this experiment, we used a Hawker Beechcraft Bonanza A36, figure.4 left. This has a single propeller with three 1 m-long blades installed in front of the cockpit about 2 m from the pilot's eye point.

figure.4 Left: Bonanza A36, Right: Retro-reflective sheet applied to a blade (white area of the blade)

Precautions were taken to avoid damaging the airplane during the experiment. The airplane was fixed to ground so it would not to move while the propeller was operating, and a different retro-reflective material (3M Company Scotchlite #680-85, black) was used than in the fan experiment. The material was lighter to avoid unbalancing the propeller, and was also self-adhesive for ease of application. The retro-reflective sheet was cut into the shape of the blades and applied to the backside of each blade as shown in figure.4 right.

The same images as used in the fan experiment (figure.2) were displayed on the propeller using a projector. The projector was placed close to the pilot's eye point in the cockpit and the display was observed from the pilot's eye point. We also varied the blade pitch angle and the rotation speed between 1000–2500 rpm to simulate flight conditions. As with the fan, we did not develop a coaxial optical system for ease of experiment, but the approximation with the projector was adequate for the experiment goals.

In this application, compact size and low weight are desirable, and portable lightweight projectors are often constructed using a single chip DMD (Digital Micromirror Device). To verify the ability to use a single chip DMD projector for RPT with a propeller, we used a BenQ Corporate MP770 single chip DMD projector with a 3200 lm output. The result is shown in figure.5 .

figure.5 Projected images using a single chip DMD projector

The result shows that a color-breaking phenomenon has occurred. The DMD projector in this experiment has a color wheel with four colors (red, green, blue and yellow). These colors are readily apparent in figure.5 left as colored stripes. This occurred because the rotation speed of the propeller (1000-2500 rpm) was not synchronized to that of the projector color wheel. The color changes a few times during a single blade rotation, and the blades are always in a different position each time the color changes, resulting in broken color images.

To solve this problem, using projectors without a color wheel, such as 3 LCD projectors, is quite simple. .We therefore carried out a further experiment using the same projector as in the electric fan experiment (EMP-1810), which is a 3 LCD projector. The results are shown in figure.6 and figure.7 .

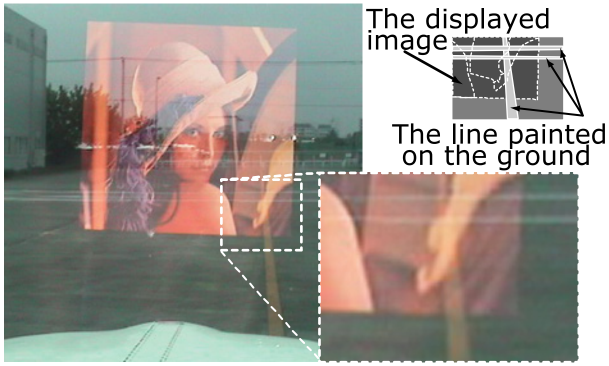

figure.6 Displayed image (standard image)

Unfortunately, it was difficult to see the displayed images in sunlight conditions because of insufficient projector brightness. On the other hand, we were able to verify that clear images are displayed on the propeller in cloudy conditions as shown in the figures. At the same time, the outside scene was also visible through the propeller; in other words, the real image was optically combined with artificial image by using RPT with the propeller. Varying the blade pitch angle and rotation speed had little effect on the displayed images.

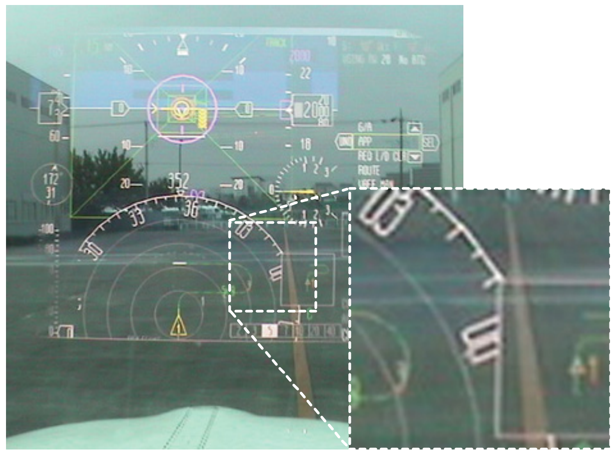

figure.7 Displayed image (tunnel-in-the-sky)

Conclusion

In this research we propose an optical-see-through method suitable for RPT using a rotating object. Using this method, we develop a simple HUD for light single engine propeller-driven airplanes. The image quality of the display system has been evaluated by preliminary experiments. In the future, we will verify the practicability of the system through flight experiments.

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