International Journal of Advanced Technology & Engineering Research (IJATER)
www.ijater.com

SOLAR SAILS

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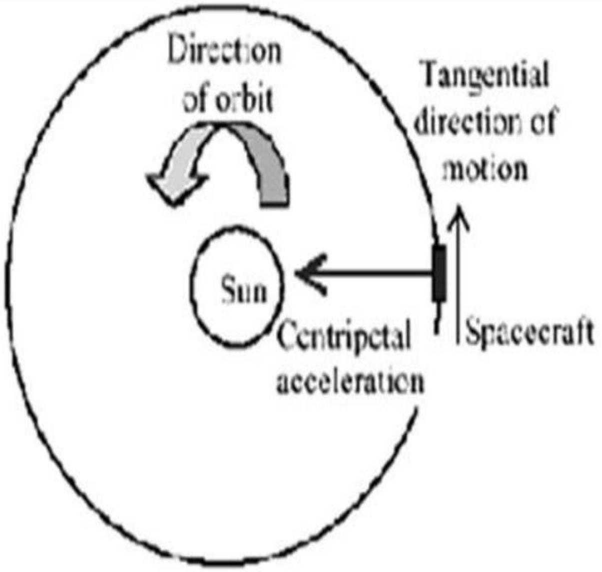
***Abstract*—One key challenging issue of facial expression recog- nition is to capture the dynamic variation of facial physical structure from videos. In this paper, we propose a Part-based Hierarchical Bidirectional Recurrent Neural Network (PHRNN) to analyze the facial expression information of temporal se- quences. Our PHRNN models facial morphological variations and dynamical evolution of expressions, which is effective to extract “temporal features” based on facial landmarks (geometry information) from consecutive frames. Meanwhile, in order to complement the still appearance information, a Multi-Signal Convolutional Neural Network (MSCNN) is proposed to extract “spatial features” from still frames. We use both recognition and verification signals as supervision to calculate different loss functions, which are helpful to increase the variations of different expressions and reduce the differences among identical expressions. This deep Evolutional Spatial-Temporal Networks (composed of PHRNN and MSCNN) extract the partial-whole, geometry-appearance and dynamic-still information, effectively boosting the performance of facial expression recognition. Experimental results show that this method largely outperforms the state-of-the-art ones. On three widely used facial expression databases (CK+, Oulu-CASIA and MMI), our method reduces the error rates of the previous best ones by 45.5%, 25.8% and 24.4%, respectively.**

***Index Terms*—Facial expression recognition, dynamical evolution, recognition and verification signals, deep Spatial-Temporal Networks**

I. INTRODUCTION

The concept of using photon pressure for propulsion has been considered since Tsiolkovsky in 1921 [1-7]. In fact, Tsiolkovsky and Tsander wrote of "using tremendous mirrors of very thin sheets" and "using the pressure of sunlight to attain cosmic velocities" in 1924 [1-4]. The term "solar sailing" was coined in the late 1950s and was popularized by Arthur C. Clarke in the short story Sunjammer (The Wind From the Sun) in May 1964 [5]. The National Aeronautics and Space Administration (NASA) used sailing techniques to extend the operational life of the Mariner 10 spacecraft in 1974-1975. A problem in the control system was causing Mariner 10 to go off course. By controlling the attitude of Mariner 10 and the angle of the solar power panels relative to the Sun, ground controllers were able to correct the problem without using precious fuel [4, 6, 7].

Once thought to be difficult or impossible, solar sailing has come out of science fiction and into the realm of possibility. Any spacecraft using this method would need to deploy a thin sail that could be as large as many kilometers in extent. Candidate sail materials should be: 1) strong, 2) ultra-lightweight (density of a few g/m2), 3) able to be folded or crushed until deployed, 4) subject to minimal sagging or stretching, and 5) resistant to ionizing radiation, such as galactic and solar particles (electrons and protons), x-rays, ultraviolet light, and magnetically trapped charged particles. Solar sails must be resistant to each of these types of radiation [8].



II. Theoritical Considerations

Since photons are electromagnetic quanta, they have associated electric and magnetic fields [4, 7, 9]. For distances larger than several solar radii, an electromagnetic plane wave can be used to approximate the interaction of photons with a sail. Assume a sail is positioned in relation to the Sun as shown in Figure 1.

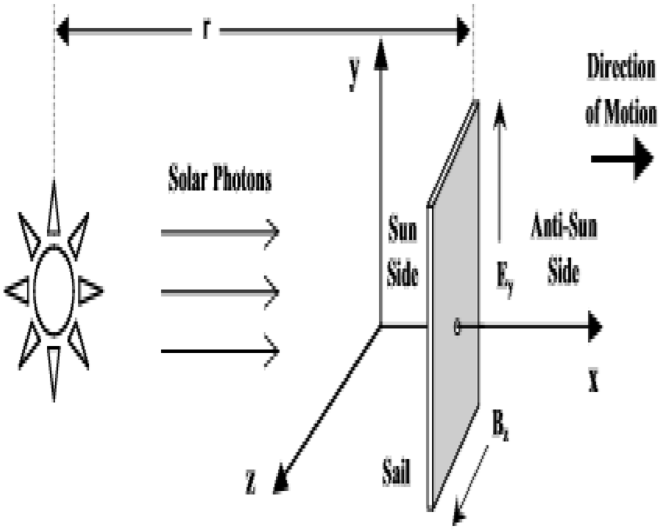


Figure 1: Solar Sail Model

In this model, the sail is positioned at a distance r from the Sun. Photon pressure will cause the sail to move along the +x axis. Using a plane wave solution for photons in a vacuum, the electric and magnetic fields will be in phase along the +y and +z axes respectively. Both the fields will be perpendicular to the direction of photon motion. The main components of the electric (Ey) and magnetic fields (Bz) can be written as

$$E_y = E_0 \sin\left[\omega\left(t - \frac{x}{c}\right)\right]$$

$$B_z = \frac{E_0}{c} \sin\left[\omega\left(t - \frac{x}{c}\right)\right].$$

The E0 parameter is the constant value of the electric field (N/C), ω is the angular frequency (rad/s), t is elapsed time (s), x is the displacement along the axis (m), and c is the speed of light in a vacuum. These equations assume the incident solar photons are monochromatic, which allows the quantity (E0/c) in (1b) to be equal to the constant value of the magnetic field (B0), which is in tesla (T).

The flux vector (S) transported by the fields is equal to

$$\mathbf{S} = \varepsilon_0 c^2 (\mathbf{E} \times \mathbf{B}) ,$$

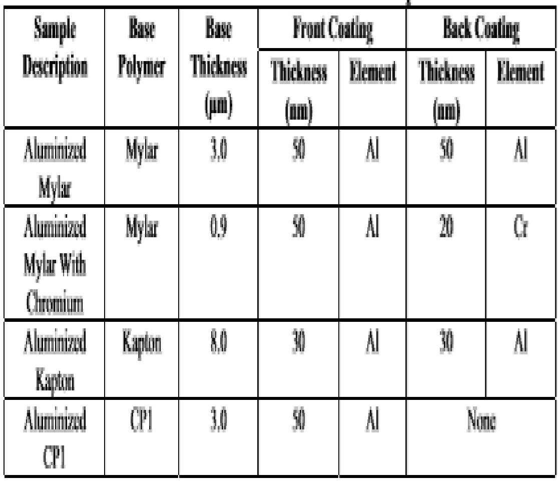
where ε0 is the permittivity of free space, E is the electric field vector, and B is the magnetic field vector. All vector quantities are shown in bold font. The flux is also known mathematically as the Poynting vector and can be calculated using (1a), (1b), and (2) as

$$S = \varepsilon_0 c^2 \begin{vmatrix} i & j & k \\ 0 & E_y & 0 \\ 0 & 0 & B_z \end{vmatrix} = \varepsilon_0 c^2 E_y B_z i = \varepsilon_0 c^2 E_y \sin^2\left[\omega\left(t - \frac{x}{c}\right)\right] i.$$

III. Sail Materials

Physical characteristics for several candidate solar sail materials can be found in Table 1. These materials shown in Table 1 were selected due to their relevance to the application, availability, and manufacturability. These sails each have a density of a few grams per square meter.

Table 1: Tested Solar Sail Material Properties



Sample Description	Base Polymer	Base Thickness (µm)	Front Coating		Back Coating	
			Thickness (nm)	Element	Thickness (nm)	Element
Aluminized Mylar	Mylar	3.0	50	Al	50	Al
Aluminized Mylar With Chromium	Mylar	0.9	50	Al	20	Cr
Aluminized Kapton	Kapton	8.0	30	Al	30	Al
Aluminized CP1	CP1	3.0	50	Al	None	

The back surface of one mylar sample was coated with 20 nm of chromium. Chromium was selected because it has a higher emissivity than aluminum and radiates heat more efficiently. The selected aluminized mylar uses stock that contained Kevlar threads to serve as a rip-stop mechanism. These threads were positioned 25 mm (1 inch) apart. The aluminized Colorless Polyamide 1 (CP1) is a moisture resistant polymer that can be stored for long periods of time without significant property degradation. The aluminized CP1 sample did not have a metal coating on the back surface. Kapton maintains it properties at extreme temperatures. Mylar, Kapton, and Kevlar are trademarks of E. I. duPont de Nemours and Company. CP1 is a registered trademark of SRS Technologies.

IV. MSFC Sail Research

The Environmental Effects Group (ED31) at the National Aeronautics and Space Administration's Marshall Space Flight Center (MSFC) maintains world-class facilities to simulate the effects of radiation on an assortment of space-qualified materials. Starting in 2001, ED31 began a comprehensive program to characterize the radiation survivability of candidate solar sail materials. Results from this research indicate that degradation in mechanical properties was observed after radiation exposure [12]. The data reinforces the fact that the thermo-optical properties do not significantly degrade. From this preliminary data, it appears the space environment will not significantly affect the propulsion performance of the sail. Electron exposure measurements are underway and will continue for the rest of 2002. Results from the electron measurements will be presented at the International Solar Energy Conference in Hawaii in March 2003. Proton and ultraviolet irradiation measurements will be completed in the future.

V. Discussions and future perspectives

The success of the IKAROS solar sail is the beginning of a new era for solar sailing. Unlike most other spacecraft, many solar sails cannot be effectively
tested on the ground because of their sizes. Several reasons for this and other dimensionality problems involved in solar sail design have been discussed by Greschik.

Hence, mathematical modelling and simulations are commonly used in solar sail studies, without any experimental validation.

Affordability would likely be a major issue in humanity's future space program development. Solar sail's ability to achieve high $V missions with low cost can significantly reduce the cost of interplanetary missions.

The possibilities of a hybrid design that consists of a solar sail that also includes an electric propulsion system has been discussed, and may provide benefits beyond those that come from using only solar radiation propulsion.

New time effective mission trajectories could arise for such hybrid sail craft that can lead to further cost reduction. Looking through human history, cost-effective transportation promotes exploration.

Further understanding and quantifying cost reduction by the use of solar sails are areas of interest for future work. In the 15th century, humanity sailed across the oceans. After six centuries, humanity is sailing in space.

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