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User-centred Control of Automated Shading for Intelligent Glass Facades

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Extended abstract (The complete contribution will be published in the Glass Structures & Engineering journal)

Solar radiation control in large-area glazing is essential for optimising energy consumption and reducing glare and overheating. Automated shading in real-world buildings is actuated when measurements of the outdoor conditions (e.g. solar tracking or irradiance) or indoor environments (e.g. lux levels) exceed pre-established set-point values. However, these traditional proxies are often insufficient to capture actual occupant visual and thermal preferences, resulting in user dissatisfaction with automatic systems and indoor environmental conditions, which in turn lead to a loss of productivity. Affective computing and the internet of things provide an unprecedented opportunity to directly include occupants in the shading control loops, but the means of capturing transient occupant preferences have yet to be fully-developed. This extended abstract describes the underlying research and a demonstration prototype of a novel occupant-centred system that captures occupant preferences in real-time and controls the shading of glass facades, thereby providing visual comfort that is effective and customised. The prototype consists of wearable sensors, cameras and a facial action unit (FAU) detection system that together provide occupant-centred information for controlling shading and/or switchable glazing. The prototype is demonstrated in an office-like lab environment and initial results are discussed herein.

Figure 1 - "Sunflower". The wearable sensor is constructed of layers of laser cut plywood. Contains a microcontroller (Flora), bluetooth and lux sensor powered by a rechargeable drone battery. The case is then completed by a translucent acrylic cover.

Introduction

Optimal design of glazed facades and control of solar radiation transmitted through the façades are key to minimising the carbon footprint modern cities [1]. This must however cannot be achieved at the expense of satisfactory indoor environment occupant comfort, productivity and well-being. Therefore a degree of daylight, access to view and avoiding overheating are also essential [2]. Previous research has shown that control strategies and dynamic / automated / smart facades have a very significant effect on the energy-efficiency of a facade solution [3]. However, a performance gap exists between predicted facade performance during design stage and actual one in operational stage. Some of this gap can be attributed to the occupant response that plays a major role in defining actual building performance [4]. In this sense, it is essential to develop new methods for capturing real-time occupant response and preferences that could be used to tailor dynamic / smart / adaptive technologies to actual occupant needs in order to implement them in viable long-term energy-efficient solutions [5]. Occupant-centred control strategies that minimise discomfort glare from highly glazed façade have previously been investigated by using real-time objective luminance [6] and illuminance measurements [7]. However a real-time, non-intrusive method

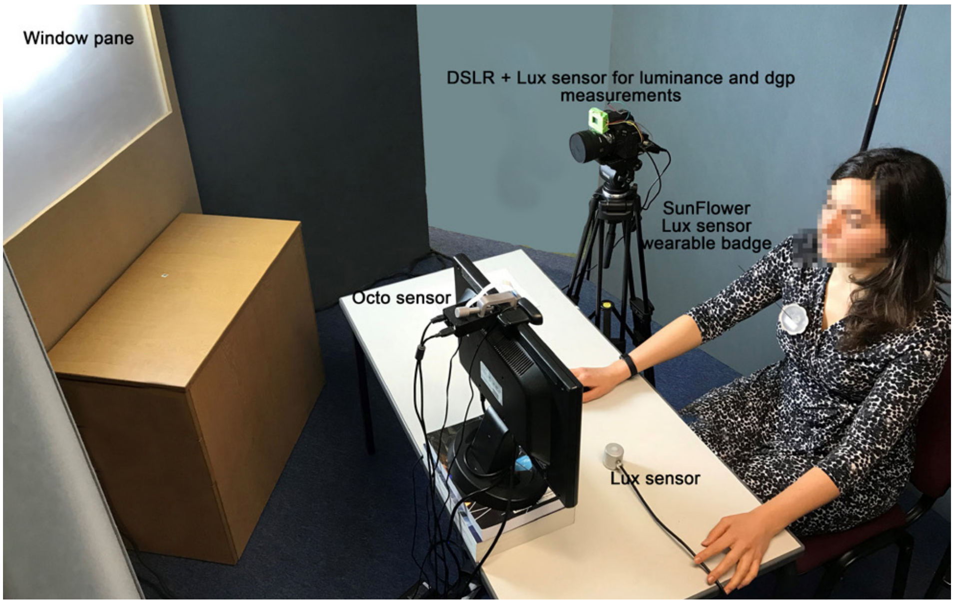

Figure 2 - View from desk. Computer monitor with 2 cameras on top. Horizontal illuminance sensor on the desk directly in front of the user. A virtual window is in the top left of the image.

that could be tailored and adapted to changing occupant demands is yet to be achieved. Affective computing [8] offers a promising methodology for capturing occupant response through Facial Action Units (FAU) detection, in combination with other Internet of Things (IoT) devices which are now becoming more prominent in home and office environments. This extended abstract presents preliminary results of a novel method for capturing transient occupant response to glare, using both affective computing and wearables technologies to identify occupants' requirements for visual comfort.

Methodology

A novel method to capture occupant response to discomfort glare was developed using a FAU sensor called "Octo" [9], comprised of a camera and micro computer which captures FAUs through a built-in algorithm, and a wearable light-sensor called "Sunflower" (Figure 2). "Sunflower" is a wireless lux sensor badge developed using arduino technology and commercially available wireless sensor technologies with a low-voltage battery pack. This novel control strategy uses occupant facial expressions, detected trough FAU, and levels of illuminance on the wearable to identify conditions of discomfort glare and, accordingly, control an automated blind.

Experimental procedure

A preliminary test was performed to assess the use of FAU and Illuminance wearables for predicting user glare discomfort. This test was carried out in a controlled office-like space, established within a laboratory with a 'virtual window' for simulating glare conditions (Figure 2). The aim of the test was to investigate if the use of learning correlations between individual FAU response and Vertical Illuminance on a wearable sensor could provide a satisfactory measure for predicting and avoiding discomfort glare conditions.

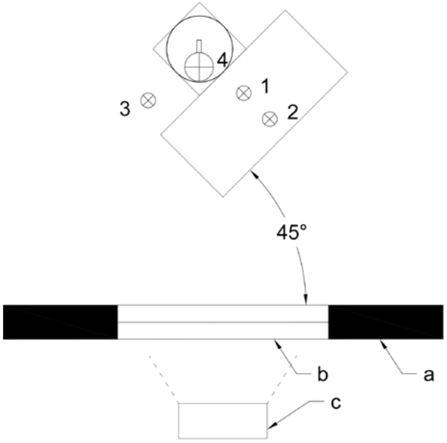

Figure 3 – View plan of the experimental setup. 1. Horizontal illuminance sensor, 2. "Octo" sensor, 3. Vertical Illuminance sensor and DSLR camera, 4. Wearables illuminance sensor. A. opaque panels, b. transparent panels. C. light source.

The space consists of a cubicle with a diffusive perspex window with a controllable LED placed behind it. A desk and chair were located at 45 degrees to the virtual window (Figure 3). The optical properties of every major surface were also characterised and a DSLR camera with vertical illuminance sensor was placed beside the occupant to measure luminance values and Discomfort Glare Probability (DGP).

During the test, occupants were asked to sit at the desk and complete tasks and surveys at the desktop computer using the monitor and keyboard provided. The experiments included: an adaptation time, where the occupants were asked to sit at the desk, and three different computer tasks, where occupants were exposed to strong light during their activities after a resting break. Different exposure levels were tested, one with a gradual increase of light exposure and two others with a sudden increase of light levels. Finally, occupants were asked to complete a survey.

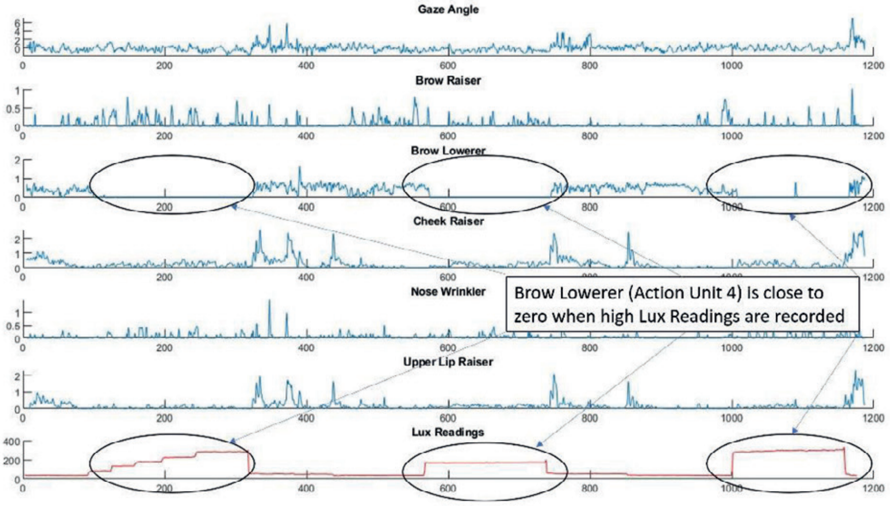

Figure 4: Example readings from the "Sunflower" badge (bottom) and various FAUs from "Octo".

Preliminary results and future work

Figure 4 shows initial results from FAU and Lux readings from the wearable sensor for one occupant. Each occupant had a unique response to the lighting environment in terms of FAC, such as Gaze Angle, Brow Raiser, Brow Lowerer, Cheek Raiser, Nose Wrinkler etc., but a correlation was always found between individual FAU response and increase of light levels on the wearable sensors. A control strategy was hence developed to learn from individual FAU response and react only if a correlation was found between increase in light levels against average illuminance on the wearable sensor. Future work will finalise the development of the control strategy and test it in MATELab [10], an experimental facility in Cambridge developed to assess occupant response to alternative façade and control strategies solutions.

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