Proceedings of the 28th IEEE
EMBS Annual International Conference
New York City, USA, Aug 30-Sept 3, 2006

A System for Automatic Quantification of Cigarette Smoking Behavior.

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Abstract— **Cigarette smoking remains the principal source of preventable disease in the United States. Although most tobacco companies have developed filtered cigarettes to reduce the levels of some toxins, smokers have adapted their inhalation patterns to compensate for these newer "light" cigarettes. We describe a new system designed to unobtrusively monitor such elements of smoking behavior. The system used a video camera to capture movies of smoking behavior. Subsequently, image processing and analysis algorithms were applied to the movie frames to form a time-series, termed the smoking topography, which quantified various parameters of smoking behavior.**

I. Introduction

According to the U.S. Department of Health and Human Services, the greatest preventable source of disease and death in the U.S. is cigarette smoking. Diseases related to exposure to toxins in cigarette smoke include lung cancer, cardiovascular disease, and emphysema. Actual exposure to toxins depends upon several factors such as years of smoking and the number of cigarettes smoked per day. These factors, however, are relatively crude measures of smokers' risk for developing disease. To augment these measures, several techniques have been developed including the use of biomarkers such as salivary continine (a nicotine metabolite) [1, 2]. Although these techniques analyze different aspects of smoke toxicity, they are expensive thus limiting their utility in large scale studies.

In previous work, we described an automatic technique for analyzing cigarette filter effectiveness [3, 4]. That technique employed digital image processing and analysis to automatically determine cigarette filter stain patterns, a method of unobtrusively detecting behavioral blocking (with fingers or lips) of filter vents on cigarettes [5-7]. This technique measures an important parameter and is inexpensive. It is limited to a single measurement, however, which is performed after the cigarette has been smoked.

A more extensive set of puffing behavior parameters can be obtained by analyzing smoking topography. Smoking topography is the time-series of an indidvual's behavior as a cigarette is smoked. Analysis of the smoking topography provides a number of measures including: the number of puffs, the inter-puff interval, puff volume and extent, and other derived measures such as velocity.

Early studies showed that the smoking topography was correlated with blood nicotine levels [8]. More recently smoking topography has been shown to correlate strongly with toxin levels including carbon monoxide (CO) as well as smokers' compensatory behavior when smoking light filtered cigarettes [9]. Another benefit of assessing the smoking topography is that such measures predict the success of a smoker's abstinence following nicotine cessation therapy [10, 11].

Several instruments are available for measuring the smoking topography [12, 13]. Although these instruments are portable, they require the smoker to inset the cigarette into a receptacle at one end of the device and draw on a mouth piece at the other end. It is likely, however, that such an inline device interferes with normal smoking behavior. In addition, constrictions of the airway will distort the topography due to added resistance, turbulent flow, etc.

In this paper, we describe a new system for assessing smoking behavior. This system was part of a feasibility study and was not intended to evaluate actual human smoking behavior. The first module in the system was a CCD video camera that recorder the smoking pattern of a computer controlled smoking machine. Following the video

Manuscript received April 3, 2006. This work was supported in part by funding from the Department of Biobehavioral Health at the Pennsylvania State University.

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recording, the individual frames are processed and analyzed to generate the smoking topography. This system is expected to provide a more accurate estimate of smoking topography by allowing the smoker to inhale normally without the constraints of in-line instruments.

II. Methods

A. *Hardware*

Figure 1 is a photograph of the cigarette smoking machine that was constructed for the experiments reported in this paper. The entire system was controlled by a computer workstation (PC) that was equipped with a motion control card and an image acquisition card. The motion control card was attached to a stepper motor that drove a linear actuator. The linear actuator was used to implement a syringe pump that enabled precise puffing simulation. The motion controller was able to simulate various smoking profile parameters including puff volume, duration, and depth of inhalation, among others.

A monochrome CCD video camera (Sony XC-ST50) was used to capture video frames. The camera responded to a wide spectrum, including the near-infrared (NIR). The camera was equipped with a long-pass filter which had a sharp cutoff frequency at 630 nm.

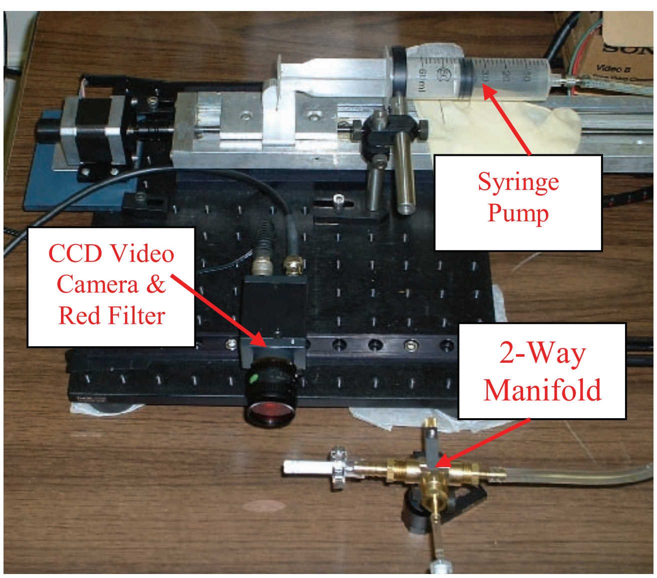

Figure 1 – Photograph of the cigarette smoking machine and CCD video camera.

The cigarette was attached to the syringe pump through a 2-way manifold. The manifold directed the entire vacuum drawn by the syringe pump through the cigarette. During the "exhalation" stage the pressure that was produced by the pump was routed through the second path to the exhaust valve.

The method used to simulate the smoking topography profile was to assess the intensity of the burning cigarette coal. The baseline of the profile corresponds to the glow of the coal when there is no inhalation. An increase in intensity is directly related to the amount of air drawn through the cigarette during inhalation. Since we were primarily interested in change in heat during inhalation, NIR images were captured and saved for subsequent processing. The long-pass filter that was attached to the camera lens blocked out most of the visible spectrum and thus eliminated most background interference.

To validate the operation of the CCD camera and filter in the NIR range, images of both a red light emitting diode (LED) and an NIR LED (980 nm) were imaged at various intensities. The red LED was attenuated by 33% by the long-pass filter but there was no discernable effect of the filter on the transmission of light generated by the IR LED.

B. *Software*

The sequence of video frames was processed and analyzed, frame by frame, to generate the smoking profile time-series (i.e., the smoking topography). The procedure involved processing each frame as an individual image. First, the presence of the cigarette was established by detecting and localizing the burning coal. During the inter-puff interval, when no air was drawn through the cigarette, the burning coal was at the lowest brightness level. This level was used as an intensity threshold to further remove background interference. All pixels below the threshold value were set to zero. The burning coal was the brightest (hottest) region in the image, thus representing the region of highest intensity (density). Using this fact, the centroid of the image was calculated, and served to localize the end of the cigarette [14]. A mask was centered at the mid-point of the burning coal (centroid), further limiting the region of interest to the small circular section around the burning cigarette end.

The time-series corresponding to the smoking topography was generated from the sequence of processed images as discussed above. Each element of the time-series corresponded to an estimate of the total intensity with the region of interest of the related frame. For each frame (image), the total intensity was estimated by integrating gray-levels over the entire region of interest (i.e., within the masked area).

The variable intensity of the glowing cigarette coal depended upon the amount of air drawn in by the smoker. In addition, the cigarette position within the camera's field of view changes with the smoker's movements. To validate the burning coal's position from frame to frame, a tracking system was implemented. The tracking system used methods similar to those developed to visualize the flow of bubbles within a fluid [15].

III. Results

To validate the proper functioning of the detection and localization algorithm (and to minimize exposure to cigarette toxins), a simulation was performed using the IR LED.

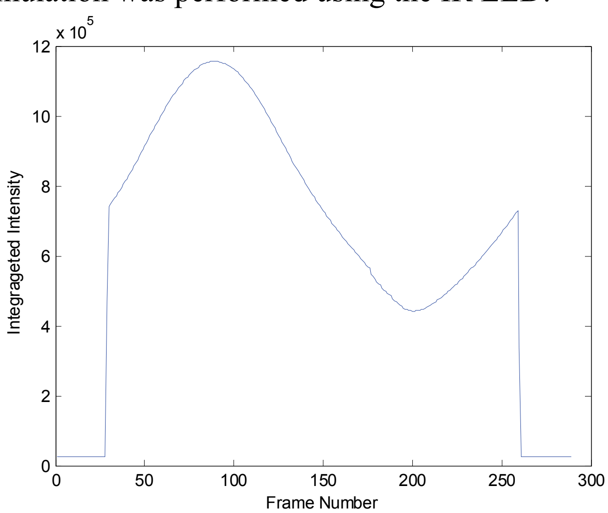

Figure 2 – Plot of the total intensity of an IR LED as its position and intensity varied over a sequence of frames.

Both the intensity and position of the LED were varied. The intensity of the LED was varied sinusoidally over a time-course simulating the puff on a cigarette. The position of the LED was moved in a straight line. The plot of the LED's total intensity time-series (simulated smoking profile) is shown in Fig. 2.

Fig. 3 is an image of the burning end of a cigarette. The image is one frame from the movie that was generated by the CCD camera. The computer algorithm automatically generated the center of intensity (centroid). The square mask, plotted in light gray, was centered on the centroid and served as the region of integration for calculating the total intensity for the frame. The value of total intensity is added to the smoking topography time-series. Since real-time processing was not a requirement the complete movie was captured and image processing and analysis were performed offline.

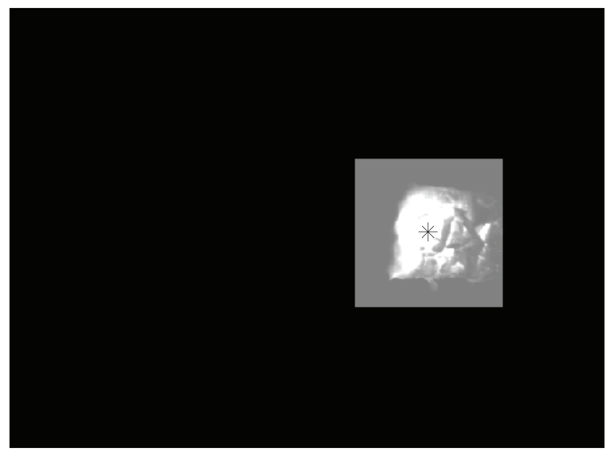

Figure 3 – Image of a randomly selected frame from a movie of a cigarette smoking session. The bright white spot is the burning tip. The star shows the location of the intensity centroid that was estimated by the computer. The gray box shows the area of the mask over which the intensity was integrated.

The gray plot in Fig.4 is an example of an acceleration and velocity curve used to drive the linear actuator and syringe pump. The acceleration and velocity are directly related to the air flow through the cigarette. The black plot in Fig. 4 shows the increased intensity of the burning cigarette coal as the air flow through the cigarette increased.

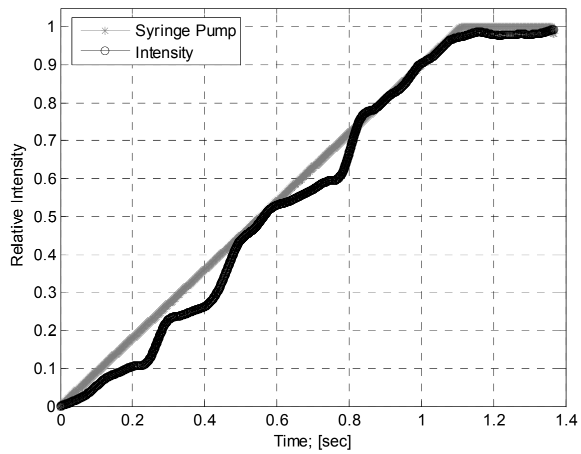

Figure 4 – Plots of increasing puff volume (Gray) as a function of time and the corresponding increase in intensity of the glowing coal on the cigarette (Black).

IV. Discussion

Fig. 2 clearly demonstrates that the algorithm successfully followed the change in LED intensity across the multiple frames of the recording session. The LED was driven by a sinusoidal voltage with amplitude 0.15 V. The sensitivity of the CCD camera was demonstrated by the system's ability to follow the sinusoidal pattern of the LED intensity. In addition, the algorithm was capable of localizing the LED as it was translated across the field of view.

As demonstrated in Fig. 3, the image processing and analysis algorithm was capable of successfully detecting and localizing the burning cigarette coal.

Finally, the syringe pump mechanism was capable of accurately simulating the change in air flow typical of the inhalation of a cigarette smoker. Fig. 4 shows the capabilities of the image processing and analysis algorithms. The estimated total light intensity generated by the algorithm closely followed the force curve that was used to drive the syringe pump.

Future work will extend the 1D prototype to a 2D system. The 2D system will be capable of capturing and quantifying the smoking topography of a human subject in a more realistic environment.

Next, the smoking topography generated by the imaging system will be compared with the CReSS system [12] which is the "gold standard" for generating smoking topography. Since the proposed imaging system does not require tubing and inline flow measurement, it has the potential of providing a less constrained environment to measure behavior. In addition, the human subject is free to manipulate the cigarette at will, thus allowing for vent blocking which will yield more accurate estimates of toxic intake.

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