Published in final edited form as:
J Am Diet Assoc. 2010 January ; 110(1): 45. doi:10.1016/j.jada.2009.10.013.

A Wearable Electronic System for Objective Dietary Assessment

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Keywords

Food portion size sensor; Objective dietary evaluation; Wearable electronic system

Introduction

Dietary reporting by individuals is subject to error (1–3). Therefore, a research program has been initiated to develop a small electronic device to record food intake automatically. This device, which contains a miniature camera, a microphone, and several other sensors, can be worn on a lanyard around the neck. It collects visual data immediately in front of the participant and stores them on a memory card in the device. The data are transferred regularly to the dietitian's computer for further processing and analysis. The device is designed to be almost completely passive to the participant, and thus hopefully will not intrude on or alter the participant's eating activities. In addition to this function, in the future the device will have other functions, such as the measurement of physical activity, human behavior, and environmental exposure (e.g., pollutants).

Hardware Design

The electronic system contains two major components, a unit worn by the participant and a data analysis software package installed in a computer at the dietitian's office. The prototype of the wearable unit is shown in Fig. 1. The circular device presently looks like a wearable MP3 player, suitable for both men and women. The appearance of the device may be tailored according to individual's preference. Currently, the device has a diameter of 62 mm, which will be reduced substantially in the future. A large-capacity (2700 mAh), rechargeable, lithium-ion battery (rectangular object in Fig. 1) is placed in back of the neck connected to the circular device using adjustable cables. Two separate smaller devices, connected to the front device by the same cables, can reach locations on the upper body and head. These devices can be earphones, microphones, accelerometers, or skin-surface electrodes for various applications, such as user interface and physiological measurements. The front device contains a number of sensors and data processing/storage components, including a miniature camera for video recording, reference lights for food dimension measurement in the visual field, an accelerometer for physical activity monitoring, a microphone for the identification of eating episodes using ambient sound, a Global Positioning System (GPS) for location identification, a central processor for data processing, and an 8 GB MicroSDHC flash memory for storing data. All electronic components are installed on an eight-layer printed circuit board. Currently, the hardware design has been completed, and the embedded software (routines that provide interface to hardware modules) is being developed.

Software Design

The recorded data in the flash memory are readily transferred to the dietitian's computer during regular office visits or by Internet uploading. The software package to process data, aiming at minimizing dietitian's workload and maximizing data processing accuracy, is currently being developed. The functions of the software are as follows.

Privacy Protection

The data in the flash memory card are intentionally scrambled for security protection. Once the data are received by the dietitian's computer, they are disassembled into individual types, and the video portion of the data is automatically scanned for human faces which are then blurred to prevent identification. After these automatic procedures, the "de-identified" data are converted to standard image formats that can be observed by the dietitian. For privacy

protection, the audio data cannot be replayed by the dietitian. They are only used internally by the computer to perform automatic video segmentation

Video Segmentation

The first data processing step is the identification of the eating episodes in the video. This is performed by software, based on the following features computed from the available records: motion patterns, presence of circular food plates, similarities of contents in the video, recorded audio signal of surrounding sound, and time of the day. The computer-identified episodes are presented on the computer screen as icons. When an icon is clicked, the corresponding eating episode is replayed with the replay rate controlled by the dietitian.

Food Identification

For each selected eating episode, the dietitian views the image sequence within the episode to determine the food items being consumed. When necessary, the dietitian browses both the video and sensor data for additional food information, such as the cooking procedure and the location of a restaurant based on recorded GPS coordinates. In certain cases, some foods may still be unknown. In these cases, once all data collection has been completed, the participant will be asked to identify such foods in the images.

Portion Size Analysis

Although digital pictures provide an excellent tool to identify food, these pictures, by themselves, do not provide sufficient information to estimate portion size (i.e., dimensions), unless a dimensional referent is present in the field of view. Accordingly, several approaches have been studied to provide such a dimensional referent.

Before a participant begins to wear the device in a study, he/she will be asked to take pictures of their commonly-used plates and measure their diameters. In addition, the participant will be provided with a checkered tablecloth for their dining table. When eating episodes occur in the participant's home, food portion size can be determined computationally when one of these referents is present in food pictures. In cases where food consumption occurs outside of the home, lights on the device will be used to project a dimensional referent into the field of view. Presently, two types of light patterns are being evaluated. The first consists of three small beams produced by laser diodes on the device that form an equilateral triangle in the visual field; the second is a light-emitting diode (LED) on the device that projects a circular spotlight into the field of view (Fig. 2). Each of these light patterns produces a dimensional referent that permits calculation of food portion size.

Mathematical Model of Portion Size Measurement

In each approach, a mathematical camera model, called the pin-hole model (4), relates each point in the digital image (called a pixel) to a corresponding point in the real-world space. The circular plate, square checkerboard, equilateral triangle formed by the three laser beams, or circular spotlight produced by the LED usually has a distorted shape when observed in the image. The degree of distortion can be evaluated by an algorithm to obtain information about object orientation and distance, based on a set of known camera parameters (5–7). For example, as shown in Fig. 2, the size of the food and beverage can be determined using the referent provided by the light image. Currently, these approaches are being evaluated and optimized.

Determination of Nutrients and Calories

Once the food and portion size are determined, the system uses a food database, such as the United States Department of Agriculture Food and Nutrient Database for Dietary Studies (8),

to convert food volumes to values for calories and nutrients. The information obtained is accumulated over the entire period of study to produce a comprehensive dietary report.

Conclusions

Recent technological advances in microelectronics offer unique opportunities to develop electronic devices and methods for objective dietary assessment. Our group is applying some of these advances to design and evaluate new systems to minimize intrusion into the participant's life. Although many of these approaches are still under development, we believe that, with further technological development, it will become possible to conduct accurate and objective dietary assessments.

Acknowledgments

This work was supported by National Institutes of Health grant U01 HL91736. The authors are thankful to Amy Subar, Catherine Loria, and Phyllis Stumbo for their valuable suggestions.

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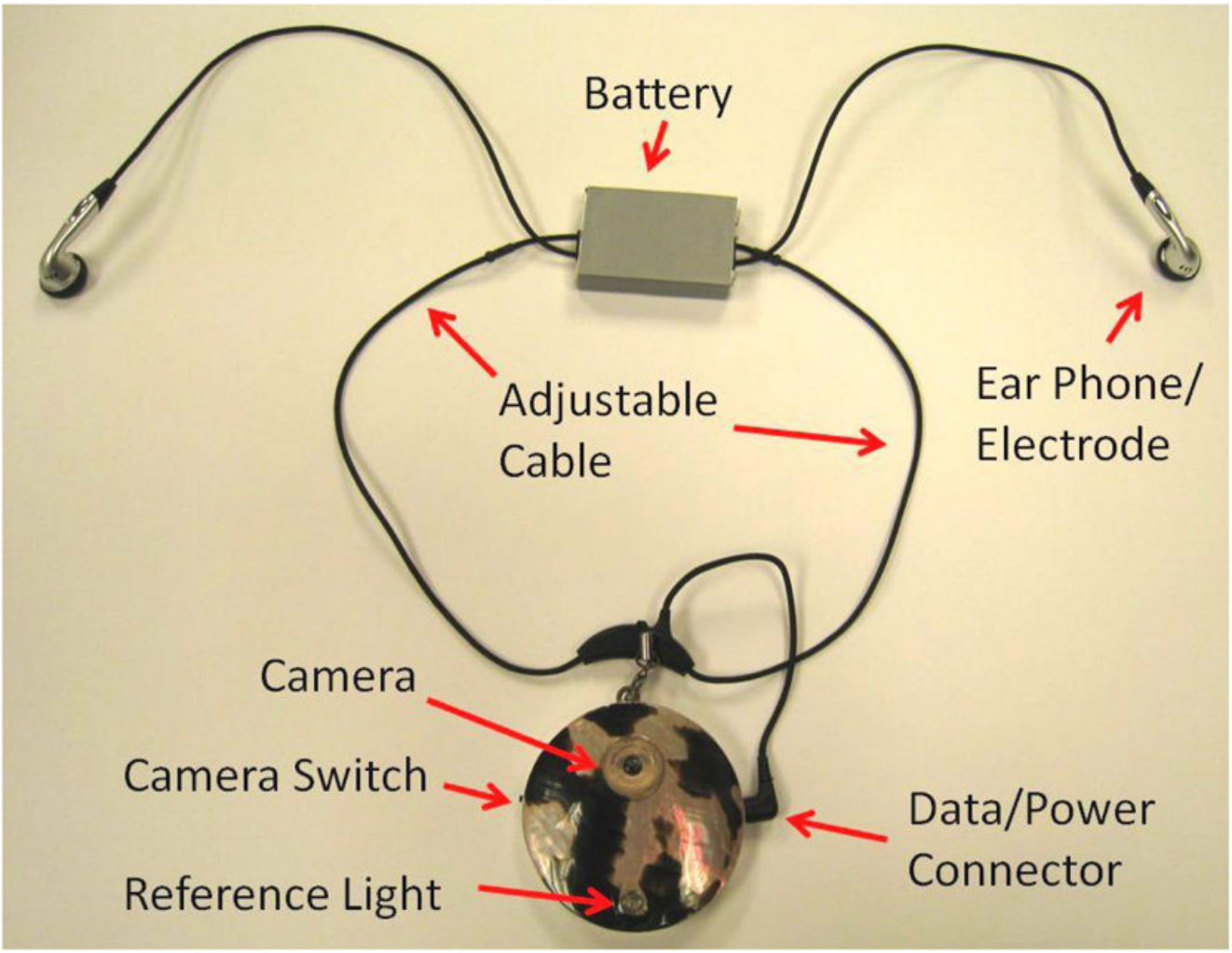

Figure 1.
Prototype of wearable electronic device

Figure 2.
A food image with a spotlight projected by the device