Visualization of Dimension Measurement Using a Consumer Grade Tablet Camera-Audio Sensor

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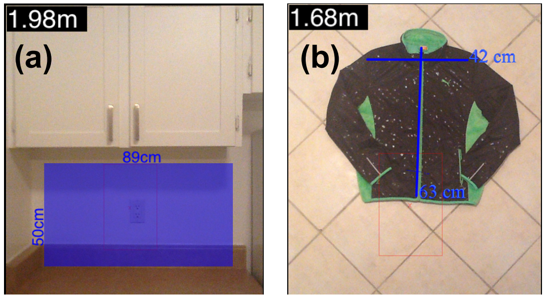

Figure 1. Visualized dimension measurement. Virtual dimension image in blue (a) rectangle and (b) line form.

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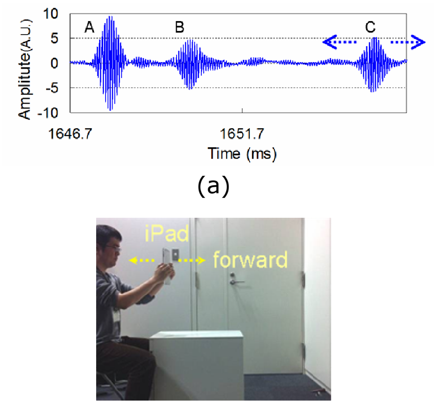
Abstract
We present a dimension measurement visualization technique using a consumer tablet device. A user is able to control the position and size of a virtual dimension image and confirm the specified dimension on the camera view. The system utilizes speaker and microphone sensor as distance detector to extract information needed for correct sizing of the visualized measurement. Our technique does not require the use of a physical marker or a view of the ground. We implemented a module that could cope with a noisy environment. We also implemented a guide mark module that enables use of the system when multiple objects are presented in the camera view.

Author Keywords
Dimension measurement; Visualization; Acoustic sensor; Smart device; Tablet

ACM Classification Keywords
C.5.3 [**Computer System Implementation**]: Microcomputers---*Portable devices*; H.5.1 [**Information Interfaces and Presentation**]: Multimedia Information Systems---*Artificial, augmented, and virtual realities*



(a)

(b)

Figure 2. (a) Temporal acoustic signal; (A) emitted pulse, (B) downward, and (C) forward direction returned pulse. Pulse C is the target signal pulse reflected by the forward object. (b) User motion in target signal selection. The tablet device is moved forward and backward.

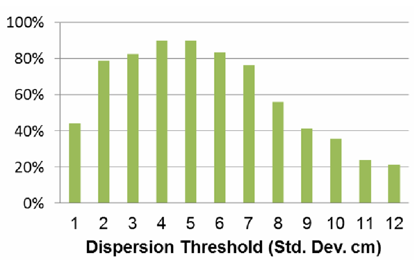


Figure 3. Success rate vs. dispersion threshold (in converted flight distance). Success rate is the rate at which the correct pulse signal is selected within one round of forward-backward user motion. At each threshold 109 trial were conducted. The dispersion verification period was set to every 10 flight time detections with a detection rate of 20 Hz.

Introduction

Smart devices, such as smartphones and tablets, have become indispensable to people in recent years. They are equipped with a variety of sensors that could be utilized to provide more sophisticated services. In this study, we examine dimension measurement and its visualization using only the basic set of consumer smart device hardware capabilities. Dimension visualization applications already exist in the smart device application market. These allow the user to enter and record physical dimensions of various objects in the photos, such as doors, carpets, furniture, etc., captured by the smart device, and have acquired significant popularity among carpenters, architects, and DIY enthusiasts with some downloaded by more than million users [1]. Recent applications incorporate measuring tools that utilize the camera and/or accelerometer to facilitate measuring without the use of a physical measuring tool [2]. Such a feature could ease the measuring process, vastly reduce user burden, and potentially provide spark for the rise of killer applications intended for broader user base.

However, existing methods have shortcomings that may be impeding a user from taking full advantage of such a sophisticated measuring tool. First, some methods require that the user prepare a visible physical marker, e.g., printed marker or CDs, which is both bothersome and complicates the execution process. An alternative method works without markers by utilizing triangulation method [2]. However, its measurement accuracy is poor, i.e., typically around 5%, and it only works with a ground-connected camera view.

We present a dimension visualization system that utilizes acoustic distance detection using a commonly available tablet device to address these issues. It works without a physical marker or visible ground surface. Furthermore, overall accuracy can be several times greater than the triangulation method. To date, a noticeable number of studies have focused on the use of smart device acoustic sensors, e.g., pure object distance detection, mobile phone localization, etc. [3]. However, to the best of our knowledge, none of the work specifically related to dimension measurement and visualization has been studied. We study some of the intrinsic issues associated with such application.

The contributions of this work are as follows. We designed a method that allows the system to work in an environment where acoustic distance measurement using common smart devices can be problematic. We introduced a reference indicator as a guide for the user to select reference depth. This is a necessary module when the camera view is not a simple flat surface, as is typical for this application. At last, we built an end-to-end dimension measurement visualization system using a tablet device and demonstrated its capability.

Prototype Design

The system consists of several modules; the acoustic distance detector, the target signal selector, the reference indicator, and the measurement visualization user interface module. The system detects distance from the device to the reference region, i.e., area indicated by the reference indicator, by means of acoustic distance detection. The measurement visualization user interface uses the distance value and user specified measurements in centimeters to display the virtual dimension image (rectangle, line) in correct size (Figure 1), assuming that the dimension image is virtually placed at a depth of the reference region. For

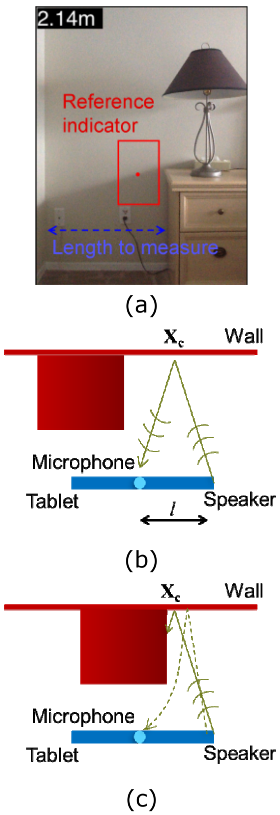


Figure 4. (a) The reference indicator shown as a box with red border shows where the distance detection is made. (b) Schematic (top view) for the object far away from the target audio pulse path (solid green line). Distance detection is successful. (c) The object is in the target pulse path and blocks the pulse propagation. The audio pulse different from the target pulse reaches the microphone due to the diffraction effect (dashed line). As a result, unintended distance detection is done.

the problematic condition where multiple reflected acoustic pulses are detected, user can utilize target signal selector to acquire appropriate measurements.

Implementation and Evaluation

Acoustic Distance Detector

The distance measurement works by measuring the time of flight of an acoustic pulse signal from emission via reflection from the reference region to detection. This process is similar to a method described previously [3]. The prototype was built using an iPad 2 tablet, which has a rear camera, a rear speaker working as transmitter with the dimension 1 × 4 cm^2 and a microphone working as receiver, both supporting a sampling rate of 44.1 kHz. The frequency of the acoustic wave was set to 15 kHz, and the repetition of pulse emission was set 2 - 20 Hz. Typical measurement yielded accuracy of 2 cm in a 2 m range.

Target Signal Selector

A speaker embedded in a consumer grade smart device typically has a relatively low-frequency band (up to 20 kHz) with the dimension in the order of 1 × 1 cm^2. For such a condition, the diffraction effect of the sound wave becomes non-negligible. The influence becomes noticeable in case where the device is close to the audio reflective surface, such as a table surface, and the emergence of reflected audio signals from the non-relevant path is encountered (Figure 2). The presence of multiple pulse signals critically degrades distance measurement because the system is not able to determine the appropriate target signal.

To address this, we have implemented an interactive way to select the most appropriate target signal. In the selection process, the user moves the tablet device forward and backward in the direction of the reference region (Figure 2b). Linked to the device motion, the target signal pulse makes the relevant flight time displacement, whereas the other pulses stay proximity to the certain flight time (Figure 2a). After some cumulative detection, the dispersion, i.e., standard deviation, of each pulse's flight time is checked. The pulse exceeding the dispersion threshold is selected as the target pulse.

It is expected that the dispersion of a target signal will vary from person to person depending on the speed and accuracy of the motion. We conducted a user test to determine an appropriate dispersion threshold. Eleven participants were asked to use the target signal selector at various dispersion thresholds. Figure 3 shows the success rate at various dispersion thresholds. The optimum range occurs between 3–6 cm dispersion threshold. Below this range, small fluctuations in vertical user motion caused incorrect selection of sound wave signal, i.e., bottom surface reflected wave was selected. Above the optimum range, user motion was too slow to meet the threshold and many trials failed to select any pulse. From these results, we decided to set the dispersion threshold to 4.5 cm.

Reference Indicator

In many cases, a user is likely to perform dimension visualization on the camera view with multiple objects or surfaces located at various depths. For instance, user may wish to measure a certain portion of a side wall that has a cabinet placed next to it. In such a case, a reference depth should be set to distance to the side wall, not to the cabinet. The reference indicator supports this by displaying a guide mark showing where the reference region is (Figure 4a).

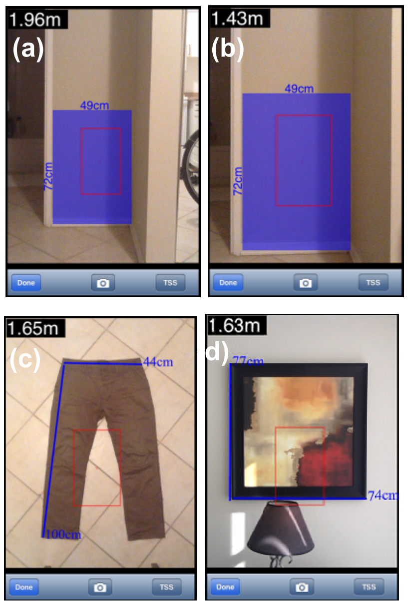


Figure 5. Visualized dimension measurement in blue rectangle form at (a) 1.96 and (b) 1.43 m reference depth. The size of the dimension guide area is 49 x 72 cm^2 for both cases. (c), (d) In blue line form. Bottom right TSS button turns on the target signal selector and top left text shows distance to the reference area shown by the red bordered box.

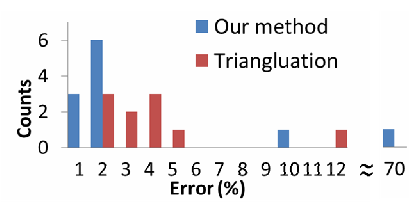


Figure 6. Distribution of measurement error. Number of trials are 11 and 10 for our method and triangulation method respectively.

The reference indicator is positioned at a point corresponding to the target acoustic signal's reflection point $\mathbf{X}_c$ shown in Figure 4. It is important to note that to obtain the reliable measurement, the area covered by the reference indicator needs to be a clear surface. The finite character of the reference indicator dimension owes to the finite spatial resolution of distance detection along the direction perpendicular to the forward direction. The blockage of the target acoustic pulse by the nearby obstacle, finite speaker size and detection of the diffracted wave may attribute to the finite spatial resolution (Figure 4). As a first step approximation, we set side length of the rectangular reference indicator as separation length between the speaker and microphone (farthest) plus an additional length enough to neglect the effect from the diffracted wave signal. The latter extra length is conservatively determined using the relation $\nu = -1$, where ν is the Fresnel-Kirchoff diffraction parameter. Due to limited space of the paper, the detail will be discussed elsewhere. The resulting dimension of the reference indicator is 26 cm x 41 cm.

Measurement Visualization User Interface

As shown in Figure 5, the dimension guide (virtual rectangle or line) is overlaid on the camera view. The dimensions in centimeters of these guide images are also displayed. Depending on the reference indicator's depth, the dimension guide images are scaled to maintain a size that reflects the displayed text (Figure 5a and 5b). The user can interactively move or change the size of the dimension guide by dragging or performing a pinch-in/pinch-out action. In case of the appearance of multiple pulse signals, user can perform a target signal selection process to improve the measurement.

By changing and moving the dimension guide to the user's intended size and location, they can confirm how a specific dimension fits in a particular area. Alternatively, a user can determine the dimensions of a particular object . Some example are shown in Figure 5. We have conducted primitive test on the system performance in several scenarios. For most cases, the accuracy of the measurement was within 2% (Figure 6). However, in some cases, target pulse selection failed and degraded the accuracy substantially. More formal investigation will be conducted in the future.

Future Consideration

The current system was valid up to a distance of 2.3 m, limiting the camera's field of view to 2 m. We believe this can be improved by using cumulative pulse signals for a better signal to noise ratio. In terms of the device scalability, we will study feasibility of our method for a more general smart device with the speaker and the camera facing in the different direction. Based on our method, we will also explore new applications such as smart device only version of online shopping product coordination system studied in Reference 4.

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