A Method for Image Processing and Distance Measuring Based on Laser Distance Triangulation

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Abstract — Distance measuring using image processing is relatively simple task when it comes to personal computers as x86 architecture. However, for embedded systems with a smaller processing power, this task becomes more difficult. A laser triangulation distance measurement technique using an embedded micro controlled system, may be interesting from the moment it allows several new applications as autonomy and mobility for blind person through image processing devices. In this work, the laser triangulation distance measurement is applied trough a laser and a CMOS camera, for an electronic virtual white cane. In order this application be considerable viable, the frames per second (fps) processing rate should be properly measured.

Keywords — White cane; assistive technology; accessibility; embedded systems; image processing.

I. INTRODUCTION

The demand for assistive technologies for persons with various types of disabilities has always existed. However, with the advance of technology has made possible to develop technological devices capable of supplying albeit rudimentary, these demands. Considering this scenario, one of the most difficult disabilities to be compensated through technology is the loss of vision, especially for the high complexity physics that involves the seen process. Despite its difficulty, several attempts have been made to develop devices capable of giving out to the visually impaired people some information about obstacles around them. Mostly of new devices for this purpose is based on ultrasound technology. Despite these ultrasound based devices work in a satisfactory way, this kind of device still presents some intrinsic problems as ultrasound reflection and interferences from the environment. Within this conception, this work seeks to find new possibilities for electronic canes evaluating the proposed technology in terms of effectiveness and reliability. The embedded image processing is already used in several industrial applications in computing platforms. With new portable cameras widely used today it is possible to develop assistive technologies based on image processing for embedded systems with high reliability of metering. The main purpose of this study is to evaluate the performance of processing image in an embedded system based on the LPC1768 microcontroller working together with a set formed by a CMOS camera TCM8230MD and a laser in order to detect and measure distances so this technique can contribute to implementing equipments such as an electronic cane. Related works about distance measuring technique and imaging processing is shown in Manduchi and Yual [1] work, where are used a camera and a laser line instead of a punctiform laser as presented in this work. At same time, Schumaker’s work [2] describes one way to optimize the image buffer treatment on an ARM-7 architecture using the TCM8230MD. The initial idea of this work is that the microcontroller can process images at a rate of 15 frames per second (fps), and latter at 30 fps, so that it can be applied to an embedded system for detecting distance with laser for an application in an electronic cane. The reason for using this technique in this paper is to try a new approach in contrast to existing studies of electronic canes which mostly use ultrasound sensors to measure distances, thus seeking to extend the possibilities for this type of device and to verify the possibility to provide possible improvements of its functionalities.

II. PROPOSED ARCHITECTURE

The electronic cane is composed by four main elements: A CMOS image capture sensor TCM8230MD[3] as an input element, A 650nm red laser with punctiform emission; A LPC1768 ARM Cortex-M3 microcontroller [4] for processing the received images from the camera and a vibration motor. As it can be seen in fig. 1, besides these components, the system is provided of battery, buzzer speaker and buttons that are used to improve functioning of the system. The microcontroller communicates to the camera through a SPI bus to send commands and through a parallel 8 bit wide bus to receive image data [3]. The microcontroller inputs selected to work as GPIOs are used for reading buttons and turn the laser on. The analog-to-digital converter is used to detect the battery level and inform through a buzzer speaker for the user that the device need to be recharged. The buzzer speaker is also used to indicate problems in detecting the laser spot. The PWM module is used to control the vibration motor by varying its current. The laser and camera work together, in order to detect the distance between the cane, which is in user’s hand, and the obstacle in front of him. The micro motor emits mechanical vibrations which varies its intensity according to the distance calculated by image processing. The distance calculation is based on the laser’s position on the image captured by the camera.
III. DESIGN FLOW

The design flow presented in fig. 2 details the development steps which will be described ahead. Additionally, the steps include other details: the method for distance detection using a laser, hardware assembly, image processing algorithm validation and system validation tests.

A. Laser detection on the image

In order to validate the strategy for image processing for seek the laser on the image, it was used a device composed by a webcam and a 650nm laser with punctiform emission. The processing was done initially in MATLAB [5] software to avoid possible problems with hardware on the embedded system. On fig. 3 the laser was directed to a region near the center of image. As it can be seen, here there are other red points from other objects scattered around different areas of the image. Also, it is possible to note that the laser point region appears as white area indicating saturation on the CMOS sensor. Thus, is difficult to distinguish between the laser center and the white colors from other parts of the image just by using the RGB values as reference.

B. Solving the camera saturation problem

Considering that this image treatment is done by a microcontroller, the use of conventional techniques for image
processing would result in an additional use of time and energy; which would result in an impracticable processing for this application. So one solution found for this problem was the use of a blue filter to minimize the medium intensity of the red color on the image. Once the amount of light emitted by the laser is enough to cause saturation in the camera sensor it is also strong enough to pass the filter and excite the red color sensor so the laser spot is still visible as is can be seen in fig. 5. The other pixels that appeared as red before were now approximate to the black color.

Fig. 5. Captured image by using a blue filter in front of camera lens.

After use the same algorithm applied to fig. 3 also to fig. 5 the result was, as expected, the exact border of the laser spot. In order to optimize the usage of memory and processing time in laser detection, the scanning area was reduced by eliminating three upper lines and three bottom lines of the scanning process. As it can be seen in fig. 6, the laser edge was correctly detected by the algorithm. The laser edge becomes bigger when it is close to the camera, so the scanning area height must be able to comprehend the laser spot when it is at the minimum distance from the camera. The value used on the scanning area was 10 pixels above and 10 pixels below the center horizontal line of the image.

Fig. 6. Result from an application of the pixel color based algorithm on fig. 5 image.

C. Laser detection algorithm

The laser detection algorithm, although simple, tries to optimize the system performance, once the embedded processing power is limited when compared to a personal computer. What the laser detection algorithm does is to scan the screen on the region where the laser may be present. If a pixel has the laser color it is changed to white, otherwise it is converted to black. Then it starts seeking column by column of the scanning area for white pixels do determine the right border and the left border of the laser spot. The central pixel is determined by the average of the pixel position of right and left borders.

D. Laser displacement model based on obstacle distance

The Once found a solution for detecting the laser point on the screen it is needed to provide a mathematical model to establish a relation the laser position on the screen and the real distance between camera and obstacle in front of the system. The model shown in fig. 5 was used to determine this relationship's main parameters.

Fig. 7. Mathematical model for calculating distances between obstacle and camera.

dA: determines the minimum distance for an obstacle to be detected by the camera. The distance can be calculated according to (1).

\[
dA = \frac{x}{\tan(\alpha) + \tan(\beta)} \tag{1}
\]

dB: determines the maximum distance for an obstacle to be detected by the camera. The distance can be calculated according to (2).

\[
dB = \frac{x}{\tan(\beta) - \tan(\alpha)} \tag{2}
\]

d: determines the distance between an obstacle and the camera, since \(dA < d < dB\). The value of \(d\) can be calculated according to (3).

\[
d = \frac{x}{(\tan(\alpha) + \tan(\beta)) - (2p\tan(\alpha))} \tag{3}
\]
**p**: is an auxiliary variable that represents the proportional value that the laser to one image border compared to the image entire horizontal length. The value of \( p \) can be calculated according to (4).

\[
p = \frac{\nu}{l}
\]  

(4)

**l**: is a variable that represents the length of the real size of the image on a distance \( d \). \( l' \) represents the real length of the distance between the laser point and the left image border on a distance \( d \). The value of \( l \) can be calculated according to (5).

\[
l = 2 \cdot d \cdot \tan(\alpha)
\]  

(5)

For this proposed model from fig. 5 to be valid, conditions (6) and (7) should be respected.

\[
\beta > \alpha \quad (6)
\]
\[
0 < p \leq 1 \quad (7)
\]

Finally, the variable \( x \), which represents the distance between laser emitter and camera. The line from fig. 8 was determined using the following parameters: \( x = 3 \text{ cm}, \alpha = 22°, \beta = 22.5° \). Through these parameters was possible to calculate the limit values for the telemetry process which were: \( dA = 3.3 \text{ cm} \) and \( dB = 2.22 \text{ m} \). The ‘x’ value was defined by the real distance between laser and camera used in the prototype for tests in an X86 architecture. \( \alpha \) was defined experimentally and \( \beta \) was calculated in order to limit the maximum distance detection to 2.22 meters.

**IV. RESULTS**

**A. Processor performance**

On fig. 9 is shown a system performance analysis trough a tool provided by Keil Software[6]. The result shows that the embedded system based on the LPC1768 microcontroller was able to process every frame from camera in less than 2 milliseconds. This can be confirmed by looking at the task number 5 where the time grid is adjusted for 2ms. This performance is enough to process images at a rate of 30 frames per second without using the maximum microcontroller processing power and providing a satisfactory response time for the user.

**B. Laser/camera set performance**

The device presented a good performance for indoor applications. In this scenario the system easily identified the laser on the image captured by the camera including several types of surfaces. However, surfaces as glass and mirrors represent limitations to the system. In this cases, depending on how the laser reflection occurs, the device may inform a wrong distance or it is unable to detect the laser, which result in an absence of the distance value and in an audible indication with the buzzer on the device. For external environments the device works with the same performance presented on indoor applications. However, for external daytime environment the excess of light makes it harder to the camera to find the laser spot. In this scenario was difficult to detect the laser spot for distances longer than 1 meter, which implies in a significant decrease on the system performance.

**C. Vibration feedback analysis**

Feedback through vibration has proved valid. However, by analyzing the environment scanning tests, it was possible to conclude that for a small variation in obstacle distance is difficult to perceive the variation in the vibration intensity.
D. Power consumption

On laboratory measurements, device average current consumption on an active state was 300mA (it means using the camera, laser, and vibration motor). Considering that the device is powered by a 2500 mAh battery, the autonomy is theoretically of 8 hours. This autonomy time is acceptable for an embedded device which does not stay activated all the time, once the device starts to work only when the user requires it. One problem that contributes for decreasing the system performance is that the vibration motor needs a duty cycle from the PWM module larger than 30% to overcome the motor's inertia. When the system is in an inactive state, the average current consumption is about 1mA. This is a high consumption for an inactive state on an embedded device. However, it is possible to reduce it by managing some power features of the microcontroller.

V. CONCLUSIONS

This paper presented a methodology for distance measurement based on a geometrical model using a laser and a CMOS camera. The model considers an embedded system with a LPC1768 microcontroller for calculating obstacle distance and detecting the laser on camera image. This methodology applies to a low-cost white cane design for helping impaired visually people. Experiments show the effectiveness of distance measurement and use of a vibration motor as a distance feedback to the user. Although the device works as expected, it is possible implement new strategies to improve power consumption performance.

REFERENCES