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# A handheld device for leaf area measurement

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A B S T R A C T

Advanced electronic technology makes handheld devices (HHD) suitable for leaf area (LA) measurement with image processing techniques. This article presents the development of an HHD applied to measure LA through image processing. The procedure is essentially a module of mobile phone software developed in Java ME that uses a HHD touch panel monitor to estimate LA. The system is composed of a control module to run specially developed software, an ultrasonic ranging module to calculate the plane distance between the leaf and the HHD, and an inclination angular measuring module to determine the plane inclination angle between the leaf and the HHD. The image processing operations on each image are as follows: semi-automatic image segmentation, binarization, noise filtering, and LA calculation. The measurement accuracy of the HHD surpasses 0.005 $cm^2$, and the cost is less than one tenth of a traditional machine vision system. Squares of 400 $mm^2$ and circles of 314.15 $mm^2$ were used to test the effects of distance and inclination angle of the HHD. The distance between the HHD and objects with inclination angle at 0°, 5°, 10° and 30° was set to 150 mm and between distances of 200 and 800 mm at 100-mm intervals. The results showed that the deviations were in the range of −0.62% to 0.79% at the same inclination angle. There were distinguishable errors between different angles by 5°. Leaf samples of tomato, eggplant, and maple representing varied shapes and sizes were used to compare the measurement performance of the HHD and an existing leaf area meter (Li-3100; LICOR, Lincoln, NE, USA). The results indicate that the HHD was an accurate device for LA measurement when the distances were in the range of 300–600 mm; especially at the 400-mm point, the maximum error of the HHD compared with Li-3100 was 0.455%, and the minimum error was 0.04%. Overall the result indicated that the developed image processing method using the HHD provided a feasible non-destructive alternative to measure LA. This new technology enables agriculture and forestry workers to conveniently, accurately, and reliably estimate the area of leaves without using expensive instruments.



## 1. Introduction

The leaf area (LA) of a specified plant species indicates the performance of mechanisms such as radiation interception, water and energy exchange, crop growth and bio-productivity. LA has been proven to be of great significance in plant growth studies and has helped with the understanding of plant-environment interactions (De Jesus et al., 2001; Gyves et al., 2008).

Blanco and Folegatti (2003) indicates that one of the most frequently used non-destructive methods is LA estimation from mathematical equations involving linear measurement; such as leaf length, or leaf width, or some combination of these variables, this is generally preferable because of their simplicity and accuracy. However, models developed by this method are suitable only for a specific plant. A portable scanning planimeter is only suitable for small plants with few leaves and not feasible for large leaves (Nyakwende et al., 1997; Rouphael et al., 2010). Machine vision inspection technique (MVIT) is a detection technology simulating human visual function (Davies, 2005). It obtains required information by means of analysis and calculation of the scene image. This technique is excellent for extracting a two-dimensional or three-dimensional shape, contour, and size of an object (Kucukkaya, 2004; Gorpas et al., 2007). The fundamental task of MVIT is to rigorously establish the geometric relationship between an image and the object, at the time of the imaging event. When this relationship is correctly determined, object information can be derived strictly from its imagery (Perona and Malik, 1990; Bejanin et al., 1994). The technique has lots of advantages such as high speed, high precision, abundant information and noncontact detection. There are many successful applications for various objects and industries (Malamas et al., 2003; Wu et al., 2004; Igathinathane et al., 2006; Heiskanen et al., 2008; Jia et al., 2010; Gadelmawla, 2011; Igathinathane et al., 2012).

The introduction of computer-based image processing systems has further boosted the application of machine vision techniques

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in assessing plant characteristics (Trooien and Heermann, 1992; Nyakwende et al., 1997; Chien and Lin, 2002). The capturing of a leaf image by a digital camera or scanner is fast, and the analysis using appropriate software is accurate (Bignami and Rossini, 1996; Baker et al., 1996). Several brands of desktop and handheld LA meters using optical or laser scanning with an accuracy of 0.1 mm$^2$ are available commercially, but the facility is generally expensive (O'Neal et al., 2002) and is not suitable for non-flat leaf measurement. This is because pictures that not taken exactly perpendicular to the leaves can cause erroneous LA evaluation. However, these devices, when compared with portable handheld devices (HHD), such as mobile phone, are still cumbersome.

From the overview of existing methods for LA measurements, it is clear that there is a need to develop an inexpensive, convenient, and reliable approach for LA measurements. This study reports on the development of a touch screen portable device with image processing capable of measuring LA. The method uses a touch panel mobile phone combined with a distance and angle surveying module commonly associated with a general calibration reference board. The total cost is less than one tenth of a traditional machine vision instrument.

## 2. Materials and methods

### 2.1. Hardware platform

Fig. 1 shows a photograph of the HHD prototype. The hardware consists of three items: a control module prototype developed using a mobile phone development board (MPDB) (Fig. 1), an ultrasonic measuring distance module (UMDM) (Fig. 1), and an angular surveying module (ASM) (Fig. 1). The MPDB (HUAYU High-tech Co., Ltd., Shenzhen, China) incorporates a Samsung S3C2440 ARM920T 400 MHz high-speed CPU, and is capable of stand-alone operation from a single +3 V power supply. It also comprises onboard volatile and nonvolatile memories, as well as a ported and embedded Linux 2.6.20 operating system. Other components include a 3-megapixel focal fixed video camera associated with a LED flashlight, Universal Serial Bus interfaces, expansion connectors (128 pins) (Fig. 1c), and a 2.8-in. color touch panel monitor. Java is used in the module to control the hardware. This board is ideal for fast prototyping, evaluation, and development of software applications. Expansion of a user's peripherals and circuits can be achieved using expansion connectors to implement a user-defined mezzanine board. The HHD prototype uses expansion connectors to connect the UMDM and ASM.

The prototype architecture is shown in Fig. 2. The S3C2440 ARM920T is the core-processing chip of the HHD. This chip serves to dispatch control commands among the modules used in the HHD such as send capture command to the camera to capture an image, and display that image on the monitor, then save that image file to FLASH memory. This chip also processes the images.

The UMDM was developed by Kingsin Technologies Co., Ltd. (Shenzhen, Guangdong, China). It is a type KS103 UMDM, and it uses ultrasonic technology to measure distance. The module feeds back the distance to CPU. The detection capability of the module ranges between 10 mm and 6500 mm, and the distance control has an error of −1 to +1 mm with a sampling rate of 50 times per second. The UMDM is used to regulate the plane distance between the object and the camera. The UMDM is connected to the MPDB via an INTER IC BUS (IIC) port.

The ASM used is of the type YLZ-502. It uses 3D-MEMS technology of Analog Devices (ADI, USA) and has an accuracy of ±0.4%. It is manufactured by CJMCU Company (Shenzhen, Guangdong, China). It is able to measure the biaxial inclination angle of the HHD at the same time, and can detect the axis inclination angle change of both axis of the HHD respectively. The measurement range for each axis is ±90°. The ASM is employed to manage the plane inclination angle among the leaf and the HHD. The ASM possesses an RS-232 serial port and provides a 16 bit string output function; it can communicate easily with the HHD chip.

The OS installed in the MPDB is an embedded Linux 2.6.20, this serves as an interpreter for the hardware and the application. To develop high-level open software, a Kilobyte Virtual machine (KVM) for Java was ported to the MPDB. The Battery, LCD, SDRM, FLASH, video Camera and CPU are integrated in the MPDB.

### 2.2. UMDM, ASM drivers and KVM mounts

Not self-contained in the MPDB, both the drivers of UMDM and ASM need to be embedded into the Linux 2.6.20 OS so that they can be identified by the OS and work with the system. The UMDM and the ASM are both character device types in Linux OS and can be accessed as byte streams. All the source code of the KVM can be downloaded from the home page of Sun Microsystems (Online JDK, 2008): j2sdk-1_4_2_18-linux-i586.bin and j2me_cldc-1_1-fcs-src-winunix.zip. The latter includes the KVM source code (Online KVM, 2006). Linux is an open and flexible OS. The embedded method of RS-232 serial port driver, IIC port driver, and the KVM is easy to find in Linux 2.6.x via the Internet. This paper does not

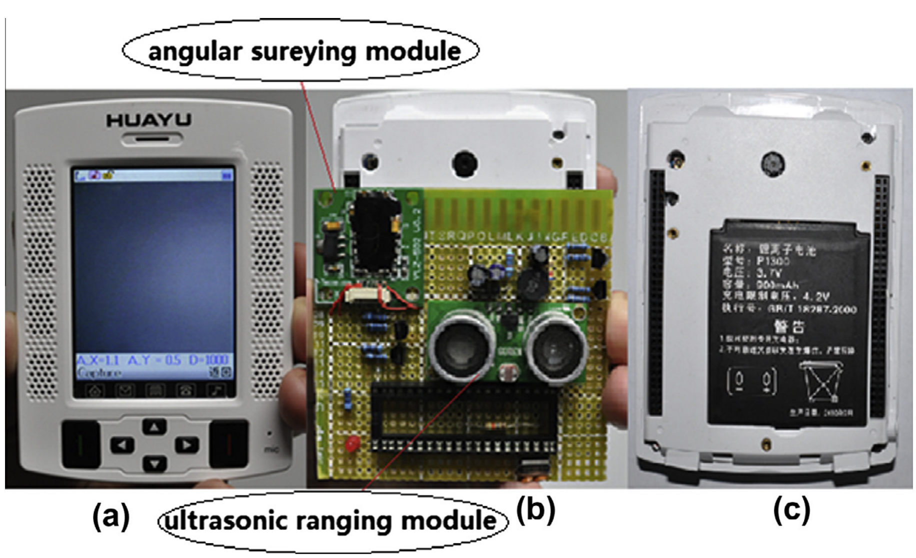


**Fig. 1.** The prototype of proposed HHD system: (a) front view of the MPDB; (b) UMDM and ASM; and (c) back view of the MPDB.