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Application note

A high quality low-cost digital microscope minirhizotron system

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ABSTRACT

An easily reproducible system is presented for minirhizotron image acquisition based on a digital microscope and entirely built with low-cost components. The system weighs 2.28 kg, is connected to a portable computer through USB, and allows collection and storage of high-quality digital images without other components or power sources. Settings at 25× magnification provide pixel sizes of 25 and 12 μm respectively with a medium pixel density microscope (640 × 480 pixel), and a high pixel density microscope (1280 × 1024 pixel). This kind of system coupled with recent developments of robotics and automatic image analysis for minirhizotron frames allows to envisage fast, low-labour and low-cost root investigation methods with a high degree of automation.

1. Introduction

Minirhizotrons provide a non-destructive, in situ method for viewing roots and recording their growth through sequential photographs. Johnson et al. (2001) described the system's components as comprising a transparent tube, a micro video-camera, a control unit to focus the camera and adjust the light levels, a VCR for recording root images on videotape, and a monitor for viewing images as they are collected. After acquisition, videotape images are numbered and roots are traced with a hand digitizing device on a monitor (Beyrouty et al., 1987) or translated into digital pictures to quantify root measurements with a computer (Smucker et al., 1987). Pateña and Ingram (2000) substituted videotape recording with a parallel port video capture device (PP-VDC).

Inexpensive high resolution miniature digital cameras are now available, and allow image storage directly in a computer, attain high resolution, reduce acquisition time, and avoid problems associated with handling video players and capture devices. Nevertheless, commercially available equipment is still expensive and based on many components and technology is not always updated. Research teams have used much simplified, self-made versions based on digital video-cameras (Vamerali et al. 2009) or webcams (Faget et al. 2010) directly connected to a computer, which often provide sufficient image data since routine root measurements are performed taking sequential images at the same position and at a fixed magnification (Vamerali et al., 2009). However, reports from these teams do not provide enough information for reproducing the equipment, or use lower resolution digital cameras than are potentially available.

In this work we present technical details on a camera system for capturing minirhizotron root images that is based on digital microscopes with medium to high image resolution, and built with low-cost, lightweight materials and minimal components to carry to the field during operation.

2. Design and construction of the camera system

2.1. Imaging components

The system was designed to directly connect a digital microscope to a laptop computer. When selecting a digital camera for a minirhizotron system, it is important to consider the image resolution capability because fine roots are very small in diameter and can be difficult to distinguish with low resolution components. Image resolution can be defined and measured in different ways according to the purpose. The size of the smallest object that can be detected is measured in units of length. The ability to resolve different objects is the smallest distance at which adjacent lines can be resolved, and is measured in line pairs per millimeter. In systems based on digital image-acquisition technology, resolution increases as the size of pixels decreases. Pixel size depends on pixel density (number of pixels per unit image length), and density, in turn, is a function of the number of pixels in an image and image size. Other properties of the system such as deformation and color contrast will also affect the ability to detect or resolve objects. Therefore a low pixel size (corresponding to a high pixel density) will potentially correspond to a high image resolution, but the exact value will depend on the specific system used. Also, 2–3 pixels may be needed to detect an object. We therefore use the size of a single pixel as an indicator of potential image resolution.

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We considered two digital microscopes: the medium resolution (MD, Dinolite AM311) and the high resolution (HD, Dinolite AD413T) models (Digitus, ASSMANN Electronic GmbH Lüdenscheid, Germany, www.digitus.info), providing images of 640 × 480 and 1280 × 1024 pixels, respectively. HD includes a built-in application for measurement and calibration. The other specifications of the microscopes are the same: 90 g, continuous magnification between 10 and 200×, 30 fps (frames per second) and an USB 1.1/2.0, compatible with Windows and MacOS X. No other component is needed and any software for image acquisition may be used with such equipment.

An artificial lighting system is provided through two USB white LED lights, of about 30 mA power requirement and 10 cd light intensity each. Lights built in the digital microscope do not provide good lighting for the minirhizotron use, and are recommended to be turned off. The LED lights are positioned on the metal block bolted to the cylinder case slab in the position shown in Fig. 2a. Preliminary trials were carried out to select the best position of the lighting system for image acquisition in order to avoid shading or blurring. Both the camera and the LED lights are powered directly through the USB port of a computer.

2.2. Mechanical components

The mechanical components include a support slab holding the microscope camera, a cylindrical case protecting the camera slab and holding the lights, a bar for handling and positioning the camera, an interface for insertion into minirhizotron tubes, and USB connections between components (Fig. 1). All components are designed to be built in aluminium in order to provide mechanical strength with minimum weight and bulk of the equipment. Connections and interfaces are plastic or polytetrafluoroethylene (PTFE) as described below. All mechanical parts were designed in AutoCAD® 2008 (Autodesk, San Rafael, CA, USA) and precision cuts and shapes were made with a bench lathe. Materials and components are listed in Table 1. A total of 3 days work was needed for precision cuts and assembling the system when all materials were ready.

2.2.1. Camera slab and case

The functions of the camera-slab are to hold the camera and to secure the camera and LED cables (Fig. 2a). The slab is positioned in a cylindrical case, and 49.50 × 36.45 mm rectangular slot is cut in the cylinder. The camera is oriented longitudinally on the slab. Consequently, in order to capture images from the minirhizotron side walls as desired, a right angle prism is placed in front of the camera to reflect the incident image at 90°, inverting the resulting image. A U-shaped block carrying the LED lights and a right-angle prism is bolted on the slot (Fig. 2a). The camera slab is placed on rail segments; both the slab and the U-shaped block can be removed for maintenance. The position of the slab is chosen so that the center of the camera corresponds to the center of the right-angle prism wall. The cylinder is closed by a plastic lid at the top end and by a PTFE lid at the linked with handle extremity. The latter is modified in order to interface with the aluminium handling/positioning bar. PTFE is stronger than plastic and easier to modify.

Scratching of aluminum parts on the inner side of the minirhizotron tubes is prevented by lining the camera case with 3 mm thick felt pads. These are compressed between 30% and 50% when inserted into the minirhizotron tube, providing a tight fitting. Consequently, the position of the camera with regard to the target soil interface remains constant at any position of the minirhizotron tube, preventing distorted images (no variation in the angle between the camera and the target) and time consuming adjustments of the focus. The pads need to be changed at each observation date.

2.2.2. Camera handle

Handles that advance the camera at fixed intervals along the minirhizotron using a ratchet mechanism (Johnson and Meyer, 1998) or pin-and-hole mechanism (Ferguson and Smucker, 1989) are commercially available (e.g. Bartz Technology Co., Santa Barbara, CA, USA). Simpler handles are described in the literature (Vamerali et al. 2009), but post-acquisition image editing is necessary for correct image alignment. The design for an inexpensive aluminium handle is provided in this paper. The handle consists of two bars (1 m each, connected through an aluminium interface) with a c-shaped cross-section that permits cables routing and provides an ergonomic and lightweight system. A graduated measuring tape may be fixed longitudinally on the front face of the bar. The handle may be connected to the cylindrical case through a PTFE mechanical interface with two bolted contact points. (Fig. 2b).

2.2.3. Minirhizotron – camera handle interface

A PTFE lid with an opening for the camera handle was used to provide connection between the handle and the minirhizotron tube during image acquisition (Fig. 2c). The lid's internal diameter is equal to the minirhizotron tube external diameter. Such close fitting is enough to steadily fix the handle. This also ensures a parallel movement of the camera along the tube, together with the felt pads described above.

3. Setting of the minirhizotron system

The camera unit can be connected to any portable computer or screen with the only condition that they are able to provide energy

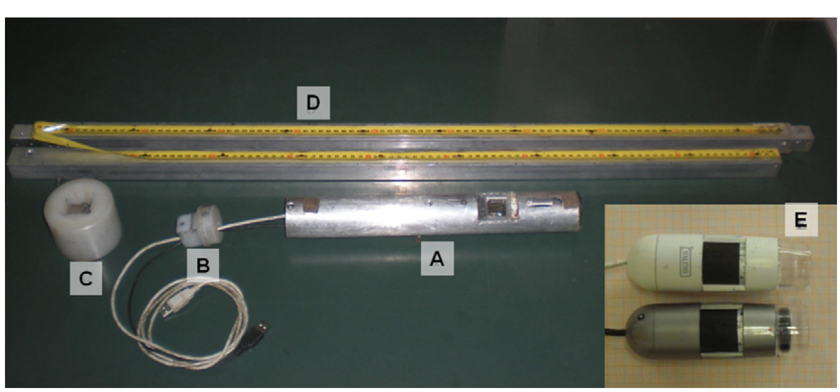

Fig. 1. Minirhizotron image acquisition system components with USB cables for direct connection to laptop or netbook: (a) camera and aluminium case; (b) PTFE handle-case mechanical interface; (c) PTFE minirhizotron tube lid for positioning of the camera handle; (d) camera handle; (e) digital microscopes Dinolite AM311 (top) and Dinolite AD413T (bottom).