Advanced Manual and Automatic Minirhizotron Camera Systems with UHD resolution

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Introduction

Minirhizotron (MR) systems are versatile qualitative & quantitative observation tools to study root and hyphal distribution, growth & longevity *in situ* or in mesocosms. However, the available technology is currently limiting the wide use of MR systems in research, especially due to i) moderate image quality, ii) high purchasing prices, and iii) labor intensive manual imaging campaigns and analyses. Imaging automation seems especially advantageous for large experimental set-ups ('rhizolabs'), featuring hundreds of MR tubes in experiments addressing e.g. root phenotyping or ecological questions; increased image quality (while not compromising on time for image acquisition) is key for adequate imaging of hyphae and root details (e.g. root hair). Thus, a modular set of new MR camera systems was developed by cross-sectoral collaboration between Bartz Technology Corp. (BTC), Vienna Scientific Instruments (VSI), and the University of Natural Resources and Life Sciences (BOKU). Key features of two developed systems are described and an outlook on future R&D is given.

Key specification of MR cameras

Specification	**Manual MR** (Fig. 1)	**Automatic MR** (Fig. 2)
Nr. of cameras / lighting	One / 2 LED strips (*dimmable*)	Two (*bi-directional*) / 1 LED ring each (*dimmable*)
Rel. position of camera ("dead space" in tubes)	<60mm	<30mm
Image resolution (native)	3280 x 2464 px (*2500 dpi, UHD*)	3280 x 2464 px (*2500 dpi, UHD*)
Image size (native, 7 cm MR tube)	33 mm x 24 mm	ca. 28 mm x 21 mm
Indexing	20 or 30 mm, circular position covering ca. 350° ("*Smucker" handle, turning indexing head*)	Continuously on gear rack, 3 circular positions cov. ca. 320° (*accuracy ± 0.05 mm on 1 m*)
Operation unit / comm. with imaging module	RaspberryPi (Touchscreen, Keyboard) OR PC Windows OS / HDMI cable (< 7 m)	Tablet computer / Wireless (*Bluetooth, RFID*); *coming soon: PC Windows OS*
Software	Bartz ICAP	*VSI; coming soon: Bartz ICAP*
Remote / automatic imaging	Manual, key stroke or Bluetooth trigger (*<10 m*)	Imaging semi automatic *(i.e. manual camera module positioning only)*
ICAP naming	According to experimental set-up / display on screen	Tube recognition by RFID chip, naming according to position
Energy supply	Wall plug or battery-powered (*via operation unit*)	Battery-powered (*both camera module and tablet*)
Camera modules per operator (in parallel)	One	Up to three (*max. recommended for 150 cm long MR tubes*)
MR tube dimensions (focus factory calibrated) / position	≥54 mm inner diameter (*Bartz-standard*) / vertical to horizontal	≥64 mm inner diameter ('*scanner'-standard*) / horizontal and slightly angled

Devices

Manual MR

Fig. 1 "Classic", manual UHD MR camera

Automatic MR

Fig. 2 Automatic UHD MR camera modules for concurrent imaging by one operator in large 'rhizotrons' facilities

Example Images

Fig. 3 *Pisum sativum* roots in a mesocosm experiment at BOKU (native image, A), Magnification (B)

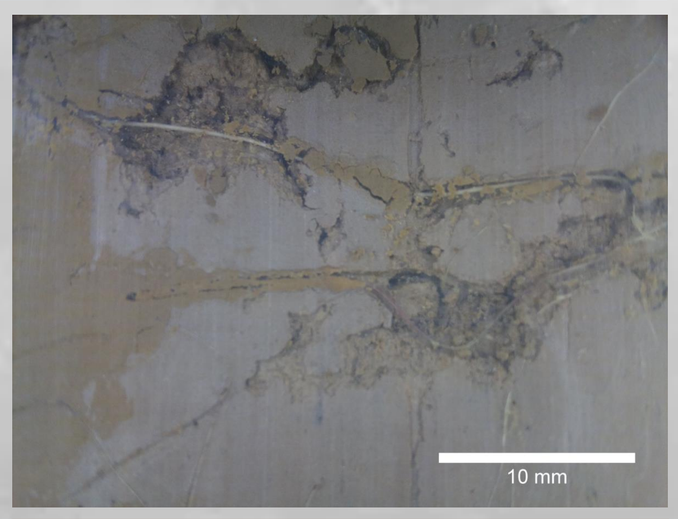

Fig. 4 *Triticum aestivum* roots in the Jülich minirhizotron facility, Germany (native image)

Conclusion & Outlook

Further efforts are needed to make MR imaging system widely available and to increase their versatility. While novel features e.g. Ultra-HD resolution and automatic imaging in horizontal MR tubes could be already implemented in the new systems, the consortium started to develop fully automatic, permanently placed MR systems and to expand imaging beyond the visible light spectrum to NIR wavebands to facilitate automatic root recognition.