Development of a portable and low-cost OCT system for horticultural research

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ABSTRACT

Optical coherence tomography (OCT), a non-contact, non-destructive imaging technique, is becoming a popular tool in phytophotonics, helping to address research questions in plant biology and horticulture. However, the stationary nature of typical OCT systems compromises its non-destructive advantage since plants often need to be dissected for an analysis with a laboratory OCT system. Here we present a portable, low-cost OCT system that enables in-situ measurements of plants. We outline technical challenges encountered during the development and showcase initial measurements of different plant tissues.

Keywords: optical coherence tomography, low-cost, portable, phytophotonics

1. INTRODUCTION

Optical coherence tomography (OCT) is a non-contact, non-destructive, real-time imaging technique widely utilized in ophthalmology and biomedical research.[1] It enables the acquisition of cross-sectional images of light scattering tissues with penetration depths reaching into the sub-millimeter range and typical axial and lateral resolutions in the lower micrometer range. Recently, OCT has also found applications in the emerging field of phytophotonics, aiding the understanding of problems in plant biology, agriculture, horticulture and adjacent fields.[2,3] It has been used to detect virus infected cucumber seeds,[4] characterize near-skin cellular structures of kiwifruits[5] and observe the skin layer development of various potato cultivars,[6] among other things. OCT, therefore, has the potential to become a valuable tool in plant science.

However, standard OCT systems are usually stationary and not easily adaptable for field use. This often results in the need to dissect plant organs and tissue for laboratory analysis with the OCT system, undermining the non-destructive advantage of the system. While portable OCT systems have been previously demonstrated for in-situ measurements of plant tissue, these systems have their own limitations, such as a heavy weight or a slow acquisition rate.[7,8]

Our work aims to improve the current state of the art of portable OCT systems by developing a solution that is not only portable and lightweight but also capable of video rate acquisition, significantly broadening the scope of OCT usage in plant science.

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2. DESCRIPTION OF THE PORTABLE OCT SYSTEM

The basic optical layout of our portable spectral domain OCT (SD-OCT) is shown in Figure 1. The system includes a superluminescent diode (SLD) from Superlum Diodes Ltd. (center wavelength of 838.7 nm, spectral bandwidth of 51.5 nm), a custom designed spectrometer that enables an imaging depth in air of about 3 mm and galvanometer scanners for two-dimensional beam scanning. For live OCT signal processing and visualization, an NVIDIA Jetson Nano running OCTproZ[9] is used. The spectrometer achieves an acquisition speed of 7400 lines (A-scans) per second. This allows an acquisition of 28.9 cross-sectional images (B-scans) per second, with each B-scan consisting of 256 A-scans. Additionally, the system offers volume acquisition, with each volume comprising 256 B-scans, resulting in a rate of 0.11 volumes per second. The optical power on the sample is below 800 µW, and both axial and lateral resolutions were determined to be approximately 16 µm.

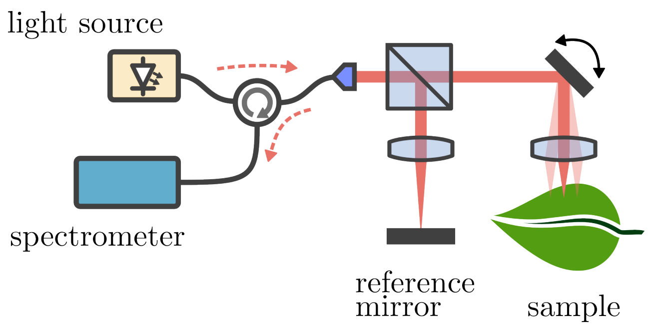

Figure 1. Optical setup of the portable SD-OCT system. A SLD is used as the light source and is coupled into a fiber optic circulator. The light from the circulator's first exit is directed towards a beam splitter cube. This cube splits the light path into two separate arms: the reference arm and the sample arm. Light that is backreflected and backscattered from both arms is guided back to the circulator. From there, it is routed into a custom designed spectrometer.

For portable use, a power bank is utilized that powers the light source, spectrometer, galvanometer scanners, control electronics, and the Jetson Nano including a touch display. All components are integrated into a custom designed and 3D-printed case. The system is composed of a base unit and a handpiece. The handpiece can either be attached to the base unit for stationary use (see Figure 2 left), or it can be detached for handheld use or vertical positioning, allowing for more flexible measurements (see Figure 2 right). A button located on the handpiece's grip enables the easy initiation of a recording during handheld use.

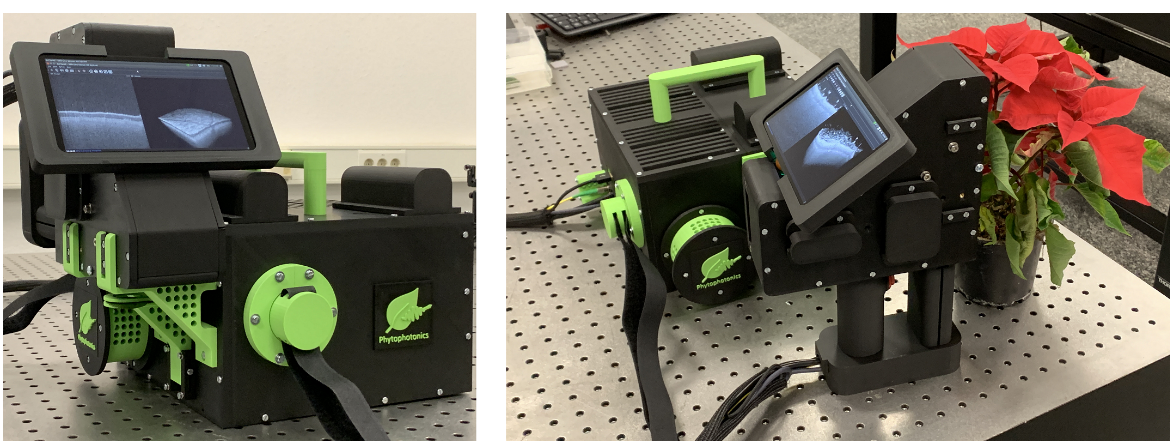

Figure 2. The portable OCT system enclosed in a 3D-printed case. Left: The handpiece is attached to the base unit for stationary use, with OCT images on the display showing a rose leaf. Right: For more flexible use, the handpiece is detached and positioned to acquire OCT images of the underside of a *Euphorbia pulcherrima* leaf.

3. RESULTS

Using our portable system, we acquired OCT images under laboratory conditions of detached healthy leaf discs of rose as well as leaf discs with two pathological conditions: after fungal infection with *Diplocarpon rosae* and with manifested chlorosis. Figure 3 displays data from three distinct samples.

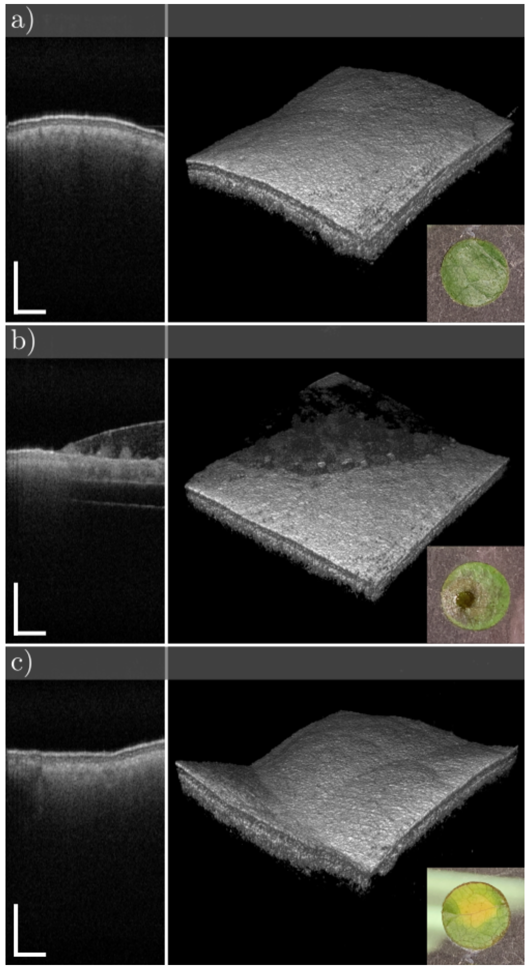

Figure 3. B-scans, OCT volume renderings, and RGB images of different rose leaf discs (8 mm in diameter). The scale bars indicate a length of 500 µm. The depicted B-scans were generated by averaging four adjacent B-scans from the acquired volume. a) healthy leaf disc; b) fungus-infected leaf disc bearing a condensed drop of water; c) leaf disc exhibiting chlorosis.

4. DISCUSSION

Although the preliminary measurements of rose leaf discs with different pathologies are promising, further analysis is required to evaluate the practical usefulness of OCT in detecting various plant diseases. It is particularly crucial to determine the earliest stage at which a fungal infection can be identified in OCT images of rose leaves. A portable OCT system capable of early fungal detection could be an invaluable tool in the development of resistant rose varieties in the future. An additional important step involves testing the portable system in a non-laboratory environment and collecting in-situ data.

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