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PLANTSCREEN™ PHENOTYPING SYSTEMS

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PlantScreen™ Phenotyping Systems are designed for integrative phenotyping on temporal and spatial level. They can be optimized for numerous plant morphologies and structures – from Arabidopsis to manifold crop plants. The PlantScreen™ system can be configured for single pots, multiple pots or trays, providing flexibility of use with numerous different species, or with a single species throughout its growth cycle.



PlantScreen™ SC Systems 122

PlantScreen™ SC Systems are bench top solutions for the automated high-precision plant image-based monitoring of small and mid-size scale plants (e.g. Arabidopsis, young tobacco and crop plants). Compact design systems for low-throughput applications with manual sample loading, which can integrate different imaging sensors for comprehensive automated plant morphological and physiological phenotyping. The PlantScreen™ SC Systems are configurable and easy-to-move if relocation of the unit is necessary.



PlantScreen™ Compact Systems 124

PlantScreen™ Compact System is conveyor-based integrated robotic solution for high-precision digital plant phenotyping and plant cultivation of small and mid-size scale plants (e.g. Arabidopsis). The transport of plants is carried out on trays with different lid patterns adapted for single or multiple plants. Digital data are acquired typically from top and side views.



PlantScreen™ Modular Systems 126

PlantScreen™ Modular System is integrated robotic solution for high-precision digital plant phenotyping and plant cultivation of mid-scale size up to large plants (e.g. corn, wheat) in greenhouse or semi-controlled environment. Single-pots are in transportation disks or multiple-pots in transportation trays carried from cultivation area towards imaging units and irrigation stations. Digital data are acquired typically from top and multiple-angle side views.



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PlantScreen™ Robotic XYZ and Transect XZ Systems 128

PlantScreen™ Robotic XYZ System and Transect XZ System incorporate a number of sensors for imaging of plant morphometric and physiological parameters in sensor-to-plant concept. The XYZ robotic arm is carrying the imaging apparatus directly to the given plant and based on user-defined protocol performs the measurements. Robotic arms of the XYZ system can be constructed to meet whatever specifications required.



PlantScreen™ Field Systems 130

PlantScreen™ Field System allows the user to monitor numerous aspects of plant growth, development and response to biotic and abiotic stresses in the plants' natural environment. The field systems can be designed and configured to meet the users specific requirements with respect to the size and morphology of plants screened and the dimensions of the target field area.



PlantScreen™ Phenotyping Systems in Controlled Environments 132

PSI designs and builds high-capacity growth chambers (FytoScopes) which allow researchers to program controlled growing conditions, with accurate measurements and regulation of temperature, irradiation cycles and relative humidity. Phenotypical monitoring of plants in controlled and programmable environment provides the opportunity to monitor plant growth and plant physiological status in precisely defined and reproducible conditions.



REFERENCES

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PlantScreen™ Phenotyping Systems

PlantScreen™ Phenotyping Systems are designed for automated high-throughput monitoring and quantification of plant architecture and performance at high precision in controlled environments, greenhouses and fields. The PlantScreen™ platform can be configured for single pots, multiple pots or trays, providing flexibility of use with various species ranging from *Arabidopsis* to manifold crop plants.

PSI PlantScreen™ Phenotyping Systems are designed for monitoring of numerous aspects of plant growth, development and response to biotic and abiotic stresses. PlantScreen™ systems can be configured to meet the users specific requirements with respect to the size and number of plants screened, as well as the environmental conditions to which they are exposed. The PlantScreen™ incorporates a number of instruments for imaging plant morphometric and physiological parameters, as well as an acclimatization chamber that may be used to equilibrate plants under controlled conditions, or even for plant cultivation. Dicotyledonous plants as small as *Arabidopsis* seedlings, and monocotyledonous plants as large as mature corn plants, have been studied using these systems.

The PlantScreen™ System is modular and designed so that you can add features as your screening requirements evolve. Currently these types of PlantScreen™ Systems are available:

- **PlantScreen™ SC Systems**
- **PlantScreen™ Compact Systems**
- **PlantScreen™ Modular Systems**
- **PlantScreen™ Robotic XYZ and Transect XZ Systems**
- **PlantScreen™ Field Systems**

In addition **PlantScreen™ Phenotyping Systems in Controlled Environment** are manufactured to allow phenotypical monitoring of plant growth and plant physiological status in precisely controlled and programmable environment.

▼ APPLICATIONS

- High-throughput screening
- Morphology and growth assessment
- Nutrient management
- Photosynthetic performance
- Abiotic and biotic stress responses
- Trait identification
- Chemical screening
- Ecotoxicology
- Nutrient effect
- Pathogen interaction



▼ PLANTSCREEN™ SYSTEMS MEASURE

• **Chlorophyll fluorescence kinetics**

Chlorophyll fluorescence is popular technique in plant physiology used for rapid non-invasive measurement of photosystem II (PSII) activity. PSII activity is very sensitive to range of biotic and abiotic factors and therefore chlorophyll fluorescence technique is used as rapid indicator of photosynthetic performance of plants in different developmental stages and/or in response to changing environment. Systems developed by PSI monitor fluorescence kinetics in pulse-amplitude modulated mode, which provides a wealth of information about a plant's photosynthetic capacity, physiological and metabolic condition, as well as its susceptibility to various stress conditions.

• **Morphometric and RGB analysis**

Wide range number of features linked to plant growth and development can be extracted from digital color RGB imaging or 3D scanning technology, when connected to the automatic software analysis. RGB digital imaging applied in high resolution is used for in-depth analysis of plant morphology, architecture and color index analysis. Industrial high performance cameras with a Gbit Ethernet connection are mounted on robotic arm together with the white LED light source to ensure high speed data transfer and precise color separation.

• **Thermal imaging**

Thermal cameras captures information in long-wavelength infrared part of spectrum. Infrared radiation refers to the temperature of the imaged object and therefore can be used for non-invasively measurement of actual leaf and plant temperature. The temperature of the plant can be used as indicator of plant water-use efficiency, which relates to stomatal conductance and transpiration. Leaf temperature assesment is important for assessing a plant's responses to heat load and water deprivation. Regulation of stomatal aperture to

balance the opposing requirements of drought avoidance and self-cooling is critical to the survival of crops under extreme conditions. Variations in mechanisms for self-cooling may allow certain plants to better withstand periods of high irradiance and low water availability. High performance industrial infrared cameras are used that can be implemented both in top and side view configuration, depending on system configuration.

• **Hyperspectral imaging**

Hyperspectral imaging has been used for many years to study patterns of plant growth from satellite imaging. This technology has been refined in PSI's PlantScreen™ Phenotyping Systems to provide 3-dimensional hyperspectral data sets of plants on a pixel by pixel basis in spectral range from 400 to 2,500 nm. Using a hyperspectral camera with image analysis software, plant reflective indices can be visualized across the entire surface of the imaged sample(s). These indices may be correlated with numerous physiological conditions, as well as the biochemical status of the plant or leaf with respect to the chlorophyll or pigment composition, water status or cell structure. Hyperspectral cameras for both visible (VNIR) and short-wavelength infrared region (SWIR) of the spectrum are available. The cameras are mounted on robotic stage with dedicated illumination source for homogenous sample illumination. Full spectral scan across the entire spectral range of the camera for each pixel of the image can be acquired, optionally specific wavelengths of interest can be recorded that may be correlated with, for example, leaf nitrogen status, or the production of anthocyanin to protect Photosystem II under high light stress.

• **Near-infrared (NIR) imaging**

The NIR imaging station consists of camera with InGaAs sensor sensitive in near-infrared waveband (900–1700 nm) and ultra-homogenous

LED illumination with two central wavelengths – 940 and 1450 nm (other wavelength within the camera spectral range can be optionally used). Camera utilizes natural spectral characteristics of the water – absorption peak at 1450 nm. State of the art design combining two measurements for water absorption and reference wavelengths enables elimination of surrounding light and shadow effects, also quantification is supported with watering and weighting data to assess water use efficiency and response to drought stress This design allows estimation of water content throughout experimental measurements.

• **3D reconstruction**

3D laser scanner used in the PlantScreen™ Systems is designed for precise structural plant phenotyping. With the use of top and side scanning the precise plant 3D model is merged together. Based on the meshed models the automatic data analysis offers computations of a range of morphological parameters. For the best understanding of plant physiology the data from chlorophyll fluorescence measurement or from the colored CCD cameras are fitted to the 3D model. Systems are specifically and individually set up according the customers needs.

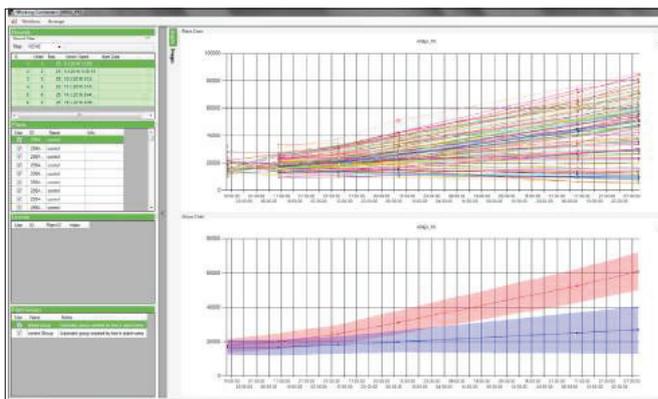
• **Watering and weighing station**

High-precision irrigation system is integral part of the system for programable delivery of both water and nutrients to the plants throughout growth and/or measurement cycles. Watering and nutrient delivery may be combined with automated weighing of plants in pots so that specific watering regimes may be programmed in software. These regimes may be used to impose drought stress or waterlogging of varying degrees of severity, imposed rapidly or gradually. Schemes for watering to exact volume, relative volume or predefined weight can be pre-defined for single plants or groups of plants.

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SOFTWARE

- Comprehensive software package control of all mechanical and imaging parts of the system, data acquisition, image analysis and data base configuration
- Default protocols for all measurements, with development kit to allow the user to create customized protocols
- Automated control of pot/tray movement and activation of single imaging stations depending on the requirement of the experiment
- Individual imaging areas can be selected to suit the sample size and configuration
- RGB digital growth analysis from 3 camera views, including thresholding and color analysis
- For chlorophyll fluorescence imaging, software allows batch analysis of images for quenching parameters, including user-identified regions of interest and averaging of pixel values on background subtracted images. Analyzed data are stored in the database with co-registration of raw image data and analyzed data
- For NIR imaging, 16 bit heat bitmaps are exportable directly to MATLAB or utilized by vendor software to produce false color images of temperature
- PlantScreen™ Scheduler Client – graphical control software for fully automated control of the whole PlantScreen™ System
- PlantScreen™ Server and PlantScreen™ Database – central database interface for all software components
- PlantScreen™ Data Analyzer – graphical interface for filtering, visualization and export of image-analysis data



The screenshot shows a data table from the PlantScreen software. The table has columns for 'Date', 'Time', 'Plant ID', 'Area (mm²)', and 'Height (mm)'. The data is organized into a grid with multiple rows and columns, showing the growth parameters for various plants over time.

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KEY FEATURES

- Chlorophyll Fluorescence Kinetic Imaging
- Morphometric and RGB Analysis
- Thermal Imaging
- Hyperspectral Imaging
- NIR Imaging
- Automated Watering and Nutrient Regimes
- Automated Weighing
- Light Adaptation Tunnel in Controlled Environment
- Environmental Control in the Imaging Cabinet
- Integrated environmental sensors
- Automated Database-Based QR code or RFID Reading
- Open database structure
- Comprehensive software package
- Integrated environmental sensors





PlantScreen™ SC Systems

PlantScreen™ SC Systems are complete stand-alone self contained (SC) robotic bench top solutions for the automated high-precision plant image-based monitoring of small and mid-size scale plants (e.g. Arabidopsis, young tobacco and crop plants). Compact design systems for low-throughput applications with manual sample loading. The platform incorporates various modules for digital analysis of plant growth dynamics and physiological performance, dedicated illumination source for light adaptation of plants prior and/or during the analysis and for plant short-term cultivation under defined conditions. The PlantScreen™ SC Systems are configurable and easy-to-move if relocation of the unit is necessary.

PlantScreen™ SC System is designed for digital phenotyping of small and mid-size scale plants up to 40 cm in height (Arabidopsis thaliana, strawberries, turf grass, young soybean, tobacco, corn plants, etc.) and can be configured for single or multiple pots in tray, providing flexibility of use with various species grown in vitro or in soil. Plants in trays are manually placed inside

of the light-isolated imaging cabinet and automatically scored with given digital sensor in user-defined intervals. Multi-sensoric digital data are typically acquired from top view. Unique QR-code or RFID identifiers are used for plant identification.

Various types of imaging sensors can be integrated in the PlantScreen™ SC Systems. Currently hyperspectral imaging camera, thermal imaging camera and kinetic chlorophyll fluorescence imaging camera with possibility of built in RGB morphometric imaging unit are available for integration into the automated PlantScreen™ SC System. All data acquired from imaging sensors are in raw format and processed format stored in an SQL database and are in range of minute after recording available for further analysis. All raw and processed data files are directly accessible and therefore can be easily analyzed by user-defined processing scripts.

SOFTWARE

- Comprehensive software package for system control, data acquisition, image analysis and data base configuration
- Species specific analysis
- Open database structure
- Remote access
- Automatic SMS and email notification service
- Online environmental monitoring
- 24-hour online support service

KEY FEATURES

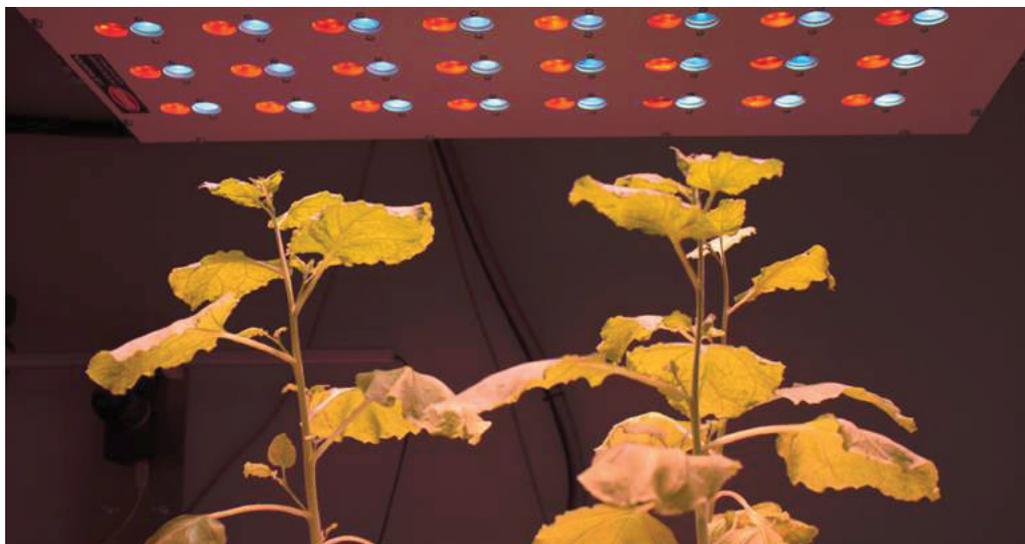
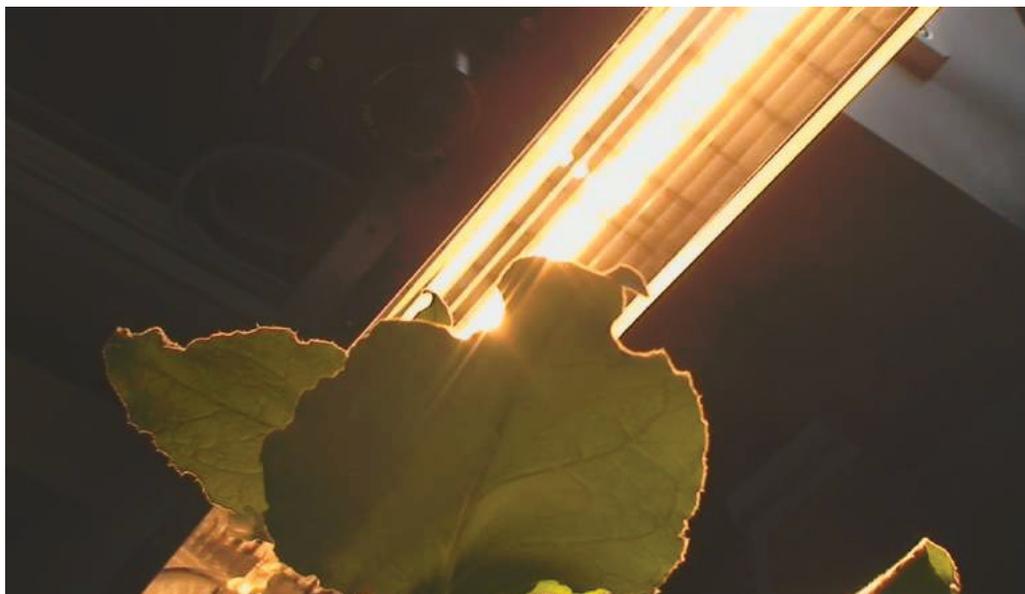
- Bench top compact design
- Manual sample loading
- LED light/dark adaptation box
- Configurable imaging sensors
- Durable and easy-to-move design
- Integrated environmental sensors
- Open database structure
- Comprehensive software package

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Furthermore suite of environmental sensors (humidity, temperature, light intensity, light quality) can be implemented inside of the PlantScreen™ SC System. The physiological parameters deduced from the measurements acquired by imaging units can be correlated with the environmental parameters acquired from a number of environmental sensors implemented within the phenotyping unit.

Comprehensive software package has been developed for system control, data acquisition, image analysis and database configuration. User friendly graphical interface is designed to control all hardware system components actions, to control and monitor environmental conditions and to design experiments with an extremely high level of flexibility. High-end industrial PC with touch screen is used for system control. Scheduling assistant with calendar function allows running multiple experiments simultaneously, provides different modes for experiment randomization, for treatment per plant or group of plants with different experimental protocols and plant handling regimes including dark/light adaptation.

All acquired imaging and environmental data are stored in an SQL database, processed and available for inspection and further analysis in range of seconds after recording via user-friendly graphical interface. PlantScreen™ Data Analyzer provides tools for data browsing, grouping, analysis, user-defined reprocessing and export. Multiple clients can be connected to the database, with different privileges assigned based on a built-in authentication mechanism. A SMS and mail notification service is integral part of the complete phenotyping system.





PlantScreen™ Compact Systems

PlantScreen™ Compact System is conveyor-based integrated robotic solution designed for digital phenotyping and cultivation of small and mid-size scale plants up to 40 cm in height (*Arabidopsis thaliana*, strawberries, turfgrass, young soybean, tobacco, corn plants, etc.). Automated transport of plants is carried out on trays that can be adapted to carry different patterns for single or multiple plants grown in individual pots or in vitro (e.g. multiwell plates) providing flexibility of use with numerous different species, or with a single species throughout its growth cycle. Multi-sensoric digital data are acquired typically from top and side views.

The PlantScreen™ Compact System is designed for the automated plant handling, plant imaging and the precise irrigation scheme at the level of individual plant or group of plants. The configuration is optimized for the controlled environment and greenhouse applications and can be customized in terms of throughput and range of integrated digital sensors according to the research needs. The system is modular and designed so that additional features may be added as the user's screening requirements evolve.

Sensors available for the PlantScreen™ Compact System are:

- RGB digital color imaging
- Kinetic chlorophyll fluorescence imaging
- Hypespectral imaging in visible and/or near-infrared region
- Thermal imaging
- 3D Scanning and modelling
- Near Infra-Red (NIR) imaging

The platform may incorporate various modules for digital analysis of plant growth dynamics and physiological performance, an acclimatization chamber that may be used to equilibrate plants under controlled conditions, or for plant cultivation, and a transportation system for automated delivery of plants to the imaging stations. An external transportation system and/or loading station can be implemented to move plants between a cultivation area and compartment with imaging stations. Combined weighing/watering station is implemented for precise irrigation or nutrient delivery schemes. Unique QR-code or RFID identifiers are used for plant identification.

Key feature for high-throughput and reproducible plant phenotyping is control of suitable growth conditions, maintenance of precise irrigation regime and adaptation of plants prior physiological phenotyping. Equilibration of plants to user-defined environmental conditions prior phenotyping is critically important when imaging leaf temperature and chlorophyll fluorescence kinetics, since data are dependent on irradiance conditions.

PlantScreen™ Compact System can be implemented inside of high-capacity growth chambers to allow program controlled growing conditions, with accurate measurements and regulation of temperature, irradiation cycles and relative humidity. Additional LED lightning solutions can be implemented to improve lighting regime of the plants grown in greenhouse environment. Light and dark adaptation tunnel for plant acclimation prior physiological phenotyping is key feature of our phenotyping platforms.

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Adaptation tunnel consists of multichannel LEDs with programmable interface for defining desired light regime and spectral quality. The precise setting of light intensity is programmable in smooth steps, with the maxima of $2,000 \mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$.

High-precision irrigation system is integral part of the system for programable delivery of both water and nutrients to the plants throughout growth and/or measurement cycles. Watering and nutrient delivery may be combined with automated weighing of plants in pots so that specific watering regimes may be programmed in software. These regimes may be used to impose drought stress or waterlogging of varying degrees of severity, imposed rapidly or gradually. Schemes for watering to exact volume, relative volume or predefined weight can be pre-defined for single plants or groups of plants.

Furthermore pack of environmental sensors (humidity, temperature, light intensity, light quality) is available for the PlantScreen™ Phenotyping Systems. The physiological parameters deduced from the measurements acquired by imaging units can be correlated with the environmental parameters acquired from a number of environmental sensors implemented within the phenotyping unit.

Comprehensive software package has been developed for system control, data acquisition, image analysis and data base configuration. User friendly graphical interface is designed to control all hardware system components actions, to control and monitor environmental conditions and to design experiments with an extremely high level of flexibility. High-end industrial PC with touch screen is used for system control.

Scheduling assistant with calendar function allows running multiple experiments simultaneously, provides different modes for experiment randomization, for treatment per plant or group of plants with different experimental protocols and plant handling regimes including dark/light adaptation or watering or nutrient delivery schemes.

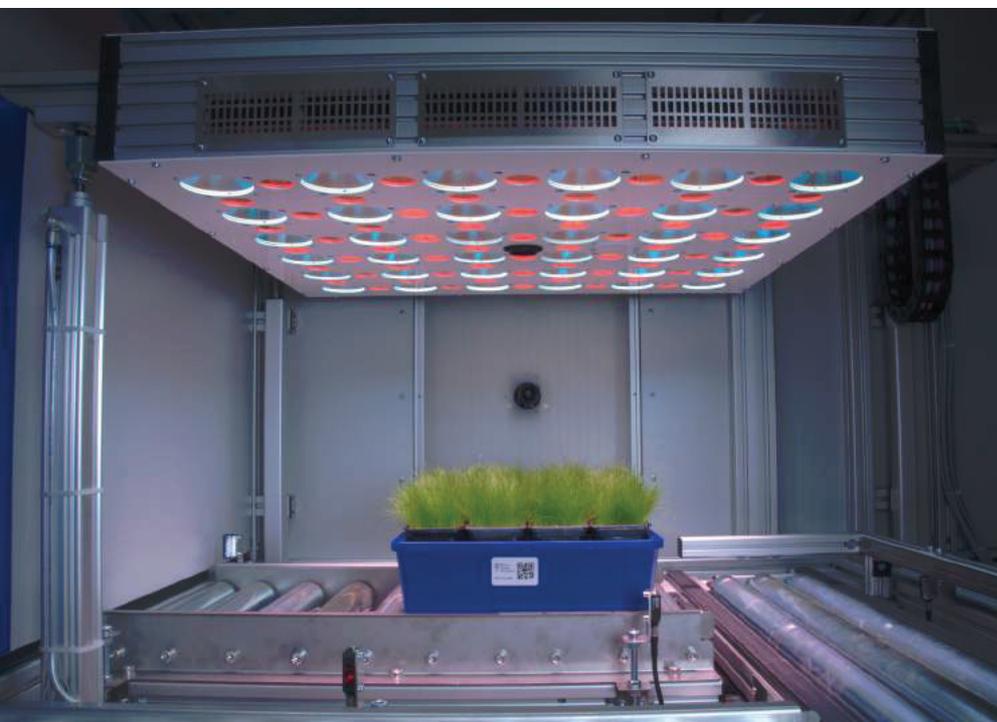
All acquired imaging, environmental and watering/weighing data are stored in an SQL database, processed and available for inspection and further analysis in range of seconds after recording via user-friendly graphical interface. PlantScreen™ Analyzer provides tools for data browsing, grouping, analysis, user-defined reprocessing and export. Multiple clients can be connected to the database, with different privileges assigned based on a built-in authentication mechanism. A SMS and mail notification service is integral part of the complete phenotyping system. 24-hour online support service is key component of the PlantScreen™ phenotyping solution.

KEY FEATURES

- Plant-to-sensor concept
- Multiple imaging sensors
- LED light/dark adaptation chamber
- Flexible transportation tray format
- Precise irrigation schemes
- Suitable for phenotyping of small up to mid-size scale plants
- Modular customized solutions
- Open database structure
- Integrated environmental sensors
- Comprehensive software package

SOFTWARE

- Comprehensive software package for system control, data acquisition, image analysis and data base configuration
- Randomization of measurements
- Species specific analysis
- Open database structure
- Remote access
- Automatic SMS and email notification service
- Online environmental monitoring
- 24-hour online support service





PlantScreen™ Modular Systems

PlantScreen™ Modular System is integrated robotic solution for high-precision digital plant phenotyping and plant cultivation of larger plants like maize, rice or wheat throughout the entire life cycle. Single pot is placed in a transport disk, which can be equipped with different types of inserts to accommodate pots of different sizes.

The system can be integrated in existing greenhouse or semi-controlled environment. Single-pots are in transportation disks carried from cultivation area towards imaging units and irrigation stations. The inner disk format is modular providing flexibility of use with numerous different species, or with a single species throughout its growth cycle. Multi-sensoric digital data are acquired typically from top and side views.

The equipment is designed for plant cultivation and growth, plant management, automated movement, monitoring of environment parameters and plant randomization in the growth buffer. Area for manual loading of plants into the system is implemented which allows manual loading and scoring of a subset of plants while automated scoring is in stand-by or waiting mode. This feature allows the user to test, analyse and score for a subset of plants

while other plants are growing on the buffer and are scored in automated mode for example ones a day.

The configuration is optimized for semi-controlled environment and greenhouse applications and can be customized in terms of throughput and range of integrated digital sensors according to the research needs. PlantScreen™ Systems are complete phenotyping solutions used for plant handling and non-invasive comprehensive and reproducible assessment of various plant traits throughout the time.

The platform may incorporate various modules for digital analysis of plant growth dynamics and physiological performance, an acclimatization chamber that may be used to equilibrate plants under controlled conditions, and a transportation system for automated delivery of plants to the imaging stations, manual handling zone and to irrigation and nutrient delivery units. Unique QR-code or RFID identifiers are used for plant identification. Plants are cultivated on the transportation buffer system and transported inside and between the cultivation area and rating area with adaptation tunnel and imaging units, and application area with automated weighing and watering

stations. Manual handling zone is defined for plant manual management, sample handling, plant loading or treatment. The phenotyping system incorporates sensors for measurement of ambient conditions including temperature, relative humidity, PAR irradiance and spectral quality of the light.

Key feature for high-throughput and reproducible plant phenotyping is control of suitable growth conditions, maintenance of precise irrigation regime and adaptation of plants prior physiological phenotyping. Equilibration of plants to user-defined environmental conditions is critically important when imaging leaf temperature and chlorophyll fluorescence kinetics, since data are dependent on irradiance conditions.



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PlantScreen™ Modular System integrates light and dark adaptation tunnel for plant acclimation prior physiological phenotyping, which is key feature of our phenotyping platforms. Adaptation tunnel consists of multichannel LED's with programmable interface for defining desired light regime and spectral quality. The precise setting of light intensity is programmable in smooth steps, with the maxima of $2,000 \mu\text{mol.m}^{-2}.\text{s}^{-1}$. Adaptation tunnel is located upstream of the imaging stations. The tunnel is constructed as a light isolated box with double automatic light-tight entrance and exit doors. The adaptation tunnel is designed for both light and dark adaptation of the plants prior reaching the imaging stations. The adaptation tunnel may be designed to accommodate one, or several lines of plants to allow dark or light plant adaptation ranging from a few minutes to tens of minutes.

High-precision irrigation system is integral part of the system for programable delivery of both water and nutrients to the plants throughout growth and/or measurement cycles. Watering and nutrient delivery may be combined with automated weighing of plants in pots so that specific watering regimes may be programmed in software. These regimes may be used to impose drought stress or waterlogging of varying degrees of severity, imposed rapidly or gradually. Water application is gentle, without spillage or splashing of soil, and is adjustable for the different pot sizes. Schemes for watering to exact volume, relative volume or predefined weight can be pre-defined for single plants or groups of plants.

Furthermore comprehensive suite of environmental sensors (humidity, temperature, light intensity, light quality) is available for the PlantScreen™ Phenotyping Systems. The physiological parameters deduced from the measurements acquired by imaging units can be correlated with the environmental parameters acquired from a number of environmental sensors implemented within the phenotyping unit.

Comprehensive software package has been developed for system control, data acquisition, image analysis and database configuration. User friendly graphical interface is designed to control all hardware system components actions, to control and monitor environmental conditions and to design experiments with an extremely high level of flexibility. High-end industrial PC with touch screen is used for system control. Scheduling assistant with calendar function allows running multiple experiments simultaneously, provides different modes for experiment

randomization, for treatment per plant or group of plants with different experimental protocols and plant handling regimes including dark/light adaptation or watering or nutrient delivery schemes.

All acquired imaging, environmental and watering/weighing data are stored in an SQL database, processed and available for inspection and further analysis in range of seconds after recording via user-friendly graphical interface. PlantScreen™ Data Analyzer provides tools for data browsing, grouping, analysis, user-defined reprocessing and export. Multiple clients can be connected to the database, with different privileges assigned based on a built-in authentication mechanism. An SMS and mail notification service is integral part of the complete phenotyping system. 24-hour online support service is key component of the PlantScreen™ phenotyping solution.

KEY FEATURES

- Tailored solutions for large plants
- Multiple imaging sensors
- Turning tables for 360° view imaging
- LED light/dark adaptation tunnel
- Precise irrigation and nutrient delivery schemes
- Integrated environmental sensors
- Open database structure
- Comprehensive software package

SOFTWARE

- Comprehensive software package for system control, data acquisition, image analysis and data base configuration
- Randomization of measurements
- Species specific analysis
- Open database structure
- Remote access
- Automatic SMS and email notification service
- Online environmental monitoring
- 24-hour online support service





PlantScreen™ Robotic XYZ and Transect XZ Systems

PlantScreen™ Robotic XYZ and Transect XZ Systems are designed for plant cultivation and growth, automated movement, monitoring of environment parameters and programmable randomization of plant phenotyping protocol on single and multiple plant level. Automated robotic arm is build above growth space for transportation and delivery of imaging sensors across a given area. Robotic system is moving laterally (X direction), in height (Z direction), and in XYZ systems also vertically (Y direction). The XZ/XYZ arm is operating in sensor-to-plant concept and carries the sensoric module with various imaging sensors directly to the plants where measurements are made based on user-defined protocols.

PlantScreen™ Robotic XYZ System is integrated robotic solution for reproducible high-throughput phenotyping of small and mid-size scale plants (*Arabidopsis thaliana*, strawberries, turfgrass, young soybean, tobacco, corn plants, etc.). The system includes durable construction for growth rooms and greenhouse applications and may be manufactured to cover virtually any area. Plants are usually cultivated on

universal growth tables that can include exchangeable grid format for various types of trays and pots for soil grown plants, it can include holder formats for screening of plants grown in vitro (e.g. in multi-well plates) or optionally hydroponic tables can be used for plant cultivation.

PlantScreen™ Robotic XYZ System may be programmed to move the imaging array sequentially between the pre-defined locations and measure a variety of morphological and physiological parameters in defined intervals. The configuration is optimized for the controlled environment and greenhouse applications and can be customized in terms of throughput and range of integrated digital sensors according to the research needs.

Optional imaging features include stations for:

- Morphometric and RGB Analysis
- Chlorophyll Fluorescence Kinetics Imaging
- Thermal Imaging
- Hyperspectral Imaging in visible and/or near-infrared region
- 3D Imaging

Simplified version of the PlantScreen™ Robotic XYZ System is **Transect XZ Systems**, which automatically scans plants along two meters long transect. Transect System is integrated robotic XZ solution that can be transported e.g. from one greenhouse compartment to other according to the screening needs. Typically, it is used to scan large sets of plants in high throughput screening or it can monitor plants affected by stress gradient. It can also be favorably used for analysis of multiple samples in large growth trays. The most common configuration Transect FluorCam FC 900-TR is usually equipped by Open FluorCam FC 800-D/3535 with high-sensitivity TOMI-1 or high-resolution TOMI-2 CCD cameras and optionally filters and proper lights for GFP imaging or PAR-absorptivity and NDVI reflectance index measurement module can be added. Also RGB camera would be optionally integrated into the Open FluorCam device for obtaining morphometric and RGB analysis too. Transect system can also contain independent RGB Morphometric imaging unit, Thermal imaging unit or Hyperspectral imaging unit instead of chlorophyll fluorescence imaging unit FluorCam.

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PlantScreen™ Robotic Transect XYZ System and Transect XZ Systems can be implemented inside of high-capacity growth chambers to allow for program controlled growing conditions, with accurate measurements and regulation of temperature, irradiation cycles, relative humidity and CO₂ concentration control. Additional LED lighting solutions can be implemented to improve lighting regime of the plants grown in greenhouse environment.

Furthermore comprehensive suite of environmental sensors (humidity, temperature, light intensity, light quality) is available for the PlantScreen™ Phenotyping Systems. The physiological parameters deduced from the measurements acquired by imaging units can be correlated with the environmental parameters acquired from a number of environmental sensors implemented within the phenotyping unit.

Comprehensive software package has been developed for system control, data acquisition, image analysis and data base configuration. User friendly graphical interface is designed to control all hardware system components actions, to control and monitor environmental conditions and to design experiments with an extremely high level of flexibility. High-end industrial PC with touch screen is used for system control. Scheduling assistant with calendar function allows running multiple experiments simultaneously, provides different modes for experiment randomization, for treatment per plant or group of plants with different experimental protocols and plant handling regimes including dark/light adaptation or watering or nutrient delivery schemes.

All acquired imaging, environmental and watering/weighing data are stored in an SQL database, processed and available for inspection and further analysis in range of seconds after recording via user-friendly graphical interface. PlantScreen™ Analyzer provides tools for data browsing, grouping, analysis, user-defined reprocessing and export. Multiple clients can be connected to the database, with different privileges assigned based on a built-in authentication mechanism. An SMS and mail notification service is integral part of the complete phenotyping system.

KEY FEATURES

PlantScreen™ Robotic XYZ Systems:

- Multiple imaging sensors
- Durable XYZ robotic arm
- Sensor-to-plant concept
- Tailored solutions for in vitro or soil cultivations
- Open database structure
- Integrated environmental sensors
- Comprehensive software package

Transect FluorCam FC 900-TR Systems:

- Perfect for high-throughput screening or monitoring plants affected by stress gradient
- Both for outdoor and greenhouse use
- Robust and stable construction with a movable camera and light sources in XZ axis
- No need to detach or move samples
- Standard measured area of 20 × 200 cm can be adapted to different size
- Comprehensive software package
- Optionally multiple imaging sensors

SOFTWARE

- Setting of individual coordinates in X, Z and eventually Y axis
- Randomization of measurements
- Comprehensive software package for system control, data acquisition, image analysis and data base configuration
- Species specific analysis
- Open database structure
- Remote access
- Automatic SMS and email notification service
- Online environmental monitoring
- 24-hour online support service





PlantScreen™ Field Systems

PlantScreen™ Field Phenotyping Systems are mobile platform for fast and accurate crop phenotyping in the field. **PlantScreen™ Field System** is an drive pivot tower with multiple sensor modules mounted on XZ-robotic arm. System is automatically moving over field plots at speed that ensures high throughput. Active sensors are used for accurate monitoring of numerous physiological and morphological plant parameters that are time- and location-referenced. Configurable environmental monitoring system is integrated. A comprehensive software package, with remote accessibility, is used to control all aspects of the system and sensor modules, as well as for data acquisition, image analysis and data base configuration.

The sensor platform may include devices for hyperspectral imaging, chlorophyll fluorescence kinetics imaging, thermal imaging and for morphometric and canopy analysis. These active sensors are used for accurate monitoring of numerous physiological and morphological plant parameters that are time- and location-referenced. Environmental sensors monitor irradiance, air temperature, relative humidity, wind speed, and other

conditions at each position in the plot where phenotyping measurements are made.

PSI's PlantScreen™ software allows the user to program movement of the system for automated deployment in the field. All measured morphometric,

biochemical and physiological measurements are collated with environmental measurements at each screening location, and may be accessed and analyzed remotely.

PSI's PlantScreen™ field systems allow the user to monitor numerous aspects



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of plant growth, development and response to biotic and abiotic stresses in the plants' natural environment.

The field systems are designed and configured to meet the users' specific requirements with respect to the size and morphology of plants screened. Every component of the field systems is designed to withstand the severest weather conditions, and to operate flawlessly.

Comprehensive software package has been developed for system control, data acquisition, image analysis and data base configuration. User friendly graphical interface is designed to control all hardware system components actions, to control and monitor environmental conditions and to design experiments with an extremely high level of flexibility. High-end industrial PC with touch screen is used for system control. Scheduling assistant with calendar function allows running multiple experiments simultaneously, provides different modes for experiment randomization, for treatment per plant or group of plants with different experimental protocols and regimes.

All acquired imaging, environmental and watering/weighing data are stored in an SQL database, processed and available for inspection and further analysis in range of seconds after recording via user-friendly graphical interface. PlantScreen™ Analyzer provides tools for data browsing, grouping, analysis, user-defined reprocessing and export. Multiple clients can be connected to the database, with different privileges assigned based on a built-in authentication mechanism. An SMS and mail notification service is integral part of the complete phenotyping system. 24-hour online support service is key component of the PlantScreen™ phenotyping solution.



▼ KEY FEATURES

- Robust autonomous system
- Multi-functional sensor platform
- Durable XZ robotic arm
- Environmental monitoring
- Open database structure
- Integrated environmental sensors
- Sensor-to-plant concept

▼ SOFTWARE

- Comprehensive software package for system control, data acquisition, image analysis and data base configuration
- Species-specific analysis
- Open database structure
- Remote access
- Automatic SMS and email notification service
- Online environmental monitoring
- 24-hour online support service





PlantScreen™ Phenotyping Systems in Controlled Environment

PSI designs and builds high-capacity growth chambers (FytoScopes) which allow researchers to program controlled growing conditions, with accurate measurements and regulation of temperature, irradiation cycles and relative humidity. Phenotypical monitoring of plants in controlled and programmable environment provides the opportunity to monitor plant growth and plant physiological status in precisely defined and reproducible conditions. This is of great advantage when monitoring growth performance and physiological status of the plant in response to biotic or abiotic stress conditions during different developmental stages. Plants can be grown in the controlled environment throughout the full life cycle.

The walk-in growing chambers FytoScopes may contain either conveyor-based or robotic imaging systems, or may incorporate conveyor systems that transport the plants from the FytoScope to the PlantScreen™ imaging system. The FytoScope chambers allow the user to set a range of programmed day/night cycles with wavelengths and other conditions

regulated for dawn/dusk transitions and to control precisely temperature and humidity. Automatic watering, weighing, dosage solution application and transport to dark or light adaptation chamber prior phenotyping unit can be programmed based on user-defined requirements.

The design of the FytoScope controlled environment chambers is modular and constructed based on user-defined requirements concerning dimension and environmental control specifications. FytoScope enables the researcher to maintain controlled growing conditions of temperature and humidity with independent selection of photoperiods.

Multifaceted programming options enable researchers to simulate natural conditions and to define a full range of “day/night” cycles with “dawn/dusk” or “cloudy sky” effects. For user convenience both actual inside conditions and target values for temperature, lighting and relative humidity are permanently displayed on the touch-screen controller, which is conveniently situated on the front side of the FytoScope. The controller allows a wide range of user programmable options to be selected. Displayed is also graphical representation of actual conditions inside the FytoScope. All data can be downloaded to a PC or controlled remotely.



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