Phenomobile: a fully automatic robot for high-throughput field phenotyping of a large range of crops with active measurements

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Abstract

High-throughput phenotyping data acquisition in the field is highly required to provide breeders with a set of accurate and heritable traits for the evaluation of the genotypes performances. An entirely automatic robot was developed, called Phenomobile, able to sample with a 100-200 plots/hour throughput using a 12m long telescopic arm moving from 1m to 4m height. The vehicle is mounted on caterpillars to operate under difficult soil conditions. The measurement heads include LiDARS, high resolution RGB cameras and multispectral cameras used in active mode with flashes. The phenomobile is driven by RTK-GPS with centimetric accuracy. Sensors are automatically triggered according to a predefined mission, and the data stored under standard format for easy processing. Fist results and conclusions are given in this paper.

Keywords: Field phenotyping, Remote Sensing, Robot, Unmanned Ground Vehicle.

1 Introduction

Acquisition of phenotyping data in field conditions is mandatory to support breeders with pertinent information on the performances of the genotypes. Although UAVs allow to characterize the genotypes with a number of traits, their application is often limited to some of the traits requiring either very high resolution imagery, high power consumption or heavy payload sensors. Further, UAV observations are mainly completed in passive mode, making the measurements sensitive to the illumination conditions prevailing during the data acquisition. Finally, flying UAVs might be limited by local regulations. Although associated with a lower throughput, Unmanned Ground Vehicles (UGV) is a versatile solution that carries a number of sensors operating in active mode from very low distance to the canopy allowing to record very high spatial resolution images. This paper presents a UGV called Phenomobile, that was specifically developed to sample a range of crops including tall crops such as sunflower or maize and crops that fills rapidly the interval left between two consecutive plots such as rapeseed or peas.

2 Description of the phenomobile

The phenomobile is made of three main components: (1) the vehicle, (2) the measurement head and (3) the data acquisition system.

a. The vehicle

The platform weigh eight tons (Figure 1). It is equipped with four caterpillars allowing to operate even under difficult soil conditions with limited damage. The platform can rotate 360° along a vertical axis above the caterpillars. It supports the diesel engine with 8 hours autonomy that runs both the hydraulic and electric units. The 12 m telescopic boom can raise the measurement head from 1 to 4 m height. A cockpit allows an operator to ensure the security when the regulations do not authorize a full autonomous driving. The vehicle is running on the alleys, making stops on specific positions to sample a group of 1 to 12 microplots on both sides of the alley. The throughput is in between 100-200 plots per hour depending on the plot size.

Figure 1. The phenomobile with caterpillars showing the 12m long boom supporting the measurement head.

b. The measurement head

The measurement head (Figure 2) is made of two units: one looking vertically, the other looking at a given incidence angle from the side. The two units are positioned to sample approximately the same crop volume. Each unit is equipped with LiDARS, high resolution RGB cameras and multispectral cameras. The cameras are operated in active mode using powerful flashes, making the measurements fully independent from the illumination conditions.

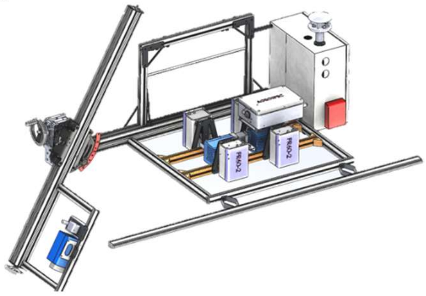

Figure 2. The measurement head with its vertical and side units. Each unit includes LiDARS (in blue), RGB and multispectral cameras operated with flashes. The white box on the right hosts the acquisition system.

c. The data acquisition system

The acquisition system is run by a PC using the ROS operating system dedicated to robotics. The acquisition system triggers the measurements that are then recorded in HDF5 format along with all the metainformation required to ensure FAIR principles in data management, including position and time stamp. The system is driven by phenoIHM (Figure 3), the application that defines and runs the mission.

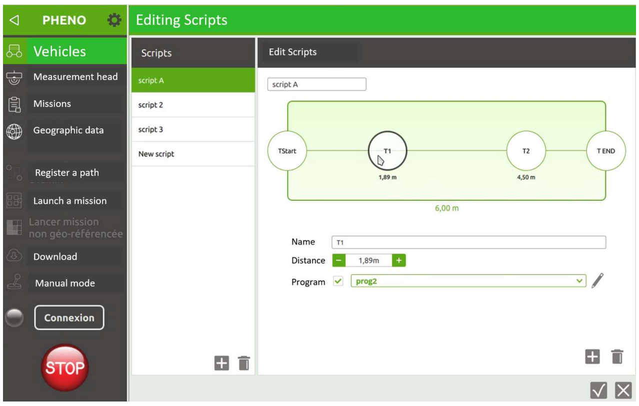

Figure 3. One typical page of the "phenoIHM" interface used to define a script for a given microplot.

A mission corresponds to a measurement session, i.e. the sampling of a group of plots completed at a given date/stage along the growth cycle. It is therefore necessary to define the vehicle and measurement head used, with all the settings of the sensors. The trajectory (path) of the vehicle is then defined, with the several stops required to sample the plots considered. Then the script that describes the set of measurements to make on a given plot is defined by the start and stop positions (beginning and end of the plot) and all the positions where images are shot (Figure 3). Several tools help to define the mission by automatically repeating a script for a large number of plots. Once a mission is defined, it can be run automatically up to its completion. Warnings and a log file allows to control the quality of the measurements both in real time and after the mission ended.

3 Sample results and conclusion

The phenomobile started to operate in 2017 in Toulouse and two more copies are currently operating in Clermont and Montpellier. First results indicate a very good accuracy (Figure 3) due to the high spatial resolution available and the independency from the illumination conditions. Further, a very high repeatability (Figure 3) is also achieved allowing to get high values of heritability (Figure 4) and very good time consistency.

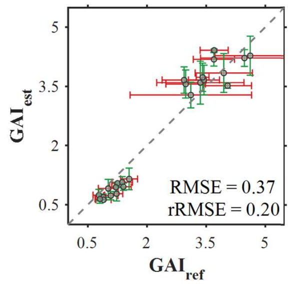

Figure 3. Comparison of phenomobile derived GAI trait as compared to reference ground measurements. Data from Greoux experiment on wheat conducted in 2018.

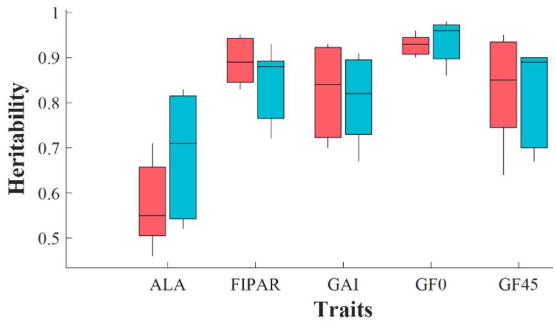

Figure 4. Heritability levels reached for several structural traits (Average Leaf Angle (ALA), Fraction of light intercepted (FIPAR), Green area index (GAI) and green fractions at 0° (GF0) and 45°(GF45)) derived from the Phenomobile over a wheat experiment in 2018 in Gréoux with well-watered (red) and water-stress modalities.

It is concluded that the phenomobile is a very efficient system for a detailed monitoring of structural traits. It is further possible to easily add sensors to access new traits, particularly those benefiting from active measurements difficult to make from a UAV platform.

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