plantFEM: A Numerical Platform for Multi-physical Simulation of Plants

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Keywords: cyber agricultural system, numerical simulation, multi-physics, open-source software

Abstract: It is vital to introduce real-world physical constraints into cyber agriculture systems in order to realistically simulate how crops grow on a farm. The physical quantities with which plants interact are enormous (Dupuy et al. 2010). Even just focusing on the morphogenesis, there are a large number of degrees of freedom for each material point, such as displacement (Tsugawa 2020), velocity/acceleration (Bizet et al. 2018), stress/strain (Hamant et al. 2008), and pore pressure (Ndour et a. 2017) fields. Consequently, there is a need for a platform to accept and organize models of various phenomena related to plant growth proposed by professional researchers in each field. We have developed a software to simulate four-dimensional cyber-agricultural systems with **plant**s described by system of partial differential equations and implemented based on the **F**inite **E**lement **M**ethod (**plantFEM**) as shown in Fig. 1, where FEM is a well-known scheme to implement partial differential equations (Gockenbach 2006). It also has a pre-processing library to build mesh-models of plants from the 2D or 3D imaging data, allowing the user to seamlessly create input data and check analysis results. We conducted two basic benchmarks; generation of cyber soybean canopies and a simulation of its mass measurement. Each soybean individual is about R1 in growth stage, with an average main stem length of 80 cm, 3 branches, and 29 total nodes. We measured the performance using two cases, Case1: single-threaded computation and Case2: computation with HPC cluster (110 CPU-cores), to confirm whether the simulation speed is fast enough. From the results, the simulation was completed in 0.790 seconds per plants in Case 1 and 0.017 seconds in Case 2. The rendered view of a plot in the cyber soybean field is visible in Fig. 2. Above all, under the standard population density in Japan (9.3 pl/m^2), it took 20 hours to create or update a 1-ha cyber soybean farm on a single-threaded laptop PC and 27 minutes on a 110-core HPC cluster. It is confirmed that statistically sufficient number of individuals can be generated in a reasonable time.. We plan to use accelerators such as GPUs and vector processors to speed up the simulations and conducting physical simulations such as lodging, photosynthesis, and canopy growth.

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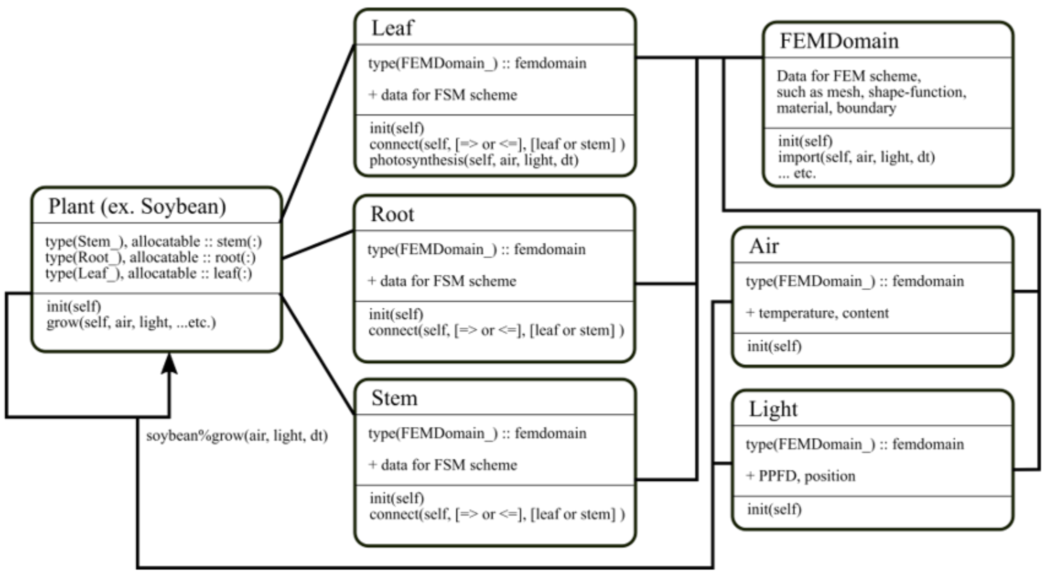

Figure 1: Class Structure and Module Inheritance Relationships in plantFEM. The FEMDomain class is used to define finite element meshes, and LeafClass, RootClass, and StemClass inherit from the FEMDomain class to generate individual leaves, root nodes, and stem nodes. In addition, crop objects are generated by combining these organ objects. Objects related to the environment, such as air, light, etc., are referenced during simulations to update physical configurations of crop objects.

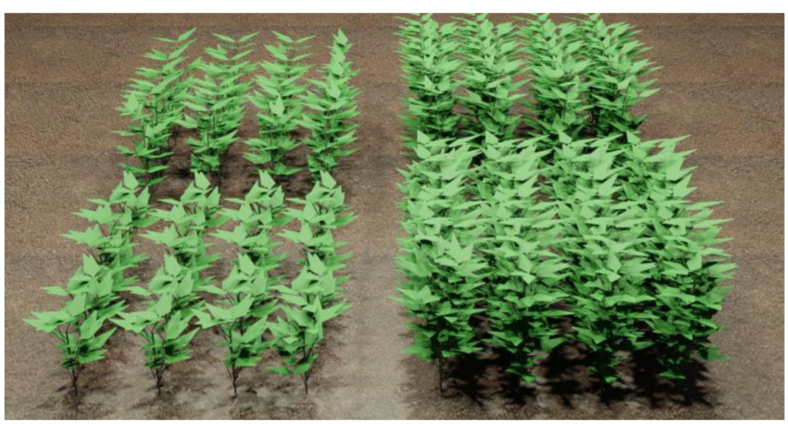

Figure 2: Cyber soybean populations generated by the plantFEM in the benchmark. The size and curvature for each leaf, stem and root node are generated probabilistically according to a normal distribution by giving means and standard deviations.