Multiple single-axis robots for automated grafting machine supplying

**Introduction**

Recent European Community directives have increasingly limited use of pesticides and chemical fumigants to counteract soilborne pathogens. The adoption of disease resistant grafted plants (as e.g. tomatoes or peppers) can be an efficient option, even if this technique is labour consuming and involves tedious repetitive actions. These aspects encourage the development of automated machines, in order to:

1. increase the productivity and the rooting success rate
2. reduce costs, allowing grafting to be more economically sustainable.

**Plant description**

In this prototype, the grafting operation is performed by a single core unit (Belforte & Eula, 2012) where a scion and a rootstock, conveniently provided by the automatic supply system here described, are processed. The supply system is constituted by a single rail, on which six independent motorized modules (sliders) can move, allowing shoots to be processed at the several working station of the machine.

Each slider consists of a stand able to hold one seedling, coupled to the guide rail by a bracket and a recirculating ball chassis, as described in the figure above. A stepper motor that engages on a timing belt by a pinion provides the driving force to the module.

**Grafting process**

The machine is fed with shoots, both for obtaining scions and rootstocks. A handling system is devoted to pick seedlings by needle-pliers from trays and place them into the sliders, conveniently positioned at the receiving position on the rail. Shifting along the rail, sliders make shoots available for classification, by the computer vision system, and then consistently to the grafting module in two different positions, one for scions and one for rootstocks. The same slider receives completed grafted seedlings and move them toward a second handling system devoted to place them on the outgoing tray, completing the entire process.

Since incoming seedlings can differ in stems size, the computer vision system is adopted to classify the shoots in two (or more) size classes. After classification, the supply system has to be able to move a scion and a rootstock of the same class to the loading position of the grafting unit.

**Optimal system design**

The optimal design of the system, in terms of number of single-axis robots and control strategy principles has been performed with the goal of maximize the throughput of the machine and minimize the occurrence of scions and rootstock mismatches, with the aid of an ad hoc discrete-events simulation tool, developed in Matlab®. Thirty minutes long working sessions of the supply system has been simulated with a number of independent sliders ranged from 2 to 7. Table above shows performances indexes in terms of number of grafted seedlings processed per minute and number of shoots discarded because of unmatching characteristic. Results of simulations adopting both control logic that explore one-step-ahead and two-step-ahead movements configurations were presented. Production rate increase with the number of sliders, achieving a maximum value of 12.1 grafted seedlings per minute with six independent sliders.

**Control algorithm and motion planning**

The control algorithm is devoted to planning the best combination of sliders movement, in order to timely serve the stations of the machine during grafting operations. This goal is achieved using an optimization procedure that generates, at each step, all possible movement combinations and discern among all these feasible solutions of the problem the most performing one. Each feasible solution within this domain is evaluated computing a cost function that mainly depends on the distances of the modules from target positions. Distances are properly weighted in order to assign different priorities to the operations (for instance, supplying shoots to the grafting module or retrieve grafted seedlings were considered as high-priority tasks) and to privilege some sliders for a specific operation. An improvement of the proposed approach consists in exploring possible sliders configurations at more than one step ahead.