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Sprayin' with Brain

Executive summary

Italian agriculture has always been recognised worldwide as an excellence; in particular, in the last year, the **IV Gamma** supply chain, with the use of **greenhouses**, has showed its increasing relevance.

Being a relatively niche market, innovations tend to arrive with a certain delay, causing backwardness in the employed technologies and procedures. An example is the **phytosanitary treatment** which is highly **inefficient**: most of the product is wasted, finishing on the ground, contaminating groundwaters, damaging the soil, and making it less productive for the future.

The **goal** of our project is to **renew** the phytosanitary process, making it **optimal** for the greenhouse treatment and reducing the overuse of chemical products.

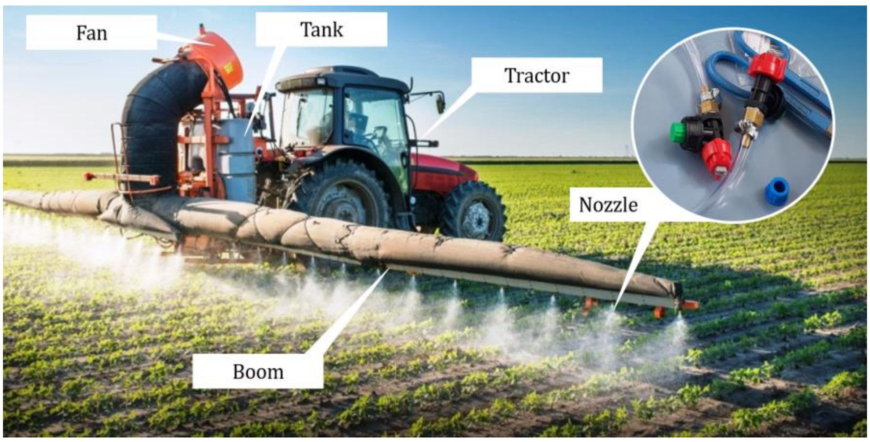
Our idea relies on three main aspects, **movement**, **sensors** and **advanced boom**; which compose the *real-time intelligent treatment machine,* an agricultural machine of new generation that is able to carry the treatment in autonomy, exploring and analysing in real-time the characteristics of the plants, and modifying its configuration to optimize the treatment.

The expected outcomes of adopting our solution are twofold:

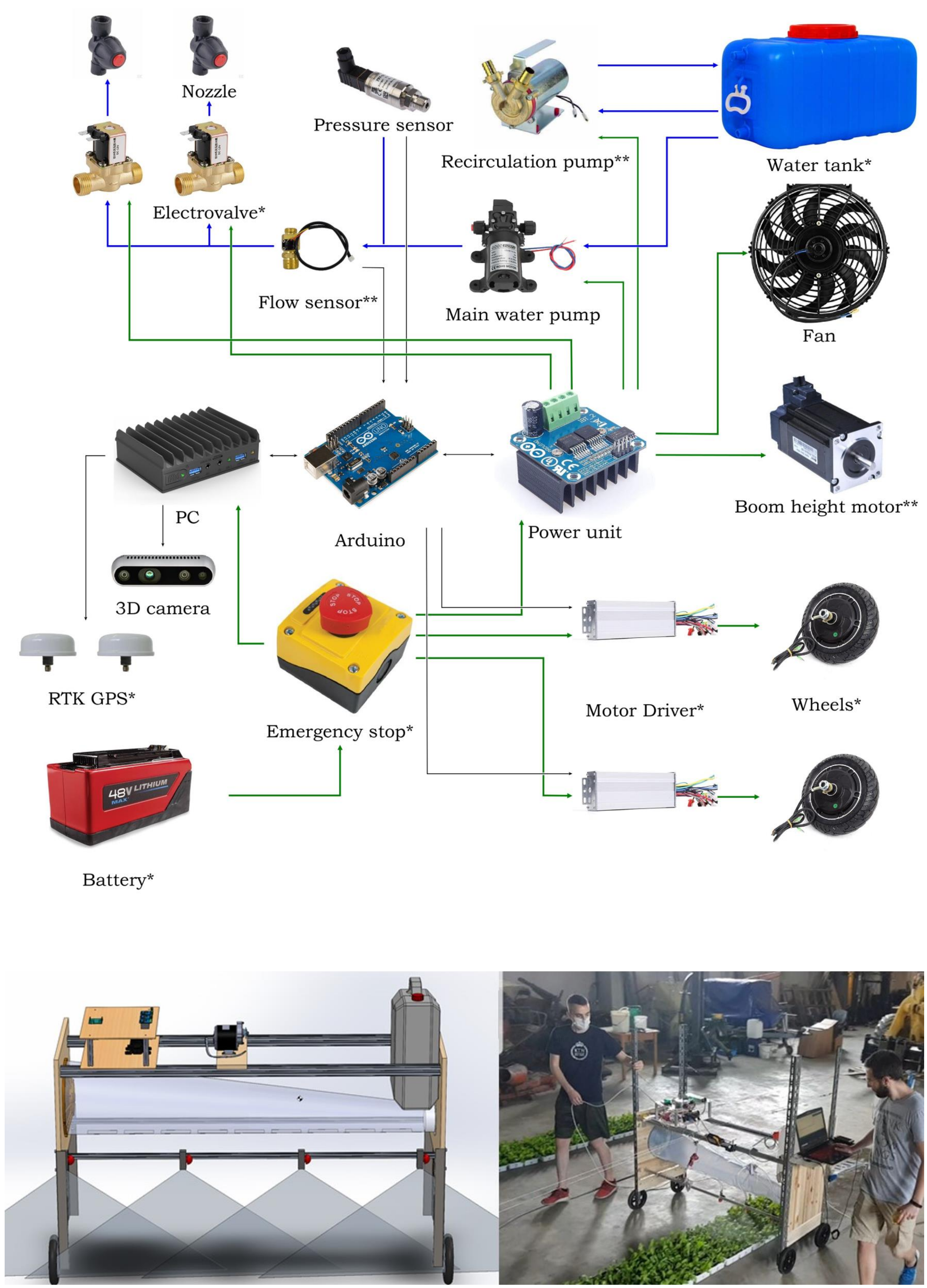
- A **reduction** in the operating **costs**, in particular labour, phytosanitary and fuel, making this idea a profitable one.
- Positive **environmental benefits**, such as the reduction of energy usage and the savings of CO_2 emissions, water, and phytosanitary products.

Key Words

- Smart agriculture
- Phytosanitary treatment
- Greenhouse farming
- Automated rover
- Computer vision



Today's agricultural machine



Solution's P&ID schematics, CAD model of the prototype, and its realization

Project description written by the Principal Academic Tutor

Sprayin' with Brain aims at increasing the sustainability and efficiency of the phytosanitary treatment in agriculture by applying techniques from robotics and artificial intelligence. A **data-driven** approach has been applied to personalize the treatment of crops in greenhouses according to the input provided by **vision sensors**, in order to drastically reduce the usage of chemicals while maintaining the effectiveness of the treatment. The initial focus of the project was on Italian greenhouses specialized in the production of the so called "IV gamma" groceries, i.e., ready-to-eat salads, and it has evolved though four steps.

- At first, students have conducted an investigation on the **state of the art** in greenhouses phytosanitary treatments, including both a literature review and on-field visits to stakeholders. The purpose of the literature review was to understand current techniques and regulations in phytosanitary treatments, while the field visits were focused on understating stakeholders' needs and requirements.
- Once the possibilities and limits were well understood, the team has produced and evaluated a wide range of **possible solutions** including monitoring the greenhouse to decide when to treat, a digital solution for the supply chain to decide what to treat, or a sensing and actuation system to decide how to treat.
- It was then decided to focus on the **concept** of an autonomous rover, adjusting the treatment parameters (coverage, droplet size, the position of the spraying nozzle) according to real-time data of the vegetation as acquired via computer vision. A **prototype** implementation was built and tested on the field with the support of external tutors from the Department of Agricultural and Environmental Sciences of Universita' degli Studi di Milano in order to validate the idea and understand its main limitations.
- The evaluation of prototype performance and a cost analysis of the complete sprayer solution have led to a study about the business **sustainability** of the product.

Team description by skill

The team is composed of six members, three of which have a **mechanical background.** This aspect was of particular importance in the first stages of the project, since it helped us defining the approach to our solution: detailed knowledge of dynamic systems, hydraulic systems and CAD modelling led us to develop, first a model, and then a prototype of a new kind of agricultural machine.

Another aspect that allowed us to accomplish our idea was our knowledge of the electronic system. Some of us have a background in the **electronic field**, while others have simply a great passion and **initiative**; thank to that, it was possible to choose the right components and mount them together in order to drive and control the mechanical parts of the system. Considering the **control part** of the system: two of us have deepen our study in the mechatronic systems and in the control theory, nevertheless, the help of other members of the group that had experience with Arduino was crucial to develop a good control algorithm.

Our skills also include the knowledge and understanding of some **programming languages** such as MATLAB, Python, and C++. All of them were used for the analysis of different scenarios: image processing, depth analysis, data recording, data analysis.

Then, the presence of a **management engineer**, was essential for the cost analysis and the business model for our solution, producing a complete evaluation of the possible revenues.

Goal

The main goal of the project is to make phytosanitary treatment in greenhouses, and more broadly agriculture, more sustainable. To obtain this goal two metrics were considered: **chemicals** and water usage, and secondarily **energy** consumption. Potential reduction of respectively 50% and 80% were found possible in the preliminary analysis. Reducing the use of chemicals improves both: the quantity of product on the ground, and therefore aquifer pollution, and the quantity of product on the plant increasing food safety. The key to maintain the **treatment effectiveness** is to distribute more uniformly the product on the plant, reaching the lower page of the leaf in an effective way was considered crucial for the success of the project. The reduction in energy consumption is a less specific but still important metric for sustainability.

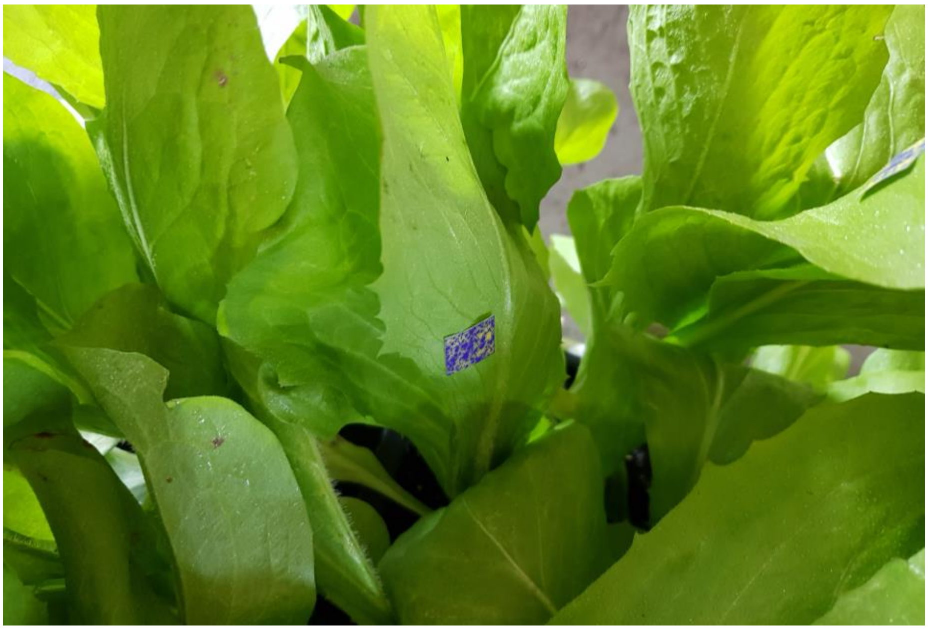
To make the product appealing to the final user the goal of **cost reduction** was considered in every part of the project. The metric selected to measure the success in this goal is the **payback time**. A low payback time can help reduce the customer resistance to change, that is the biggest difficulty expected for the commercial success of the product, making also feasible alternative financing options.

Understanding the problem

Agriculture has always been a fundamental science and activity for a country, being the base of its primary economy. However, despite the importance of cultivations, the technology employed has always been behind most of the other sectors, leaving large space for possible **improvements.** The focus of this project is on a specific area of agriculture, particularly affected by the lack of technology adopted: greenhouses. Indeed, most of the actual research targets only problems regarding the open-field crops, which are considerably different from the covered case. As a consequence, the machines used in greenhouses are adapted from the different open-field applications, causing excessive tractor **pollution** and **inefficiency** of the crops' treatments. One of the major costs and environmental impact of greenhouses' production is linked to the use of phytosanitary treatments, which is the procedure of killing, inactivate, or remove pests from crops through the distribution (spraying) of chemicals. Italian agriculture has the highest use of phytosanitary products in Europe, with more than 140,000 tons each year (33% of all Europe usage, while contributing to less than 20% of the production). By contrast, the European Union has set of major goal to reduce by 2030 the use pesticides by -50%, leading to a necessity of improvements in sustainability and efficiency for greenhouse treatments.

Focusing on the particular area of phytosanitary treatments, there is a clear problem that causes most of the chemicals impact and inefficiencies. During a treatment, the product is distributed on the plants through the use of nozzles attached on a bar, supported by the tank filled with the treatment's liquid and moved by a tractor. Ideally, the droplets sprayed should impact only the plants, guaranteeing a **uniform coverage** of both upper and lower page of all the leaves, however most of the product is wasted in the soil. This huge inefficiency considerably impacts the **costs** of each treatment and the lost water and chemicals constitute, along with the tractor emissions, the major **environmental impact**. Moreover, a minor part of the droplets can be lost in the air, exposing workers to safety issues.

Output of the computer vision algorithm.



Hydro-sensitive paper after the treatment, coloured in blue where water impacted.

Exploring the opportunities

Only 50% of the treatment effectiveness is related to the chemical product used, while the rest depends on correctly choosing what, how, and when to treat, leaving space for possible improvements. Indeed, currently used machine are static and adapted from the open-field; there is no concern about the plants' condition when the treatment is performed and always the same parameters are used, leading to an inefficient distribution. As a consequence, there are plenty of possibilities to design **sensors** able to analyse the current state of the plant, in real-time or along larger time periods, so that the perfect treatment conditions can be set-up. Moreover, controllable **actuators** can be used to adjust the available spraying parameters to the most efficient ones.

In addition, a large part of the environmental impact and costs of a treatment is related to the use of tractors. However, there are already some developed **autonomous** machines that can perform open-field treatments, opening the possibility for similar concepts tailored to the greenhouse's environment. One of the major benefits would be the complete **electrification** of the treatment, that would enable wider control possibilities on the treatment and a zero-emission motion.

Generating a solution

Among all the areas of improvement, the most promising one was found to be a smart **rover** that can adjust in real-time the spraying parameters, according to the data provided by a 3D **computer vision** system. This solution can bring, with a relatively small investment for the user, significant environmental advantages, and cost savings. In addition to the reduction in the usage of phytosanitary, an electric rover would be much lighter with respect to state of the art solutions, thus requiring less energy for its movement, and corresponding reduced operating expenses. The autonomous driving capability would allow additional savings by reducing the operator workload by 30%.

In order to assess the performances of the proposed solution, a simplified **prototype** was built. A total of **37 tests** were carried out, each one with a different combination of parameters, to find the most promising combination for the different plant conditions, in particular the growth stage. Hydro-sensitive papers were used to study the distribution of the product on the leaves. Due to the large number, almost 3,000, of papers used, an automated algorithm was developed to assess the results. The tests were **successful** since they showed the possibility to maintain the effectiveness of the treatment with less product. However, they also highlighted that, due to the uniformity of the conditions inside the greenhouse, changing the spraying parameters in real-time would allow only marginal benefits. For this reason, the focus of **future work** should be on further optimization of the spraying parameters and the testing of a complete rover that includes the autonomous driving capabilities.

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