LaserPest:
Non-Chemical Substitution of Pesticides

Using innovation for a sustainable Agribusiness

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Impact Statement

The impacts on human health and biodiversity on the use of pesticides are a huge issue, and its real cost probably unknown. An estimated 3 billion tonnes of pesticides are used each year in the world.

Only in the USA the social costs due to the application of pesticides per year have been assessed: In public health, 1.1 billion, pesticide resistance, 1.5 billion, other crop losses caused by pesticides, 1.1 billion; bird losses due to pesticides, 2.2 billion; and ground water contamination 2.2 billion.

The figures provide a dimensional idea of the damage caused by pesticides.

Substitution of pesticides, leading to a 50% reduction of the pesticide use, is a short term goal of the European Union by 2030.

This paper makes an innovative proposal, that is technically feasible, affordable, and could lead to the practical elimination of chemical pesticides.

Reference

A section with references to previous research work is included in the last chapter of this paper. There are many studies and papers published about the use of pesticides, but we have focused on finding reference that is relevant to the LaserPest project only.

The authors are specially interested in the use of non-ionizing, coherent and non-coherent irradiation at certain wavelengths to eliminate pests, and the reference studies cited have a direct relation to the goals of the Laser Pest project.

Abstract

Pesticides are a thread to human health and bio-diversity. They are found in food, wine, and water on many studies. Pesticides are mainly used in advanced economies such the USA and Europe.

In developing countries pesticides have less use, but that is responsible of the loss of harvest as much as 2 to 43% in Brazil, 25 to 43% in Asia and 20% to 90% in Africa depending on the type of crop.

Pesticides accumulate on the soil and are rinsed down by the rain to ground water, contaminating water reserves.

Although there are several initiatives in Europe to cut down the use of pesticides, the reality is that their use is only growing. Facts such climate change are fueling more pests to Europe, and the globalization is leading to pests moving faster than ever.

“Greener” alternatives are being researched, but problems such as pesticide resistance and the unknown long term effects of are still present.

The authors are proposing the use of non-ionizing focused irradiation to eliminate insects, weeds, and molds from crops as a substitution of pesticides. The technology has been proven to be effective in laboratories. In the USA there are commercial weed killing robots based on Laser irradiation to eliminate the use of Glyphosate.

In this paper new technologies such as pulsed laser processing are discussed. They can efficiently eliminate insects, larvae and even eggs from crops without damaging the harvest, with surgical precision.

Computer vision is used to identify and classify the pests, providing selectivity to the treatments and resolving the possibility of harming biodiversity.

Background

The use of pesticides in agriculture has been a subject of debate for decades, as it poses a significant threat to the environment and human health. In response to this issue, the European Union (EU) has been implementing policies to reduce the use of pesticides in the agricultural sector.

The EU's initial efforts to reduce pesticide use began in 1991 with the introduction of the Directive 91/414/EEC, which aimed to harmonize the approval process for pesticides across member states. However, it wasn't until 2009 that the EU set more ambitious targets for pesticide reduction with the adoption of the Sustainable Use of Pesticides Directive (2009/128/EC).

The Sustainable Use of Pesticides Directive requires member states to develop National Action Plans (NAPs) for the sustainable use of pesticides, with the objective of reducing pesticide use and promoting the use of alternative pest control methods. The NAPs include measures such as training and certification for pesticide users, promotion of integrated pest management practices, and the establishment of buffer zones to protect non-target areas from pesticide drift.

In addition to the Sustainable Use of Pesticides Directive, the EU has also introduced regulations to limit the amount of pesticides residues on food and feed products, with the adoption of the Maximum Residue Levels (MRLs) Regulation (Regulation (EC) No 396/2005). The MRLs set legal limits for the amount of pesticide residues that can be present in food and feed products sold in the EU, with the aim of protecting consumers from potential health risks associated with pesticide exposure.

Despite these efforts, the use of pesticides in the EU remains a concern, with some studies showing that pesticide residues are still present in a significant percentage of food samples tested. **(1)**

The E.U. Commission is taking action to reduce the overall use and risk of chemical pesticides by 50% and the use of more hazardous pesticides by 50% by 2030. **(2)**

Significant efforts are required to develop alternatives to critical active substances used in plant protection. Active substances with certain properties defined in Regulation (EC) No 1107/2009 are considered as candidates for substitution. For Plant Protection Products (PPPs) containing these active substances,

Member States are required, when assessing an application for authorization, to evaluate if these PPPs can be replaced (substituted) by other adequate solutions (chemical or non-chemical).

Proposals should target one or more pesticides candidates for substitution in the EU and those pesticides which have been reported to be losing their efficiency due to the emergence of resistant pests.

Therefore, further efforts are needed to reduce pesticide use, and promote sustainable alternatives in the EU agricultural sector. Previous intents failed before and the global warming situation is leading to a stronger exposure to pests that are migrating from warmer climates.

1.- The Use of Pesticides

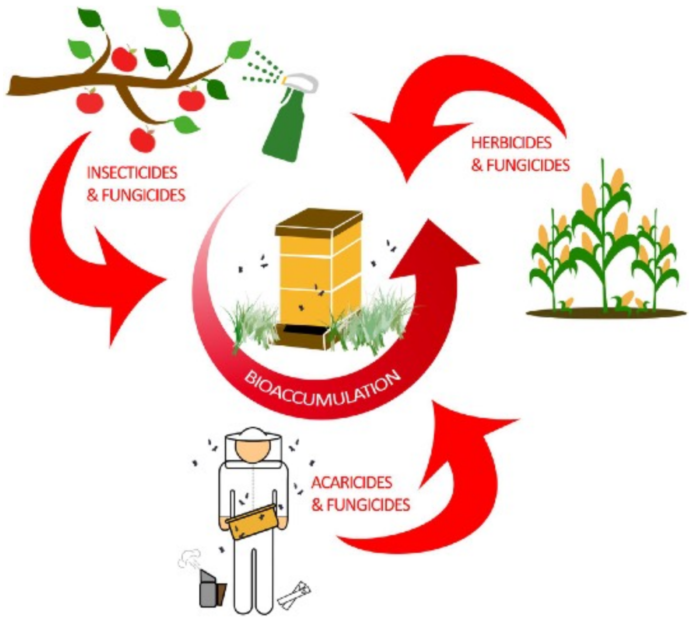
The use of pesticides and herbicides in Europe is creating a soil contamination problem. (3)

The widespread use of pesticides and herbicides in Europe has resulted in a significant soil contamination problem, with detrimental effects on both human health and the environment. These chemicals are typically applied to crops in order to protect them from pests and diseases, but they can persist in the soil for long periods of time, particularly if they are not biodegradable. As a result, the soil becomes contaminated with these chemicals, which can then seep into nearby water sources through runoff, leading to further contamination of rivers, lakes, and groundwater. **(5)**

Polluted fields drain pesticides and herbicides by rainwater into rivers and groundwater, and are present in crops even years after. **(3),(5)**

This contamination can have serious consequences for human health as food consumers.

However for those living near or working on farms where these chemicals are used the health risks are much higher. Exposure to pesticides and herbicides has been linked to a range of health problems, including cancer, neurological disorders, and reproductive issues.



Moreover, the use of these chemicals can have a negative impact on the environment, by reducing soil fertility, and harming wildlife and biodiversity.

Potentially harmful to health pesticide levels are detected in everything from water, fruits, to wine. (4)

Pesticides can have harmful effects on human health, and exposure to high levels of these chemicals has been linked to various health problems, such as cancer, neurological disorders, and reproductive issues.

Studies have found that pesticides are present in various foods and beverages, including fruits, vegetables, and wine, which can be a significant source of exposure to these chemicals. **(9)**

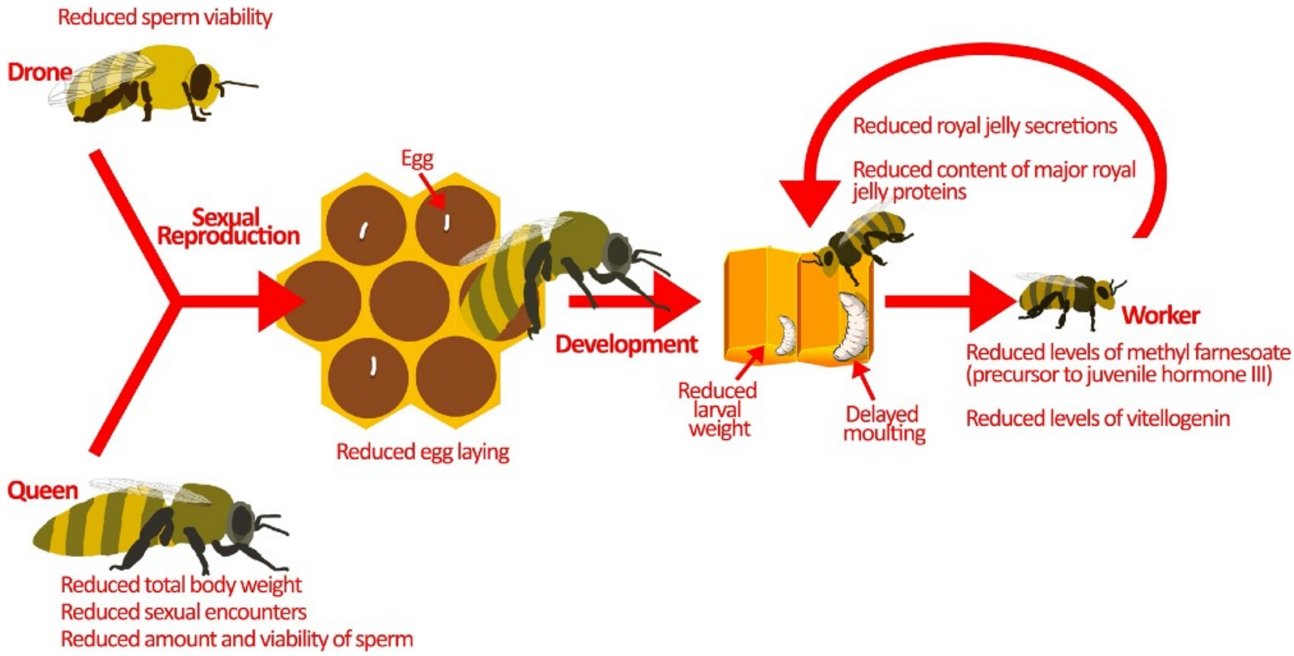
Pesticides can also contaminate water sources, which can have severe consequences for human health if consumed. **(5)**

Bees are specially affected by the use of pesticides.

Pesticides can have a devastating impact on bees and other pollinators. Bees are essential for pollinating crops and ensuring food security, but exposure to pesticides can impair their navigation and foraging abilities, reduce their reproductive success, and even cause death. **(6)**

This is particularly concerning given the significant decline in bee populations in recent years, which has been linked to the use of pesticides in agriculture.

The substitution of pesticides for other “greener" chemical formulations is probably not the best solution. Different publications provide very complex and confusing terms as indicators of such a



greener or less harmful features (7)

While reducing the use of pesticides is essential to mitigate the negative impacts of these chemicals, simply substituting them for other chemicals with unknown long term effects, may not be the best solution.

Many so-called "greener" chemical formulations can still have negative environmental and health impacts.

A more sustainable approach to pest management has been promoted. The integrated pest management (IPM), which combines various pest control methods, such as crop rotation, natural predators, the use of pheromones, and highly selective pesticides, to minimize the use of harmful chemicals while maintaining crop yields.

Additionally, organic agriculture and "bio" practices calls for the elimination of the use of pesticides and herbicides in agriculture.

There are many examples where a substitution herbicide or pesticide that was deemed safe, and later it was discovered to be harmful for health or the environment over the last years.

Over the years, there have been numerous examples where pesticides or herbicides that were initially deemed safe for use were later found to be harmful to human health or the environment. This has led to significant concerns about the safety of these chemicals and the adequacy of regulatory systems in place to protect public health and the environment. Some of the most notorious cases include the use of DDT, which was later found to have toxic effects on wildlife and humans, and the use of neonicotinoids, which have been linked to the decline of pollinators such as bees, or Glyphosate.

The case of Glyphosate (Round up) is an example on how an approved herbicide approved by FDA in 1974 and that was deemed safe for decades was declared seven years ago as "probable carcinogenic" by the WHO (World Health Organization).

In March 2015, the World Health Organization's International Agency for Research on Cancer (IARC) classified glyphosate as a "probable carcinogen" based on evidence that it can cause cancer in humanas (linked with non Non-Hodgkin lymphoma). It caused different diseases in laboratory animals and in humans exposed to high doses. **(8)**

There is a general lack of trust on chemical laboratories that produce tests for the purpose of safety certification approval, that are proven to be biased with the sole purpose of putting new "more sustainable" products to the market.

There is growing concern about the reliability and independence of chemical laboratories that conduct safety tests on pesticides and herbicides. Some critics argue that these laboratories are biased towards approving new products for the market, regardless of their potential health and environmental risks. **(8)**

Additionally, many of these tests are conducted by the same companies that produce the chemicals themselves, raising concerns about conflicts of interest and the adequacy of regulatory oversight. As a result, there is a general lack of trust in these tests and the regulatory systems that rely on them to ensure the safety of these chemicals.

In order to address this issue, many countries in Europe have implemented regulations and policies aimed at reducing the use of pesticides and herbicides, promoting sustainable agricultural practices, and protecting soil and water resources. **(2)**

We are showing a study of pesticide use in France in 2013 with vineyards as an example on how National and European reduction programs are failing.

The research by "Que Choisir", a French consumer group, sampled 92 bottles of French wines, including red, white, and rosé wines from various regions, to test for the presence of pesticides. The results showed that all of the samples contained at least trace amounts of pesticides, and 41% of the samples contained pesticide residues above the legal limit. **(9)**

The pesticides detected included fungicides, herbicides, and insecticides, some of which are classified as potential carcinogens. The research highlights the widespread use of pesticides in French vineyards and the need for stricter regulations and enforcement to ensure the safety of consumers and the environment.

The research found that over 70% of the bottles contained traces of at least one pesticide. The study also found that organic wines were not completely free of pesticides and that fungicides were the most commonly found pesticide in the samples.

The research highlights the challenges of reducing pesticide use in vineyards, particularly in France where vineyards absorb 20% of the country's agricultural pesticide use despite accounting for only 3.7% of the agricultural acreage. **(9)**

The French government was committed to a 50% reduction in pesticide use by 2018 based on 2007 use levels. That reduction target was impossible to achieve by 2018. (10)

In 2008, the French government set a target to reduce the use of pesticides in agriculture by 50% by 2018, based on 2007 use levels. The objective was to reduce the impact of pesticides on the environment and human health. The government implemented various measures to achieve this goal, such as banning the most harmful pesticides, promoting the use of alternative methods like crop rotation, and providing financial incentives for farmers who reduced pesticide use.

However, it was later revealed that the target was impossible to achieve by 2018. Despite some efforts to reduce pesticide use, the overall trend showed that pesticide use in France actually increased instead of decrease between 2010 and 2012. **(10)**

French Wines Sampled for Pesticide Residue, October 2013
Data from Que Choisir

Region	Number of Wines Sampled	Wines with more than 5 detected pesticides: 6-10 (Number/%)	>11 (Number/%)	6 or more (Number/%)	Wines with total pesticide residue >50 ppb concentration: 50 - 100 ppb (Number/%)	>100 ppb (Number/%)	Total >50 ppb (Number/%)
Bordeaux	20	7/35%	1/15%	8/40%	4/20%	10/50%	14/70%
Bourgogne	7	5/71%	0/0%	5/71%	2/28%	3/43%	5/71%
Champagne	4	4/100%	0/0%	4/100%	0/0%	4/100%	4/100%
Côtes du Rhône	21	7/33%	1/5%	8/38%	3/14%	3/14%	6/28%
Languedoc-Roussillon	22	9/41%	0/0%	9/41%	6/27%	7/32%	13/59%
Loire	6	3/50%	1/17%	4/67%	1/17%	3/50%	4/67%
Provence	4	0/0%	0/0%	0/0%	0/0%	0/0%	0/0%
Vins du Sud-Ouest	3	2/67%	1/33%	3/100%	0/0%	3/100%	3/100%
Vins de France	5	2/40%	2/40%	4/80%	2/40%	3/60%	5/100%
Total Sampled	92	39/42%	6/6%	45/49%	18/20%	36/39%	54/59%

This was attributed to various factors such as weather conditions, pest outbreaks, and limited adoption of alternative methods by farmers. The French government has since revised its target to a 25% reduction in pesticide use by 2020, with a long-term goal of reducing overall pesticide use by 50% by 2025.

The authors don't believe this kind of target will be possible to reach, except if new breakthrough technology is developed, and that is the reason for Laser Pest Project.

3.- Solution background

3.1.- The case of weeds: Killing weeds without Glyphosate

Laser can eliminate bad herbs by destroying the bad weeds. A weed killing robot is in use in the US to eliminate the use of Glyphosate (Round up) herbicide. (See image below)

With regards to weed control, laser systems can be used to destroy the plant by focusing a high-energy laser beam on the targeted area, essentially burning the weed. **(11)**

This approach has been used in the US as a way to eliminate the use of Glyphosate (Round up) herbicides which have been linked to health problems, cancer, and other environmental concerns. **(8)**

AMERICAN LASER ROBOT KILLING WEEDS APPROACH

As a summary: Laser technology has shown promising results in the agricultural sector by providing a non-chemical alternative for eliminating unwanted weeds. The technology has been tried and tested however only in rain fed crops, with "American size" AMR robots such as the one shown.

3.2.- The case of Bad insects: Killing Malaria bearing mosquitoes without a Pesticide

This approach has been promoted in the US to minimize Malaria transmission with mosquitoes and has been proven to be effective in Florida.

By focusing the laser beam on the targeted pest, it heats the insect's body causing it to die.

Unfortunately and from the first research and trials for this project in American Universities and the published research, nothing was commercially done.

No further research is documented beyond what is being included on the reference paper, where only a study of the wavelengths used and the Laser Fluence (energy delivered per effective area) to kill mosquitoes in a laboratory set up. **(12)**

Some figures of the killing rate per fluence and the fact that both 1064 nm (NIR) and 532 nm (green) wavelength were used with similar results, are interesting facts that lead the authors to envision an affordable alternative solution to pesticides. **(12)**

Also, nothing is mentioned on that paper **(12)** on how to steer the irradiation to the insect before the "Laser shot", or in how to differentiate a bad bug mosquito from a bee for example.

MOSQUITO BEING ZAPPED BY INFRARED LASER

Selective Lasering elimination of insects is a must, One of the main issues with the use of pesticides is that most of them block the nervous system of the pests leading the insect to die. And that works for almost any insect being sprayed. The lack of selectivity is one of the problems of pest elimination by the use of pesticides.

Bee declining populations are an example of the damage being caused to nature by the uses of non-selective methods. **(6)**

As a summary: The authors believe, this method has the potential to heavily reduce the use of chemical pesticides and their negative impact on the environment and human health.

3.3.- Temperature effects on pests and grapevine

1. Study about: *Larval development of Empoasca vitis and Edwardsiana rosae (Homoptera: Cicadellidae) at different temperatures on grapevine leaves*: At the temperature regime of 20°C night and 30°C day temperature, either no egg hatch was observed, or early development of first-instar larvae was not successful. **(21)**

2. Study about: *Mortality of Eggs and Newly Hatched Larvae of Lobesia botrana (Lepidoptera: Tortricidae) Exposed to High Temperatures in the Laboratory*: The results showed partial egg mortality at 40 C, increasing with exposure hours and periods, and as eggs matured. Egg mortality was not affected by exposure to 37 C. Larval survival already decreased significantly at 37 C and was even lower at 40 C. **(22)**

3. Study about: *Grapevine Responses to Heat Stress and Global Warming: This paper details several High-Temperature Effects on Grapevine Physiology and Berry Composition.* Negative effects on plant growth and health seem only to be reported after some minutes of high-temperature exposure. **(23)**

As a summary: Research is showing that small changes in temperature (i.e. low laser energy doses) might affect early stages of target pests, while short-time temperature increases do not affect the grapevines. But this needs further exploration.

3.3.- Laboratory research of Laser irradiation of insect early stages

1. Sustainable laser-based technology for insect pest control. **(24)**

   The study analyzed the lethal dose required to kill 90% of a population for two major pest aphid species. They showed that irradiating insects at an early stage (one-day old nymph) is crucial to lower the lethal dose without affecting plant growth and health.

   The laser is mostly lethal, but it can also cause insect stunting and a reduction of survivors' fecundity, which is also a positive collateral.

   Energy was delivered on a short-time scale (< 100 ms), so that a wide portion of a crop field can be treated in a reasonable time, the treatment is very efficient on the time necessary. The fundamental effect of lethality seems to be a rapid increase of the body temperature.

   The estimated energy cost and the harmless effect of laser radiation on host plants show that this physics-based strategy can be a promising alternative to chemical pesticides.

2. A Laser Irradiation Method for Controlling Pieris rapae Larvae: **(25)**

   Laser power, irradiation area, laser opening time and irradiation position were positively correlated with the P. rapae mortality.

   The optimal parameters for each factor were the following: laser power, 7.5 W; irradiation area, 6.189 mm2; laser opening time, 1.177 s;

   Results showed that the antifeedant percentage of P. rapae larvae within 24 h post-treatment was 98.49%, whereas the mortality rate was 100%.

   More effective controlling effect was observed with the younger larvae. These results can provide a theoretical basis for future pest control using laser pest-killing robots.

Conclusion: **Small changes in temperature (i.e. low laser energy doses) seem to mostly affect the early stages of insects, disabling their development to an adult stage. But this needs further exploration.**

4.- The non-chemical Pesticide substitution solution: Let’s Laser the pests

Our goal is to achieve a heavy reduction on the use of pesticides (understanding the word "pesticides" in a wide sense, that includes herbicides, insect killing chemical compounds, mold killing compounds and similar products) .

Our proposal is based on the development of a substitute treatment, disabling the pests by using coherent and non-coherent irradiation of specific wavelengths, to produce a similar effect to pesticide use, but with none of the harmful effects on human health and the environment.

Moreover the non-chemical approach technology resolves:

- The contamination of the food
- The contamination of the soil
- Selective elimination of the pests leaving beneficial insects unharmed
- The issue of increasing resistance to pesticides

Additionally:

- The byproduct of the treatment (dead insects, burn weeds) is a fertilizer
- The byproduct of the treatment (dead insects) is natural pest repellent for few days

Let's try to define the proposed technology in a nutshell. LaserPest is:

An electrical battery operated smart robot, equipped with Computer Vision cameras, different sensors an embedded computer controller, one or several focused irradiation devices and wireless connectivity to report to a data platform

LaserPest is a transversal approach that will work with most crops. We are thinking into vineyards, Produce (Fruit and Vegetables), grains and many others.

Let’s discuss now the main features of LaserPest

4.1.- Chemical contamination of the food and soil

The LaserPest process it's a non-chemical approach.

It doesn't use any chemicals in the process and furthermore they buy products or waste that the process produces is pure organic matter that produces beneficial effects on the crops.

4.2.- Selective elimination of the Pests

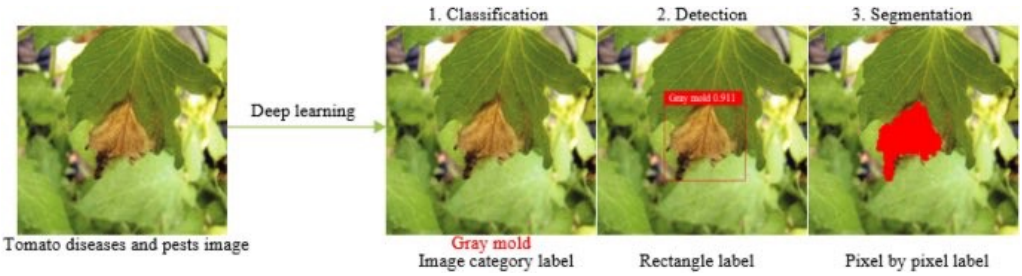
One of the big issues of using pesticide chemicals for the elimination of pest is that most of them are non-selective and cause a strong harm to biodiversity. Bees declining population is an example of the effect of chemical pesticides in the environment.

Identifying and differentiating harmful insects and weeds from non-harmful ones is a crucial challenge in implementing a non-chemical elimination approach like LaserPest processing. It requires accurate and reliable identification methods to ensure that only the intended targets are being eliminated.

One solution to this problem is developing specialized Computer Vision technology, which is a field of study that focuses on enabling machines to automatically recognize and interpret images and video data. By using machine learning algorithms and training data, Computer Vision can accurately identify and classify different types of insects and plants, separating the harmful ones to others.

LaserPest features a highly selective process. Computer vision today is a mature technology, providing effective means of identification and classification of almost any object.

Computer vision and the real time data from the cameras, will provide the LaserPest robot the ability to selectively eliminate pests in the crops.**(13,14,15)** by using RCNN and Deep learning. The image below is showing a typical computer vision classification process with Tomato crops.



Computer Vision technology is used to create a database of images of harmful pests and weeds, which can then be used to train a machine learning model to recognize and classify them.

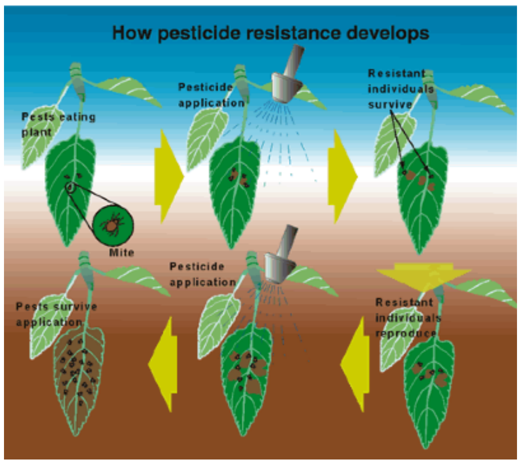
Things are not as easy as it may seem. The model will work at first for a specific crop with specific threads (Pests, weeds, molds etc). The model can be changed in few minutes to treat a different crop, and detect different threads. This a Software Defined Equipment (SDE) with a flexible arquitecture.

By using embedded computing calculation the irradiation will be focused to detected pest, the intended targets are eliminated while leaving other beneficial insects and plants unharmed.

Selectivity summary: The combination of irradiation technology and Computer Vision has the potential to provide a reliable and effective non-chemical approach to eliminate harmful insects and weeds without damaging beneficial organisms.

4.3.- Natural resistance to the treatment

Natural resistance is a powerful protective mechanism common to all living organisms that has been responsible for the survival of our species during countless millennia in the past.



One example of natural resistance in humans is what happened with antibiotics. Some bacteria that are capable of causing serious disease are becoming resistant to most commonly available antibiotics. Antibiotic resistant bacteria can spread from person to person in the community or from patient to patient. The same is happening with insects and chemical pesticides.

In the case of Pesticides, insects becomes resistant by evolving physiological changes that protect them from the chemical.

One protection mechanism used by insects is to increase the number of copies of a gene, allowing the organism to produce more of a protective enzyme that breaks the pesticide into less toxic chemicals.

As an example of the efficiency of irradiation, Lasering the insects will not have the possibility of natural protection mechanism that trigger treatment resistance like in the case of chemicals. 90 to 100% of the Lasered insects are dead within 24 hours even using low power pulsed Laser.

4.4.- Pest repellent: The "death recognition system"

When insects die, almost immediately we are creating a secondary beneficial effect of repelling the same and other insects.

That effect that has been documented in different scientific studies and it being called "death recognition system”.

Dead insect bodies create a stench that is reported to be a natural repellent for many different live insects.

This "death recognition system" likely evolved over 400 million years ago with some insect species evolution.

We recommend reading “The Ancient Chemistry of Avoiding Risks of Predation and Disease” July 28 2009 M. Yao et al. Journal of Evolutionary Biology, Springer. **(16)**

Furthermore, there is ongoing research into the use of "death smells" to protect crops and other plants from insect pests. The idea is based on the observation that many insects are able to detect and respond to chemical cues produced by dead members of their own species, as well as by other insects’ death.

Some Scientists are researching how death smells that might protect crops from almost any insect. As an example of research: A log treated with the fatty acids present in dead insects, repelled wood beetles in a forest for a full month. (David Rollo, McMaster University, Canada, 2012).**(17)**

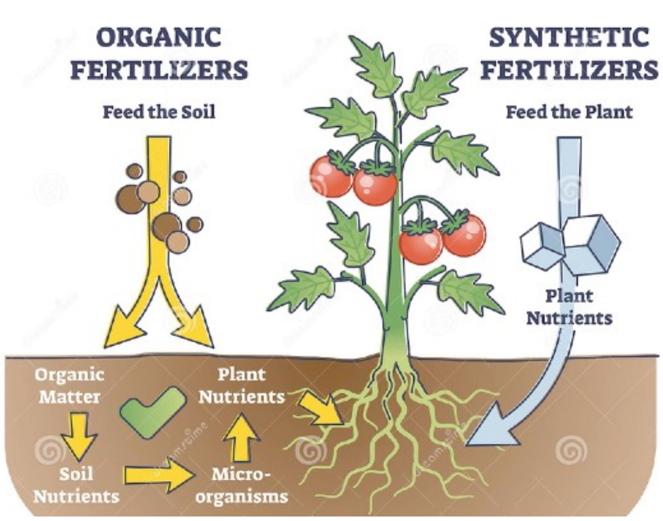
In the mentioned study it was found that a log treated with the fatty acids present in dead insects was able to repel wood beetles in a forest for a full month. The researchers hypothesized that the beetles were able to detect the scent of the fatty acids and avoid the “dead” area as a result.

This approach has the potential to be an environmentally-friendly and sustainable alternative to traditional insecticides. However, further research is needed.

LaserPest treatment effects Summary: Irradiation and Laser technologies are an optimal solution for the pesticide substitution: Treated pests cannot create natural resistance to the treatments, and dead insect bodies are organic insect repellent.

4.5.- Dead insect bodies are organic fertilizers

Insect bodies are indeed rich in nitrogen, which makes them a valuable source of fertilizer. When insects feed on plant material, their bodies accumulate nitrogen from the plants. This nitrogen can then be released into the environment when the insects die.



Frass is a by-product of insect breeding that is composed of insect waste and cuticles. Insect breeders often use frass as a natural fertilizer because it contains high levels of nitrogen and other essential nutrients that plants need to grow. Frass is also rich in beneficial microorganisms, such as bacteria and fungi, that can help to promote healthy plant growth.

Using insect frass as a fertilizer is an environmentally friendly way to boost plant growth without relying on synthetic chemicals. It is also a sustainable way to recycle insect waste, which would otherwise be discarded. As such, frass is becoming increasingly popular among organic farmers and home gardeners alike.

This fact was reported in the book “New Generation of organic Fertilizers” Metin Turant et al. Published by IntechOpen July 2022 and is also researched in some other studies.**(16)**

Frass has been evaluated as a potential organic fertilizer and has been found to have many benefits when added to soil. Some of these benefits include:

- Increased germination, sprouting, and growth: Frass contains high levels of nitrogen, which is an essential nutrient for plant growth. Nitrogen promotes the development of leaves and stems, which can help plants to grow more quickly and produce higher yields.

- Increased nutritional content of plants: Frass contains other essential nutrients besides nitrogen, such as phosphorus, potassium, and micronutrients. These nutrients can help to increase the nutritional content of plants, which can be beneficial for human and animal consumption.

- Increased tolerance to abiotic stress: Abiotic stresses such as drought, high temperatures, and salinity can have a
  negative impact on plant growth.
  Frass contains beneficial microorganisms that can help plants to better tolerate these stresses.

- Activation of the plant's defense: Frass contains compounds that can activate the plant's defense mechanisms against pests and diseases, which can help to reduce the need for chemical pesticides.

The best feature of organic fertilizers is that they feed the soil, while synthetic fertilizers feed only the plant.

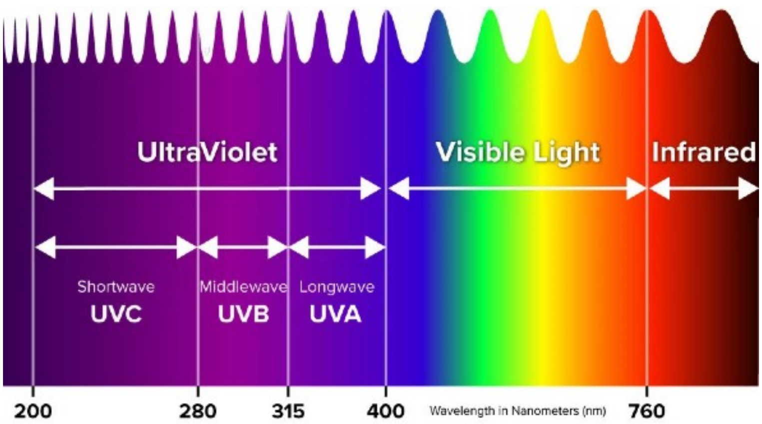
Effects of laser treatment summary: LaserPest is an optimal solution for the pesticide substitution: Treated pests are nitrogen-rich soil fertilizers and may provide additional natural eco-benefits to the crops.

4.4.- The effects of Ultraviolet-C light on inactivation of mold disease: The vineyard's Mildew

We have previously discuss one fact regarding the use of pesticides in winemaking. The case of France where vineyards absorb 20% of the country's agricultural pesticide use despite accounting for only 3.7% of the agricultural acreage.

One of the issues when understanding the staggering amount of pesticides used in vineyards, is the fact that in humid climates it's related to mold disease. Killing mold is a specific case in the use of pesticides, where there is alternative technology that has been tried and tested to be effective by using ultraviolet C irradiation.

Ultraviolet is a type of non-visible irradiation that spans from 400 nm to 200 nm wavelengths. Ultraviolet spectrum is sub-classified in three types UVA, UVB and UVC (see image below). While UVA radiation is responsible for most of the tan colored skin in humans by activating melanin, shorter wavelengths (B and specially C) produce damage to the DNA and RNA.



Ultraviolet C irradiation has been used to kill mold for many years. Mold responds quickly to the DNA damage that the 254 nm Ultraviolet C “germicidal" lamp sources generate. This process has been approved by the American environmental protection agency (EPA) as an approved treatment for mold inactivation.

The problem is however a phenomenon call photo-reactivation, where the visible blue light helps to regenerate the damaged DNA. More information in the reference section. **(18,19)**

Recent research by Kerik Cox, an associate professor of plant pathology add Cornell university has demonstrated the effectiveness of the ultraviolet-C radiation on killing the mold in vineyards, while performing the treatment in the nights. In the absence of sunlight the mold cannot regenerate the photo reactivation of the DNA, thus inactivating the mold spores and the reproduction such a mold. **(20)**

The Cox prototype is shown in the image right.

Although more research is necessary, this approach presents a promising solution to the minimization of the use of pesticides on to treat vineyard mold diseases, that are common to many European regions. Different studies have also demonstrated the ability of ultraviolet C irradiation to kill and prevent mold in fruit groves, and in species that are especially prone to molds such as the strawberries.

Summary: This case illustrate the ability of irradiation, to be an effective treatment against different pests. Both coherent and non-coherent light sources can be used to provide different treatments.

5.- Technologies involved in the LaserPest development

5.1.- Computer Vision, Identification and classification

Object detection is a computer vision technique providing means to identify and locate objects in an image or video. With this kind of identification and localization, object detection can be used to count objects in a scene and determine and track their precise locations, all while accurately labeling them i.e. classifying the objects into different groups.

The computer vision process is well known and we are not discussing here the technologies and algorithms involved in the system.

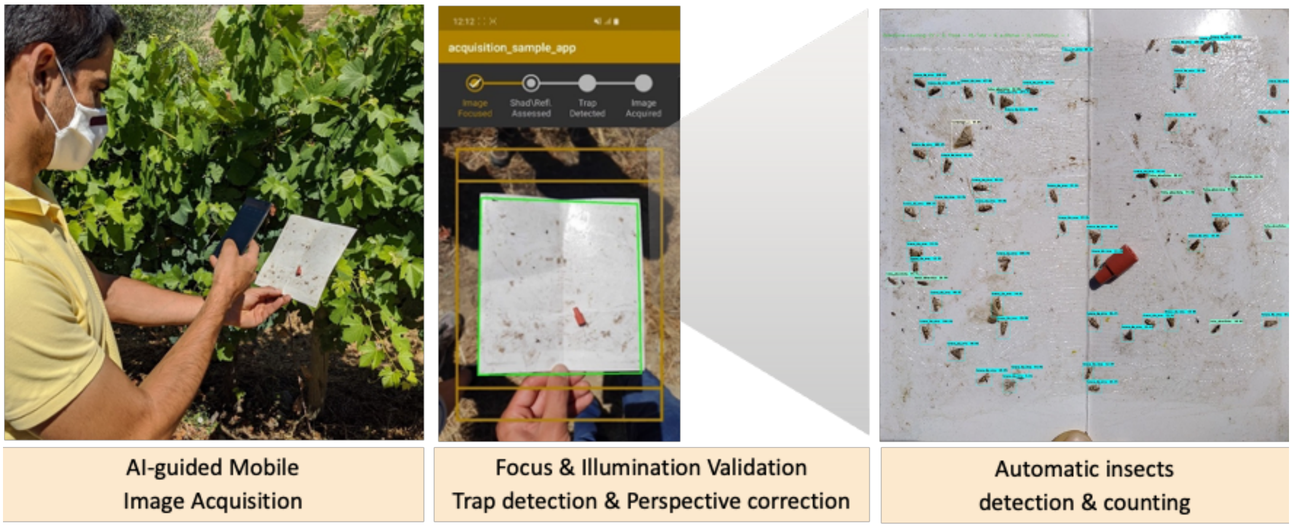
5.1.1.- Computer Vision background and state of the art

While researching on computer vision applications for automated pest detection the authors discovered an interesting project in Portugal. "Eyes on traps” is a project that uses sticky insect traps and a smart phone to take pictures of the vineyard pests and forward the images to servers where they were stored, creating a database with thousands of images. Data from external environmental sensors along with a time stamp was also forwarded to the server.

Computer vision tools were used to identify and classify the harmful insects. Refer to **(13,14,15)**

The project was carried out by The Fraunhofer Institute AICOS and GeoDouro an engineering company specialized in Agribusiness with the cooperation of Sogrape one of the largest wine producers and bottlers in Southern Europe.

Some result scan be appreciated in the images below.



For LaserPest similar technology may be used. However there are many differences between "Eyes on Traps" and “Laser Pest” The main difference is that the images of the insects and weeds will be taken:

- With a set of professional C.V. industrail cameras, instead of smartphones.

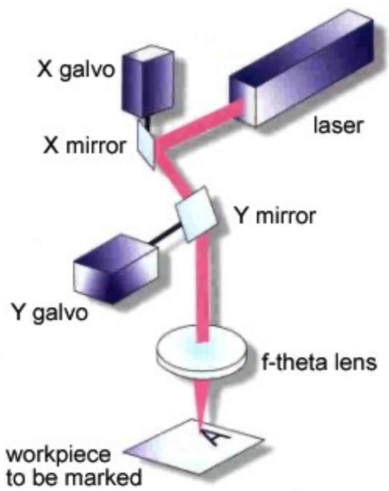
  This will ensure better image quality (Light, focus etc)

- The insect will be photo shot in its natural habitat most frequently on the leaves, and not over a yellow or white background sticky trap. The green background makes worst contrast. See image.

However the authors believe that on present state of the computer vision technology, the challenges of image classification of insects are achievable based on previous experience by using high resolution and focusing the objects.

5.2.- How the Laser works

We are using here a similar set up to the Laser markers and surface processing equipment. A Laser source beam is directed to a steering module, that moves the beam in two axis using specially coated mirrors that reflect most of the incoming coherent light energy.



The Laser controller also controls the ON/OFF Laser port. Many modern Lasers have the possibility of being pulsed. That opens many new features, as pulsing provides tight control of the average energy that the object being Lasered is exposed to.

Further discussion of the Laser steering and the pulsing follows. However this is only a soft disclosure of the main features regarding the use of Lasers for type of application. A typical laser processing layout is shown on the image right, where the Z axis is the focus and on the image example this is resolved by an F theta lens

Although this set up is widely used on the stationary Laser processing applications, where the focus is set to a fixed distance by an F-Theta lens, in the intended Laser Pest application; the distance to the processing object will be estimated by the Computer Vision system and a Lidar 3D scanner, using sensor fusion technology.

Sensor fusion is the process of combining sensor data in a process, that the resulting information has less uncertainty than would be possible when these sources were used individually.

Perception is another important method that refers to the processing and interpretation of sensor fusion data to detect, identify, classify and track objects.

5.2.1.- Laser beam steering

A Laser beam is positioned using mirror galvanometers. Galvanometers are electrical devices that are able to move a small mirror very fast, by using magnets and coils, where electrical currents are induced.

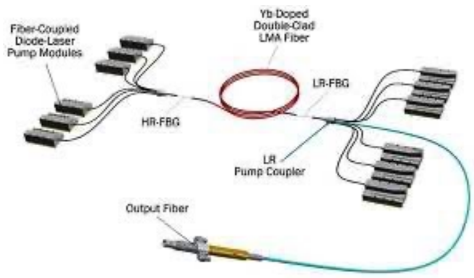
Mirror galvanometers are widely used as beam positioning or beam steering elements in laser scanning systems. For example, for material processing with high-power lasers, two galvanometers are mounted over an aluminum block (see image right) to perform a cartesian X and Y Laser beam steering.

A typical laser processing layout is shown on the image left where the Z axis is the focus and on the image example this is resolved by an F theta lens.

The laser beam has to be steered automatically to the insect that has been detected to be harmful for the plantation by the computer vision cameras.

5.2.2.- Practical Fiber Lasers

A practical, commercially available Q switched Fiber pulsed laser is shown in the image below. They are usually manufactured in powers ranging from 20 to 100 Watts, they are not expensive, and the Laser source usually last over 30,000 hours lifetime. That makes fiber lasers the ideal option for the Laser Pest Robots.

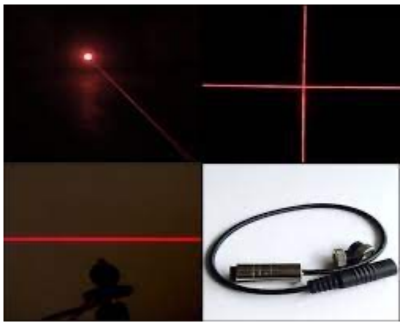


5.2.3.- Positioning computation

The cameras deliver among other data information the position whereabout of the target relative to the position of the camera. An embedded computer system will have to compute the positioning data provided by the camera and establish that direction where the laser beam has to be steered.

Laser processing beam falls into the non-visible infrared spectrum. In this case and for industrial applications a Laser guide or pointer usually in red color (around 650 nanometers) is used to establish the steering positioning before the Laser is shoot.

This technology can be used to make a fast but very effective correction of the steering system in real-time.



The computer vision camera can easily locate the red cross hair pointer laser that is a steer with the same galvanometer steering system that the main shooting Laser.

This can be done by producing just short a short pulse of red pointer laser that will help to establish if the pointing to the target is correct or not.

This type of pointer Lasers feature low-cost, long life, and many times are sold integrated into the Laser optics from the factory. Other colors are available such as green or blue. An offset distance shall be used in order not to disturb the insect and prevent the insect to escape.

5.2.3.1.- From the image to the laser shot

This process is iterative, i.e. the same algorithm will be executed until certain conditions are met. For this we will use the following components:

- One Industrial CV Camera,
- The CV insect recognition algorithm,
- Laser guide (small power visible pointer)
- Laser guide recognition algorithm
- NIR Laser steering beam system (processing pulsed NIR fiber Laser)

Both the Laser guide (the visible pointer and the processing NIR Laser feed the mirror galvosteering head that controls the aiming on X and Y axis. Initially three processing directions are planned.

- The first camera will look at the left of the plantation row (about 60˚). We will call this camera left.
- A second camera will look at the right side of the plantation row (about 60˚). We will call this camera right
- A third a camera with a wide lens (about 120˚) will look at the soil we will call this camera soil.

Now we have referring to the process on each of the cameras. To simplify the explanation we will refer to the processing on just one of them. The process is basically the same with three cameras.
The camera will take images of a native (non interpolated) pixel resolution of:

$W_{image}\ x\ H_{image}$.

This algorithm developed by Fraunhofer AICOS will produce an output providing the position of the object in the camera image as well as its dimensions:
$(B_x, B_y, B_w, B_h) \in (\mathbb{N}_{W_{image}}, \mathbb{N}_{H_{image}}, \mathbb{N}_{W_{image}}, \mathbb{N}_{H_{image}})$ where:

B_x is the coordinate X in the image,

B_y is the coordinate Y in the image,

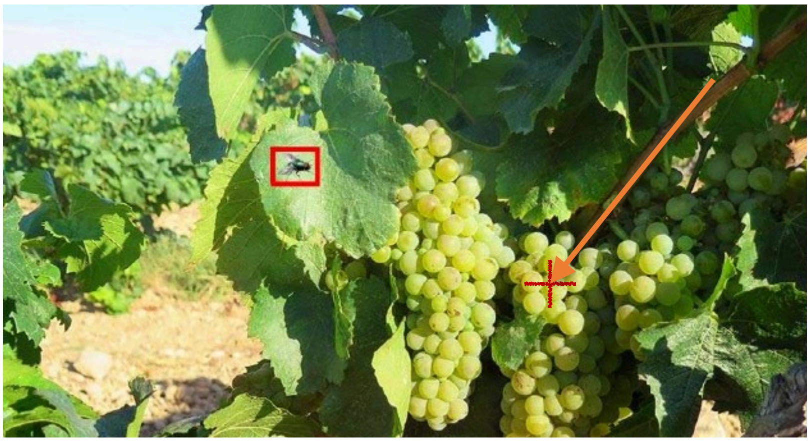
B_w is the width of the bug in the image and

B_h is the height of the bug in the image.

The upper left corner red location rectangle is located on the coordinates (B_x, B_y) and the size of the red location rectangle is (B_w, B_h).

Computer vision laser guide (visible pointer) identification.

The laser guide or pointer identification algorithm will produce an output recognizing the laser guide positioning in the image $(L_x, L_y, L_w, L_h) \in (\mathbb{N}_{W_{image}}, \mathbb{N}_{H_{image}}, \mathbb{N}_{W_{image}}, \mathbb{N}_{H_{image}})$ where L_x is the coordinate of X in the image, L_y is the coordinate of Y in the image, L_w the width of the Laser in the image and L_h is the height of the Laser in the image.



The galvo mirror set is shown without the enclosure on the right image. The laser guide pointer is visible.

The NIR processing beam follows exactly the same path. Thanks to the visible guide pointer laser beam the NIR processing Laser will be steered with precision to the targe object. In this case the insect on the leaf.

2.- How it works: Iterative method

The iterative method is composed of two steps: aiming and focus adjustment.
Aiming follows the following method:

1. Image acquisition
2. C.V. object identification and classification, if no thread detected shooting method ends here
3. Laser guide pointer pulsed on if thread detected
4. Image of Laser guide pointer acquired
5. C.V. identifies Laser guided pointer position
6. Laser guide pointer pulsed off
7. Compute position adjustment from object to Laser guide pointer position if difference less than Δ adjustment method ends here
8. Execute position adjustment
9. If position more than Δ adjustment go to step 3
10. If position less than Δ adjustment Go to focal adjusment.

The focal adjustment method will be as follows:

1. Acquire distance information
2. Compute focal adjustment if adjustment less than Δ focal. Shot NIR Laser
3. Execute adjustment
4. Repeat Method

3.- Steering adjustment

The adjustment steering will be using the following formula:

$$(\alpha_1, \beta_1) = (\alpha_0, \beta_0) + \lambda * \Phi(B_x, B_y, L_x, L_y)$$

Where (α_0, β_0) is the current postion of. The mirrors in degrees, λ is the adjustment factor that will be assumed to be 0.75 (Typical direct convergence iteration model adjustment factor), y Φ the transformation function of the image coordinates to the mirror angles.

The function can be expressed as:

$$\Phi(B_x, B_y, L_x, L_y) = (\alpha, \beta)$$
$$\Phi_\alpha(B_x, L_x) = \alpha = 180 - \arccos(\frac{B_x}{D_p^2 + B_x^2}) - \arccos(\frac{L_x}{D_p^2 + L_x^2})$$
$$\Phi_\beta(B_y, L_y) = \beta = 180 - \arccos(\frac{B_y}{D_p^2 + B_y^2}) - \arccos(\frac{L_y}{D_p^2 + L_y^2})$$

Where D_p is an experimental constant that can be described as the average distance in pixels. Please note that this value can be replaced for the function $\sigma(B_w, B_h, L_w, L_h)$.

From that and calculating the size identified by the Computer Vision system give us a distance measurement to the object.

Please note the distance is proportional to the size of the identified area.

The effect of this formula would be to place the laser-guide closer and closer to the insect's position with each iteration, until that point is very close to the insect but not spotting the bug directly, (we call that offset) to avoid disturbing the bug so it is not to escaping the NIR Laser action.

Four images are shown on the next page where they iterative laser steering method is demonstrated.

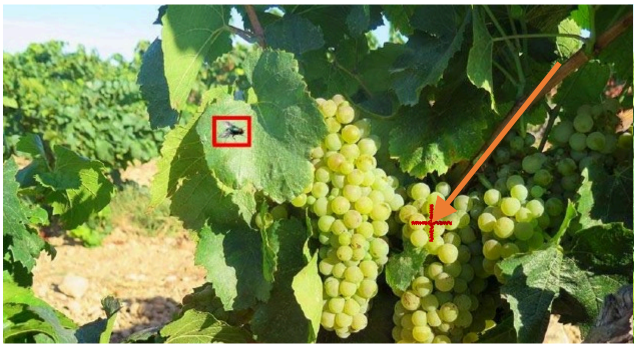


Image 1 Laser guide pulses, and adjustment computing is done

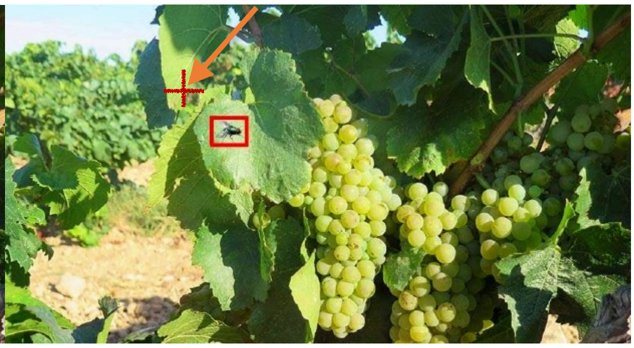


Image 2 First Iteration Laser guide is now closer but overshot object

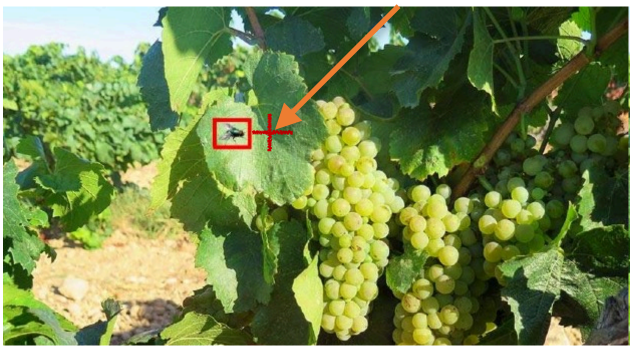


Image 3 Second Iteration Laser guide on object

Image 4 NIR Laser corrects offset and shots object

4.- Focal adjustment

The focal adjustment will be using the following equation:

$$f_1 = f_0 + \theta * \delta(B_w, B_h, L_w, L_h)$$

The practical effect of using this equation is to obtain a sharp focus. However we are further discussing the Laser focusing.

5.- Focus and shooting discussion

There are two possible Laser object processed methods. On the left image a sharp focused spot is scanned up and down and left and right to disable the insect. On the right image the laser out of focus and the spot size it's a few millimeters wide.

This type of unfocused “large" spot will have higher energy at the center of the spot with softening energy edges. However because a low power is usually need to disable an insect, using an unfocused Laser migth be good enough without the need of a completely focused scanned Laser beam.

The two method options will be explored on the research, finding what is the best, either working with a focused laser with a small spot size (as low as 100 μm), or using a wider unfocused spot but using a higher pulsed energy to get the same Fluence and effectivity as in the first example.

6.-Identification and treatment of egg and larvae stages

We would like also to experiment the possibility of identifying and classifying the eggs and larvae stages of the pests, to disable the pest at the early stage.

For that purpose a higher resolution camera (probably 8-12 Megapixel native resolution) will be required, which implies also higher computation by the CV algorithm for egg and larvae detection.

This algorithm might be quite different of the adult stage detection discussed before.

The eggs are much smaller and can be confused with different objects and matter such as white dust or dry water drops.

We have however the hope that we will be able to detect the eggs and larvae stages based on the white color and the round shape distinctive aspect. Please check the photos below of the vineyard weevil from the egg stage to the adult stage.

5.2.4.- Laser processing. Wavelength, Pulsing, Thermal effects

Laser Wavelength selection provides a tool to make the choice between hot and cold Laser processing.

While a lot of heat is generated while processing with that Far InfraRed (FIR) Laser at 10 *μ*meters, much less heat and very different results are obtained using Near InfraRed (NIR) lasers at 1 *μ*meter. Also low cost visible spectrum lasers at for example 500 nanometers (green) or blue and ultraviolet laser sources below 450 nanometers are available but they can be hardly focused in the distance, as the diode source featires a large dispersion and poor beam quality.

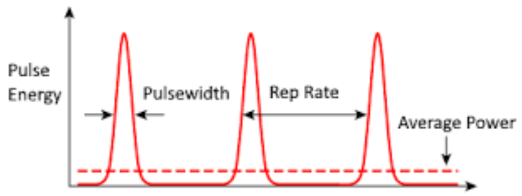
Laser source price is an important variable in this project. We are making our first choice using affordable fiber laser sources that can easily be pulsed using Q switch technology. They work in wavelengths of 1064 nm and provide a good balance between cool processing and low cost.

Laser Pulsing Technology provides a high-power burst of energy for a short period of time. This technology is very effective in obtaining different results in some high-tech complex laser process.

Fiber Lasers are easily pulsed using Q switch or MOPA technologies.

The pulse width and the repetition rate selection allows surgical precision of the Laser processing. This results in a short pulse incorporating that energy, and thus a high peak power, with minimal thermal effects.

As a well known example Pulsed Lasers are used in tattoo removal, selective skin ablation for beauty treatments and in soft-tissue surgery without damaging the background.



Laser Pulses

When a laser beam comes into contact with soft-tissue, one important factor is to not overheat surrounding tissue (pulse width). Laser pulses must be spaced out (Pulse repetition rate) to allow for efficient tissue cooling between pulses. A similar method can be used to kill the insect without damaging the plant.

The outer exoskeleton of the insect will be heavily damaged by the pulsed laser exposure. The background (usually a leaf) will be unharmed. **(21), (22), (23)**

By pulsing the Laser we can provide an increase in the temperature of the processed area where are the Pest is present. Let's have an increase in temperature will kill the insect, larvae and eggs. However the heat will not be noticeable or harm the background leaf. The following research supports our first theories.

- *Larval development of Empoasca vitis and Edwardsiana rosae (Homoptera: Cicadellidae) at different temperatures on grapevine leaves:* At the temperature regime of 20°C night and 30°C day temperature, either no egg hatch was observed, or early development of first-instar larvae was not successful. **(21)**

- *Mortality of Eggs and Newly Hatched Larvae of Lobesia botrana (Lepidoptera: Tortricidae) Exposed to High Temperatures in the Laboratory:* The results showed partial egg mortality at 40 C, increasing with exposure hours and periods, and as eggs matured. Egg mortality was not affected by exposure to 37 C. Larval survival already decreased significantly at 37 C and was even lower at 40 C. **(22)**

- *Grapevine Responses to Heat Stress and Global Warming:* This paper details several High-Temperature Effects on Grapevine Physiology and Berry Composition. Negative effects on plant growth and health seem only to be reported after some minutes of high-temperature exposure. **(23)**

<u>Summary</u>: Research shows that small changes in temperature (i.e. low laser energy doses) might affect early stages of target pests, while short-time temperature increases do not affect the grapevines. But this needs further exploration.

5.2.5.- Laser processing:*Impact of laser radiation in insects‘ early stages*

We are referring to the following research that is detailed in the reference section, and their conclusions

1. Study on *Sustainable laser-based technology for insect pest control*. **(24)**

    a. They analyzed the lethal dose required to kill 90% of a population for two major pest aphid species

    b. They showed that irradiating insects at an early stage (one-day old nymph) is crucial to lower the lethal dose without affecting plant growth and health.

    c. The laser is mostly lethal, but it can also cause insect stunting and a reduction of survivors' fecundity.

    d. Energy was delivered on a short-time scale (< 100 ms), so that a wide portion of a crop field can be treated in a reasonable time (one day).

    e. The fundamental effect of lethality seems to be a rapid increase of the body temperature.

    f. The estimated energy cost and the harmless effect of laser radiation on host plants show that this physics-based strategy can be a promising alternative to chemical pesticides.

2. Study on *A Laser Irradiation Method for Controlling Pieris rapae Larvae*: **(25)**

    g. Laser power, irradiation area, laser opening time and irradiation position were positively correlated with the P. rapae mortality.

    h. The optimal parameters for each factor were the following: laser power, 7.5 W; irradiation area, 6.189 mm2; laser opening time, 1.177 s;

    i. Results showed that the antifeedant percentage of P. rapae larvae within 24 h post-treatment was 98.49%, whereas the mortality rate was 100%.

    j. More effective controlling effect was observed with the younger larvae. These results can provide a theoretical basis for future pest control using laser pest-killing robots.

Summary: Small changes in temperature (i.e. low laser energy doses) seem to mostly affect the early stages of insects. But this needs further exploration, namely if this also applies to our target pests.

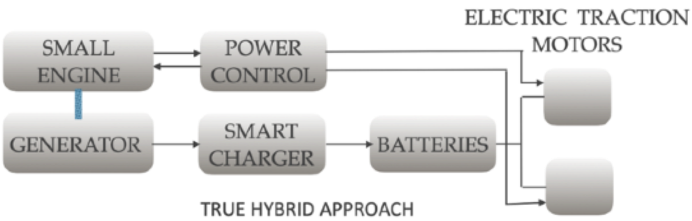
6.- Proposed embodiment. A custom Autonomous Mobile Robot (AMR)

An Automatic Guided Vehicle (AGV) is a type of unmanned guided vehicle (UGV) that moves throughout a facility by following a set of predetermined paths. An AGV is NOT a sub-class of mobile robot. As an example AGVs cannot navigate around an obstacle.

An Autonomous Mobile Robot (AMR) is a different class that has more capabilities than an AGV.

AMRs are capable of free-movement, and real-time path planning that enables them to collaborate in material handling tasks with humans.

The authors believe the second definition (AMR) matches better with the best proposed embodiment Also electric propulsion fits the sustainability target best.



SMALL COMMERCIAL AGRI-ROBOT

The AMR can be charged with a small solar panel set up locally.

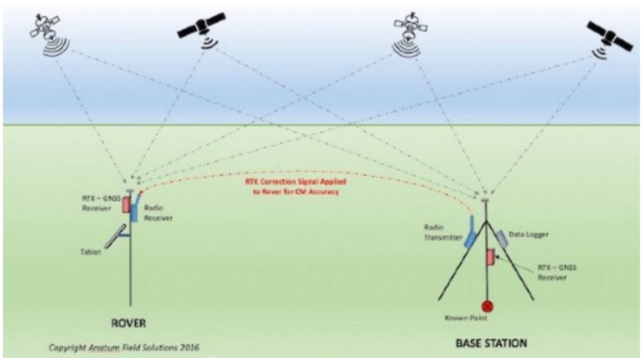
For extended autonomy and range a true-hybrid system can provide many hours of working time. A true hybrid system is based on a pure electric vehicle with a small DC generator to recharge de batteries when needed, True hybrids don't have mechanical coupling between the electric and the DC generator motor.

6.1.- AMR Steering and Sensors

The steering will be managed by a Single Board Computer and smart software that is able to make decisions and get the AMR out of obstacles, vegetation etc.

The AMR will be automatically steered by sensors (LIDAR, 3D CAMERAS etc). Sensors will keep the AMR about the center of the plantation rows.

The AMR will have an advanced GPS with high precision such as RTK (Real Time Kinematic). RTK provides centimeter-positioning precision by using a reference GPS interconnected in the vicinity of the AMR.



HOW PRECISION RTK GPS WORKS

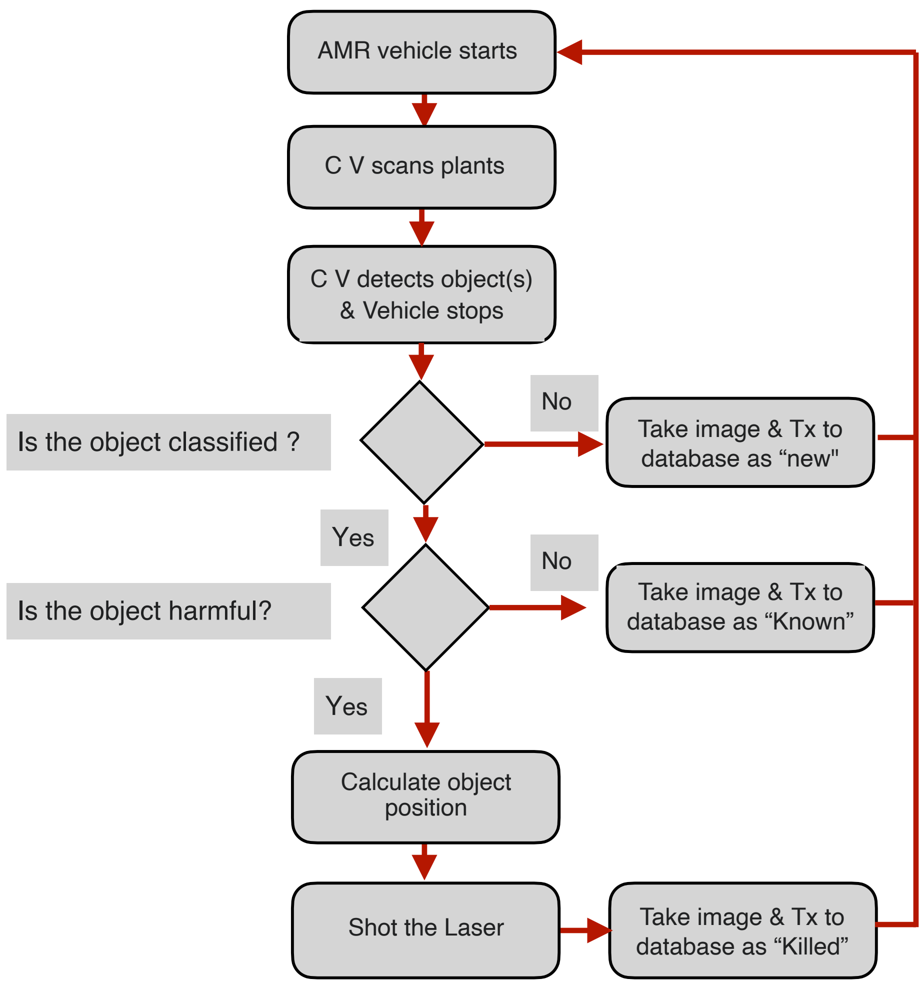
The RTK GPS provides a low-cost method of providing high precision AMR steering even in complex environments such irregular plantations.

A security system will provide means of interrupting the operation in case a human or a large animal is present around the AMR. FIR sensors can be used for that purpose.

6.2.- Laser Pest Logic (Computer Vision, AMR steering, and Laser processing)

The basic LaserPest logical process is described as follows:

- AMR vehicle starts moving between the groves.
- The multi-camera computer vision system scan the plants and the terrain.
- One or several objects being a plant or insect is detected.
- Vehicle stops briefly to obtain a better image of the potential thread
- Computer vision system classifies objects.
- If the Object is classified as a harmful thread the Laser steering computer calculates the estimated position from data given by Computer vision camera. An image is taken and forwarded to the server
- The laser is shot. The thread is Laser processed.
- The Computer vision system takes another image after Lasering the thread image forwarded to the server
- If the Object is not found in the harmful classification. The Laser is not shot.
- If the Object is classified as a harmless an image is taken and forwarded to the server as harmless
- If the Object is not classified is considered as new. An image is taken and forwarded to the server as new object.
- The AMR vehicle starts moving again.



BASIC LOGIC FLOW

The previous data flow, is not a comprehensive method. It doesn't include all of the processes that might be necessary. For example the pointer Laser guide to help the Laser beam steering is not included for clarity.

The computer vision will take an image of the processed "killed" object, and repeat automatically the process in case the computer vision system figures out that the object has not been adequate adequately processed.

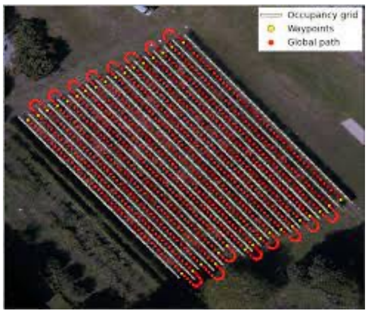
Different variants of the logic process shown before might be tried in the process of improving Laser Pest.

6.2.1.- Following the plantation path

After completing one plant row the AMR vehicle will automatically take the next row

Plants are scanned and treated two times. One at the first pass and the other on the other side row.

The image at the right provides an idea of the expected optimal processing path.



LASER PEST ROBOT PATH

6.3.-Connectivity and process traceability

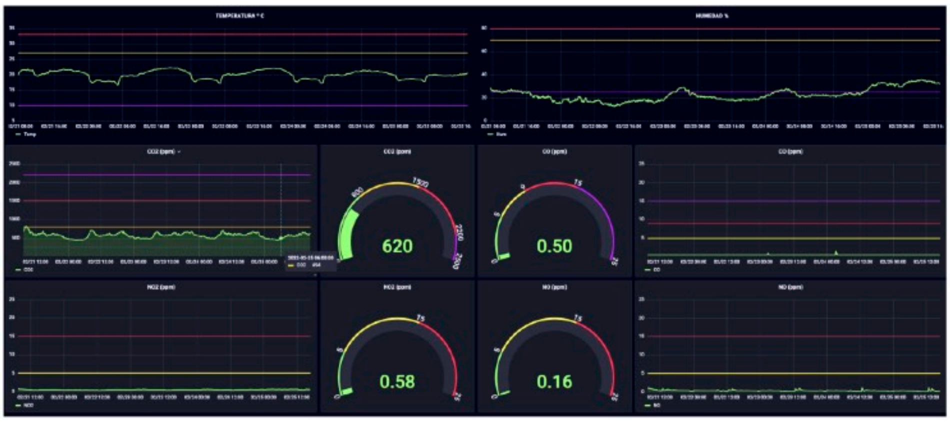
4G/LTE connectivity will forward image and sensors' data in real time to an on the cloud data platform. In rural environments not always 4G LTE coverage is available. However, forwarding the images and other exploitation data from the Laser Pest process is an essential part of this project.

For that reason the controller will have an SSD hard disk storage memory, where image and sensor data will be temporally stored, in the case 4G/LTE coverage is not available. The controller will provide means of detecting when the wirelees coverage is good enough to forward the data automatically.

7.- Data Platform

A preliminary specification of the data platform needed for the Laser Pest project will look as follows:

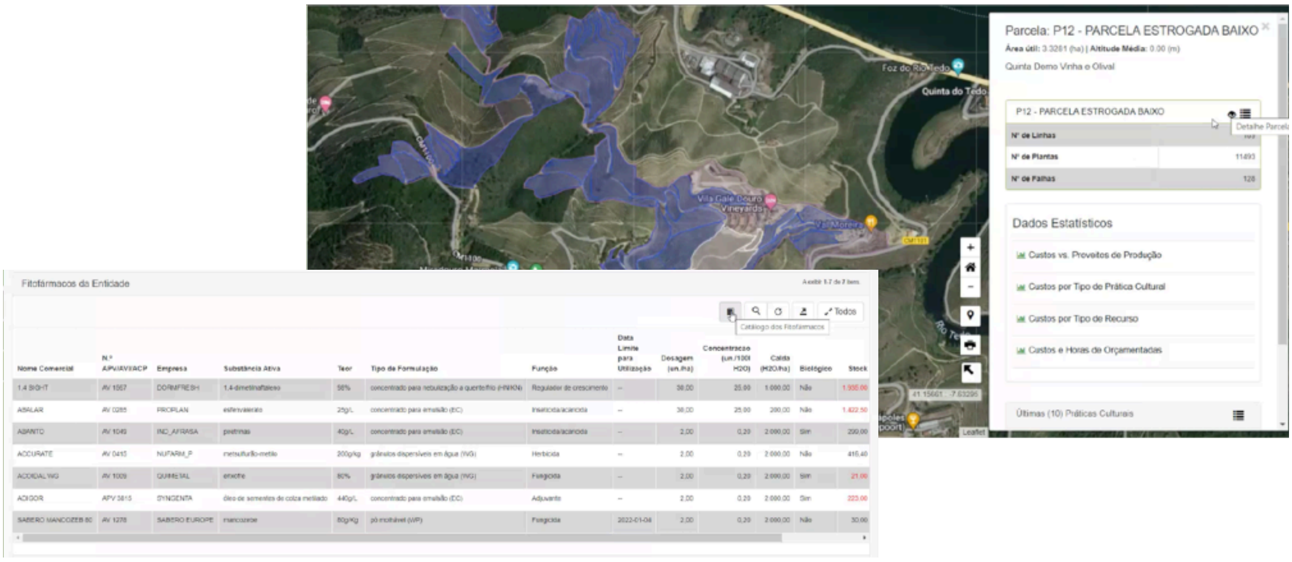
- Data platform to be hosted on a Virtual Private Server (VPS) on-the-cloud.
- Non-SqL database will store at least:
    - AGV telemetry (Battery status, environmental, Alarms, etc).
    - Positioning (GPS location, Time stamp, Inertial Measurement Unit)
    - Laser processing events along with time and process location stamp.
    - Classification given.
    - Image of the processed pest (Before and After)



7.1.- Predictive Models & Digital Twin

We plan to create a complete Agri-business platform to manage the LaserPest process and tracking the KPIs, while effectively accounting and reporting the reduction of pesticide use. We will inspired on the GeoDouro works on the "eyes on traps” project.

The images below are part of the Geo Douro platform.



The reduction in the use of pesticides could be enhanced by the use of artificial intelligence and predictive models. We are willing to incorporate to the authors team experts in the creation of predictive models and digital twins for Agri-business.

We are envisioning the creation of advanced predictive models that help the management of pests for the use case (vineyards). This feature will also help the minimization on the use of pesticides, if the LaserPest treatment is done in the right time, at the right place.

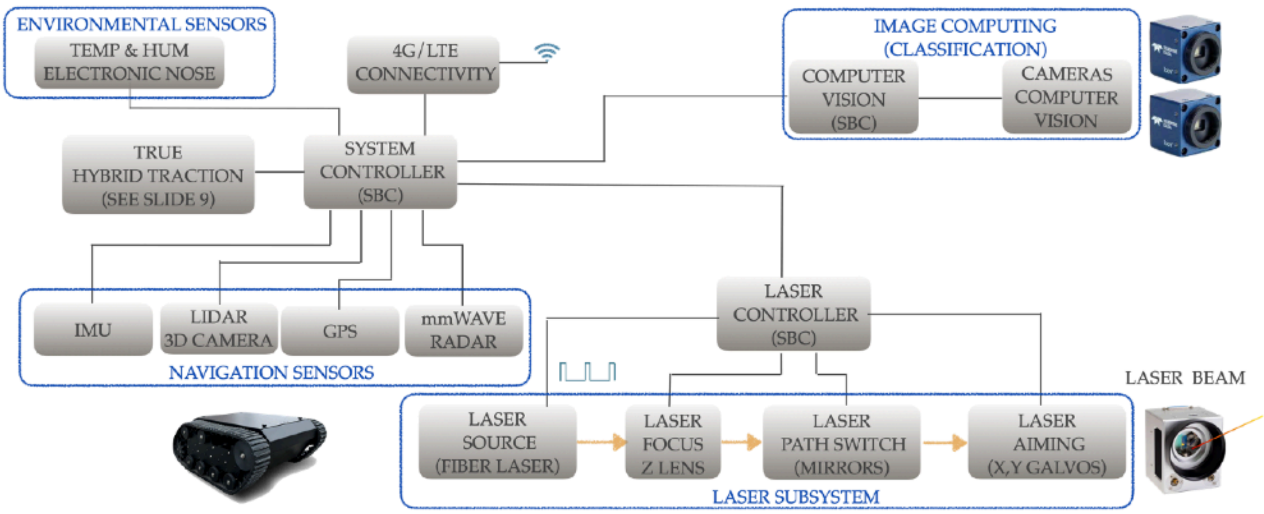
That makes the LaserPest project more sustainable as it helps to save on the use of resources. The idea is to make Laser Pest treatment right before is needed.

8.- General Layout

A general hardware layout of the Laser Pest project is shown below.

The layout has been simplified for clarity, but basically we can define different sub-system blocks:

- The computer vision system with cameras
- The laser subsystem (laser controller, Laser source, Laser steering)
- The navigation system (GPS, RTK, IMU)
- The environmental sensors
- The connectivity module
- The true-hybrid electric vehicle traction system (Electric traction motors, battery, DC generator, BMS)
- The system controller, based on an Single Board Computer that runs the software logic process described before



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