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# Robot safety issues in field crops

## EU Regulatory issues and technical aspects

***Abstract.***

The use of robots in Precision Agriculture is becoming of great interest, but they introduce a new kind of risk in the field due to their self-acting and self-driving capability. Safety issues appear with respect to people working in the same field in human-robot collaboration (HRC) framework or to the accidental presence of humans or animals. A robot out of control may also invade other areas causing unpredictable harm and damage.

Currently, the safety of highly automated agricultural equipment (HAAM) is the responsibility of the manufacturer, who equips them with LiDAR (Light Detection And Ranging) or bumpers, forces them to move at a slow pace, and in most cases also requires them to be under continuous human surveillance.

While the belief that AI can make machines increasingly "self-responsible" is growing, the complexity of machines is increasing, the concept of "inherently safe" seems difficult to achieve in a short time.

Active and passive control systems, such as remote control systems that have been applied for decades in equipment safety seem to be useful in more densely populated rural areas to enable robot deployment in precision agriculture.

***Keywords.*** *robot, agriculture, safety, laws*

## Introduction

Agriculture is hungry for technology. The Green Revolution had brought farmers the possibility of growing crops with a low effort, bringing them those technical means that before were only accessible to industry: mechanics, chemicals, new plant varieties, and new ways of doing irrigation. However, problems related to market globalization, environmental issues, and climatic change make agriculture's sustainability issues arise again.

Such issues can be addressed in different ways, and Precision Agriculture (PA, today part of Agriculture 4.0) is a promising direction. PA continues offering technology to farmers, profiting of new enabling technology, including Highly Autonomous Machinery.

In Precision Agriculture, robots can help reduce the labor in fields in a collaborative framework (NSF, 2016) that in the framework of agriculture can be recognized in terms of :

- robotic arms and other appliances installed on human-driven field vehicles and appliances, as in orchard operations, are of growing interest (Onishi,2019);

- Flying robots (UAVs) to be used for surveying (e.g. mapping disease or pests) and enabling localized Variable Rate Application (VRA) of chemicals/water represent an already available commercial solution (Aslan,022);

- autonomous rovers, with the same functions as UAVs but working on the ground - while in the open air, the most popular robots are represented by robo-mowers; robo-tractors, operating with common tools, such as tillage, seedling, weeding, harvesting, are becoming popular in the field.

All of these applications are raising issues of safety in the Human-robot collaboration (HRC) context (Rysz & Mehta,2021; Vasconez et al., 2019).

In the EU and Italy, most safety issues regarding robots fall under the manufacturer's responsibility, who is required to comply with the standards applicable to common machines, even if robots have more complexity in controlling their activities.

This study aims to explore the issues arising from the use of robots in field crops and the main aspects to be addressed to adapt to technical and regulatory points of view, taking into account the present and ongoing regulation in the EU and Italy.

## The EU legal framework on robot safety

Like any other products, robots can be placed on the EU market only if safe.

Even if there is no specific regulation on robot safety, the EU safety regulatory landscape is composed of several legal acts that set out safety requirements applicable to the design and manufacture of robots used for agricultural purposes.

Indeed, normally, robot systems (e.g. drones, UA-tractors, robotic arms, mobile platforms), their components, and types of equipment (such as laser, electrical equipment) meet the legal definitions provided by those legal acts and fall under their scope of application.

When a robot fits the definition of "machinery" set out in the Machinery Directive (MD, Directive 2006/42/CE), such legislation applies unless the MD provides differently. Art. 3 of MD excludes some means of transport, such as agricultural and forestry tractors (which are regulated by the EU Regulation 167/2013, and means of transport by air, like UAVs, which are held by a complex regulatory framework composed of several legal acts (e.g., Regulation EU-2018/1139; Regulation EU-2019/947).

However, MD applies to any types of machinery mounted on these means of transport (like robot-arm, if this product fits the MD legal definition of "machinery").

The majority of robots used in field crop operations fall under the scope of MD; however, in particular cases of risks that are not covered or partially covered by the MD, it can be necessary to additionally apply further European Directives, such as the low voltage directive (LVD, Directive

2014/35/EU), the electromagnetic compatibility Directive (EMCD, Directive 2014/30/CE), the Pressure Equipment Directive (PED, Directive 2014/68/EU).

Manufacturers have the primary responsibility of ensuring product safety. Therefore they must comply with all the mandatory health and safety requirements set out in the applicable legislation. They must take into consideration also national legislation. Indeed, European Directives must be implemented into national laws by each member state, while EU Regulations are immediately binding by law.

Manufacturers must ensure that their robots meet the mandatory health and safety requirements by following the applicable conformity assessment procedures.

In this contest, European standardization is also an essential component. All the Directives underpinned by the “new approach” principles (such as MD, LVD, EMCD, PED) set only mandatory essential requirements, leaving standardization bodies to develop the technical details needed to meet those requirements.

Harmonized standards published in the Official Journal of the European Union are assumed to demonstrate compliance with the European safety legislation under which they are developed. These harmonized standards provide one voluntary means of conformity to the essential requirements. Like directives, standards are often translated into national standards. For example, for highly automated agricultural machines (HAAM), the standard UNI-EN ISO 18497 (2018) *Agricultural machinery and tractors — Safety of highly automated agricultural machines — Principles for design* is fundamental since it confers, within the limits of the scope of this standard, a presumption of conformity with the corresponding essential requirements of MD. In Italy, since 2019, this standard has been translated into UNI-EN ISO 18497 (2018).

In general, manufacturers only need to worry about compliance with European and national standards. If the robot is compliant with all the relevant European and national harmonized standards from the perspective of the EU Member State in which it is built, it can be legally sold in any other EU country (Van Rompaey, 2021).

An up-to-date list of all standards can be found in the COVR Toolkit (COVR,2022).

Like other EU Directives on product safety, MD requires products to obtain a “CE mark,” which allows them to be traded on the EU market.

*The MD implementation in Italy*

In Italy, the MD has been implemented into a legislative decree (D.Lgs. 17/2010), which aims to ensure the health and safety of workers, consumers, domestic animals and even goods, about the risks arising from the use of machinery.

Because of this, the legislative decree states that shall be put on the market or put into service only machinery that satisfies the relevant provisions of the decree and does not endanger the health and safety of persons and, where appropriate, domestic animals or goods, and the environment, when properly installed and maintained and used for its intended purpose or under conditions which can reasonably be foreseen (art. 3, par. 1).

The manufacturer of machinery, or his authorized representative, must carry out a risk assessment to determine the health and safety requirements which apply to the machinery and then take into account the results of the risk assessment in designing and constructing the machinery (Annex I, general principle, no. 1).

According to article 3, par. 3, before placing machinery on the market and/or putting it into service, the manufacturer shall ensure that it satisfies the relevant essential health and safety requirements set out in Annex I; ensure that the technical file referred to in Annex VII, part A is available; provide the necessary information, such as instructions; carry out the appropriate procedures for assessing conformity following article 9; draw up the EC declaration of conformity accordingly to Annex II, part 1, Section A and ensure that it accompanies the machinery; affix the CE marking in accordance with Article 12.

Machinery bearing the CE marking and accompanied by the EC declaration of conformity is considered to comply with the decree's provisions (art. 4, par. 1). The same happens when machinery is manufactured in compliance with a harmonized standard, the references of which have been published in the Official Journal of the European Union. In this case, the machinery shall be presumed to comply with the essential health and safety requirements covered by such a harmonized standard (art. 4, par. 2)

When considering market surveillance, the competent Italian authorities to monitor the conformity of machinery and partly completed machinery are the Ministry of Economic Development and the Ministry of Labor and Social Policies, though their inspection bodies (art. 6).

Specific sanctions are listed in article 15 in case of violations of the legislative decree provisions.

*The ongoing revision of MD*

As part of the EU Commission Work Programme 2020 under the priority "A Europe fit for the Digital Age" (EU Commission, 2020a), the MD is currently undergoing a revision process that will contribute to the digital transition and strengthen the EU single market. In light of this, on the 21st April, 2021, the Commission presented the proposal for a Regulation on machinery products (EU Commission, 2021).

The proposal intends to revise the MD to solve some criticality (e.g., lack of legal clarity and coherence with other legislation - especially the LVD or the PED, shortcomings in monitoring and enforcement of the MD) (EU Commission, 2018) and to address safety gaps due to new risks arising from emerging digital technologies (EU Commission, 2020b).

The proposal is expected to 1) ensure a high level of safety and protection for machinery users and other people exposed to it, and 2) establish a high level of trust in innovative digital technologies for consumers and users. Such objectives will assure a level playing field for economic operators and improve the competitiveness of the machinery sector. Specifically, the proposal addresses six topics: (i) new risks originating from emerging technologies; (ii) legal uncertainty of MD provisions due to a lack of clarity on the scope and definitions; (iii) insufficient provisions for high-risk machines; (iv) monetary and environmental costs due to extensive paper-based documentation; (v) better coherence with other EU product-safety legislation; (vi) divergences in interpretation due to transposition (EU Commission, 2020).

First and foremost, it must be noted that by proposing the conversion of the MD into regulation, the Commission aims at avoiding divergences in interpretation throughout the European Union.

As for the new risks, the proposal aims to cover the safety risks stemming from new digital technologies, particularly collaborative robots designed to work alongside humans and become more autonomous. According to Article 5 of the proposal, high-risk machinery products are machinery products that pose a risk to human health, taking into account their design and intended purpose. Due to the evolution of state of the art in machinery sector, the proposal aims to adapt the current MD list of high-risk machinery products.

By way of illustration, the proposal introduces new machines that present high risks, such as machinery embedding AI systems ensuring safety functions, in Annex I. AI is not explicitly defined in the proposal since it refers to the definition provided for in the AI Regulation that will be (hopefully soon) adopted. As highlighted in Recital no. 45 of the proposal, software ensuring the safety functions of machinery based on AI should be classified as high-risk due to data dependency, opacity, autonomy, and connectivity. These characteristics may significantly aggravate the probability and severity of harm, influencing the machinery's safety. Moreover, there is a lack of experience and data in the AI market, so the conformity assessment of software ensuring safety functions based on AI should not be carried out by the manufacturer alone (EU Commission, 2021). As reviewed in the proposal, the conformity assessment procedure maintains the manufacturer's internal check option only for machinery that is not considered high risk. However, in the case of high-risk machinery, as provided in Article 21, Annex VII, and Annex IX of the proposal, the validation during the conformity assessment procedure should be carried out by a third party, i.e., conformity assessment bodies (notified bodies). This principle applies even when manufacturers use the relevant harmonized standards.

The proposal also defines autonomous mobile machinery in Annex III, par. 3.1.1 letter c) as *"mobile machinery that has an autonomous mode, in which all the essential safety functions of the mobile machinery are ensured in its travel and working operations area without permanent interaction of an operator."* The absence of permanent interaction of a driver and/or operator is the essential characteristic of autonomous mobile machinery. However, the current MD framework does not provide a specific discipline for this kind of mobile machinery. Specifically, the MD provides liability for the car's movement by the driver who may be carried by the car or who may accompany the car or who may drive the car by remote control. However, it does not set up requirements for autonomous machines.

The proposal aims at filling this void: in Annex III, par. 3.1.1 letter b), the proposal defines "driver", underlining that in the case of autonomous mobile machinery, they are the person who remotely supervises the autonomous mobile machinery product regardless of the distance and the means of control communication. As regards supervision, par. 3.2.4 of Annex III specifies that autonomous mobile machinery products shall have a supervisory control function specific to the autonomous model, allowing the operator to receive information about the machine remotely and stop and start the machine when unforeseen or dangerous situations occur. The machine should not be able to operate if the supervisory control function is not active. As mentioned above, the driver/operator should supervise the machinery "regardless of the distance": in line with this principle, par. 3.2.4 specifies that the supervisory function should be allowed when they see directly or indirectly the machine's movement and working area. Therefore, the driver must have a complete and accurate view of the working area's operation, movement, and machine positioning.

## Technical aspects

The main difference in machines is given by the way they are controlled - we can easily identify three levels:

1) hardware, including:

- mechanic control, used to reduce vibrations and direction (e.g. springs or dumpers)

- sensor-driven electro-mechanic control (e.g. crane, hoover, car washers)

- sensor-driven logic almost instantaneous in response (e.g. edge computing)

2) remote control: humans are expected not to be aboard while steering is performed by a (skilled) driver (or player), while the previously mentioned control systems are expected to correct environmental disturbances (terrain, air turbulence), to make the remote control easier, reliable and prompt.

3) reduction or avoidance of human control: this is the level that characterizes Highly Automatized Machinery, known as robots. They can be analyzed in terms of mobility, perception, processing, cognition, and navigation (Rubio et al., 2019).

- Mobility - Quasi-static robots include mechanical arms and other movements aimed at physico-chemical treatments (including UV and Laser), formerly used in closed areas (e.g., in post-harvest production chain for fruit selection, packaging), more recently include those applied on human-driven vehicles (e.g. for pruning and picking fruits, including hoeing, VRA of fertilizers, chemicals and other disease prevention systems). Land-based robots, are mostly 4 wheeled with both synchronized and differential drive, and tracked rovers with skid/slip steering. Air-based robots are mostly represented by unmanned-aerial-vehicles (UAVs, aero-drones). More advanced ones are capable of taking off and landing autonomously.

- Perception - Control of a robot cannot take place without sensing - sensors can be used for (self)almost instantaneous control and without transduction (e.g. spring) or in a measurement-like tool-chain, which is mostly oriented to sense the environment. In this case, a physical signal as a force/torque is converted to a low power electric signal: cell load (pressure), accelerometer, gyroscope, tactile, infrared, ultrasonic, beacons, laser range finder, vision based (CCD), color-tracking, contact, proximity, among others. Such signals are successively encoded and used to generate signals sent to actuators.
- Processing - Digital processing introduces a latency commonly non perceivable by humans, but which may introduce issues of synchronization that can generate delay and reaction times that can easily affect human activities and determine malfunctioning of different levels. Such an issue has been treated with particular attention in developing ROS (Robot Operative System) an open-source, meta-operating system for robot development, a robot communication protocol which is recently becoming very popular in the agricultural domain.
- Cognition - This term refers to the processing features related to the way the robot interacts with the environment. To implement such models, Artificial intelligence and, in particular, Machine Learning are approaches that are merged to classical control strategies to achieve higher robustness (reduce the risk of failures).
- Navigation - One of the most important aspects of a mobile robot is represented by navigation capabilities. It is common to test a robot through a virtual simulation environment where a robot avatar can be assigned a mission. A popular platform for this purpose is Gazebo, an open-source 3D robotics simulator fully integrated into the ROS framework. Navigation software developers aim to embed every rule required to navigate every environment, from a starting point to a target, accounting for any possible collisions.

The risk estimation for harmful incidents caused by agriculture & machinery is considered by the ISO 25119 (2010) norm in terms of 1) severity of the accident, 2) possibility to avoid dangerous circumstances, and 3) probability of harm occurring, which requires to collect a number cases to coin new rules.
A list of hazards for robots has been already identified (Mitka, 2018) and is reported in table 1.

Table 1 - List of hazards from the use of field robots (Mitka, 2018)

| | | |
|---|---|---|
| Unexpected Start | Unexpected deceleration/stop | Unexpected acceleration |
| Unexpected change of direction | Wrong direction at start-up | Failure to start |
| Failure to stop | Failure to react to commands | Avoid damaging people, infrastructure, crops |
| Robustness against noise and uncertainties | Recognize worn and tools | Quick detection and isolation of faults |
| Low modelling and low computational requirements | Manual resetting | A lock to prevent switching on the system by accident |
| Leakage of moisture of liquids | Software or camera failures | |

Listed hazards are mainly aimed at identifying failures and their causes, and are used to compile suggestions to the manufacturer to amend design features, address special tests, and regular maintenance. In Robots, anomalies can be detected at the perception level by testing and replacing sensors and actuators (points 1-9). They include a sensor for obstacles (point 9). Robustness of the system can affect the system's behaviour at multiple levels, from the mechanical (points 10,11,16).

Safety operations include the possibility of intervening manually (point 14,15) and quickly (point 12). Being equipped with a processing/cognition system, robots should be able to detect most of the anomalies and any other condition out of the given range (points 1-7) and be able to determine a stop to any movement introducing a zero-level (no processing) cut-off of power of the main engine. High level (low priority) events can follow a pre-processing before sending alarms to a surveyor - interference (points 10,13) can prevent communication with the survey system (points 8,10).

Navigation is one of the most stressed issues in field robot development - it integrates perception, processing, cognition, and a model of the environment, the latter being mostly considered a source of obstacles and which determine several sources of hazards (points 10, 13 and 17). The issue is more seriously considered in the HRC framework, where laborers and robots share the same 'operative cell'.

In more rigorous regulatory contexts, the responsible for operation must stay close to the robot and intervene in case of failure or unexpected event. In low hazard conditions, robot-cameras offering a view of the field of operation are used by a surveyor who may be located in a remote operations room. Wire-based fences are already applied to robo-mowers and used only for navigation purposes. Instead, monitoring and localization of robots are currently under development but not available yet. (e.g., Khattak et al., 2019).

## Conclusions

Autonomous field robots, including UAVs, autonomous rovers and robotic arms equipped with different tools, are of increasing interest for Precision Agriculture. However, they also raise safety concerns (Rübcke von Veltheim & Heise, 2021).

Robots are complex machines, and failures may occur because of many causes. Any robot component is a fruit of logic, and every mechanical, electronic and software component results from a production cycle where each step may introduce faults.

While manufacturers are focusing on producing reliable machinery accomplishing standards focused on commercialization, the ruling system aims to identify the responsibilities related to the use of robots in the open air.

In the EU, the regulatory system may have important feedback on agriculture robotization, already envisaged in past economic considerations of Cost-Benefit analysis on Precision Agriculture (Snyder et al.,1998).

The key point stands in the surveying system, which is asked to provide full supervision of the robot's activity and operative environment, and could represent an economic barrier in smallholdings.

Adding an automated survey system introduces complexity and scaling issues on the one side, but could help reducing costs of human supervision on the other side (Lowenberg-DeBoer et al., 2019; Lowenberg-DeBoer et al., 2021).

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