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Possible innovative technical measures for risk prevention during the use of mobile machines with remote guide/control.

*Marco Pirozzi[a], Luciano Di Donato[b], Laura Tomassini[c], Alessandra Ferraro[d]

[a]*Inail, Via Fontana Candida 1, Monte Porzio Catone, Italy*; [b]*Inail,* Via Roberto Ferruzzi 38, Rome, Italy; [c]*Inail,* Via Roberto Ferruzzi 38, Rome, Italy; [d]*Inail,* Via Roberto Ferruzzi 38, Rome, Italy;

* Corresponding author. Tel.: +39 06-94181564; fax: +039 06-54876413. *E-mail address:* m.pirozzi@inail.it, ale.ferraro@inail.it

Abstract

The application of remote control systems on different types of machines used outdoors has found a greater diffusion in recent years. In many sectors (agriculture, forestry, earthmoving, etc.) machines with a remote control system are designed to trace and control the distribution of machines, to track and modify the operating parameters of the machines for remote diagnostics and for the management of work activities. In this way it is possible to measure and to improve the operating efficiency of the machine by the measure of the duration of the various operations performed, and by the alert related to malfunctions / failures, carrying out work activities.

The absence of the operator on board involves both the elimination or reduction of some types of professional risks (eg. risk of overturning, risks of musculoskeletal disorders, etc.) and the possibility that the machine is lacking in some devices protection (the machine is in automatic driving mode).

At the same time, this can introduce new problems relating to possible dangerous events both for operators who are directly involved in the remote control of the mobile machine and for other workers / persons potentially present in the work area (dangerous area).

The machine itself could then find obstacles in its path due to the environment in which it operates while the operator or other workers or other persons could be affected by the projection of objects / materials during processing. The problem is that remote-driven machines often do not have adequate auxiliary alarm systems and / or adequate remote auxiliary visual systems.

This document shows the research project of Machine and Work Equipment Laboratory of INAIL (Italian National Institute for Insurance against Accidents at Work) on this type of mobile machines. We are studying the implementation and use of remote driving and machine management in relation to:

- the aspects relating to the reliability and level of performance required by the current applicable legislation for the control system;
- taking into consideration the possible errors in the transmission of information and all the possible interactions that may occur during specific work activities;
- define and identify the technical innovative safety measures that shall be implemented on the machines and on the operators/workers;
- provide a technical document for the machines equipped with the technologies considered containing the requirements and solutions identified.

In particular, the tag is to design and test an innovative safety system based on the use of smart sensors and wearable sensors (Rfid) for monitoring and managing the conditions / situations of danger present in the use of mobile operating machines. Particular attention is paid to the critical issues related to context interferences (workers, equipment, environment) potentially present in the remote driving of mobile operating machines. The idea is to use a WSAN network (Wireless Sensor & Actuator Network) to obtain continuous monitoring and "process", even automatically, dangerous situations obtaining a safe management of all the areas involved in the work.

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1. Introduction

In recent years we have seen the development of new types of operating machines that use the different technologies of wireless data transmission (wifi, bluetooth, gps, etc.) for their driving or remote management. The use of control systems based on these technologies, together with their cost reduction, spread not only to the load lifting sector (cranes, bridge cranes, etc.), but also in others work sectors that including construction, earth moving, agricultural and forestry.

The use of innovative machines involves the elimination or reduction of some types of risks related to the presence of the operator, eg. risk of overturning, risks of musculoskeletal disorders, etc.. At the same time, it introduces new issues in terms of possible dangerous events that may involve the operator of the machine and also other subjects potentially present in the work area. Machine manufacturers and users not always fully consider these critical issues in their activities. It is also necessary to consider the possible problems linked to the availability on the market of apparently equivalent remote control systems that may be very different in terms of reliability, with reference to circuit techniques and the quality of the components used.

This paper describes the research project of Machine and Work Equipment Laboratory (INAIL) on mobile machines' remote guide/control. The study focuses its attention on the implementation of safety systems in the use of driving and remote control machines.

2. State of the art of mobile operating machines with remote control/guide

There are different types of operating machines with remote guide and management that differ for driver assistance tool and remote control systems. It allows to manage the machine through the transmission of information e.g. managing the different working methods for carrying out specific operations and remote diagnostics.

These last two aspects must be taken into consideration in equal measure and are and must be closely related. The analysis and management of all the information relating to the "operational and non-operational" parameters of the machine, together with the characteristics of the machine's control system, contributes to define the overall safety level.

It is therefore useful to characterize the remote control systems in those that allow monitoring the operational parameters of the machine and those that carry out the actual driving of the machine and / or the movement of parts of it (including the organs processing). [1]

In earth-moving and construction field, machines equipped with monitoring systems for operating parameters allow:

- preventive diagnostics (for example in relation to the engine, hydraulic components and hydraulic systems);
- checking the behavior during the operation of the machines (for example, detection of excessive stresses due to absorption of power and fuel consumption);
- planning maintenance activities (based on the actual number of hours of operation);
- detecting the anomalies and the improper use of the machines themselves (for example with warning lights and sensors activated in case of failure or approach to hazard zones).

It allows to avoid long machine stops which produce high costs. For example, information may be obtained on the lack of lubrication of moving parts of machines which causes multiple failures due to the consequent oxidation and frictions on these mechanical parts. [1]

With regard to the parameters relating to the work methods, particular interest is directed to the continuous monitoring of the machine position, which is useful for multiple purposes, also considering the type of machine itself and the process performed. For a mobile self-propelled operating machine the location of its position in real time allows, in case of failure, to reach it with the assistance service. To identify the exact position of the machine it is possible to use different satellite systems (GPS, GNSS, Galileo, etc.) which, together with the signals coming from fixed radio stations on the ground, ever allow great precision (from ten meters to a few cm) to define longitude, latitude, altitude data. The satellites send a pulse and the GPS receiver inserted in the operating machine intercepts four or more impulses and then decodes them, starting the process of defining the position using the calculation method based on "trilateration". This procedure allows the determination of the position of a point based on measurements of distances from others of known coordinates, rather than measures of angles.

The location of the operating machine, the simultaneous acquisition of information relating to the different parameters characterizing the various working methods and the use of specific software allow to remotely set-up the work and control the final result by optimizing the production cycles.

The first applications were introduced on the earthmoving and agricultural sector and later extended to the asphalt laying sector. [2] Today it is possible to manage the leveling of the asphalt through wireless systems that allow a high degree of precision by returning the plano-altimetric profile and eliminating the installation of pegs and guide wires. There are so-called "intelligent" vibratory roller compactors which, by measuring the "rigidity / density" of the ground and / or the "rolling resistance" of the compactor roller, allow optimization of compaction according to the type of ground by modifying the interaction of the roller with the ground. The GPS system enables to map the area and return in real time to the operator the areas where the compaction has been carried out correctly and where it is instead necessary to intervene further. The operator can see this information in real time either by an integrated monitor inside the machine and by a remote control unit. [2] Similarly, the same technology, assisted by specific software, is used to perform milling operations and asphalt laying operations.

[4] In the agricultural sector, where precision farming has existed for a long time, and in the forestry sector, they are now frequently used:

- basic or very advanced electronic technologies, responsible for both the acquisition of data (monitoring) and the use of information within the production context (operational control). These technologies generate and use information in the initial and final stages of the production cycle;
- positioning technologies with which the information for the production cycle is integrated with further indispensable data when it is necessary to know a spatial dimension of the production process;
- hardware information technology for physical data management, ie the availability of systems and supports or physical channels for their visualization, storage, transmission (through various types of telecommunications networks and systems) and usability;
- information technology software used to process information and interface the digital functions of the hardware for usability purposes for end users.

In this sector are used:

• semi-automatic driving systems (Gps and/or Gnss) and in some cases also automatic systems with large monitors that are generally installed on tractors so that in the field they can move with higher precision than that guaranteed by an operator. The use of these systems makes it possible to eliminate the overlapping of worked land and thus savings seeds, fertilizers and plant protection products;

• sensors applied to machines and equipment for internal and external management;

• isobus systems for tractors and operators that allow a two-way exchange of information between the basic machine (tractor) and the operating machine (interchangeable equipment);

• variable operating machines capable of reading prescription maps for all cultivation operations;

• mechatronic operating machines able to modify their functionality in real time based on the variable working conditions.

The use of these technologies contributes to obtain agronomic, and therefore productive, economic and environmental benefits, resulting from the optimization of the inputs. In particular, the use of driver assistance systems and remote control allow the machine to retrace the same path followed in the previous operations with an approximation of 2-3 cm. This allows to increase the productivity of the different processes, especially when their use is coordinated with the management system of the manufacturing enterprise, maximizing efficiency and reducing operating costs. The implementation of these systems allow to verify, in real time, both how the machine works and the variables of the human factor in its use. The satellite position detection system together with the historical data storage management programs can also be used to draw up real technical reports with the precise and temporal detail of each machining operation performed by the machine.

Fig. 1. Application scenarios of machines with remote control

3 Safety aspects related to the use of these machines

In relation to the safety of the operator, the possibility of having a machine managed remotely has two main effects: the first is that the risk situations connected to the use of the machine are modified, the other is that machines have safety and control devices deeply different. Consider, for example, the processes that involve moving a self-propelled operating machine in situations and environmental contexts such that the operator on the machine can be exposed to multiple risks, such as:

- those linked to the hazard of overturning during the work carried out on a slope or due to an imbalance of the load moved which leads to instability of the machine,
- those related to the fall of the worker during the ascent and down from the machine,
- but also those attributable to the fall on the operator of any load / material transported / worked.

We must also consider the risks associated with the possible contact with mobile transmission and processing elements present on the operating machine and finally all the possible health problems related to physical stress (musculoskeletal disorders) and exposure to polluting and toxic agents. The use of remote control machines eliminates or reduces the above described risks and consequently allows the elimination or modification of the relative safety devices with which the machine must be equipped. For example the possibility of eliminating the installation on the machines of the following operator protection devices could be evaluated/ considered:

- Driver retention systems;
- Rollover protection structures (ROPS);
- Falling-object protective structures (FOPS);
- Operator protection structures (OPS).

The driver retention systems and ROPS perform the function of protecting the operator in the event of overturning, while FOPS and OPS respectively perform the function of protecting the operator in the event of falling objects from above and penetration of objects into the driving position.

As already observed, in many cases it is however necessary to provide for the implementation on the machine of different safety systems in relation to the possible problems related to the movement of the machine or parts of it.

4 Main issues in the use of remote controlled machines

The current study deals specifically with safety aspects of operations performed with the aid of remote controlled machines, without considering applicability aspects, linked to the investment capacities in new technologies and of some technical problems still not completely resolved. [5] The manufacturer and stakeholders of machines safety (employer, employees and affected persons) must consider, in pro/con assessment, new risks could come from innovative technologies such as:

- presence of new risks connected for example to context interference;
- the need to guarantee the security of data transmission if networks are used to exchange information between the operator and the machine;
- ability to implement reliable safety functions and control systems.

For example we can certainly say that the use of remote controlled machines in sectors and processes characterized by the possibility of having the simultaneous presence of machines and operators can determine events and accidents, even of different nature, due to such presence or the presence of obstacles environmental. It should also be considered that the operator can be very close or relatively far from the machine that controls him/her because of the need or not to have direct visibility of the work area. Therefore, the operator must have control not only of his own operating machine, but must have the management of possible interferences. To manage risk and emergency situations, the functionality of control systems must work in all conditions. [6]

These are control systems based essentially on the use of wireless technologies with information that must be reached by both operator and machine. Moreover the machines often are not equipped with suitable auxiliary alert systems and/or suitable auxiliary visual systems.

In this context it is necessary to consider the critical issues related to various types of remote control system and various types of transmission data and communication protocols. It is important to focus the study on security and reliability of data communication and of software connection systems.

The systems can be used if for example they are able to ensure, with a reasonable degree of reliability, even in the event of malfunctions, that:

- it is not possible to connect to a machine other than the one selected;
- data transmission to and from the machine is immune to transmission errors;
- it is not possible to connect to a machine without the consent of the user or an operator who is near the machine.

5 Possible solutions

The Machine and Work Equipment Laboratory of INAIL has launched an extensive research project that aims to identify and define innovative safety systems and measures to be implemented on the remote-controlled mobile machine and on the operator who interacts with the environment and with other subjects operating in the work area. For the definition of safety measures, the aspect related to the "management" of the possible actions to be performed in function of the "alerts" produced by the occurrence of certain boundary conditions is relevant. The management of "alerts" must process appropriate information to be effective; it could need the implementation of other specific safety function. The manufacturer must carry on a deep analysis of the reliability and performance level reached for these new solutions, according with control systems requirements.

The solution must be validated for this type of work context.

On the basis of identified risks, considering the process characteristics and the need to "follow" the movements of the machine or part of it, the idea is to implement specific sensors (smart and wearable) to be installed both on the operator (s) and on the machines.

These sensors, together with the use of intelligent actuators to be installed on the machine, allows continuous monitoring of the various operating and boundary conditions that occur during processing carried out with remote control machines.

Furthermore we want to study how better manage, also automatically, hazards rising from obstacles or other workers, obtaining a safe management of all the areas involved in the work (work and proximity areas).

The research group is considering WSN (Wireless Sensor Network) and WSAN (Wireless Sensor & Actuator Network) designed to connect peripheral devices (precisely sensors and actuators) in areas of limited extension with limited traffic and extremely low consumption. [3]

These types of networks are interesting for "coverage", transmission capacity, energy consumption and mobility by traditional wireless networks.

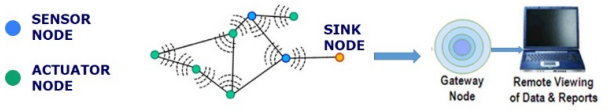

Fig. 2. Wireless Sensor & Actuator Network

Exchange of information in the sensor network can be "routed" through data transmission systems, sending and receiving data directly from/to machine and operator, but also through the use of real data transmission networks. These networks are based on specific communication protocols that must have security requirements.

These considerations highlight the need to study the possible implementations of sensors (smart and wearable), of RFID systems and information and communication technologies on remote controlled machines, starting from the characteristics of the command and data transmission systems used today and specifically studying the characteristics of reliability and the levels of safety achievable.

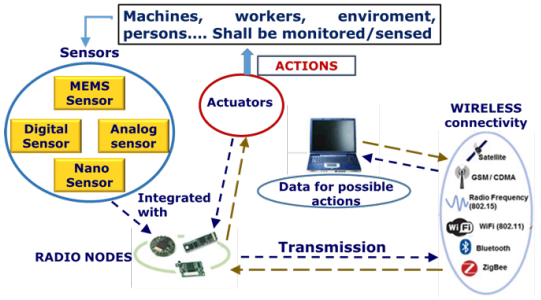

Fig. 3. System for monitoring of operating and boundary conditions

5 Conclusions

The connection of intelligent sensors and actuators with the systems designed to store and elaborate their data can be a useful and practicable element of innovation in the field of mobile machines remotely controlled and working in outdoor. This especially in relation to the widespread need to connect a transducer to the control system with maximum simplicity and reliability. This will allow the operator to manage alarms and danger situations through specific actions that the machine can perform automatically without the intervention of the remote operator.

The use of smart wearable (RFID) and WSAN will allow operators in work areas (potential dangerous areas) to interact with the machines and avoid damage due to possible interferences with the machines.

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