A Mechatronics Security System for the Construction Site*

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ABSTRACT: As part of the Future Home project, research was conducted to look into ways of improving the security and develop methods and reliable systems to detect possible failures and to avoid any harm to the machinery and installations and, above all, to the workers in the construction site.

The work described in this article deals with the development of a particular security system, using both existing commercial technology and specially designed equipment.
The compulsory safety helmet required for all worker in construction sites is used as the base to accommodate miniature positioning and communication instruments (see figure 1). The position and ID of each worker is sampled periodically and sent via radio to a monitoring station, where the information is compared to a database containing the tasks and processes being performed in the site. According to this, workers and machines' positions are known in each instant and risk situations may be recognized immediately and therefore damage can be prevented. If certain workers and particular machinery and equipment elements are not supposed to be in certain locations for safety reasons, an automated system can be used to detect the situation and make the adequate decision to prevent a possible accident. The proposed system is meant for modern construction systems where workers and automated/semi-automated machines coexist.

KEYWORDS: Construction Site Safety, Automatic Construction System, Positioning in Construction, IT in construction.

1. INTRODUCTION

Thousands of construction workers are injured or killed in construction accidents each year. Construction companies must inspect each site with safety engineers and provide safety programs, but unfortunately accidents still happen due to the inadequacy of these provisions. When a construction site accident occurs, the owners, architects, insurance companies and manufactures of equipment can be held responsible for inadequate safety provisions. The general contractor and all subcontractors are required to provide a reasonably safe site, warn of hazards inherent to the site and work, hire careful employees, co-ordinate job safety and supervise compliance with safety specifications.

As part of the Future Home project [Balaguer, Atkin], research was conducted to look into ways of improving the security and develop methods and reliable systems to detect possible failures and to avoid any harm to the machinery and installations and, above all, to the workers in the work site.
The work described in this article deals with the analysis of risk sources and situations in modern construction sites and look into ways of reducing the accidents that may be caused. A security system is then proposed, and a prototype is developed and tested to prove the feasibility of the proposed scheme.

The compulsory safety helmet required for all worker in the site is used as the base to hold miniature positioning and communication instruments (see figure 1). The position and ID of each worker is communicated periodically via radio link to a monitoring station, where the information is compared to a database containing the tasks and processes being performed in the site. If a given worker is at what the system considers a hazard source it acts according to the nature of the source.

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Figure 1. Equipped Safety Helmet.

As far as the human safety is concerned, the objective is to prevent the operatives from suffering accidents related to falling or collision with dangerous objects such as moving crane loads and other machines in operation. The danger can be communicated to the worker in questions via alarm or voice using the head phones fixed to the helmet.
The following sections describe the analysis of risks, proposes a security strategy and described the developed prototype system.

2. RISKS AND SECURITY SYSTEM

One of the big challenges of new construction methods is to give a solution to all type of accidents traditionally associated to construction and to minimize new risks that may appear with the introduction of automation and robot-like machines in the worksite.
According to analyzed accident statistic figures [CA3-01], the most common risks for the operatives may be reduced to: fallings, collision with mobile and fixed objects and workers trapped between objects. All these hazards are due to the continuous interaction between the workers, and the machines or any other dangerous fixed or mobile object. Once defined the risks sources, a security system may be designed to prevent accidents from happening, which should cover machines and humans.

2.1 Security Levels

As mentioned above, an adequate security system should cover two levels namely:

- Machine level
- Human level

The machine level refers to the failures in the machinery, possible erroneous operation, bad conditions of the components, etc.
The main omnipresent machine in construction sites is the crane, which is the main source of possible accidents all over the world. Crane accidents claim at least 50 lives in the United States alone each year, according to data kept by the Occupational Safety and Health Administration (OSHA) besides the many more injuries they caused [CA3-01].
In particular, there are several risks associated to conventional Gantry cranes, such as failures and breaking of the cable, translation brake failures and swinging of the load. These are risks that have been taken into account during the development of the prototype crane used in this project [Balaguer].
Moreover, the position of the crane is known to the control computer and may be communicated to any other process in the construction site provided that the infrastructure can support it.

As far as the human level is concerned, the objective is to prevent the operatives from suffering the accidents related before. The strategy to adopt consist in the definition of different safe and prohibited zones around the workers and the sources of danger, so that in the moment in which these areas comes into contact a danger situation is triggered and warning is generated.

2.2 Prohibited Zones

Prohibited zones are spaces/volumes that are associated to the source of danger, which indicate that if a worker accesses it he or she risks suffering an accident. The source of danger can be a fixed or a mobile object, and therefore a distinction is made to differentiate the prohibited zones: static and dynamic prohibited zones.

2.2.1 Static prohibited zones

The dangerous volume is fixed around a given position to delimit a deep hole for example, or a fixed machine. Traditionally, the way to delimit this kind of zones is by mean of techniques like perimeter fences, light barriers, safety mats, electromagnetic induction, etc.

The disadvantages of these systems are that, as being static systems, they do not allow the entrance to the zone even when the machines are not moving, so the zone where the operatives can work is reduced.

2.2.2 Dynamic prohibited zones

In this case the prohibited zone is defined as the volume associated to a moving source of danger, such as a crane's load (see figure 2), and therefore it moves with it.

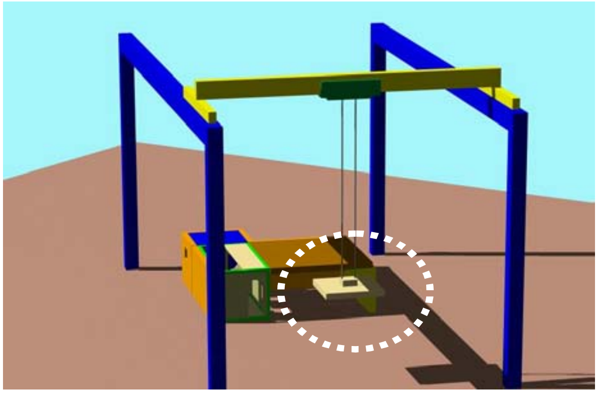

Figure 2. Prohibited zone associated to the load

3. SECURITY

Taking into account the fact that machines like the crane are the main source of danger present on-site, the objective of the security system is to avoid the operatives entering into the crane's operating range. It is necessary to define:

- The virtual dangerous volume around the source of danger (the crane's load), with dimensions that are dependent on parameters such as the speed of the load and the desired level of security.
- The virtual safety volume around the operatives.
- All the equipment necessary to control these relative positions and to send the adequate orders to the machines and to the operatives in case of danger (interfaces).

All this requires a computer system to verify that there is no collision between the predefined safety zones and to stop the movement of the crane when a dangerous situation is detected.

At this point, we may differentiate between two types of security:

- **Passive Security**

We refer to passive security to situations when the operative in danger is alerted with no intervention of the control PC.

This security system can be implemented by equipping the crane with a radio transmitter with a pre-determined emission range. The operative wears the correspondent receiver so that, when he enters into the emission volume defined as dangerous, an alarm will be issued.

- **Active Security**

On the other hand, we call active security when there is a control computer that drives all the security process.
This is an appealing system, since it is possible to have a control center from which several processes are controlled with the possibility of defining all the parameters via software (ratio of

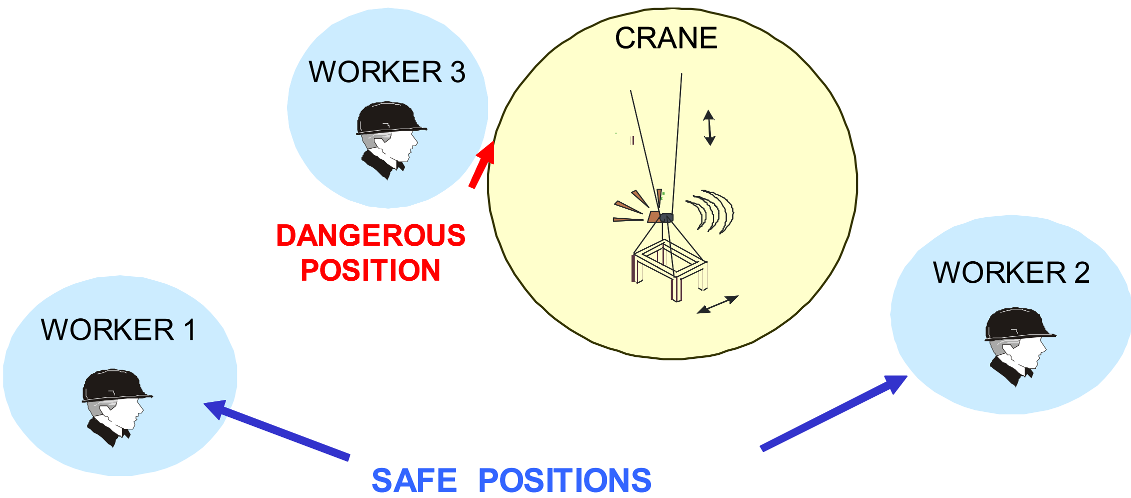

Figure 3: Safe and Dangerous relative positions

danger, type of alarm if necessary, number of workers and machines in observation, etc.).

This PC-based control system:

- Examines the positions of the machines
- Examines the positions of the operatives
- Defines a safety margin and
- Acts consequently if that margin is broken.

Operatives can move even inside the workspace when required, provided that the particular source of danger is not present at that moment (crane load or machine moving parts) (figure 3). When the PC in the control station detects a dangerous situation it proceeds to give notice to the operatives (sonar) and machines implicated to reduce the speed or halt the operation. Such a system is able to record the evolution of movement of workers and machines to be used for further analysis when required.

4. PROTOTYPE DEVELOPMENT

To test the feasibility of the proposed security system a prototype was developed considering the above discussed ideas. The three main part that constitute the system and considered in the design are shown in the figure 4 and listed bellow:

4.1 Mobile objects

These are the crane or any other mobile machinery or tool. It is necessary to develop the system for trolley and bridge positioning, object and people identification and communications. The object used in this case is the prototype automated crane developed in this same project [Abderrahim]. The crane was equipped by positioning sensors and advanced anti-swinging control system and necessary limit switches to keep the trolley in the workspace and avoid accident. Its control computer is able to communicate the position and other information to the security control centre.

4.2 Operatives

Design and development of the necessary equipment for positioning, detection and avoidance of dangerous zones, identification and bi-directional communications is implemented.
The idea is to take advantage of the compulsory safety helmet and develop the necessary miniature instrument to fit in the helmet and perform the task required: positioning, voice communication, data communication, as well as radio frequency identification tag.
Since the objective is the design and testing of the system rather than the hardware itself, commercial equipment were therefore used and integrated in

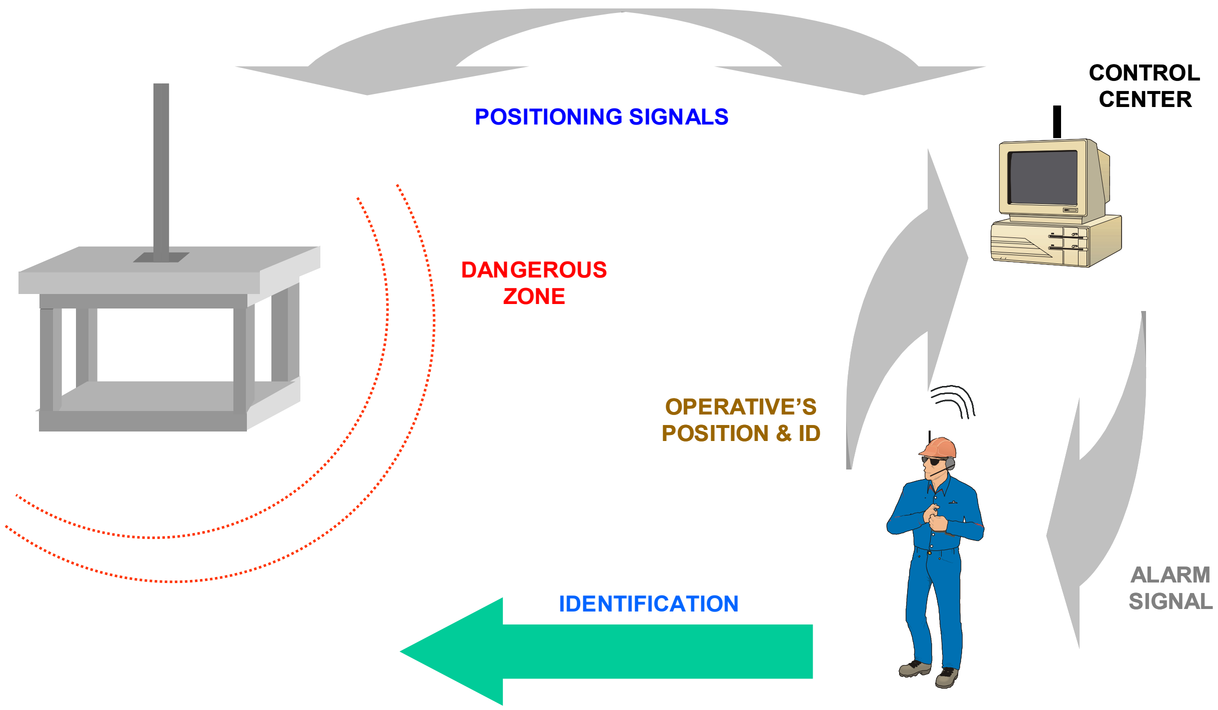

Figure 4: Security Prototype Elements

our lab developing the necessary components:

Helmet: a standard commercial construction safety helmet was used. It is readily prepared with fixing for the bi-directional voice communication system.

Positioning: A Garmin GPS receiver was used to detect the position. This type of measuring is adequate for open construction site and would not work inside the buildings. Any other similar positioning technique is appropriate. The position sampling in this case is 1 second; an important parameter to take in consideration for decision making regarding risk situations. The position reading is transmitted to the control center via radio.

Voice communication: A bi-directional communication system (Headphones and Microphone), transmitter and receiver integrated into a high quality ear defender and hands free communication in high noise environment (figure 1). The system is adaptable for the safety helmet attachment.

Micro Video Camera: A commercial micro camera with omni directional antenna was used. The camera weights 20 grams (without the battery) and transmits to a distance up to 300 meters.

4.3 Control centre:

The control centre integrates all positioning, bi-directional communications and alarm-situation data, with a PC and Human-Machine Interface. The system can be configured and used by an operator via an intuitive graphical user interface (GUI) as shown in the figure 5.
The position of the operator and the dangerous zones can be visualized by simple graphical representations. When an operator enters a dangerous zone, this can be seen on the right side of the interface. The view from the micro camera can be shown on the top left part of the interface allowing the user to see in real time the environment around the worker.

The Radio Link to the Control Centre

The radio link devices for the prototype presented in this work to ensure the communication between the GPS and the control centre have been built at the Robotics Lab of the University Carlos III.. The radio links for the camera and voice communication are commercially available. Sensorial information fusion is performed via software.

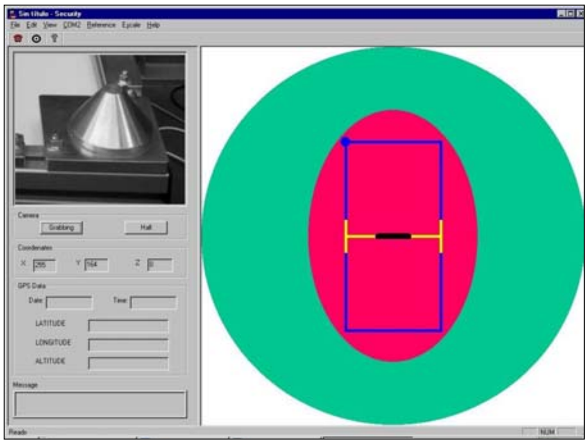

Figure 5.Graphical User Interface in the Control Centre

The result this design and integration is the whole safety system, where any collision between dangerous and safety zones is detected by the central supervision point. The system was implemented and tested with one instrumented safety helmet and produced satisfactory results.

5. CONCLUSIONS

Before developing the security system, a great deal of valuable information was collected and analyzed with help from construction safety experts. The results and ideas of this work are therefore realistic and applicable to a real scenario. The developed system has been tested and proved to detect potential danger of collision when an operator enters a dangerous zone. The system is able to warn automatically the operator in a potential risk position and also can use this information for other purposes. However, it is important to note that the system is a prototype and further development is expected to make it work for a number of workers on the construction site. An adequate IT infrastructure should be available on the site to allow the implementation of any modern security system.

6. ACKNOWLEDGMENT

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