An IT Infrastructure and safe collaboration in modern construction site

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Abstract—**This paper deals with machine collaboration in modern construction sites like that proposed in the FutureHome building system and suggests a scenario for implementing a safe collaborative system. The collaboration is meant to happen between automatic machines and between machines and operators. Safety issues are discussed and treated as part of the FutureHome collaborative building system. An adequate IT infrastructure in the construction site is a key element for implementing a safe collaborative and information rich environment.**

Index Terms— **CIC Construction, IT infrastructure in Construction Site, Machine collaboration in the construction site.**

I. Introduction

THIS work is motivated by the importance of the correct materials handling and the necessity of establishing how such a process can be achieved in a modern construction site. Damage to products and operatives can easily occur and this leads to waste and delays. A Modern Construction Site such that envisaged in The FutureHome project foresees the use of an important number of prefabricated elements and modules that are delivered to the site fitted with as many equipment as possible from the factory.

The assembly of prefabricated modules in a FutureHome building is expected to be performed in an automatic or semi-automatic manner and therefore this imply a manufacturing like environment where machines are operated, programmed and synchronized in a defined way. Any set of operations performed by more than one operator or more than one machine or even by operators and machines in order to achieve an end have to be achieved in a collaborative manner between the parties involved. An essential step to take in order to develop the work further and achieve the set objectives, is to identify the machines/operatives present in a modern construction site as well as the possible on-site factory. The following step consists of the determination of the collaboration required and ways of achieving it in a safe manner. It is also important to establish the required communications and IT infrastructure, automatic ID systems and the positioning and inventory of all elements in the site. The IT infrastructure is an essential requirement to implement collaboration on the site.

The paper describes a possible architecture of a collaborative construction system, where automatic and semi-automatic machines are present in the construction site besides the operators and traditional machines, where a good communication resources and IT infrastructure allow fast flow of information and continues assessment of the progress of the construction process.

II. Collaboration and IT Infrastructure

In the context of construction, Collaboration may include all those joint efforts towards achieving any part of the construction process, using the abilities of each collaborator. In addition to the construction and assembly process this include the joint efforts involved in moving parts, elements and tools required to perform all activities taking place within the construction site and leading to fulfilling the desired goals (efficient construction).

Most of the activities taking place in a construction site are actually performed in a collaborative manner. *Machine driving:* Any machine operation by a worker is considered collaborative working where the operator is the link between the machine and the construction system such as the planning and the scheduling. *Crane operating:* moving parts using the crane is done in collaboration between the operator the machine (crane) and the schedule producing the instructions. Automatic cranes and machines should be equipped with the adequate communication facilities to report their position and the task progress. The information is then fed to a site dynamic

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database, which represents an essential part of the IT infrastructure. Due to the dynamic nature of the site and the motion of the parts, materials, machines and individuals, the IT infrastructure is expected to offer radio and wireless access points for permit an easy exchange of data.

The above examples are correct for all the activities taking place in the construction site such as lifting, assembly, ordering goods and storing deliveries. All these operation may be performed through adequate Man Machine Interfaces (mechanical, joy sticks, Graphical devices, scanning devices, etc.) to allow achieving all tasks safely and without any damage (to personnel, machinery and parts).

III. Construction Site Operatives

The modern construction site (FutureHome) is expected to be a Computer Integrated Construction (CIC) site [1] where the work is assisted by computer tools from the early stages of design until the construction assembly of prefabricated elements/modules on site. This involves the use of automatic and/or semi-automatic machines for the lifting of loads, moving parts and loading/unloading machines in addition to the presence of traditional machines involved in the delivery of parts and goods.

Examples of machines, which may be used, include

A. *Automatic earthmovers and excavators*

This type of machines can be employed in the preparation of the site before starting the construction. Examples of these machines have been developed, and proved to achieve 2-3 cm position accuracy [3]. It is thought that their use in real application is still very limited [4]. Figure 1, however; shows a real commercial application of the Computer Aided Earthmoving System (CAES) that combines GPS positioning with an onboard computer and wireless communication [5].

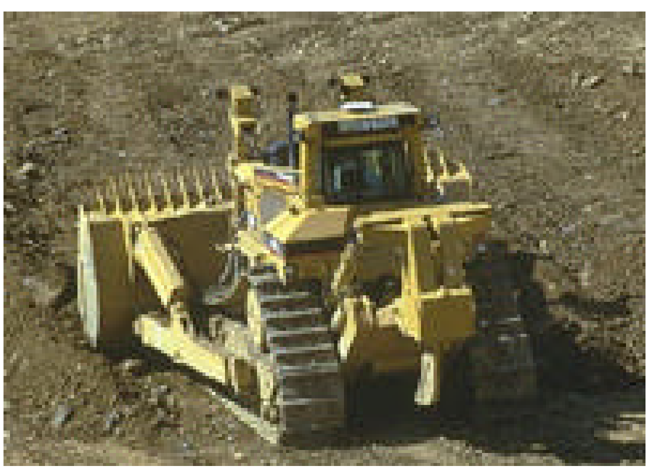

Fig. 1. An example of an earthmoving machine fitted with Trimble GPS guiding system.

B. *Automatic Cranes*

This type of machine can be used for moving parts from one position to another in the construction site with a minimum intervention of the human operator. The operation itself is similar to that of robotic manipulators. Several machines of this type with intersecting work zones allow moving objects between any two points in the site, using the intersection zone to transfer the load from one crane to another if necessary. An automatic crane should have the ability to recognize the element/object to be moved and move it to the right target position with sufficient accuracy. An automatic/semi-automatic crane should be equipped with all features and sensors of robotic manipulators such as joint position sensors and control, kinematic control, I/O ports for communication and hand-shaking with other machines and devices. An important desirable feature is the ability to access the building site database to extract information related to the parts to be handled and the tasks to be performed. After the completion of a given task, the new status information such as its new position and whether it is assembled correctly or not should be updated on the database. It is important to indicate that in a FutureHome building site the modules/elements and parts in the site are fitted with proper labelling/Auto-ID devices. This is to allow their recognition by the machines and operators involved in the construction system, which/who would contrast their current status against the information stored in the site records when required. An example of such crane is the prototype developed at the Roboticslab of the University Carlos III of Madrid [6]. A suitable gripper design for such a crane was accomplished taking in mind the modular building structure and the auto-ID labeling of materials and parts to be handled [7].

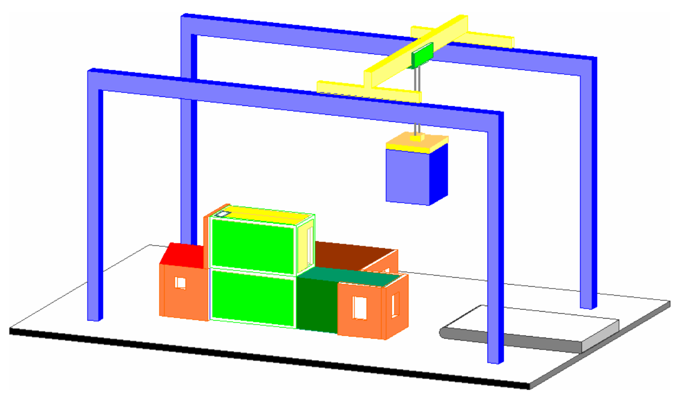

Fig. 2 A schematic drawing of the automatic crane developed at CA3.

C. *Construction Manipulator*

These are large-size robots designed to manipulate heavy objects such as those encountered in construction sites like prefabricated panels or large brick-like blocks [8] [9]. The ROCCO robot example (figure 3) is able to handle up to 500 kg with a reach of 8.5 m to erect external walls [8].

D. *Intelligent Autonomous Vehicles*

The IAV can be wheeled or chained autonomous vehicles, which may navigate freely within the construction site. This type of vehicles should be equipped with a good control and navigation system as well as accurate position sensors such as GPS. The accurate positioning used with an adequate map of the site environment would ensure a safe utilization of Autonomous Vehicles. IAV can be used for moving goods personnel or sent to fetch goods from distant locations of the building site. The store keeper may load some parts or equipment on an IAV and order it to deliver to a given location where another worker may receive the parts and the instruction about what to do with them. An autonomous vehicle may be used as the base of a mobile manipulator, which may perform the loading, and unloading of goods.

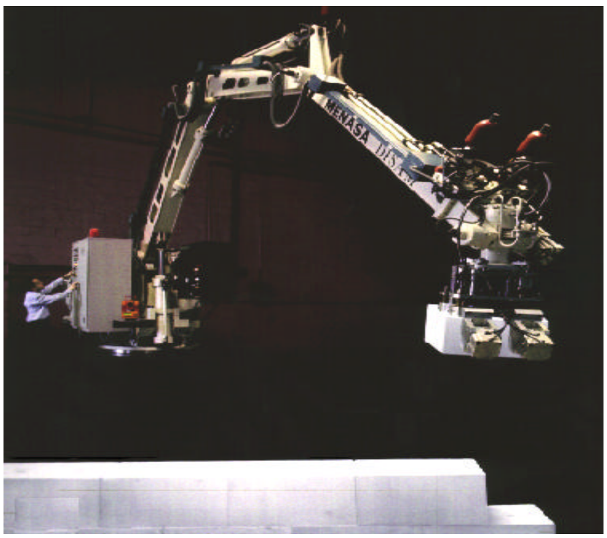

Fig. 3. The ROCCO construction robot

IV. Safe Collaborative Working

After identifying the types of machines present at the construction site, ways for implementing a collaborative working scheme of these has to be established. One important issue is that among the machines there are some fully automated, semi-automated and traditional ones. This can be a key element when choosing how the collaboration can be implemented.

The FutureHome like modular building system is expected to be Computer Integrated Construction system which is furnished with a good IT infrastructure and reliable communications resources. All collaborating machines must have access to information sources in the building site and to selected data related to the project. According to the project planning and schedules, each modules of the building is delivered and then assembled to the main structure in its target location according to a given orientation.

It is of crucial importance for the automation and collaboration in the site that machines should know their position relative to a precise reference. The position of the buildings under construction, parts and building modules are all expressed relative to the same reference. This way parts and objects are moved to their correct target positions in the building site with minimum possible error.

The information stored in the site database should be updated after every operation affecting the state of the parts, machines and building modules in the site. This information is therefore made available to all machines, operators and agents in the site. The database should contain the CAD designs and the current state of the work and assembled modules. This information could be used by the CAD itself, or other virtual reality environment software, to display the completed part of the building.

A. *Automatic Auto-ID labeling*

The automatic and semi-automatic machines (and even the operators) must be able to recognize the elements and modules of the building they are about to handle. Those elements and modules are therefore required to identify themselves to the machines through the use of adequate Auto-ID labeling/tagging techniques and devices.

After examination of several Auto-ID techniques in current use it seems that the most appropriate for implementation in the FutureHome building system are Radio Frequency although, Barcodes may be used depending on the circumstances.

Barcodes: Barcode are used as an identification system in almost all sectors. This system is already implemented in industrial production as well as in consumer orientated service. The use of Barcode is more adequate for store keeping and ensuring an adequate stock of tools, parts and construction good is available in the construction warehouse (store). Stock level can be verified automatically and orders may be issued also automatically if necessary.

Advantages: They inexpensive and easy to produce, can be very durable, and enjoy wide use and acceptance. There is a large choice of printing and reading equipment in the market. The identification can be achieved with high accuracy.

Disadvantages: Labels can be damaged by common contaminants, and can hold limited data capacity. They are read-only and only one tag can be read by a reading station at a time.

Radio Frequency ID (RFID): Read/write RFID involves the use of a radio frequency (R/W) station in conjunction with transponder tags. They can read and change or add information to the tags as they pass. This type of labeling/tagging is more adequate for larger parts and modules of the FutureHome building system. The tag is able to store the reference of the module and possibly more information related to how to handle it, which can be interpreted as instructions to the handling machine.

- Tags range from one-bit Electronic Article Surveillance tags to sophisticated read/write systems with up to 1MB of addressable memory and size as little as (0.4mm x 0.4mm x

60 microns).
- The reading distances ranges from only a few centimeters up to 100 meters.
- Tags can be read stationary or at 100 km/h or more.

Although a great effort has been made for the last few years to convince more sectors and government agencies to adopt RFID Auto-ID systems, currently they are being used for:

Intermodal container identification, Rail and truck rolling stock identification, Animal (livestock and domestic) identification, Flexible manufacturing (tracking and control), Cutting tool identification, Vehicle identification / access control and Personnel identification in access control

RFID Advantages:
- Great flexibility,
- Read/write capabilities or permanent (non-erasable) ID,
- Non-contact, non-line-of-sight reading,
- Immunity from obscuring paint, dirt, grease, etc.
- Automatic operation
- Wide range of tag options
- Extremely high data integrity

RFID Disadvantages:
- Cost of tags
- Limited interchangeability of tags (at present, due standards)

As part of the collaborative system the development of a mobile tracking/identification unit for the determination of the position of the modules and elements of the FH building is desirable. The system consists of RFID reading/writing station to which a Differential GPS receiver or a similar positioning system is attached. Both devices are connected to the same mobile portable computer or to a PDA for the data logging. The logged information is therefore transmitted to the site information database via radio instantly or later via physical link. This way the system measures the position with great accuracy and writes it on the part's/module's RFID tag and at the same time pass this information and the reference of the tag to the site database [10]. Figure 4 shows a schematic information flow of the suggested system.

B. *Machine positioning*

The positioning method is the key part of all CIC systems and without it real construction automation cannot be achieved. There are indications that the most promising systems for positioning are Laser based and GPS/GPS like systems. The GPS systems are characterized by temporal and spatial coherency. These are desired features since they are needed to guarantee perfect coherency between the co-ordinates from the designs and the co-ordinates measured on the site by the system [11]. GPS implemented in differential

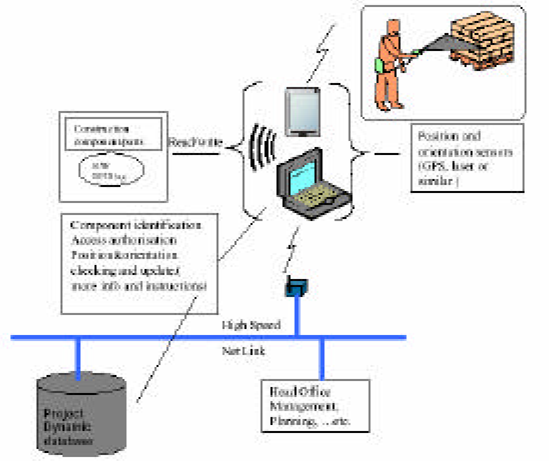

Fig. 4. Schematic representation of the information flow of the mobile parts tracking system, and the manner it may be used (top right)

mode can provide machine positioning accuracy about 2cm.

Each automatic or semi-automatic machine should be equipped with a positioning system such as the DGPS. These machines are also desired to have an identification system like the one shown in figure 4. Here the collaboration consists of teaching the moved parts/elements/modules their new position after a handling operation and storing it in the parts/modules RFID tag memory. This information is made available to the rest of the building system by logging it to the site database.

Besides automated, semi-automated and traditional construction machines in the building site, workers themselves may incorporate some automatic aspects in the way they provide their services. An automatic localization and identification of the workers can be implemented using technology already existing in the market. Radio Frequency Auto-ID (RFID) devices can be used for this purpose. The whereabouts information of workers could be used for managerial and statistical purposes as well as for security reasons. This could also be used for accessibility control to given location in the building site. A prototype security system implementing this philosophy has been already developed for the scenario of modern construction site [12]. The system based on equipping the worker helmet with, GPS, bidirectional data and voice communication and a miniature video camera proved to work efficiently. If a machine is moving a building element where the maneuver may be considered dangerous and an unauthorized worker RFID tag is detected in the maneuver zone, the operation is halted or an acoustics warning is issued automatically to the intruder. This event should be registered on the information system and the concerned parties informed automatically. This part is considered as machine-human collaboration

C. *Database and Shared Information*

The site information database is expected to contain all aspects of the building system data, and make it available to all those sub-systems, that request it. The exchange of the information between the sub-systems is what makes the collaboration in the building site possible.

The following is a list of some items that the information database should include:

- Building CAD designs and drawing using 3D solid objects
- Accurate map of the site
- A list of the 3D solid objects, which may represent the pre-fabricated modules with several entries to contain:
  1. Reference to be used with RFID tag
  2. A second reference to be sued with the barcode if applicable.
  3. Delivery date (interval)
  4. Manufacturer details (in case a contact is required)
  5. Dimensions
  6. Delivery point (position) in building site
  7. Assembly point on the building (position & orientation)
  8. More info or instruction about the part/module
- Schedule of the project related to the above information
- Planning (other than schedule)
- Security related data
- Restricted areas to some members of the personnel
- Dangerous areas (may be temporary)
- Machines list with their entries and fields for position and state
- A list of the personnel members which should have several entries for each member such as:
  1. Reference
  2. Work zone (may time/period related according to tasks)
- External sensors data to be shared with the rest of the building system, for example weather sensors

Many more information and data entries can be used in addition to the identified above.

The information stored in the site database can be changed on request from the building sub-systems. For instance if a module have been moved to a new location this has to be reflected on the database. Therefore the automated machines would look for it in the new location according to the database.

The dangerous zones [12] are changed or moved according to the task being performed. In these areas, only required personnel are allowed and therefore the list can be entered/updated by an authorized operator.

D. Machines Co-ordination

Automatic machines' co-ordination can be implemented by software in the same manner this is done for robot manipulators. This can be achieved by exchanging information between the machines to avoid collision between them. The exchange of loads between machines such as automatic cranes can be done in the intersection of the working zones.

During the initial step, the first machine brings the load and releases it in the intersection of working zones, the first machine is moved away from the load and then communicates some information if required (position and orientation of load) to the second machine. The second machine approaches the load, picks it and moves it to the target position and then communicates its current state to the database. This way the collaboration between the two machines is achieved safely.

E. Forbidden Zones

Forbidden zones for machines are the areas that can be reached by the machine but are excluded intentionally from the workspace. This can be done for safety reasons or to avoid damage due to possible collisions between machines and built obstacles. For instance, the intersection of working zones mentioned in the previous section becomes a forbidden zone for a crane when the other is present in that area.

In the case of automatic cranes the forbidden zones are expected to increasing in volume automatically along the progress of the building. When the automatic crane consults the database it looks for the completed construction work and from there, the machine control calculates the forbidden volume. Each time a new module is assembled the forbidden zone is updated.

All the aspects of collaboration aspects and safety of workers and machines [12] are taken in consideration to propose a architecture of the system from the information/data point of view and the basic IT infrastructure as shown in the schematic presentation in figure 5. It is important to note the presence of wireless communication, Computer workstations, automated machines with their positioning, radio communication and auto-ID readers, mobile parts tracking stations (as proposed in figure 4) and finally the RFID monitored gates through which goods, materials and parts are delivered and inventoried. Workers can be controlled and monitored and protected by means of an instrumented helmet [12]. Note the presence of the PDA, which use in construction is not new [13], and which are available in the market already fitted with their GPS.

V. CONCLUSION

This paper deals with machine collaboration in the FutureHome building system and suggests a scenario for implementing a safe collaborative system. The collaboration is meant to happen between automatic machines and between machines and operators. Safety issue and mentioned, although the subject in the context of this work is treated and a solution is suggested in [12].

It is clear that the expected modern construction site such

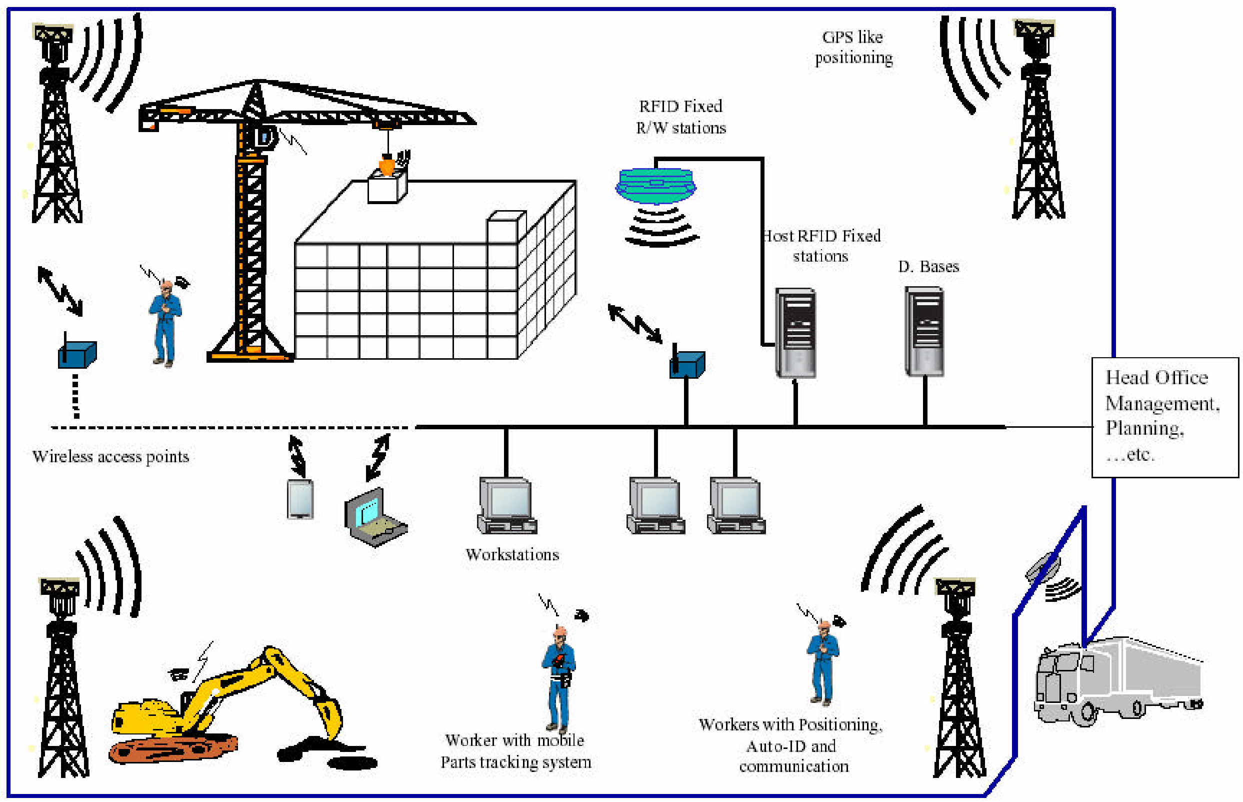

Fig. 5. A schema of the proposed architecture of the collaborative automated/semi-automated modern construction site

that envisaged in FutureHome building system will have the necessary infrastructure to allow for the implementation of the suggested system. However, the cost of some systems such as that of positioning may still high. The implementation of good positioning system for each machine is necessary for achieving construction machine automation. The automatic machines should also be equipped with parts/module identification facility such as the one suggested in section IV A. Collaboration aspect are expected to be extended to cover the building site store supplies by checking automatically the available goods, tools and parts and issuing orders if required. In a similar manner delivery dates are checked and an appropriate action is issued by the system if delays are detected.

The construction site should have a protected perimeter, with RFID gates and only through them all goods, deliveries, workers and machines enter and exit to allow the automatic control and inventory of the whole site (figure 5). With the adequate mechanical or graphical interfaces man-machine exchange of information and collaboration can be implemented in an efficient manner.

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