

A Conceptual Study Towards Delivery of Consumable Materials to Aircraft Assembly Stations Performed by Mobile Robots Based on Industry 4.0 Principles

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Abstract

This paper aims to present a conceptual study that integrates mobile robots and communication systems developed for delivery of materials to workstations of aircraft assembly lines. In the interest of providing deliveries of material in heights, a concept of a customized UAV (Unmanned Aerial Vehicle) has been proposed herein in order to assist the labor needs related to logistics requirements. A picker aerial vehicle has been designed to perform the operations through a man-machine interaction based on a proper software application developed for this specific intention. In order to integrate this whole process, an AGV (Automated Guided Vehicle) is used to deliver the materials on the floor and to transport the proper aerial vehicle to take-off in specific places. Accordingly, it is understood that these integrated automated systems commanded by CPS (Cyber-Physical Systems) could manage the information, perform tasks and contribute to a better process. Therefore, the major contribution and novelty of this paper is to show how an adapted UAV in conjunction with a special AVG and a tailor-made software application could bring several benefits to the aircraft manufacturing industry. Thus, this approach has looked for better results in terms of productivity, safety of people and costs related to down-time, number of ground support equipment and wastes associated with movements. A case study has demonstrated earnings of approximately USD 300 k per year. This proposal can also improve the flexibility of work tasks; manage production routines due to the balancing of the assembly line and easiness to attend requests online, adding value and providing a greater efficiency of the process based on Industry 4.0 trends. A proper framed-model is presented as a novelty in order to evidence advantages reached when robotics and internet of things are combined.

Keywords: Industry 4.0; Mobile robots; Delivery; Materials; Aircraft

Introduction

Aircraft market is forecasted to generate around 250 billion dollars between 2016-2025, while North America is responsible for at least 36.4% of that [1].

This market is characterized by demand and its dynamic and competitive environment. The key to successfully compete in this adverse scenario is to continuously strive towards higher levels of productivity, which is particularly essential for companies producing in high-wage countries [2].

While productivity can simply be defined as the ratio between input and output, the underlying drivers behind productivity growth are manifold and include elements, such as technology, human capital and production processes [3,4].

Thus, aircraft industry competitiveness prompts manufacturers to innovate and develop modern manufacturing processes including reduction in all types of wastes.

Faced to these trends and needs, Industry 4.0 concepts have been looked for improving the whole process to increase companies' productivity. Briefly, industry 4.0 can offer productivity gains based on collective term for technologies and concepts of value chain organization [5]. Within its context, Cyber-Physical Systems (CPS), Robotics and Internet of Things (IoT) are examples of components possessing Industry 4.0 fundamental concepts.

Thus, this work presents a proper-framed model that shows how an adapted Unmanned Aerial Vehicle (UAV), in conjunction with a proper

Automated Guided Vehicle (AGV), assisted by intelligent systems (based on CPS and Internet) could perform delivery of consumable materials to aircraft manufacturing stations avoiding manpower traffic, favoring the waste reduction.

The structure of this paper is as follows: The first and second sections review the current scenario of aircraft industry and explains the motivation and problem statement of this paper; section 3 is devoted to the relevant literature on Industry 4.0, mobile robots and CPS in production processes; the fourth section presents the novel contribution developed to solve the problems mentioned; the next two (5 and 6) sections regard, respectively, to the role of materials and methods applied on it and the innovative results reached by using Industry 4.0 concepts in this specific sector of manufacturing; finally, the advantages of this novelty approach are presented to explain the potential gains that can be reached when the proposed method is applied to the production of aircrafts.

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Background Scenario and Objectives

Aircraft industry

According to Red [6], new aircraft deliveries have been forecasted to slightly increase since 2012. The expected number of units will be more than 16,000 as shown in Figure 1.

Aircraft manufacturers are pursuing process innovation in order to attend the increase of production demands. Continuous improvement and a high level of efficiency together with maximum process reliability is the key note for your success in a competitive market.

Based on this, full-integrated automated solutions tailored to specific needs and coordinated with the entire area of maintenance, TI (Technology Information) and third party services are looked for by aircraft manufacturers.

Thus, robotized systems have been developed in order to bring benefits of trouble-free material flows and a high-efficient production.

Motivation and problem statement of this paper

Faced to the requirement of waste mitigation related to people traffic on manufacturing shop floor, there is a pursuit for increasing productivity and leading to a lean manufacturing system.

In this context, a gap related to an integrated proposal has been noticed in order to assist the whole process of materials delivery in heights.

Therefore, the contribution and novelty of this paper is a tailor-made solution based on the integration of mobile robots and their systems to improve the aircraft manufacturing needs of waste management, besides being an unprecedented approach.

Literature Review

According to Lasi et al. [7], the automation systems provide conditions for industries to produce products with highly mechanization. Technological advances and improvements along the time brought changes that are called "industrial revolutions" and characterized as follows:

- **1st industrial revolution:** Mechanization of the production.
- **2nd industrial revolution:** Electrical energy application.
- **3rd industrial revolution:** Application of digitalization.

On this way, an integration of the digitalization applied on factories with internet technology oriented to fabrication of machines and

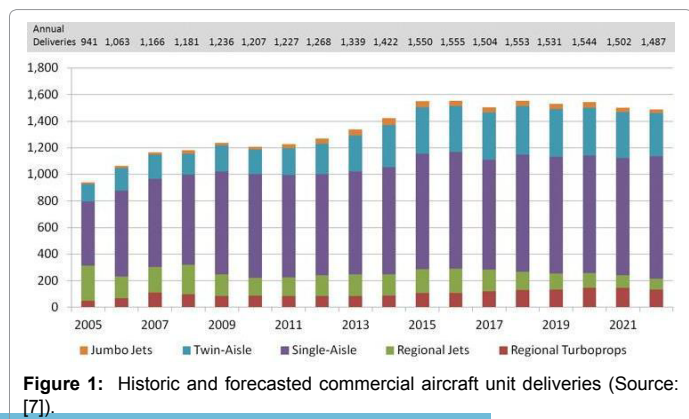


Figure 1: Historic and forecasted commercial aircraft unit deliveries (Source: [7]).

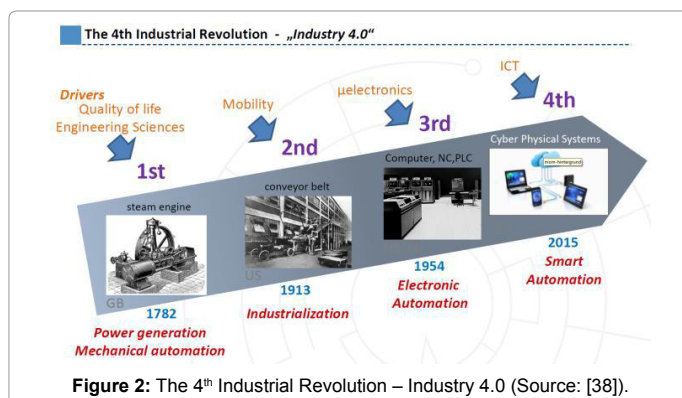


Figure 2: The 4th Industrial Revolution – Industry 4.0 (Source: [38]).

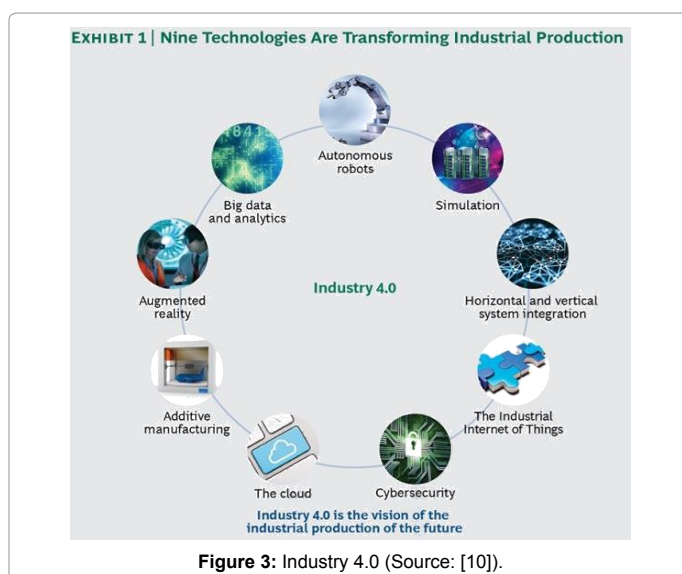


Figure 3: Industry 4.0 (Source: [10]).

products has been resulted in a relevant change in industrial production. The trends of this advanced production concept comprise efficient and smart manufacturing systems that the products control their own fabrication processes.

Figure 2 shows the industrial evolution along the years and the 4th industrial revolution. Toward future expectation, the term "Industry 4.0" was established as the "4th industrial revolution".

Industry 4.0

The focus of Industry 4.0 is to provide conditions to manufacturing processes govern themselves in a decentralized and modular system. It can be done by smart sensors that tell machines how they should be processed based on "cyber-physical production systems". On this way, the IoT (Internet of Things) allows the connection between the embedded devices and networking via cloud in order to control and monitoring the production. So, it brings to the factories a decentralized intelligence in M2M (machine-to-machine communication that assists the production shop floor [8].

Figure 3 illustrates that the Industry 4.0 (the 4th revolution), representing the integration of Cyber and Physical systems concept, has been the ultimate hot topic since its first introduction in 2011 [9].

Through the emergence of Internet of Things (IoT), the IoT-connected network in industrial area enormously favors the production lines and processes at manufacturing sites. Industry 4.0 changes the

rules of the game for manufacturing. Connecting real machines with information technologies and the Internet increases productivity. It contributes to produce at lower costs and meet customer needs with more flexibility. Industry 4.0 principles support companies in identifying and implementing a "Smart Factory" based on collective term embracing a number of contemporary automation, data exchange and manufacturing technologies.

According to Boston Consulting Group (BCG) [10], Industry 4.0 is supported by 9 pillars of technological advancements:

1. **Big data and analytics:** In manufacturing shop floor, it favors the quality of production, saves energy consumption and improves the equipment's maintenance. All extracted data from many different sources (machines, systems and management data) can be comprehensively evaluated to support any decision-making on real-time;

2. **Autonomous robots:** These devices on manufacturing environment are building up for a greater utilization, becoming more flexible, autonomous and cooperative. They can interact with one another and work safely side-by-side with people. Autonomous robots are becoming cheaper day-by-day and having a wider range of functionalities than the conventional ones;

3. **Simulation:** Based on digitalization, products, materials, systems and production processes have been used in engineering development phases to simulate (in 3D condition) the manufacturing that will be established in future operations. 3D simulations represent the physical world in a virtual model through the real-time data. Thus, it can trial and simulate machine settings in the virtual condition before the real situation, reducing machine's setup times for example;

4. **Horizontal and vertical system integration:** Companies' departments usually are not integrated by IT systems in a full condition. On Industry 4.0 concept, facilities, departments (engineering, production, maintenance, services, procurement, etc.), functions are connected and automated with data integration network that enables the management of the enterprise in both levels;

5. **The industrial internet of things:** It means a wide network of devices connected to internet that includes machines, smartphones, tablets and sensors on manufacturing shop floor that exchange data. All machines are networked and use embedded computing systems, allowing them to communicate and interact with one another to provide the control and monitoring of processes;

6. **Cyber-security:** It is a form of security to protect the industrial systems against the threats that can come through the internet access. It includes physical access control for users by passwords, to ensure security, reliable communication, identification and management of access for all the machines networked.

7. **The cloud:** Due to volume of data available and the increased needs of data sharing across sites and company boundaries, the storage in cloud has become fundamental. This technology allows the accessibility of data from anywhere at any time by remote access and very fast. Cloud favors the productivity and functionality of machines and its related systems;

8. **Additive manufacturing:** Printing from 3D models has been used to fabricate prototype parts and end components for all segments of industry. Additive manufacturing methods produce customized products that offer construction advantages like complex shapes, lightweight design and reduction of tooling and fixtures. Researches on this technology have been increased;

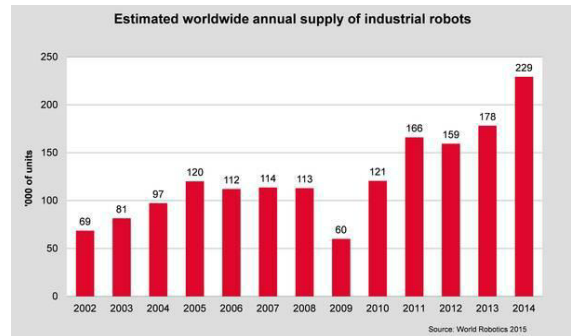


Figure 4: Estimated supply of robots (Source: [11]).



Figure 5: Estimated supply of robots (Source: [39]).

9. **Augmented reality:** This technology is not widespread yet, but companies are looking for using it much more to improve their work tasks and assist the decisions making on manufacturing shop floor. In the virtual world, operators can interact with machines by clicking on a tablet or smartphone and it overlays the digital information on top of real environment. It usually uses global positioning system (GPS) to pinpoint the user's location and its compass to detect device orientation.

Mobile robots

Inside the Industry 4.0, robots are a key role in the smart factories. According to International Federation of Robotics [11], since 2010, the demand for industrial robots has accelerated considerably due to the ongoing trend toward automation and the continued innovative technical improvements of industrial robots. Between 2010 and 2014, the average robot sales increase was at 17% per year. The number of robot installations had never increased so heavily before. Between 2005 and 2008, the average annual number of robots sold was about 115,000 units. Between 2010 and 2014, the number rose to about 171,000 units. This is an increase of about 48% and a clear sign of the significant rise in demand for industrial robots worldwide, as exemplified in Figure 4.

Within this trend, mobile robots have been used due to their capacity of locomotion. They have the capability to move around in their environment and are not fixed to one physical location.

Mobile robots can be "autonomous" which means they can navigate in an uncontrolled environment without the need for physical or electro-mechanical guidance devices. Alternatively, mobile robots can rely on guidance devices that allow them to travel a pre-defined navigation route in relatively controlled space like AGV.

AGVs are the solution for addressing the problems of production efficiency and flexibility and are becoming more and more important [12]. An AGV application on aircraft manufacturing industry is showed

in Figure 5 below. The AGVs are autonomous vehicles for moving and locating heavy loads precisely. They need a way of positioning. The procedures can be divided into two categories:

1. **Auto positioning:** A mobile device finds its own instant location according to a fixed point with a known position [13];
2. **Remote positioning:** A mobile device defines the instantaneous positions of other objects according to their own location [14].

The device's screening may also be done with infrared [15]; however, it has a higher cost of implementation compared with QR code reading systems [16]. Coordinate points using RFID are also used for local coordinate determination [17] and magnetic marks increase the precision [18].

The use of technologies for determining aforesaid parameters can be used for a robot positioning with the same defined points in relation to the environment [13]. The QR code has many advantages such as: ease of production and replacement, data storage, error correction capability due to degradation or dirt and rapid reading is possible in all directions by computer vision [19].

Considering that it is not economically feasible to redesign the factory to accommodate the delivery systems (AGV and UAV), other methods to define the trajectory must be provided in order to avoid imprecise information about the location.

Therefore, the path between two points of interest should have a way to determine its position to avoid gaps of location. Several ways of tracking could be done:

1. Indoor positioning systems using peripherals to track according to a coordinate using light [20], wireless points [21-23] or even ultrasonic tracking to increase the precision [24].
2. Direct learning the environment using computer vision [25] with RGB cameras [26] to reconstruct spatially an environment [27].

Knowing that the environment of the assembly line is always changing, the computer vision can be a suitable way to make the direction decision based on the location of the target assembly station.

In addition to AGV, UAVs are mobile robots that meet a wide array of needs. These vehicles are available to help serve organizations in need of reliable, affordable unmanned systems for intelligence, surveillance, and reconnaissance missions as well as for experimentation and tasks purposes.

Commonly known as a drone, UAS (Unmanned Aerial System) or by several other names, it is, briefly, an aircraft without a human pilot aboard. The flight of UAVs may operate with various degrees of

autonomy: either under remote control by a human operator, or fully or intermittently autonomously, by on-board computers [28].

UAVs are often preferred for missions that are too "dull, dirty or dangerous for humans" [29]. They originated mostly in military applications, although their use is expanding in commercial, scientific, recreational and other applications, such as policing and surveillance, aerial photography, agriculture and drone racing [30].

UAVs typically fall into one of 6 functional categories:

1. **Target and decoy:** Providing ground and aerial gunnery a target that simulates an enemy aircraft or missile;
2. **Reconnaissance:** Providing battlefield intelligence;
3. **Combat:** Providing attack capability for high-risk missions;
4. **Logistics:** Delivering cargo;
5. **Research and development:** Improve UAV technologies;
6. **Civil and commercial:** Agriculture, aerial photography and data collection.

Aircraft inspection is a great application for drones inside functional category of civil application. UAVs have been used for airplane inspection, as an alternative to humans on cherry pickers.

Equipped with high-resolution cameras, these aircrafts are programmed to scan and assess the planes, reporting back to engineers on any damage which may require further inspection or maintenance work [31]. Checks that would usually take more than a day could be performed in a couple of hours and potentially with greater accuracy [32]. Figure 6 illustrates a special UAV application for aircraft inspection.

Thus, automated systems have the potential to make tasks easier, safer and more reliable when these exemplified mobile robots are used in the hangar.

CPS and CPPS

Cyber-Physical Systems (CPS): This are computational collaboration systems connected with the surrounding physical world and its on-going processes, providing and using, at the same time, data-accessing and data-processing services available on the internet [33-35].

Cyber-Physical Production Systems (CPPS): This consists of autonomous and cooperative elements and sub-systems that are getting into connection with each other in situation dependent ways, on and across all levels of production, from processes through machines up to production and logistics networks. Modelling their operation and, also, forecasting their emergent behavior raise a series of basic and application-oriented research tasks, not to mention the control of any level of these systems [35].

Based on the latest and foreseeable future developments in information technology (IT), CPPS includes ICT (Information and Communication Technology) and MST (Manufacturing Science and Technology) in order to assist 4th Industrial Revolution, also named Industry 4.0 [36].

CPPS will enable and support the communication between humans, machines and products alike. The elements of a CPPS are able to acquire and process data, and can self-control certain tasks and interact with humans via interfaces (Figure 7).

The development of computers led to the numerical control of machine tools and robots, the microprocessor was the heart of computer

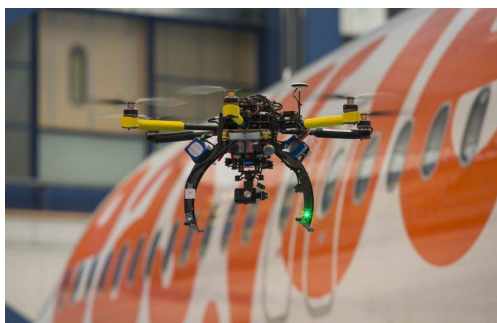


Figure 6: UAV inspection of an aircraft (Source: [31]).

numerical control (CNC), the application of computer graphics resulted in computer-aided design (CAD) systems. The development of manufacturing systems was unimaginable without computer networks.

A Novel Contribution

One of the most common concerns in the production systems of aerospace manufacturing is to carry out work in heights and regions of difficult accessibility.

This situation occurs in structural assembly lines where segments as fuselages and wings are built, final assembly lines (systems installation and completion) or even in maintenance tasks of aircraft already in the field. Figure 8 shows a region of elevated height on assembly of Boeing 777 in Seattle. In order to enable production tasks, the use of platforms, scaffolding and security systems for people are needed.

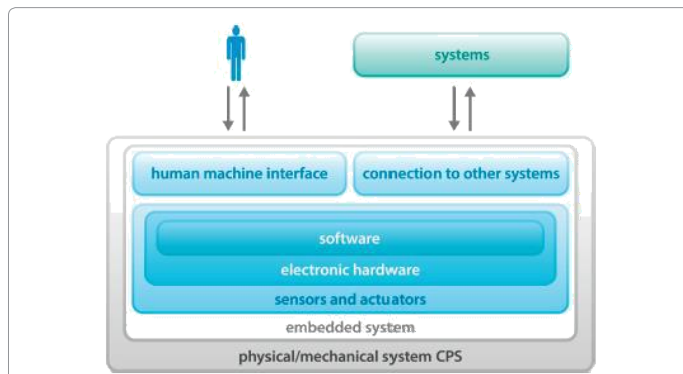


Figure 7: Interaction between humans and machines in cyber physical systems (Source: [41]).

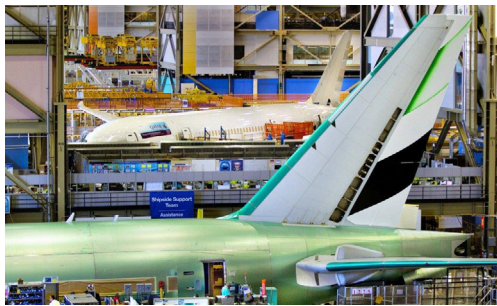


Figure 8: Assembly of vertical stabilizer of Boeing 777 aircraft (Source: [42]).

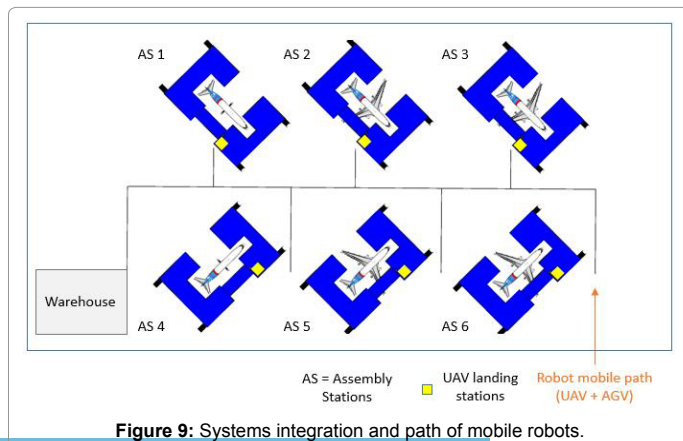


Figure 9: Systems integration and path of mobile robots.

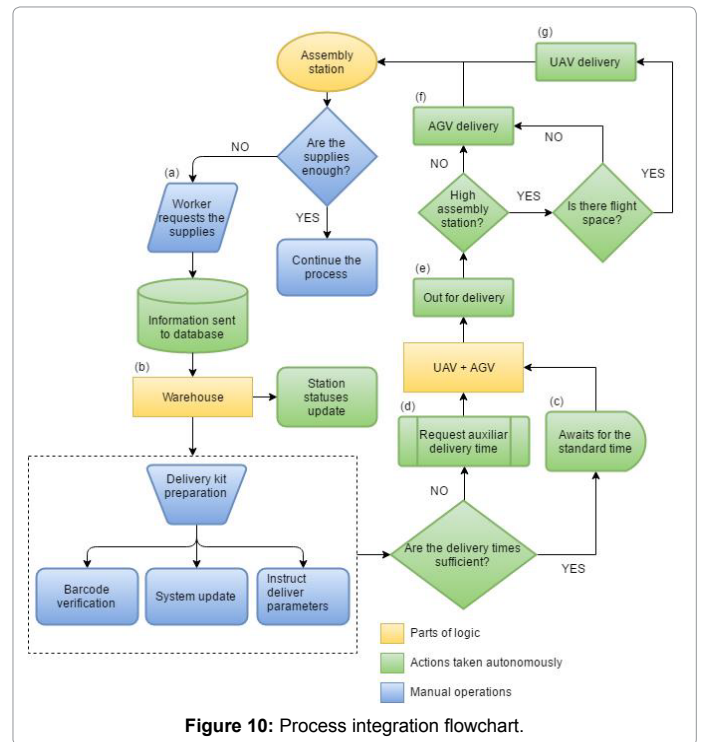


Figure 10: Process integration flowchart.

In this context, ground support equipment (platforms, scaffolding, ladders, bridges, etc.) have a key role in supporting the productive activities to meet the aircraft assembly needs. Although the use of such equipment is essential for manufacturing routines, this substantial use can generate significant impacts on financial issues related to wastes that do not add value to the product and, also, occupational safety issues.

These issues have become increasingly important due to the relentless pursuit of reducing manufacturing costs linked to the reduction of assembly cycles, elimination of production wastes and ensuring the safety of people, aimed at increasing the competitiveness of business. Faced to these conditions, another very important issue is the daily supply of consumables needed for execution of the productive tasks. Consumables could be: Drills, sealants, adhesives, gloves, tools, etc.

Depending on the height, operators need to be tied with safety belts to perform their routine tasks. As the supply of consumables is not done automatically, the operator itself needs to accomplish it. Thus, operator needs to untie, go down from the platform and go to the warehouse of materials to get the necessary items. This frequent action demands a high time to perform, generating wastes in unnecessary movements by people walking between processes that increase the downtime.

Thus, an integrated approach has been developed in order to provide conditions to deliver consumable materials to aircraft assembly stations by mobile robots managed by CPPS applications without human intervention.

An integrated approach

A potential solution for these difficulties presented herein is the use of automated devices to perform these tasks. Through a remote drive using digital interface, an autonomous vehicle AGV transport the supplies from warehouse to stations located in the assembly stations. In order to reach the working height of the operators, an UAV is used to deliver the materials requested by operators, avoiding the problems mentioned above and optimizing the production management.

Figure 9 depicts the full scope of integration of mobile robots for use in aircraft final assemblies, where the AGV and UAV are subsystems responsible for transportation and elevation of materials from the floor to the height on platform.

For the aerial situation, 06 docks stations were considered for assembly of Boeing 747 aircraft, represented in blue. Its height is 7.0 m from the floor and all docks and warehouse are inserted in an area of 300 m (length) \times 180 m (width).

Proper framed-model

As a structure developed to integrate robots, systems and devices in CPPS condition, a proper framed-model has been presented to improve the production processes.

It is also important to emphasize that this approach looks for the concept of surgeon operator. It consists of providing the needed materials for implementing tasks only in the prime area of the work, reducing waste and promoting productivity, ergonomics and quality during the process. Figure 10 presents the framed-model.

The proposed integration model has been developed to perform required interfaces among production operators located at assembly stations, inventory manager in warehouse and mobile robots (AGV + UAV) responsible for transportation of supplies, represented in the flowchart by yellow blocks.

The cycle begins when the operators request the materials needed on the workstations (a) via a mobile program. At this time, the statuses of all assembly lines are updated (b) by the warehouse with the data provided by the operator, since each worker has a different speed of labor that must be considered.

The data gathered provides the information to set the supplies up in the delivery kit. The delivery time will be settled by the demand from all the stations. If the standard delivery time defined by the assembly line is enough, the distribution will be executed within the defined times (c). Otherwise, if the production's takt-time is faster than the established distribution time, the delivery must be performed in advance (d) in a way to ensure enough to assure the critical tasks. Thus, the AGV carries the UAV with the supplies kit forward to the assembly stations.

The AGV's system concept has been developed with a proper programming that defines the right path and avoids obstacles on the way to stations (e). Figure 11 illustrates the arriving of AGV system carrying the UAV and materials to be delivered to the assembly stations.

Lower height points at stations are suitable for deliveries without UAV's need (f). If the height of the workstation is too high that precludes

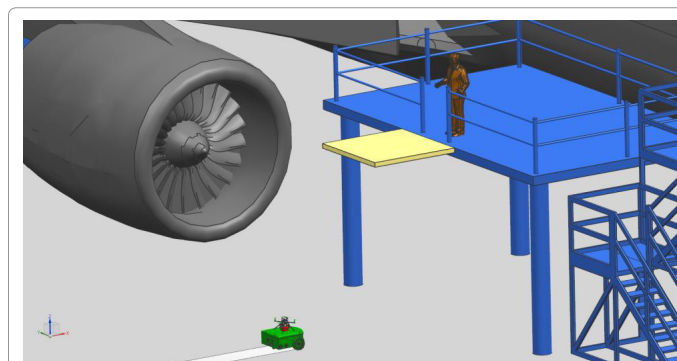


Figure 11: AGV carrying the UAV and kit to stations.

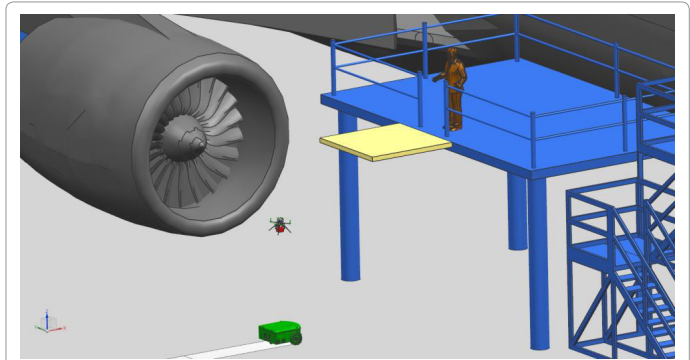


Figure 12: UAV taking off from AGV.

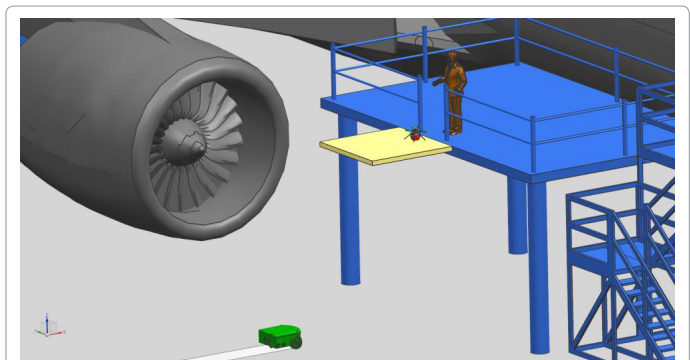


Figure 13: UAV landing on worker's bench.

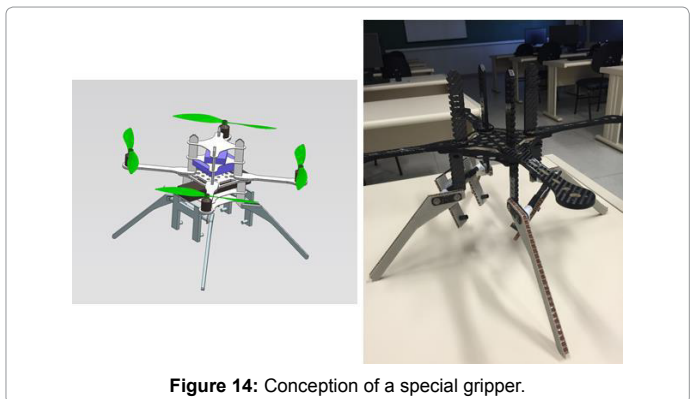


Figure 14: Conception of a special gripper.

the worker to get the supplies without wasting time, then, the UAV system deliveries the supplies to a bench by the worker's side (g). Figures 12 and 13 explain the UAV's flight to stations.

This concept has been developed in order to assist the consumable materials' delivery by autonomous mobile robots based on systems integration, IoT, simulation, data analyzes and cloud oriented by Industry 4.0 concepts that will be detailed in the next topic below.

Materials and Methods

This integrated approach is multi-disciplinary and reaches beyond the classical systems used nowadays at aviation industry. It is based on a combined application of several Industry 4.0 technologies by their mutual integration and connection that acts to provide an advanced manufacturing system.

The concept of Industry 4.0 settles that the equipment should

interact in a way to fulfill the needs of a manufacture purpose. The challenge is, then, to provide mechanisms of cooperation and seek new methods to manage the activities in a way to assure the efficiency of the process itself [41]. Therewith, in order to ensure the project stays inside the desired concept, the parameters to manage the production line should be well-defined.

The interoperability between the AGV and the warehouse, in a way to provide assistance to the operator in the assembly line, makes the project easy to implement. As it is independent from the platform used, it is also highly flexible and optimized to the environment that it is applied.

We can see that, from Figure 10 (Process integration flowchart), several decisions are decentralized, as it is supposed to be in an Industry 4.0 implementation. The data provided by the parts of logic are connected via an Industrial Wireless Network (IWN), each one with its own IP address and can also be addressed individually to shore up its effective operation.

Mobile robots

Based on a commercial UAV named Pelican, a customized gripper has been designed in CAD system to provide condition for standardized boxes attachment where the consumables are loaded. Figures 14 and 15 below show the design of UAV and its assembly.

For the conceptual design, standardized boxes (represented in red



Figure 15: UAV's gripper attaching the box.

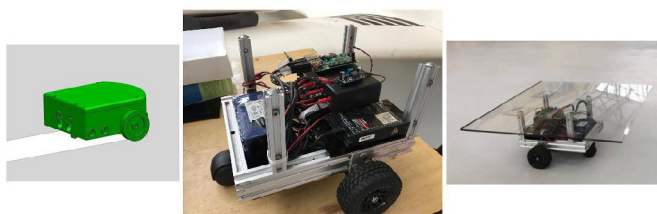


Figure 16: AGV's conception and its assembly.

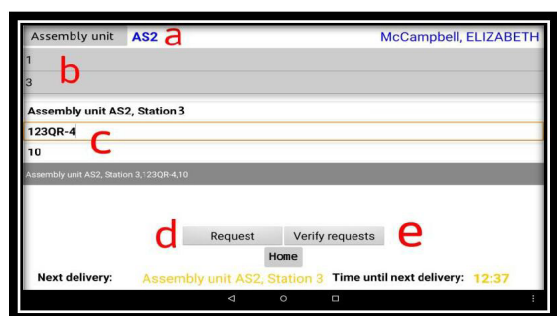


Figure 17: Supplies request App screenshot.

color above) were designed in 3 different sizes (100 × 100 mm, 120 × 120 mm and 150 × 150 mm) to load the consumable materials requested by operators on assembly stations, according to their different needs.

Regarding fabrication, mechanical parts were manufactured by 3D-printed technology (another branch of Industry 4.0) and some of them by honeycomb material as showed in Figure 16 below.

Furthermore, the special AGV has been tailor-made designed to assist the boxes of materials transportation and carriage of UAV to assembly stations, as showed in Figure 16. It is important to emphasize that an acrylic plate was attached to AGV to provide condition to carry the UAV during the path.

Horizontal and vertical system integration

Based on the whole integration of processes and the use of materials and technologies related to Industry 4.0, the management system developed for this specific application could bring advantages to make the operation easier and provide conditions for an intelligent management of routines.

Thereby, this proposed management integrated system has been structured to run as follows:

Setting the database

The database is a tailor-made system for this project to assure a perfect integration between the agents (assembly stations, warehouse and mobile robots) of the main logical processing.

This system provides means to assist all steps of framed-method (Figure 10) in a way to correct any common mistakes and to notify its origin.

Database would be also responsible to provide future inquiry on tools used, worker involved and serial number of material and receptor plane of the indicated action.

The mobile app

Since modern smartphones can carry several sensors due to its robust architecture, compact size and powerful processing, it is a suitable tool for the project.

The particular software application proposed herein consists of two main stages:

1. **Operator requests:** It is shown on the mobile app all assembly stations that can request the supplies and the availability for delivery.

The following Figure 17 shows the interface of the App for an employee request.

In this case for example, Elizabeth Mc Campbell wants to request 10 unities of Part Number 123QR-4. She inputs, from a list available on her mobile device, to inform her assembly unit AS2 (a) and selects her station 3 (b). With the textbox input she can either scan the barcode or manually type the code 123QR-4, and then, the amount for it (c). With the button 'Request' (d) the command is sent to the warehouse. The 'Verify requests' (e) button shows the previous undelivered supplies to check for errors or change the quantity.

2. **Warehouse statuses update:** It shows the requested supplies (part numbers and quantity) by operators, and at the same time, the inputs are updated on database providing information for a future track back.

The following Figure 18 shows the warehouse interface that provides the delivery of material request by operators on assembly stations.

Based on data provided by operators, the assembly line can be tracked and updated by the inputs using the cloud storage for the manager. The manager then can identify bottle-necks and excess of work force. All data is accessible for the production manager with his privileges. The manpower and the warehouse employee have only access to its requests, but not to the line pace.

Inside the scope of App development, Figures 19 and 20 are only accessible for production manager or higher hierarchy from anywhere with Internet access.

All the data provided by the cloud storage can be accessed with the 4 buttons, as exemplified in screen of Figure 20 and showed in Figure 21 as a conceptual example.

Figure 21 is, to some extent, an example of Big Data and Analytics, because the production manager is able to follow the whole status of shop floor.

After the two main steps are done, all tools and materials that are being consumed give the feedback to supply chain staff for future repositions [39-42].

Results

As a proof-of-concept and certification of the efficiency of the customized method proposed in this paper, a case study is presented in this chapter.

This case shows and testifies the progress and positive results achieved by the application of the proposed approach for delivering of materials to aircraft assembly stations performed by mobile robots and assisted by a proper App developed for that.

This study case presents the trials realized at a hangar in a reduced scale in order to test the overall solution tailor-made for this specific application. As explained before, this approach developed to delivery

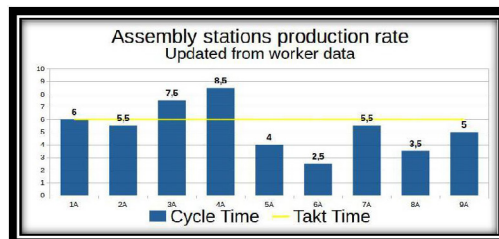


Figure 20: Cycle time updated with the data provided by workers on the assembly stations.



Figure 21: Hangar used for trials.



Figure 22: Assembly station simulation.

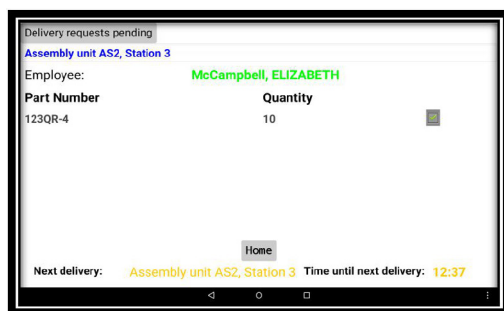


Figure 18: Warehouse interface that provides the delivery supplies.

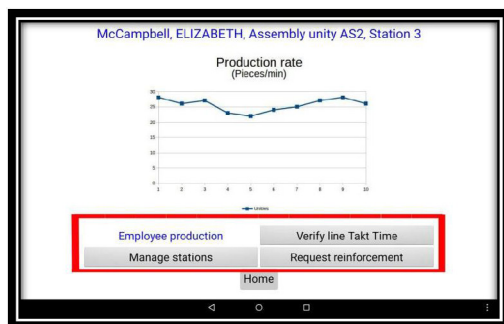


Figure 19: Elizabeth's rate of assembly for the work period.

materials to stations of work has been conceived based on Industry 4.0 principles. It will show the trials comprising all steps needed to perform the logistics process. The mobile robots' (AGV + UAV) conjunction managed by the proper App has been demonstrated herein. The trials took place in a hangar of aircrafts' maintenance and repairs (Figure 21), being very representative to validate the solution proposed in this research paper.

Eight small aircrafts (6.0 meters length) were located inside the hangar to simulate the real condition of an aircraft assembly floor. After that, 01 aircraft was chosen to simulate the tasks performed in the height of vertical stabilizer (VS). With the assistance of a lifter truck, a bench was positioned by VS's side to simulate the UAV landing station. Figure 22 presents the scenario prepared for the trials.

Using a tablet with the App installed, the operator requested the material needed according to parts list contained in the database. On real time by network connection, information was available to warehouse that provided the preparation of the kit to be supplied to assembly station, as explained in section 5.2 (Figures 18 and 19). For the trials, an obsolete galley was used to simulate the warehouse area and a man performed the box preparation. It was utilized a commercial plastic box (100 mm × 150 mm × 110 mm) for loading some tools

to simulate the consumable materials requested by the operator at assembly station. Figure 23 shows below a galley used to simulate the warehouse, the box being loaded with some tools and the mobile robots ready to go.

After the kit preparation, the robots (AGV + UAV) went to assembly station. It is important to say that the farthest aircraft from the warehouse was chosen in order to simulate a larger distance of delivery. In this case, the distance travelled on the floor by robots (AGV + UAV) was 41 meters (from warehouse to take-off point at assembly station). Figure 24 illustrates the robots moving on the shop floor and parked on take-off point at assembly station. Then, UAV took-off and flew 2.5 meter of height for delivering the box on landing station (Figure 25).

All trials had been accomplished by 02 professors, 05 engineers and 02 technicians on the shop floor represented below. Due to being a proof-of-concept, a reduced scale was adopted. For example, the AGV path from warehouse to take-off point was 41 meters (Figure 25).

During the trials, the delivery operation was performed in two ways: by men and by robots. It was planned to get data for comparison in order to calculate the savings and advantages reached by automation. Table 1 presents the cycle times (3 times of each) to perform the whole operation that comprises all steps: request by operator, box of materials' preparation, moving on the floor and flight for delivering. Using



Figure 23: Warehouse simulation and box preparation.



Figure 24: Robots moving and ready on point to UAV flight.

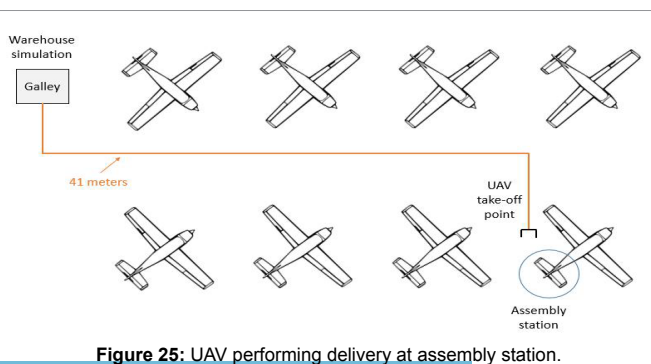


Figure 25: UAV performing delivery at assembly station.

	Time (s)	Average of time (s)
Men	115	114
	110	
	118	
Robots	90	94
	95	
	97	
Δ (s)	20	

Table 1: Trials' cycle times.

	N	Mean	StDev	SE Mean
Men	3	114,33	4,04	2,3
Robots	3	94,00	3,61	2,1

Difference = μ (Men) - μ (Robots)
 Estimate for difference: 20,33
 95% CI for difference: (10,38; 30,28)
 T-Test of difference = 0 (vs not =): T-Value = 6,50 P-Value = 0,007 DF = 3

Figure 26: Result of 2-Sample T-student test.

Conditions	Values
Time of delivery (min)	2.37
Number of shifts	2
Manpower/aircraft	10
Deliveries/ shift	3
Number of aircrafts	6
Work days/month	22
Manpower cost /hour (\$)	80
Annual saving (\$)	300.326,40

Table 2: Savings estimated for a real case.

Minitab 16 Statistics software, it was performed a 2-Sample T-student test to assert whether the time difference was statistically significant. Results are presented in Figure 26.

As the calculated P-value is less than 0.05 and considering 95% Confidence Interval, the time difference is significant. Thus, the relevant saving related to time 20 s could be obtained with the proposed approach application. It is important to emphasize that this gain regards just 01 person requesting materials in just 01 assembly station. As a case study, some conditions were considered in order to represent a full-scale assembly line situation (moving path 07 times bigger, in other words = 275 m versus 43.5 m) as showed in Table 2.

Moreover, immeasurable savings related to competitive advantages can be described as follows:

1. Reduction of waste related to people's moving on shop floor to get materials;
2. Reduction of the number of scaffolding and ladders used to assist people to go up and down;
3. Ergonomic and health risks when people working in heights;
4. Innovation and unprecedented solution for this specific need.

Discussion

As explained before, due to the demand of aircrafts expected to be delivery in the world, aircraft industry needs further implementing modern technologies and methods to optimize their production lines. Besides this, a proper-framed model proposed herein intends to favor the competitiveness of those companies.

This paper pursues the principles of Industry 4.0 in productivity and reduction of wastes on aircraft shop floor. Accordingly, an integrated

approach based on Industry 4.0 is introduced with new technologies that enable the organizational innovation which in turn can account for significant part of productivity growth in factories. Therefore, this paper examines a proper framed-model commanded by a CPPS that collaborates as an organizational driver and manager of information able to integrate the smart systems for execution of tasks. Thereby, the proposed model connects three dimensions of communication such as: production, warehouse and database by allocating their collaborative actions to each one.

Thus, it can be seen how each collaborative action provides an intelligent process that contributes to higher productivity. The impact of Industry 4.0 principles on each element of the proper method is exemplified and suggested how them can play a pivotal role in increasing productivity.

Conclusion

Finally, this novel contribution has looked for better results in terms of productivity and modernization of aircraft manufacturing processes reached when robotics and internet of things are combined based on financial savings presented in the case study. This proposal can also improve the flexibility of tasks and managing of production routines due to a smart programming tailor-made for that, adding value and providing a greater efficiency of the business based on Industry 4.0 trends. It is important to emphasize that this unprecedented approach supports the aircraft manufacturing gaps' environment.

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