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Cloud Computing as an Industry 5.0 Enabling Technology

La computación en la nube como tecnología fundamental en Industria 5.0

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ABSTRACT

In the year 2021, the European Commission announced Industry 5.0 by publishing a document titled *Industry 5.0: Towards a sustainable, human-centric and resilient European industry*, in an attempt to find solutions to the numerous industrial challenges of today. However, Industry 5.0 is still in its early stages, and industries are facing issues in implementing services that meet its requirements. In addition, many companies hesitate to adopt Industry 5.0 services and applications, as they consider that it requires a high initial investment. However, cloud computing offers a solution to this challenge by changing the way in which services are implemented, allowing companies of any size to build powerful and scalable services. Hence, the contribution of this paper lies in the proposal of a cloud architecture and a demonstration of the way in which cloud computing is an enabling technology for Industry 5.0 services, showcasing its benefits through a use case. Through cloud computing, researchers will be able to develop services that meet Industry 5.0 requirements, such as sustainability, resilience, and human-centricity, while doing so at affordable costs.

Keywords: cloud technology, new production paradigms, modern applications and services, sustainability

RESUMEN

En el año 2021, la Comisión Europea anunció la Industria 5.0 mediante la publicación de un documento titulado *Industry 5.0: Towards a sustainable, human-centric and resilient European industry*, en un intento por encontrar soluciones a los numerosos desafíos industriales de la actualidad. Sin embargo, la Industria 5.0 aún se encuentra en sus primeras etapas, y las industrias enfrentan dificultades para implementar servicios que cumplan con sus requisitos. Además, muchas empresas dudan en adoptar los servicios y aplicaciones de la Industria 5.0, pues consideran que requieren una alta inversión inicial. No obstante, la computación en la nube ofrece una solución a este desafío al cambiar la forma en que se implementan los servicios, lo que permite a empresas de cualquier tamaño construir servicios potentes y escalables. En vista de lo anterior, la contribución de este artículo radica en la propuesta de una arquitectura en la nube y en la demostración de la manera en que la computación en la nube es una tecnología que habilita los servicios de la Industria 5.0, mostrando sus beneficios a través de un caso de uso. Mediante la computación en la nube, los investigadores podrán desarrollar servicios que cumplan con los requisitos de la Industria 5.0, tales como sostenibilidad, resiliencia y un enfoque centrado en el ser humano —lográndolo, además, con costos asequibles.

Palabras clave: tecnología en la nube, nuevos paradigmas de producción, aplicaciones y servicios, sostenibilidad

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Introduction

Recently, the European Commission announced Industry 5.0 by releasing a paper titled *Industry 5.0: Towards a sustainable, human-centric, and resilient European industry* [1]. Unlike Industry 4.0, which is technology-driven, Industry 5.0 is considered to be value-driven, providing different goals and emphasizing research and innovation to support industries in their long-term service to the planet and its people [2], [3].

On the other hand, Industry 4.0 integrates information and communication technologies with industrial tools to establish a digital, intelligent, customizable, and information-driven factory [4]. A complete and exhaustive list of Industry 4.0 requirements includes modularity, integration, collaboration, flexibility and scalability, virtualization, distributed and decentralized architectures, holistic management, high customization, ubiquitous vision, robustness, real-time information, autonomy and intelligence, data-optimized decisions, cybersecurity, work-life balance, and improved efficiency and productivity [5].

However, the development of industrial sectors is accelerating due to the introduction of new production paradigms (*e.g.*, Industry 4.0 and Industry 5.0). This development and evolution is updating the business environment, and companies are facing challenges that require a significant change in organizational structures, infrastructure, organizational culture, and work skills [6].

Industry 5.0 has been anticipated to generate higher-value jobs that allow for more freedom in creativity and design thinking. Additionally, employees need to learn how to

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work collaboratively with smart devices and machines, and, customers, engineers, stakeholders, and end-users all want instantaneous cost savings, implementation flexibility, scalability, and resilience, which drives management changes and requires new technological solutions [7].

Industry 4.0 was not envisioned as a human-centric approach, unlike Industry 5.0, which revolves around three core requirements: sustainability, resilience, and human-centricity. *Sustainability* refers to the creation of products and services through economically stable and solid processes that can minimize environmental impacts while saving energy and natural resources [8]. Moreover, systems and services (especially distributed ones) will experience failures, so the way in which they are built to respond to these failures is a critical part of building *resilient* systems and factories, ensuring that value-driven services are provided even in times of crisis [9]. Finally, a *human-centric* proposal puts fundamental human needs and interests at the center of any process or service [3].

The implementation of Industry 5.0 requirements is a big challenge that technologies with assured sustainability, scalability, and standardization could support, not only in large technology-oriented enterprises, but also in small and medium-sized companies, where the balance between implementation costs and real benefits is also a concern [10]. Therefore, companies must identify the technologies that best meet their needs and allow them to develop value-added services, thereby satisfying Industry 5.0 requirements at affordable initial costs [11].

In the literature, [2] proposed a method that aims to solve the problem of integrating various innovative agents (artificial intelligence, humans, the Internet of Things, robots) within an Industry 5.0 plant-level collaboration through a generic semantic definition utilizing an event-driven process. In addition, [7] discussed the classifications and challenges of Industry 5.0 and the sophisticated technology required for this industrial revolution, highlighting the role of digital twins, blockchain, unmanned aerial vehicles, and additive manufacturing, but stating that such technologies require adequate investments. [12] pointed out a lack of consensus on the definition and scope of Industry 5.0, as well as a limited understanding of its technological components, design principles, and intended values. [13] explored the impact of digital twins on industrial manufacturing in the context of Industry 5.0, discussing their potential applications and key modeling technologies. [14] proposed a secure communication model for Industry 5.0 based on edge computing. This proposal introduced cryptography and three-factor authentication to ensure confidentiality, anonymity, and integrity. [15] discussed how the literature explores the relationship between Industry 4.0 and Industry 5.0, operations management, and sustainability. [16] analyzed emerging technologies, frameworks, and concepts such as *network-in-box architecture*, open *radio access networks*, *softwarized service architectures*, and *enabling services*, among others, to fulfill Industry 5.0 requirements, and [17] proposed a blockchain-based data mechanism to enable resilience in Industry 5.0, combining sharding and two-layer Merkle tree structures in conjunction with random low-density parity codes.

However, most of these papers failed to discuss implementation cases, demonstrate compliance with the basic principles of Industry 5.0, or analyze financial implications, like the costs incurred in implementing and maintaining such sophisticated and technologically advanced systems, particularly regarding smaller businesses, potentially limiting their accessibility.

In addition, many companies hesitate to develop services and products in the context of Industry 5.0, as they consider that this requires a high initial investment (*i.e.*, to purchase, configure, store, and secure servers, in addition to providing them with the appropriate environment in terms of temperature, energy, and Internet access, among other variable and fixed costs), which may be even higher if the services and applications to be implemented necessitate redundancy in order to guarantee computing and processing capacity, scalability, and availability. This implies creating multiple computing centers across diverse geographic areas [3], [18].

Cloud computing offers a solution to these challenges by changing the way in which services and applications are implemented and deployed in production environments, allowing companies of any size to build powerful, resilient, and sustainable human-centric services. Cloud computing is a model that enables ubiquitous, convenient, and on-demand access to a shared pool of computing resources (servers, storage, applications, or services) that can be rapidly provisioned and released with minimal management effort [19].

Below are some of the advantages of cloud computing.

1. There is no need to spend time and money purchasing and managing servers or infrastructure. This reduces —or practically eliminates— the initial investment.
2. A lower variable cost can be achieved compared to what one would get on one's own, as cloud providers use economies of scale.
3. It provides increased speed and agility in developing applications, as it allows accessing resources in very short times.
4. It frees developers from investing time in tasks that add no value, allowing them to focus on the requirements and services to be developed.
5. There is no need to predict how much capacity and infrastructure will be needed to deploy an application or service.

Industry 5.0 demands sustainable and robust services (at affordable costs) that run without time and place restrictions to serve people at any given time. Furthermore, Industry 5.0 infrastructure must enrich its computing capabilities to allow real entities and devices to operate in conjunction with cloud platforms that generate knowledge using data-driven algorithms [20]. Cyber-physical systems (CPS) providing intelligent, human-centric assistance services through cloud and ubiquitous technology will be fundamental in Industry 5.0 [21].

Cloud computing can be the vehicle to drive the implementation and evolution of Industry 5.0 systems and services. Therefore, the contribution of this paper lies in the proposal of a cloud architecture and a demonstration of how cloud computing is an enabling technology for Industry 5.0 services, showcasing its benefits through a use case. Through cloud computing, researchers will be able to develop services that meet Industry 5.0 requirements (*i.e.*, sustainability, resilience, and human-centricity) at affordable costs.

Industry 5.0

The existing literature on Industry 5.0 has failed to provide a definitive conclusion of the term; it is unclear what values Industry 5.0 can deliver at the firm and industrial levels. Therefore, it is important to analyze the meaning and design principles of Industry 5.0, as well as the way in which it can contribute to economic and environmental resilience and sustainability at both the industrial and societal levels.

The term *Industry 5.0* was coined by Michael Rada [1]. According to him, the main distinguishing factor between Industry 4.0 and Industry 5.0 is the increased level of interaction between humans and machines. This interaction allows humans to express themselves freely through personalized goods and services.

Industry 5.0 enables the provision of more personalized goods and services through the participation of users in the design process [38]. While Industry 4.0 primarily focuses on technology-driven advancements, automation, and data-driven efficiency gains, Industry 5.0 shifts the emphasis towards sustainability, human-centricity, and societal well-being. It recognizes the need for industries to operate within ecological limits, mitigate environmental impacts, and prioritize the welfare of workers and society as a whole [41]. Industry 5.0 is a technological-organizational framework that emphasizes human well-being and a sustainable society. There is a need to ensure that Industry 5.0 is truly human-oriented, with a focus on empowering workers and creating sustainable and resilient production systems. This human-centric approach is further emphasized in the proposal of an Industry 5.0 collaboration architecture, which aims to integrate innovative technologies with human actors [39].

Industry 4.0 was centered around digitizing and automating industrial processes, leading to increased productivity and economic growth [7]. Industry 5.0, on the other hand, emerges as a society-driven agenda, aiming to regulate the digital industrial transformation in a way that aligns with sustainability goals [8]. [3] examined the conceptualization, inception, and perception of Industry 4.0 and Industry 5.0. They suggest that, while Industry 4.0 is technology-driven, Industry 5.0 is value-driven and involves fundamental societal needs, values, and responsibilities. However, it also depends on the output of Industry 4.0 for technological advancements and technical fixes.

Industry 5.0 harnesses the core ideas of servitization (*i.e.*, offering services alongside products) in order to improve the way in which consumers experience products and services. This shift means that enterprises not only *sell* things; they provide *whole solutions* that meet individual needs. Industry 5.0 refines the way in which companies interact and integrate with consumers by means of real-time data analysis and artificial intelligence-driven insights, leading to personalized customer experiences [41].

Among the three principles of Industry 5.0, sustainability is the most extensively discussed in the literature. Even research about human-centricity, resilience, and different enabling technologies discuss sustainability aspects to some extent. However, it should be noted that the literature focuses primarily on the concept of *sustainability* or in its core principles, rather than on the application of specific technologies, methodologies, platforms, or architectures [42]. In light of this, this paper presents an architecture that works in conjunction with modern cloud services to demonstrate how cloud computing is an enabling technology for Industry 5.0, showcasing its benefits through a use case. Through these foundations, researchers will be able to develop services that meet Industry 5.0 requirements at affordable costs.

Platform architecture

The present perception of Industry 5.0 is that it is a movement to restore human connections across all processes. The customer's need for mass personalization is driving this new industrial paradigm. CPS, introduced by Industry 4.0, must progress into Industry 5.0, fundamentally changing the way we live, work, and interact with one another [7]. Industry 5.0 services are significantly understudied, as its technological constituents, components, and functionalities are ill-defined [12].

Industry 5.0 services require a platform that obtains and synchronizes physical and virtual data, so that companies and systems can make adequate real-time decisions. Additionally, this platform must react to real-time events and combine concepts such as *multilayer architecture*, *service orientation*, *information modeling*, *integration*, *data capture*, and persistence [22]. This section presents a platform (Fig. 1) that works as a modern distributed cloud system and can elastically scale to handle and integrate all business applications, services, and data —even the most massive data requirements. Moreover, it provides guarantees regarding delivery, processing, performance, resilience, sustainability, and human-centricity.

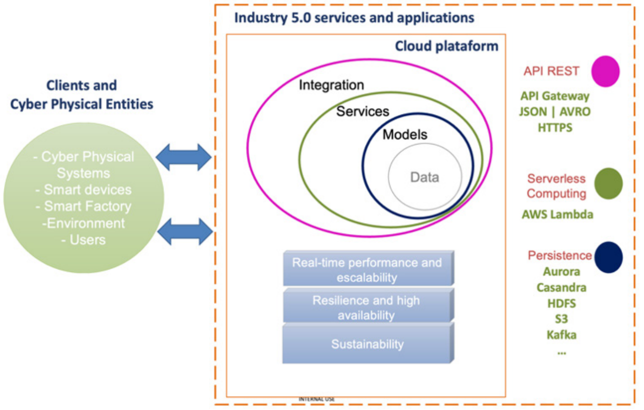

Figure 1. Proposed architecture
Source: Author

In modern manufacturing systems, typical resources must be converted into smart entities with the ability to sense and act within the environment, generally evolving into CPS. CPS are divided into three levels according to their different tasks, physical rules, functionality, or structure within the environment: unit, system, and system of systems [23]. Services are made available to clients (human or cyber-physical) through an integration layer implemented using REST. This integration is necessary because applications and services cannot function in isolation. Therefore, this layer allows discovering and incorporate services, applications, or data across the Internet. It also serves as a gateway to the business logic encapsulated in applications and services. REST is a set of ideas that help to understand how to use HTTP. It is a prevalent style for developing web-based applications and services, as it has demonstrated scalability, fits well with user-centric models, and minimizes coupling between distributed applications [24].

Industry 5.0 opens new business opportunities through innovative user-centered services. Here, the product-centered approach is replaced by a service-through-product approach. Today, product design must encompass the device, the services enabled by it, and the infrastructure that supports said services. *Services* refer to activities carried out using the virtual model within the virtual environment. The virtual model encapsulates important characteristics related to the object as a resource, such as its behavior, dimensions, functionality, requirements, connections, state, or experience. These services allow for prediction, simulation, experimentation, optimization, and detection using cloud technologies, data-driven deep learning algorithms, and Big Data techniques.

For service implementation, the serverless computing paradigm is proposed. The term *serverless* means that the code (in functions) runs on external servers that charge only for the execution time, without the need for provision or management [25] —note that the code is triggered in response to events. Serverless computing is highly scalable and capable of running instances in parallel, providing very high performance and availability in the face of multiple concurrent events while the cloud platform handles the provisioning of resources in the background. Additionally, cloud computing automatically manages the redundancy necessary for code execution, load balancing between different instances, and the segregation of infrastructure in multiple locations. Thus, data, models, and services can be deployed on a cloud platform that provides support for complex decisions in a ubiquitous, decentralized, and distributed manner.

Human-centric case and implementation details

Implementation transforms use cases into applications and services for users, allowing to demonstrate the feasibility and benefits of the proposed technologies. Our use case consists of developing a service for real-time human fall detection through computer vision (functional requirements). In addition, the service must satisfy the requirements that govern Industry 5.0 (non-functional requirements).

One of the main components of the proposed solution is the cloud platform used. We selected Amazon Web Services (AWS), the most prominent option due to the wide variety of services it offers. To train the model, the YOLOv5m architecture and the *Fall Detection* dataset published in Roboflow were used. This dataset contains 4497 images, divided into 2874 for training, 1324 for testing, and 299 for validation [26].

YOLO (You Only Look Once) is an object detection algorithm that has been around since 2016. It was developed by Joseph Redmon, and it is one of the fastest object detection models. YOLO uses a single neural network that predicts bounding boxes and class probabilities directly from full images, making it a one-stage object detector [44]. YOLOv5 is a newer version of the original model. It was introduced in 2020 by Ultralytics, the developers of YOLOv3, and it is built on the PyTorch framework. YOLOv5 is fast, easy to use, and capable of achieving state-of-the-art results in object detection tasks [27]. The YOLOv5 architecture introduced an end-to-end, differentiable approach to object detection by unifying bounding box regression and object classification into a single neural network.

Fundamentally, the YOLOv5 network comprises three core components. The *backbone*, a convolutional neural network, is responsible for encoding image information into feature maps at varying scales. These feature maps are then processed by the *neck*, a series of layers designed to integrate and refine feature representations. Finally, the *head* module generates predictions for object bounding boxes and class labels based on the processed features [44].

YOLOv5 is incredibly fast. In Google Colaboratory with a Tesla P100 GPU, YOLOv5m reported a speed of 0.0082 seconds per frame with a mAP0.5 of 63.9, which means more than 120 frames per second. Training was carried out using Google Colaboratory in order to get free access to a Tesla K80 GPU. To train the model, the batch size was set to 64, the learning rate 0.01, and the number epochs to 100. Additionally, the YOLOv5m initial weights, stochastic gradient descent (SGD, *i.e.*, the optimizer), and images with a resolution of 640 were used.

Each YOLO variant introduces distinct innovations aimed at optimizing both speed and accuracy. For example, YOLOv4 and YOLOv5 integrated advanced backbones and loss functions (*e.g.*, Complete Intersection over Union, or CIoU) to improve object localization. In addition, YOLOv5 introduced techniques like structural re-parameterization as well as small object detection layers to improve performance. These improvements have been shown to significantly increase the mAP for detecting smaller objects, especially in urban environments where small, fast-moving objects are common. In addition to their improved accuracy, YOLO models have been optimized for speed and efficiency, making them ideal for edge computing applications in autonomous vehicles, where computational resources are often limited. Lightweight versions of YOLO, such as YOLOv5, have incorporated various architectural optimizations such as lightweight backbones, neural architecture search (NAS), and attention mechanisms in order to improve inference time without sacrificing accuracy [37].

The final model obtained a weight of 40 MB, a mAPval.5:.95 = 0.5142 and a mAPval0.5 = 0.8666. The model was stored in the Amazon Simple Storage Service, or S3. Fig. 2 presents graphs regarding model metrics such as precision, recall, loss, and mAP during the training phase.

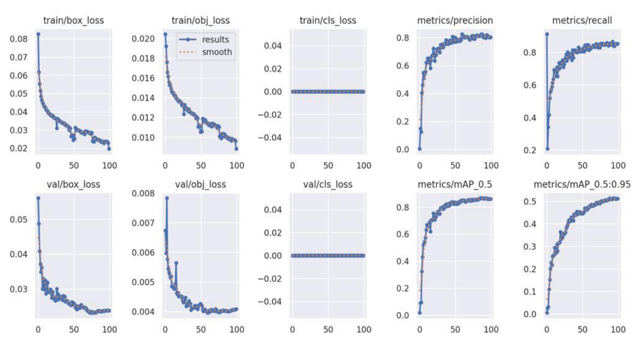

Figure 2. Model metrics
Source: Author

YOLOv5 is known for its speed, simplicity, and accuracy; it is an enhanced version of previous YOLO models that operates at a high inference speed, making it effective for real-time applications. As previously mentioned, YOLOv5 uses PyTorch, which makes its deployment faster, easier, and more accurate [43]. YOLOv5 comes in several versions: YOLOv5s, YOLOv5m, YOLOv5l, YOLOv5x. In particular, YOLOv5m is a medium-sized model with 21.2 million parameters that offers a balanced combination of speed and accuracy. This model is often regarded as a versatile choice for a wide range of object detection applications and datasets [44]. Furthermore, YOLOv5m has less than half the parameters of YOLOv5l (46.5 million) and less than a quarter compared to YOLOv5x (86.7), making it excellent for running in hybrid applications and on devices with limited computing resources. This is why we used it in this research.

We also employed AWS Lambda, an event-driven serverless platform that is capable of executing code in response to events and requests (up to hundreds of thousands per second), automatically managing the necessary computing resources and infrastructure [29].

The integration layer employed Amazon's API Gateway to convert the Lambda function into a REST service that executes serverless code in response to HTTP events. Thus, complete systems can be built without provisioning a single server, thereby reducing the initial investment [25]. The API Gateway makes it easy for engineers to create, publish, monitor, and secure services at any scale. The integration layer acts as a gateway for applications and clients to access data and business logic in real time. The API Gateway can process up to hundreds of thousands of simultaneous calls, controls authorizations, and monitors and manages different service versions. When the client sends a request (in this case, POST), REST transfers a representation of the resource's state to the requester. This message is delivered via HTTPS (encrypting data in transit) using JSON for the message structure.

Fig. 3 shows the service running in real time. Images can be captured using mobile phone cameras, IP cameras, unmanned aerial vehicles (drones), or automatic guided vehicles (AGVs). Each image is transmitted as a Base64 string and transferred via 5G or WiFi.

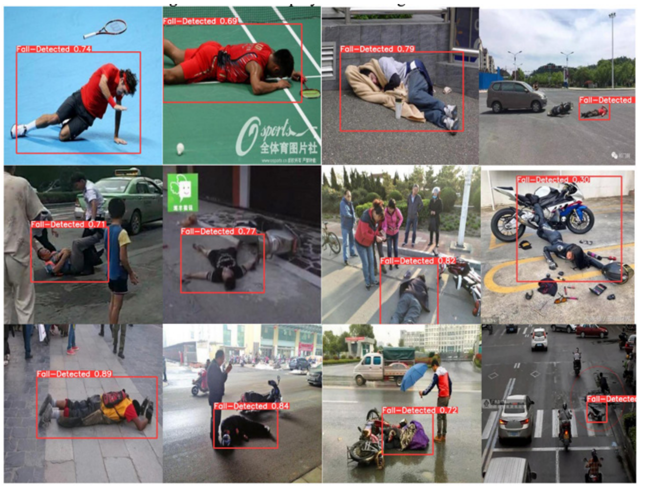

Figure 3. Service running in real time
Source: Author

Results and discussion

An implementation consists of developing a solution that meets all the established requirements, focusing mainly on the quality attributes (non-functional requirements) that it enables. This section analyzes the way in which the above-presented implementation complies with the three fundamental principles defined by Industry 5.0. The discussion includes a section on dataset limitations and cloud platform constraints, as well as a breakdown of the costs involved in implementing this use case.

Dataset limitations

Since falls can result in accidents that might require treatment and lead to death in the worst cases, studies aimed at designing fall detection systems have been conducted. However, given the risks and costs associated with acquiring data, most fall-related datasets have a limited number of participants, which can lead to small and therefore unrepresentative datasets with imbalances between classes. In response to these challenges, innovative approaches have been sought, such as combining datasets from different sources, in order to overcome the limitations associated with data acquisition. Storing real-life datasets of falls often requires long-term facilities, complex setups, cooperation from external institutions, large time investments, ethical permissions, high operating costs, and beyond. Furthermore, they require substantial computational resources for analysis, as well as a lengthy process of recording, extracting, and labeling data. Due to these difficulties, most studies have been carried out using simulated datasets, meaning that the analyzed falls do not occur naturally. Although these datasets are created in controlled environments, obtaining simulated data is also challenging, given the risks associated with simulating falls and the costs of data acquisition, which include human supervision, specialized equipment, and significant time investment [40].

When dealing with imbalances between classes, model evaluations should not depend only on the overall accuracy, as this is influenced by the most representative class. Metrics like recall, loss, AUC, and mAP are crucial for providing an accurate view of performance, especially for the minority class, as was done in this research.

Cloud platform constraints

Although they offer robust security features, cloud platforms like AWS exhibit several potential privacy, security, and technological constraints. These include the shared responsibility model, potential misconfigurations, evolving security threats, and the complexities of managing access control and data encryption. As technologies evolve, new security risks emerge. For example, the rise of generative artificial intelligence introduces new challenges related to the data used to train models and prompt injection attacks. While AWS offers encryption options, managing encryption keys and ensuring proper encryption at rest and in transit is essential. Additionally, ensuring data privacy, especially when dealing with sensitive information, can be challenging due to strict regulations and the need for robust security measures.

Organizations must implement robust security measures to protect sensitive data, especially in regulated industries. This includes encryption, access controls, and monitoring, as well as compliance with relevant privacy regulations. AWS handles the security of the infrastructure, but the customer is responsible for securing their data, applications, and access. This shared responsibility model requires the careful planning and implementation of security measures. Incorrectly configured resources, such as security groups, storages (*e.g.*, S3 buckets), or security policies, can create security vulnerabilities. Protecting the network perimeter and internal network traffic is essential, and regular reviews and audits must be performed to identify and remediate vulnerabilities. Finally, educating employees about security and privacy risks while automating security tasks to improve efficiency and reduce manual errors is also helpful in mitigating these constraints.

Human-centric services

Industry 5.0 seems to coexist with Industry 4.0 as a parallel phenomenon. Industry 5.0 opens new business opportunities to develop personalized, innovative, and human-centric services, which will most likely reach users through products. Human-centric and personalized services that enable intelligent assistance, monitoring, diagnosis, prediction, or simulation are necessary in Industry 5.0. However, these services need to be deployed on a platform that provides decision support anywhere and at any given time (real-time ubiquity and a holistic nature), and they must demonstrate high availability (resilience), scalability, efficiency in the use of resources, and the ability to handle high workloads and structured and unstructured data.

Here are a few benefits of the human-centric service developed in this use case:

- Elderly care monitoring: The fall detection model and service can be integrated into camera-assisted monitoring services or smart home systems to identify when elderly individuals fall, allowing for quick help.
- Workplace safety: In high-risk work environments like construction sites or factories, the fall detection model and its related services can be implemented to monitor employees and detect accidents, alerting supervisors immediately to provide assistance.
- Public safety: Security cameras installed in public areas such as streets or parks can use the model and service to detect falls and accidents, allowing emergency services to help in a timely manner.
- Sports injury detection: the fall detection model and service can be used in sports centers to monitor athletes during training sessions, helping to quickly identify injuries and allowing medical staff to intervene if necessary.

Resilience

All systems and applications, especially distributed ones, will experience failures. The way in which systems are built to respond to these failures is a critical part of building resilient systems. Redundancy at each system layer makes it possible to deal with the failure of a key piece of infrastructure or service. This is done using techniques such as clustering, balancing loads between services, and segregating the infrastructure into various locations [30], [31].

Cloud computing provides an effective solution to this challenge [32], as the implemented services can be stored in the cloud, providing decision-making support. The AWS region used for this deployment was Northern Virginia (us-east-1) which has six availability zones (AZs). In AWS, the concept of region refers to a physical location in the world where data centers (AZs) are grouped together. Each AWS region consists of several separated and independent AZs within a certain geographic area. AZs consist of one or more discrete data centers with redundant power, networking, and connectivity. They provide higher levels of availability, fault tolerance, and scalability than a single data center would offer. The traffic between AZs is encrypted, and these zones are physically separated from each other by a significant distance, even though they are all within a 60-mile range of each other [33].

AWS claims that this infrastructure allows services such as Amazon S3 to have a guaranteed availability of 99.99% and durability of 99.999999999%. To test resilience in this implementation, AWS CloudWatch was used to schedule an event that invoked the developed service every three minutes. This event was executed for 31 days (14 880 invocations), exhibiting an availability of 100%.

Sustainability

AWS focuses on efficiency and continuous innovation across all aspects of its infrastructure, striving to supply its operations with 100% renewable energy by 2025, five years earlier than the original target of 2030, and driving towards net-zero carbon by 2040. By 2021, 13 AWS regions were already powered by over 95% renewable energy [34].

In 2018, 86% of the companies in the S&P 500 index published a sustainability report, up from only 20% in 2011. 451 Research, a technology market research and advisor company, conducted a study on the energy and carbon efficiency of enterprise data centers and server infrastructure, focusing on US enterprises with a revenue between ten million and one billion dollars. 451 Research found that the AWS infrastructure is 3.6 times more energy efficient than the median of US enterprise data centers, and up to five times more energy efficient than the average in Europe. They also found that AWS can lower the carbon footprint of customer workloads by nearly 80% compared to the surveyed enterprise data centers, and by up to 96% once AWS is powered with 100% renewable energy [35].

Finally, AWS released their AWS Customer Carbon Footprint Tool to show customers their historical carbon emissions, allowing them to estimate the emissions avoided by using AWS instead of an on-premises data center and review forecasted emissions based on their current use [36].

Costs and initial investment

The proposed architecture is service-oriented and uses serverless computing (AWS Lambda), so it does not require an initial investment for the deployment of services in production. Furthermore, it can process thousands of requests instantly (automatic scalability and flexibility), with high availability and no place and time restrictions, billing on-demand at a price of $0.0000000167 USD per request.

A breakdown of the costs for the proposed solution is presented below. The S3 costs are influenced by aspects such as the storage occupied each month, the number of retrievals for each object, and the amount of data transferred. For Lambda, the cost is calculated based on two aspects: the processing time (in milliseconds) and the number of calls to the function. The average response time of the Lambda function (service) using 2048 Mb and YOLOv5m is 600 ms, which is practically equivalent to a real-time response. Lastly, the costs for AWS API Gateway are calculated per million requests.

Table 1 shows the costs per million images analyzed. They are less than $5 USD per month, much lower than the costs required to develop this service locally, which must additionally include expenses for Internet access, electricity, security, and rent, among others. This solution also avoids having to predict the capacity required by sudden increases in service demand.

Table I. Costs for the AWS services used in this implementation.

Service	Measure	Rate (USD)	Implementation	Total (USD)
S3 Standard				
Storate	50 TB/month	0,023	50 MB	0,023
Recoveries	1000 requests	0,0004	only in cold start	< 1
Transfers	1 GB	0,033	only in cold start	< 1
Lambda	Configuration: x86, 1 024MB	Processing time = Request duration (= 600 ms) * requests – Free Tier		
Processing time	GB memory / milliseconds	0,0000000167	200 000 000	3,34
Requests	1 million requests	0,2	1 000 000	0,2
API Gateway				
Invocations	1 million calls	1	1 000 000	1
CloudWatch	Free Tier	0		0
			Total	**$ 4,563**

Source: Author

Table II. Comparison with other relevant papers in literature.

Source	Tested with implementation case	Does it analyze costs?	Is Human-centric?	Is it Sustainable?	Is it Resilient?	Other implemented principles	Affordable costs?
Tóth et al. [2]	No	No	**Yes**	No	No	Collaboration	No information provided
Alabamian [7]	No	No	Just the concept	Just the concept	Just the concept	No	No information provided
Ghobakhloo et al. [12]	No	No	Just the concept	Just the concept	Just the concept	No	No information provided
Ly [13]	No	No	**Yes**	**Yes**	No	Digital Twins	No information provided
Garrido et al. [15]	No	No	Just the concept	Just the concept	Just the concept	No	No information provided
Zeb at al. [16]	No	No	Just the concept	Just the concept	Just the concept	No	No information provided
Liu et al. [17]	**Yes**	No	No	No	**Yes**	Security	No provides information
This research	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Affordable costs**	**Yes**

Source: Author
Note: *Just the concept* means that the study only analyzed the concept without proposing or implementing a solution

Finally, Table II analyzes the requirements that this research meets in comparison with other literature reports. Note that there are few studies that have implemented or tested compliance with the fundamental characteristics of Industry 5.0, which have also failed to analyze the costs involved or prove the affordability of their solutions.

Conclusions

Environmental concerns, sustainable and resilient solutions, and human-centric and personalized approaches have become the main drivers of Industry 5.0. In this context, companies must identify and invest in technologies that meet their needs and allow them to develop value-added services with greater efficiency, resource productivity, and affordable costs. Cloud computing is key and fundamental element in this regard, playing an essential role in helping companies and organizations to reduce carbon emissions and facilitate sustainable and resilient research and innovation. Furthermore, cloud computing offers a viable, cost-effective solution, changing the way in which services are implemented and enabling companies of any size to build modern, powerful, and scalable applications. Consuming only what one needs is critical to building a sustainable future at affordable initial costs, and this is the foundation of cloud computing, wherein resources are provided on demand with very little waste. In fact, cloud providers like Amazon already offer services that allow companies to analyze the environmental impact of their applications and know how much they would reduce their footprint by using Amazon infrastructure.

Cloud computing can enable a sustainable and resilient model, transforming businesses, accelerating progress, and addressing environmental impacts and footprints. Furthermore, it frees developers and engineers from investing time in tasks that add no value, allowing them to focus on developing human-centric requirements and services. Lastly, cloud computing allows facing the challenges related to initial investment and generates cost savings in relation to infrastructure and storage, in addition to providing greater flexibility, security, efficiency, and competitiveness. The cost of the studied implementation —which used serverless computing, eliminating the time and expenses spent in infrastructure acquisition and management— was $4.56 USD per million images analyzed.

As future work, the integration of these new services and applications with ubiquitous technologies such as drones and AGVs, which enable execution at any given time and place, could be explored.

Author contributions

All authors: conceptualization, methodology, software, validation, formal analysis, investigation, writing (original draft, review, and editing), data curation.

Conflicts of interest

The author declares no competing interests.

Data availability

Not applicable.

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