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SIMULATORS AS VISUAL AIDS TO REINFORCE COURSES IN AUTOMATION AND INDUSTRIAL ROBOTICS

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ABSTRACT

The basic automation courses present in various engineering careers, have seen the need to implement new methodologies that bring students closer to real practice. During the pandemic, the need to implement teaching methodologies such as simulation based on visual aids to achieve this objective was observed. That is why this literature review aims to generate a scope on the use of simulators in automation courses, and to present the simulators that have been successfully used in the teaching of this course, in addition to highlighting the advantages of its use in education.

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1. Introducción

The need to streamline production and reduce human intervention in industrial processes led to the development of automation and industrial robotics, technologies that have been implemented in industries worldwide for over a century and are now the most important pillars for good production performance. Due to the adoption of automation by global industry, it has become necessary for engineering professionals in the industrial field to integrate industrial automation and robotics courses into their curricula, which are now mandatory courses for the degree.

In more developed countries, engineering programs have automation laboratories to put students in contact with the theory they have learned. However, in underdeveloped countries, students have very limited opportunities to interact in automation laboratories, mainly because universities focus on investing in natural science laboratories, neglecting those related to these technologies. He points out that these courses should seek to narrow the gap between theory and real industrial practice, so ensuring that students have contact with devices, systems, and techniques similar to those used in real industry should be a priority. In a conventional automation course, practical work is carried out in laboratories, where the use of development boards, sensors, robots, and PLCs is necessary (Bhardwaj et al., 2021).

On the other hand, an alternative to the use of physical laboratories emerged with the Covid-19 pandemic, which forced the academic world to implement virtual environments with visual support in order to continue teaching remotely. In the case of automation and robotics laboratories, visual aids such as videos in simulation programs were a great alternative because they can imitate or replicate real-world processes and objects with high precision, allowing students to come into contact with realities that they would not be able to experience in a real environment. In this context, simulators are visual aids with great potential for teaching automation courses.Furthermore, the use of visual aids in education improves learning by providing students with relevant visual information to complement theoretical classes.

Considering the context outlined above, the main objective of this review is to identify visual environments such as simulation that can serve as visual aids for teaching automation and robotics courses in engineering programs.

2. Simulators as visual aids for teaching automation and robotics:

Visual aids play an important role in modern education, transforming verbal or textual information into visual information in order to improve student understanding. According to authors such as , the incorporation of visual tools helps students to better understand concepts and develop their imagination.

Simulators, as visual aids, are tools that allow the replication of real-life environments of a specific event or situation. In education, simulation has been used to expose students to situations similar to those they would face in a real environment. Although the use of visual simulators in education was already present in some higher education institutions, it was only available to private institutions. On the other hand, with the arrival of the pandemic and the resulting lockdown, the need to use simulators as visual aids for education became evident, especially for courses such as engineering, where the use of laboratories was suspended due to the pandemic.

During automation courses, especially at basic levels, priority is given to teaching about the various sensors, actuators, and controllers that exist for automating processes. Teaching basic circuits and prototypes usually requires the purchase of items such as protoboards, development cards, sensors, and actuators. However, students often have limited access to these items. Simulators are an alternative when it is not possible to purchase these items and provide visual support for students to understand what they have learned in theory. Currently, there are several free online visual aids that allow circuits and their operation to be simulated.

Authors such as those who, as teachers, implemented the use of simulators in basic electronics courses, pointed out that these not only allowed classes to continue during the pandemic, but were and should continue to be a complement to laboratory exercises and classroom teaching. On the other hand, they point out that circuit simulators serve as an effective virtual visual tool for introducing students to electronic components, avoiding the fear caused by first-time exposure to these elements, as well as the

dangers of damaging components through mishandling. Simulations enable students to interact in safe environments while putting the theory they have learned into practice.

3. Metodología

Considering the objective set and having presented the status of the use of simulators as visual aids in teaching automation courses, the following research question was formulated:

What are the existing simulation environments that can serve as visual aids for teaching automation and robotics courses?

Due to the limited information available on the variety of simulators used for teaching automation courses in specific databases, we opted to conduct a narrative literature review. This type of review does not have a structured methodology, but it allows the topic to be addressed in a more extensive and flexible manner. The Google Scholar search engine was also used as a means of consulting research, as it provides access to a wide variety of academic resources (articles, theses, books, patents, conference papers, and abstracts).

4. Resultados

As mentioned above, simulation as a visual support tool has gained importance in teaching after the pandemic, making its implementation for automation and robotics courses necessary to create a more dynamic learning environment and build confidence in students. Within the world of simulations for teaching automation and robotics, simulators with visual representations in 2D and 3D can be distinguished. In general, 2D simulators are intended for the simulation of electronic circuits, while 3D simulators are mainly used in robotics and to visually represent various types of industrial machinery (Table 1).

Table 1. Characteristics of simulators used as visual aids for teaching industrial automation and robotics courses

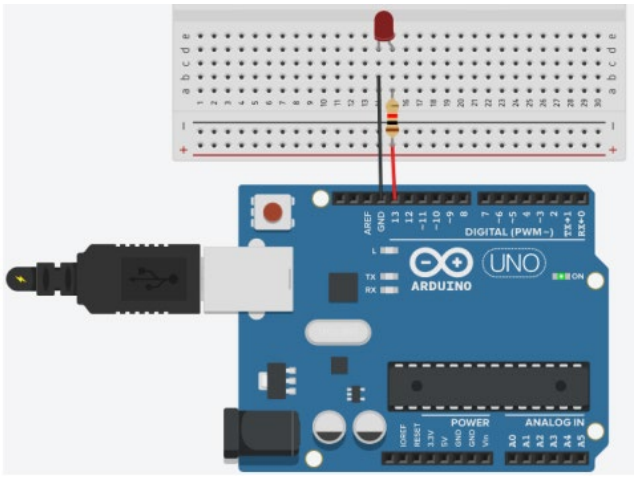
Simulator	Type of simulation	Item	Platform
Tinkercad	2D	Circuits	Web
Fritzing	2D	Circuits	Windows, macOS, and Linux.
Wokwi	2D	Circuits	Web
Factory I/O	3D	Industrial machinery	Windows
SIMULINK 3D Animation	2D y 3D	Electronic equipment	Windows
HOME I/O	3D	Domotics	Windows
Virtual Breadboard (VBB)	2D	Circuits	Windows
AutoSIM-200	2D y 3D	Industrial machinery	Windows

Fuente**:** Elaboración propia, 2024

Below are some of the virtual visual environment simulation platforms that have the necessary features for learning industrial automation and robotics and have been used by teachers for implementation in these courses:

It is a free application developed by Autodesk, which allows users to design, program, and simulate electronic circuits in its circuits section (see Figure 1). This simulator is one of the best-known applications among university students studying engineering. In the field of education, Tinkercad is emerging as a valuable visual support simulation tool for electronics, as it provides access to a wide variety of electronic components, sensors, actuators, protoboards, and includes microcontrollers such as Arduino. Authors such as point out that as teachers, they consider Tinkercad to be the main option for helping students understand how each electronic component works separately when using simulation on Arduino boards.

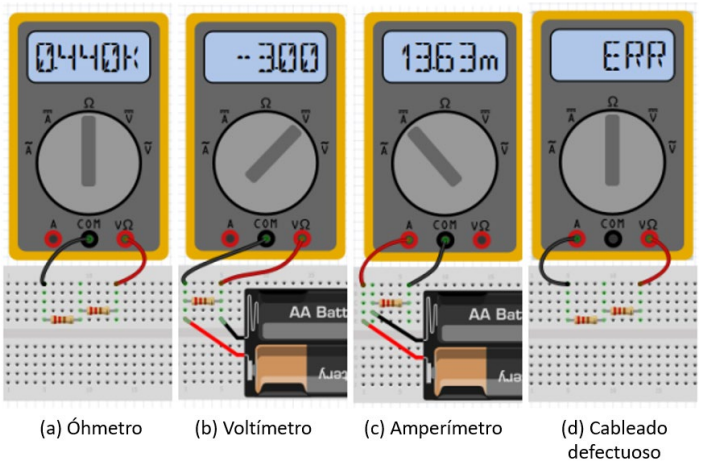
Figure 1. Visual diagram of the circuit for simulating the lighting of an LED using Tinkercad.



Source: Tupac-Yupanqui et al. (2021)

It is an open-access program that allows users to create, design, and simulate electronic circuits. Its main purpose is to serve as a tool for teaching electronics to beginners. However, its capabilities are limited to DC circuit analysis. Otherwise, it is a very functional, easy-to-use program with realistic visual representations. Regarding its use in education, authors such as have formulated simulation practices in Fritzing, highlighting that its use allows students to work in three different views: protoboard, schematic, and PCB, all with realistic visual graphics (see Figure 2). points out that the use of Fritzing for the design and simulation of E-textiles in students helped students understand how this type of garment works and achieve better grades in E-textiles courses compared to students who used traditional teaching methods.

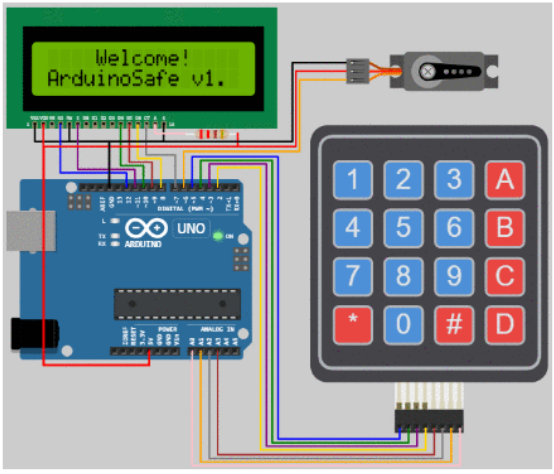
Figure 2. Visual representation of a simulation of the properties of a multimeter in Fritzing.



Source: Faíña (2022)

Wokwi is an Arduino project simulator that also features ESP32 and STM32 microcontrollers and many other boards, sensors, and various electronic components (see Figure 3). The bibliography includes various research studies by teachers who have used Wokwi as a practical visual support tool for teaching IoT courses, highlighting the use of this platform because the simulator has cards with internet access and Bluetooth, which allows IoT projects to be simulated.

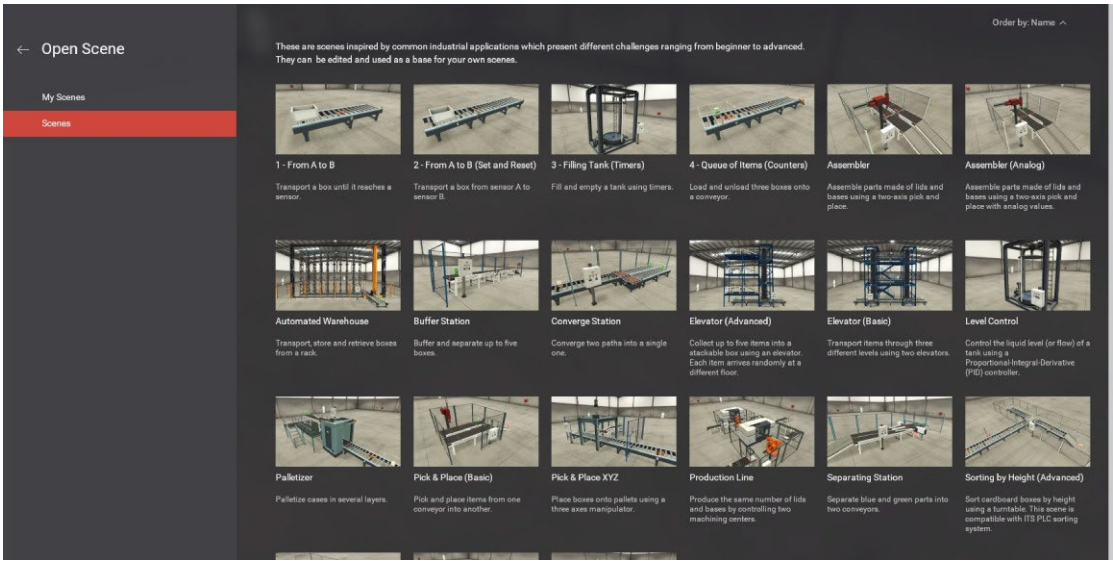
Figure 3. Visualization of the simulation of an electronic security system with a password



Source: Faíña (2022)

Factory I/O is a visual 3D factory simulation platform that allows users to learn automation technologies. It is an easy-to-use platform that allows users to build virtual factories using various commonly used industrial parts (see Figure 4), which are true to their shape and characteristics in a real environment. Work such as that of , who used this simulator to teach a course related to PLCs (Programmable Logic Controllers), points out that Factory I/O has very high visual quality with a high degree of realism. Authors such as used Factory I/O to teach automation in a master's program at the Pontificia Universidad Católica de Valparaíso (PUCV) in Chile, where students highlighted that the platform offers a very realistic and immersive visual environment, which helps them understand the course by allowing them to visualize the real behavior of physical components. Other research professors, such as , also used Factory I/O to simulate virtual control and automation practices, taking advantage of the platform's eye-catching, practical, and visually realistic features.

Figure 4. List of ready-to-use 3D visual scenes inspired by typical industrial applications.



Fuente: Factory I/O (n.d.)

MATLAB is business math software often used in algorithm development, data analysis, numerical calculations, and other areas. Simulink, however, refers to a MATLAB add-on that generates interactive graphical environments for modeling, simulating, and analyzing dynamic systems. Simulink 3D Animation integrates Matlab and Simulink algorithms into Unreal Engine®, a real-time simulation tool,

to simulate and visualize dynamic systems in a photorealistic 3D environment. This MATLAB tool has been used for virtual laboratory simulation, where the authors highlight the software as one of the most widely used visual simulation tools in universities due to its high-quality visual graphics (see Figure 5).

Figure 5. Commercial signal generator and corresponding Simulink model.

Source: Bedillion & Nizar (2015)

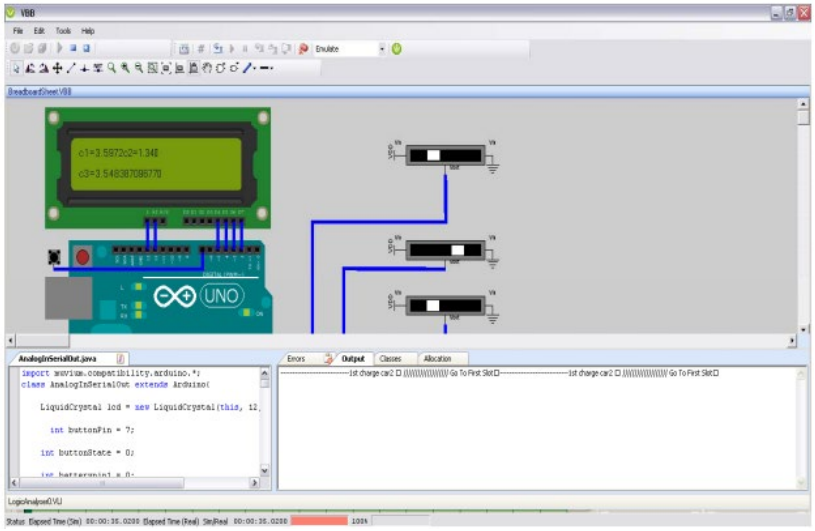
HOME I/O is a visual interactive simulation platform for smart homes and surrounding environments, created with the aim of encompassing a wide range of curriculum objectives within Science, Technology, Engineering, and Mathematics, allowing students to learn about home automation, thermal behavior, energy efficiency, and other topics that are part of everyday life in a home. Various research projects, such as those carried out by have used HOME I/O as a means of visualizing and simulating automated environments, as these generate a "situational awareness" by exposing them to highly realistic virtual environments (see Figure 6).

Figure 6. Simulation environment of an automated blind in a room in HOME I/O.

Fuente: Home I/O (n.d.)

Virtual Breadboard (VBB) is a paid Windows Store app that functions as a visual and interactive programming tool for teaching electronics to students or hobbyists, allowing users to design and interact with circuits without the risk of damaging physical components. Researchers have successfully used this application to simulate their projects, highlighting the importance of simulation tools such as VBB that serve as visual aids for understanding and laying out projects involving circuits (see Figure 7).

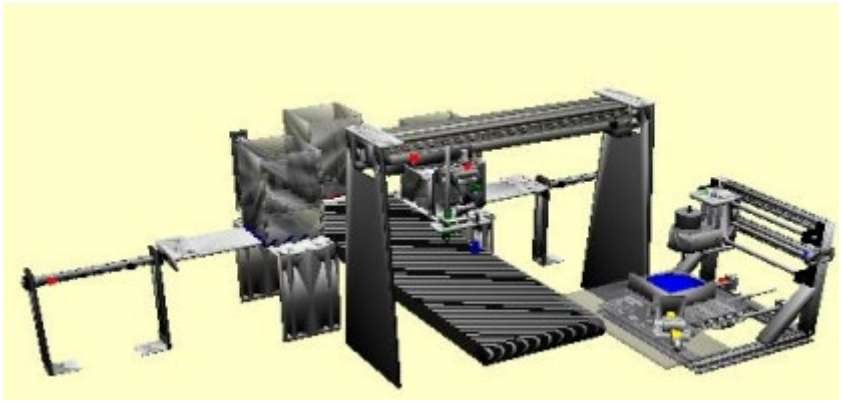
Figure 7. Simulation of a circuit with an Arduino board in VBB



Source: Benela & Jamuna (2013)

AutoSIM-200 is software designed for training in automation technologies, allowing users to test their programs or designs in a virtual system before applying them in reality. It also allows users to view available or user-designed industrial components in 2D and 3D views. No research was identified where this software has been used in education; however, it has been used to simulate PLC-based pneumatic systems and as a tool to simulate and visualize the correct operation of production line projects (see Figure 8) as in and .

Figure 8. Virtual model of the manufacturing cell in AutoSIM-200



Fuente: Chávez (2020)

While there are programs exclusively for teaching automation and control courses, some research professors have chosen to create and propose their own visual simulation platforms. By developing their own simulators, professors seek to adapt them to the needs of the courses they teach.

They developed an Arduino simulation-based learning system, which was evaluated by other experienced STEAM (science, technology, engineering, and mathematics) teachers, 81% of whom showed great interest in applying simulators in their classes.

They also proposed and validated a unified automation and robotics simulation system, or USARsim, which is a simulator aimed at automotive automation and robotics. It is built on a commercial game engine, exploiting very realistic visual performance and high-quality physical simulation. This simulator is open access and inexpensive compared to the game engine that supports it, making it ideal as a visual teaching tool. USARsim has been used in other research to simulate robots with highly realistic dimensional and mass modeling, and has even been used in conjunction with graphic design tools such

as Adobe Photoshop to customize simulations by combining a high level of graphic detail (see Figure 9) with real-time calculation speed and a flexible user interface.

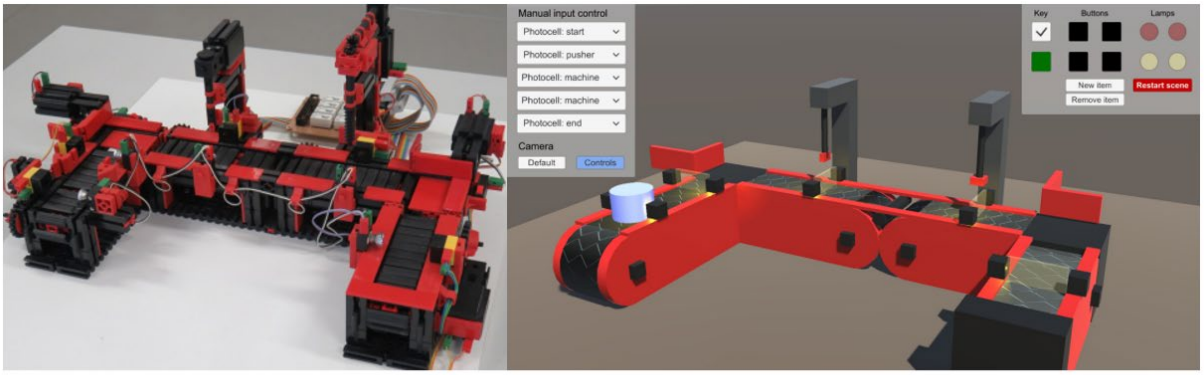
Figure 9. High degree of realism in USARsim simulations

(a) Ambiente y robot simulado (b) Ambiente y robot real

Source: Alemany (2011)

Another simulator called FTsim was developed by teachers in collaboration with a small group of students, who define its achievement as a 3D visualization and simulation tool. Like USARsim, this simulator was also developed based on a game engine and seeks to mimic the behavior of Fischertechnik training models (see Figure 10). Authors used USARsim as a visual support tool during the boom in virtual classes due to the social confinement generated by Covid-19. Another study used the simulator to design and simulate training factories under the principles of Industry 4.0 for industrial engineers.

Figure 10. Fischertechnik model simulated in FTsim



(a) Modelo Fischertechnik real (b) Modelo simulado en Ftsim

Sourcee**:** Ile & Lotric (2018)

Simulation as a visual tool for teaching automation and robotics courses offers great benefits for students and teachers as a practical teaching method. Its visual nature makes learning more attractive, sparking curiosity and motivating students. The following are the main advantages of simulators in teaching introductory automation and robotics courses, as deduced from the research found:

- It provides safety in practice, especially for beginner students who are interacting with electronic components for the first time.
- The visual aids provided by simulators are of very high quality, as they are very faithful to real electronic components.
- Simulators with 2D and 3D views are available, allowing students to visualize their project from different angles.
- Most platforms have project galleries that can be used directly by teachers as visual aids.

- Simulators can be used as visual inspection systems to compare the quality of designed parts or circuits.
- They avoid the time and cost of purchasing electronic components and prevent delays in practical work due to their unavailability.
- Simulation has proven to be effective in understanding courses where it has been used compared to traditional teaching methods.
- Simulators used in education are usually free to access and easy to understand and use.

4. Conclusions

The use of simulators as visual aids for teaching automation and robotics students has grown due to the advantages they offered during the pandemic, when one of the alternatives to attending physical automation laboratories was based on the use of simulators. Simulators offer vital visual aids that allow students to efficiently identify electronic components and recognize the operation of various industrial machines and robots. In this way, students become visually familiar with real-life objects with which they will interact in the professional environment. The review identified the visual aid-based simulators most used by teachers when implementing them in their automation courses, with TinkerCad, Wokwi, Fritzing, and Virtual Breadboard (VBB) being the most used by teachers for teaching and simulating electronic circuits, while simulators such as Factory I/O, Home I/O, Simulink 3D animation, and AutoSIM – 200 were used for 3D simulations and robotics. On the other hand, the development of simulators by teachers was also identified, where these were designed according to the needs of the target courses. It should also be noted that the use of simulators to carry out virtual laboratory practices does not seek to replace physical laboratories, but rather to expand their use as a visual support tool for teaching.

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