International Interdisciplinary Congress on Renewable Energies, Industrial Maintenance, Mechatronics and Informatics
Booklets

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Title: Design of the operation of a rotating machine for the acquisition of multi-view stereoscopic images for the 3D reconstruction of objects

Authors: CORONA-PATRICIO, Cesar-Agustin and RETA, Carolina

Editorial label ECORFAN: 607-8695
BCIERMMI Control Number: 2021-01
BCIERMMI Classification (2021): 271021-0001

Pages: 14
RNA: 03-2010-032610115700-14

ECORFAN-México, S.C.
143 – 50 Itzopan Street
La Florida, Ecatepec Municipality
Mexico State, 55120 Zipcode
Phone: +52 1 55 6159 2296
Skype: ecorfan-mexico.s.c.
E-mail: contacto@ecorfan.org
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Introduction

3D reconstruction is a set of techniques that allow inferring the geometric and photometric information of a physical object from one or more images. The reconstruction of objects has many applications, including cultural heritage preservation, medicine, engineering, content creation for virtual environments, among others (Durou et al., 2020).

This paper covers the subject of image acquisition for 3D reconstruction from multiple views captured with a stereoscopic camera. Figure 1 shows the image capturing process, in which a camera moves around an object to generate images from multiple viewpoints. The captured images are obtained in the digital format provided by the stereoscopic camera.

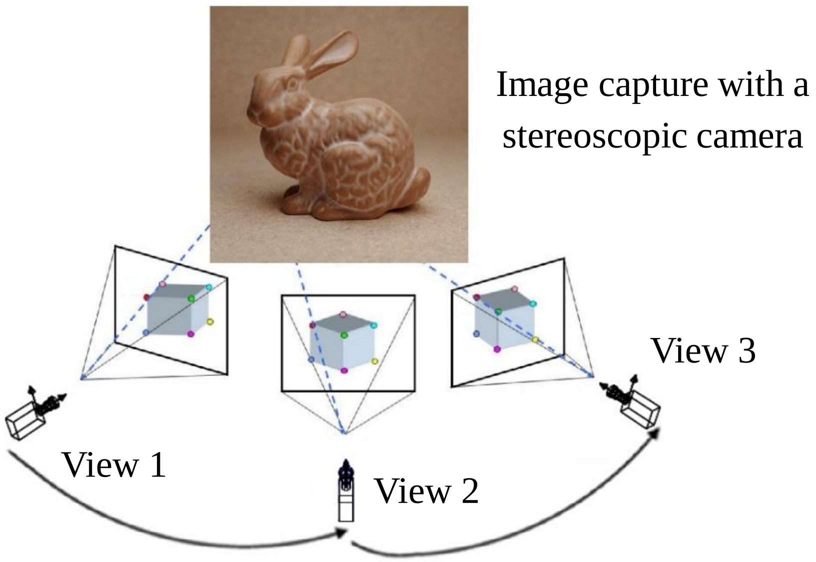


Figure 1 Multi-view image capturing process. *Source: Own elaboration based on images of Cordes et al., 2012; Yilmaz & Karakus, 2013; Stanford University, 2014.*

Proposed method

In this work, a positioning machine that allows moving a stereoscopic camera so that visual characteristics of an object can be obtained from different viewpoints is proposed. The purpose of using this machine is to acquire the necessary information of the object for its 3D reconstruction. The mechanical design and the electronic design and control of the proposed machine, are presented in the following sections.

a) Image dataset.

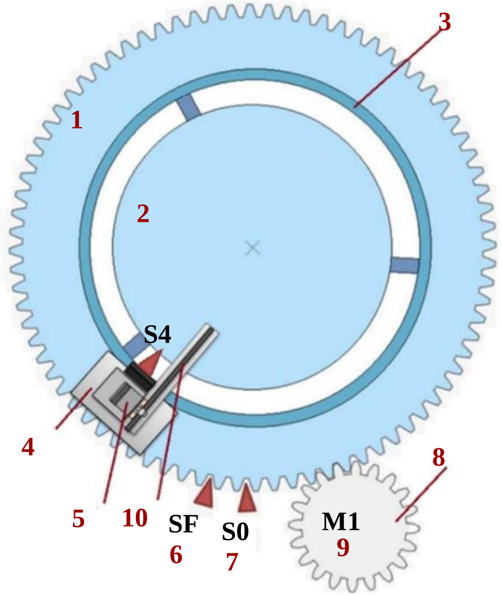
b) 3D reconstruction.

Figure 2 Captured images of an object from different viewpoints and its 3D reconstruction. *Source: a) Dataset of North, 2018, b) Own elaboration.*

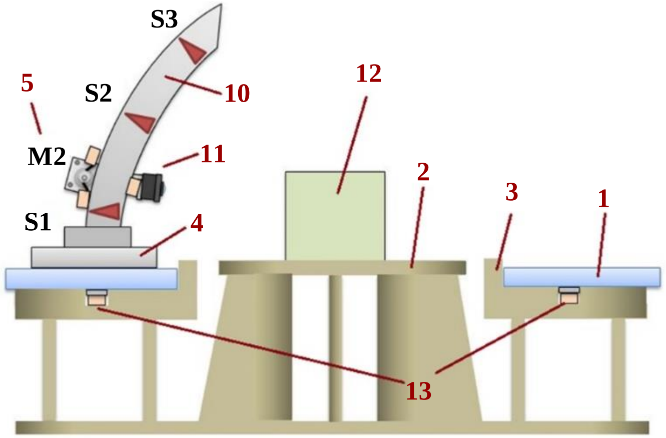
Proposed method

Mechanical design of the image acquisition machine

The proposed machine is presented in Figure 3. The camera is mounted on a base, resting on a rotary table. Motor M1 allows placing the camera around the object, and motor M2 allows setting the camera´s elevation. Sensors S1, S2, and S3 indicate the elevation levels of the camera. Sensors S0 and SF allow setting the initial position of the sequence to be performed in automatic mode. A proximity sensor S4 is used on the camera to detect strange objects near the camera that may introduce noise or collide with the camera.



a) Top view of the machine.



b) Frontal view of the machine.

1. Hollow rotary table
2. Base to place the object
3. Support for rotary table
4. Base where the camera can move 360°
5. Bipolar DC stepper motor (**M2**)
6. Auxiliary proximity sensor (**SF**)
7. Initial position proximity sensor (**S0**)
8. Gear to rotate table
9. Bipolar DC stepper motor (**M1**)
10. Rail for moving up and down the camera
11. Stereo camera and support structure
12. Object to be digitized
13. Bearings where the table rests

S1, S2, S3. Proximity sensors for placing the camera at three different heights

S4. Proximity sensor to detect obstructions in front of the camera.

c) Components of the machine.

Figure 3 Views and components of the proposed image acquisition machine. *Source: Own elaboration.*

Proposed method

Electronic design and control of the machine

Table 1 presents the signals used in the electronic design and control of the machine. This table describes the input and output signals used for control employing a PLC.

INPUTS	TYPE	DESCRIPTION	ORIGIN
INI	BOOL	start auto sequence	button
ESTOP	BOOL	emergency stop	switch
AUT	BOOL	automatic mode	selector
HOME	BOOL	set motors to home	button
FC_M1	BOOL	suitable motor frequency indicator of motor M1	ATTINY85 1
FC_M2	BOOL	suitable frequency indicator of motor M2	ATTINY85 2
VMAX_M1	BOOL	very high M1 motor speed indicator	ATTINY85 1
VMIN_M1	BOOL	very low M1 motor speed indicator	ATTINY85 1
S0	BOOL	starting position of motor M1	proximity sensor
SF	BOOL	auxiliary sensor to move motor M1	proximity sensor
S1	BOOL	bottom rail position of motor M2	proximity sensor
S2	BOOL	middle rail position of motor M2	proximity sensor
S3	BOOL	upper rail position of motor M2	proximity sensor
S4	BOOL	obstruction of the camera	proximity sensor
mDIS_M1	BOOL	disable motor M1	switch
mDIR_M1	BOOL	direction of motor M1	switch
mGP_M1	BOOL	enable pulse generator for motor M1	switch
mDIS_M2	BOOL	disable motor M2	switch
mDIR_M2	BOOL	direction of motor M2	switch
mGP_M2	BOOL	enable pulse generator for motor M2	switch

OUTPUTS	TYPE	DESCRIPTION	DESTINATION
MS0_M1	BOOL	micro-step configuration of motor M1	pin MS0, driver motor M1
MS1_M1	BOOL	micro-step configuration of motor M1	pin MS1, driver motor M1
MS2_M1	BOOL	micro-step configuration of motor M1	pin MS2, driver motor M1
MS0_M2	BOOL	micro-step configuration of motor M2	pin MS0, driver motor M2
MS1_M2	BOOL	micro-step configuration of motor M2	pin MS1, driver motor M2
MS2_M2	BOOL	micro-step configuration of motor M2	pin MS2, driver motor M2
DIS_M1	BOOL	disable motor M1	pin EN, driver motor M1
DIR_M1	BOOL	direction of motor M1	pin DIR, driver motor M1
GP_M1	BOOL	enable pulse generator for motor M1	ATTINY85 1
DIS_M2	BOOL	disable motor M2	pin EN, driver motor M2
DIR_M2	BOOL	direction of motor M2	pin DIR, driver motor M2
GP_M2	BOOL	enable pulse generator for M2 motor	ATTINY85 2
CRIT	BOOL	alarm signal	LED

Table 1 PLC input and output signals. *Source: Own elaboration.*

Proposed method

Figure 4 shows the PLC operation modes. The block diagram in Figure 4 shows a recommendation based on the GEMMA guide (CITCEA, 2021). This diagram is used to visualize which modes of operation are relevant for the functionality required by the machine.

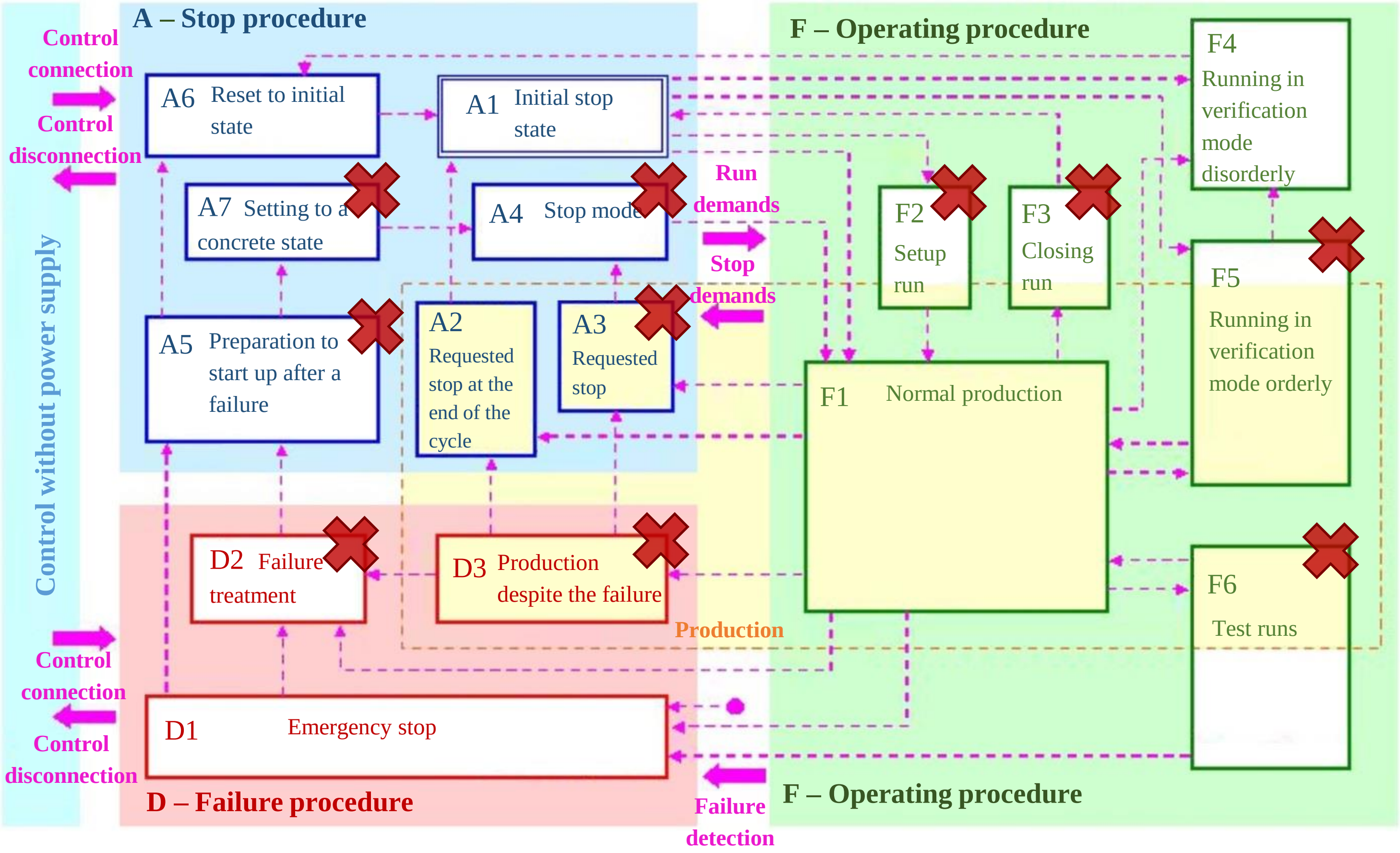


Figure 4 PLC operation modes. *Source: CITCEA, 2021.*

Proposed method

Figure 5 presents the main GRAFCET diagram, which was designed following the GEMMA guide (Urrego, 2011). The GRAFCET diagram presented in Figure 5 consists of 6 steps. Step0 is where the machine is reset to the initial state. In Step1, the verification of the speed of the motors is initiated, which allows displaying an alarm when speed limits are exceeded. Step2 is used to set the camera to the HOME position. It should be noted that the operation of the machine can be manual or automatic. During Step3, the operation is automatic. During Step5, the operation is manual. Step4 is a preparation stage to enter manual mode. An emergency stop can be set at any time, where the machine is sent back to the initial state.

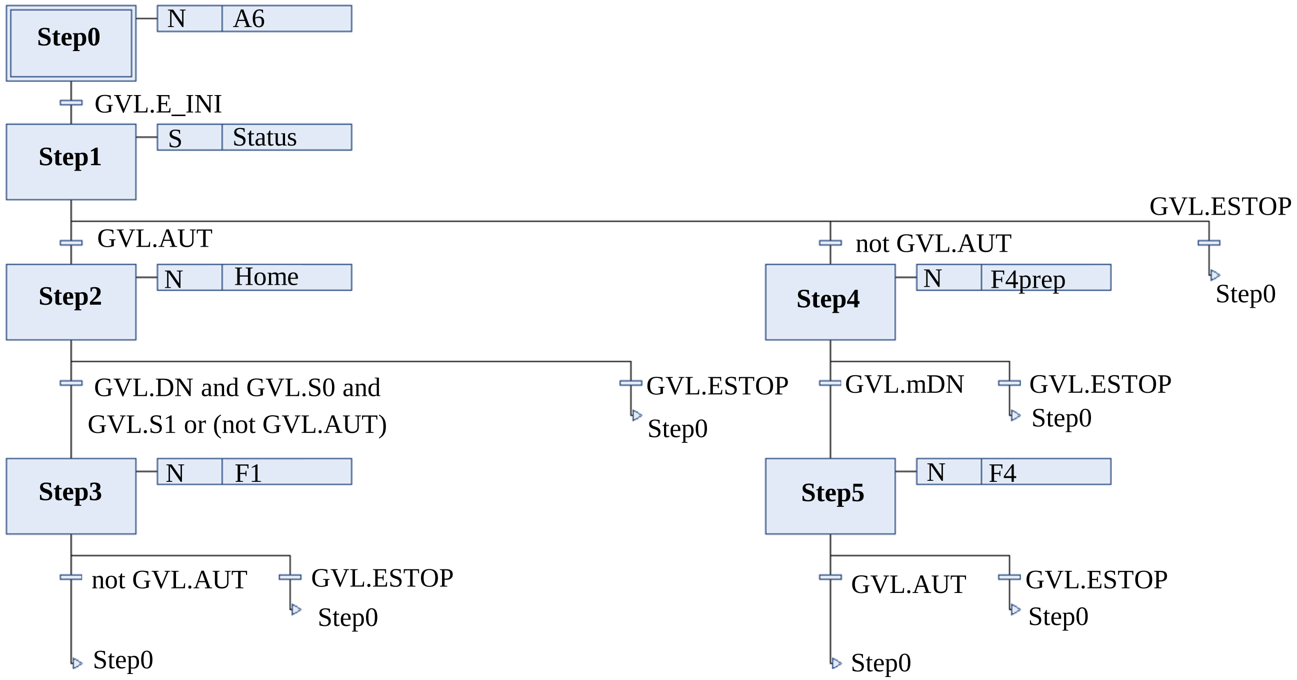


Figure 5 Main GRAFCET diagram. *Source: Own elaboration.*

Results

Graphical interface for machine operation

A simulation was carried out in CODESYS software (3S-Smart Software Solutions GmbH., 2021) using a virtual PLC to verify the operation of the logic described in the GRAFCET diagram in Figure 5. Figure 6 shows the interface developed to validate the operation of the machine. The status of the input signals can be changed using buttons. The status of the output signals are displayed with LED indicators. The simulation performed with this interface helped to verify the correct operation of the machine's manual, automatic, and emergency stop modes.

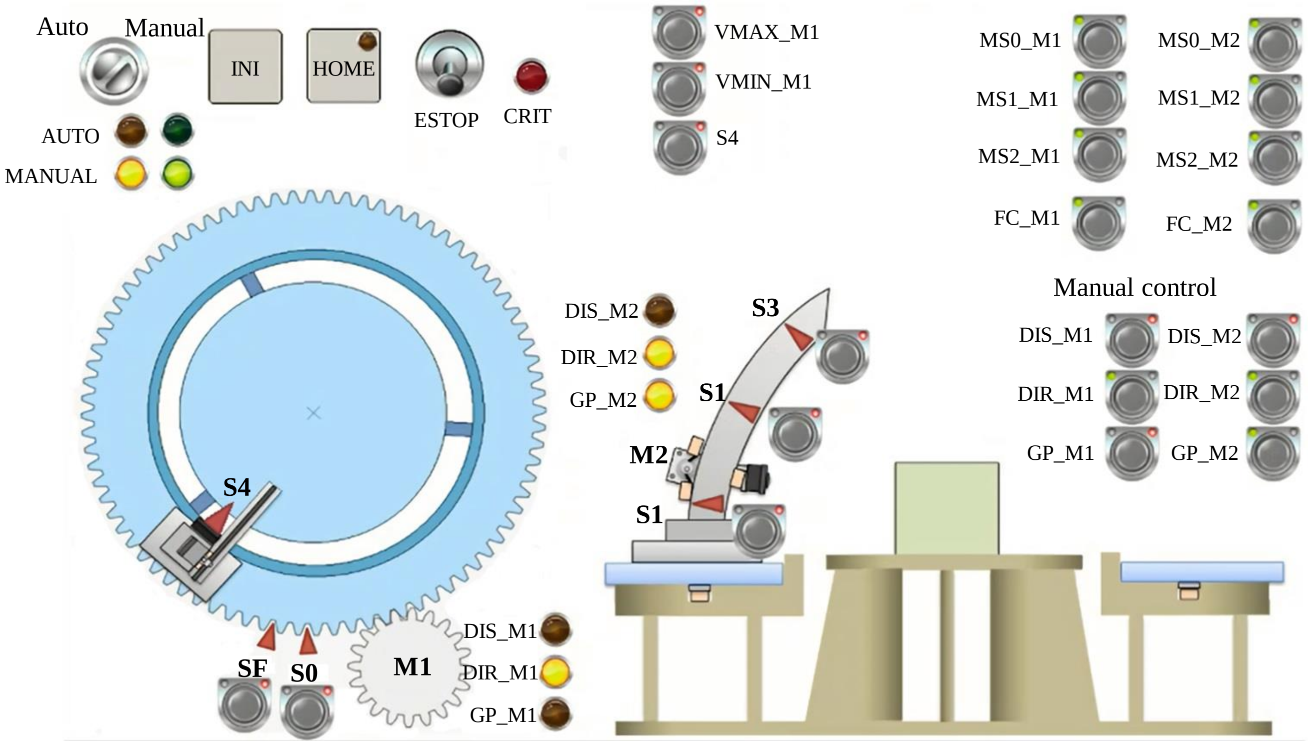


Figure 6 Graphical interface for machine operation. *Source: Own elaboration.*

Results

Visual results of the image acquisition process

A sample of the results that can be obtained with the proposed machine is presented in Figure 7. The shown images are synthetic, created using Blender software (Community, B. O, 2021) to exemplify the acquisition from different points of view, considering three elevation levels. In Figure 7, the images are organized into three elevation levels. Each elevation level has five views. In each view, images are shown for both the camera position and the image captured from that position. The views are obtained by rotating the camera around the object with equal increments of 72° between each view, where view 1 is the starting position at 0° at each level.

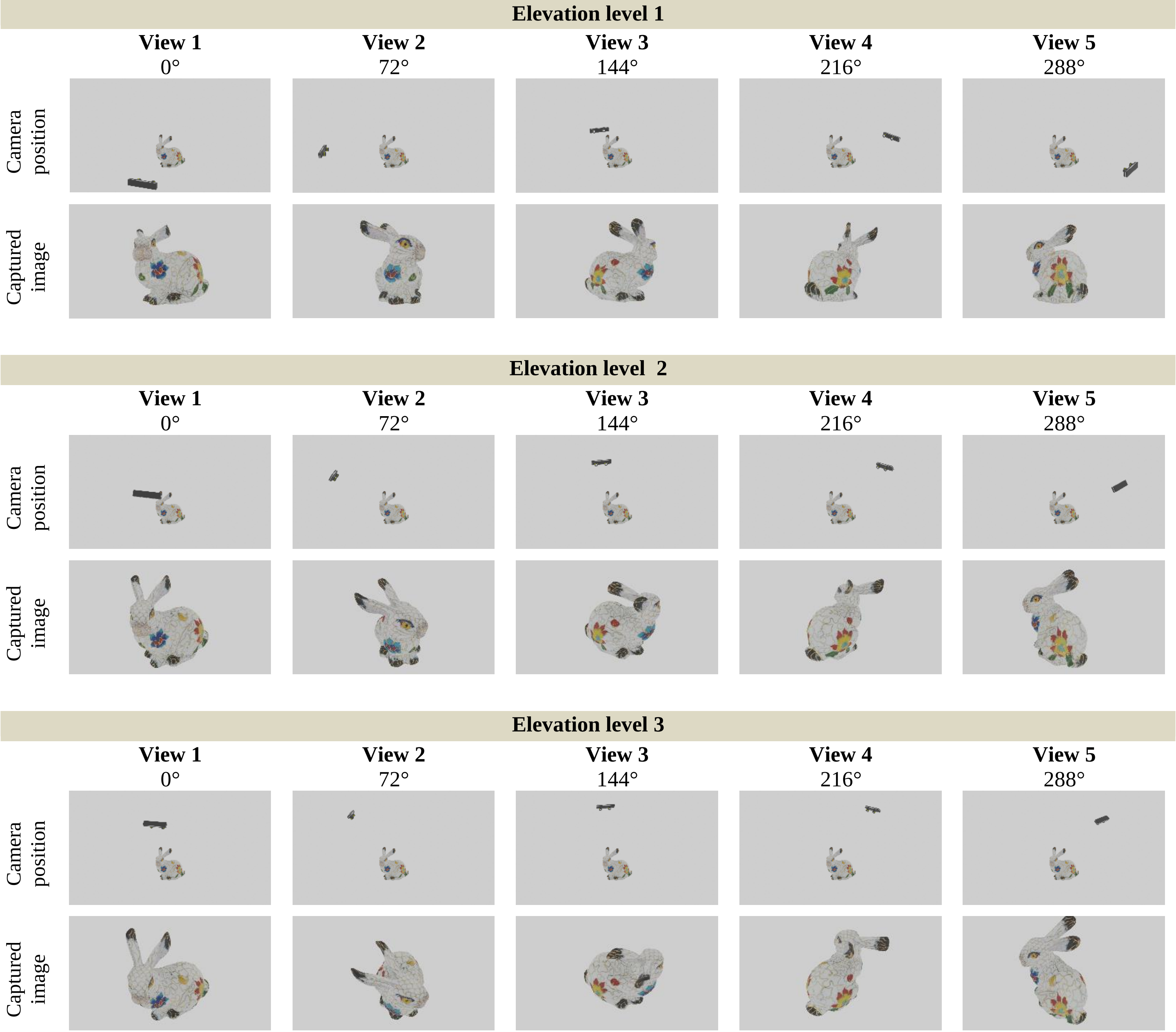


Figure 7 Visual representation of the acquisition process.
Source: Own elaboration based on model of Zou, 2011.

Conclusions

This paper proposes a machine that allows the acquisition of images for a reconstruction process based on multiple views, where the object to be digitized is kept fixed, and the camera rotates around it. All the necessary components for its operation were defined as well as different operation modes and the programming logic of a virtual PLC to control it.

A graphical interface was developed to simulate the operation of the proposed machine. The simulation allowed verifying the operation of the manual and automatic operation modes and the conditions for emergency stop.

An automated image capture sequence was proposed, which allows the camera to capture images at equally spaced intervals at three elevation levels. The visual sample images of the acquisition process demonstrate that, with the proposed capture sequence, it is possible to collect images of the entire visible surface of the object, except for its base, since views are obtained from all around the object and at different heights.

As future work, the physical construction of the machine is proposed, defining the necessary materials and its dimensions. It is also suggested to propose techniques for the reconstruction of objects using the images acquired with this machine, as well as to explore opportunities for improvement by replacing the PLC with a microcontroller or an SBC card.

Appendix

This section presents a description of the 6 stages of the image acquisition process of the proposed machine (illustrated in Figure 5) and the GRAFCET diagrams generated for each stage of the process.

Figure 8 shows the initial setup, in which the drivers are configured to work with micro-steps. The motors are enabled to maintain torque, and the necessary signals are reset to stop them in their last position.

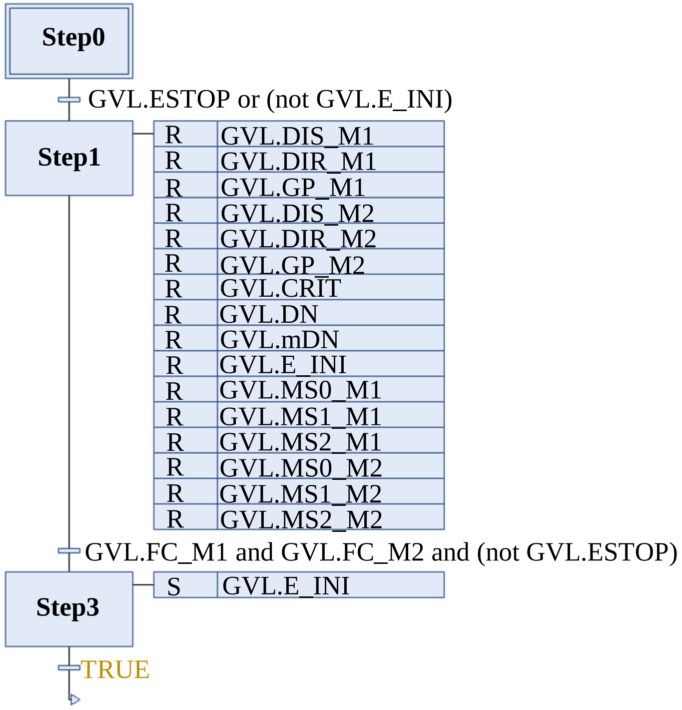


Figure 8 Initial state. *Source: Own elaboration.*

Figure 9 shows a visual alarm. It is activated when the speed limits are exceeded or when a strange object is detected with the S4 sensor in front of the camera.

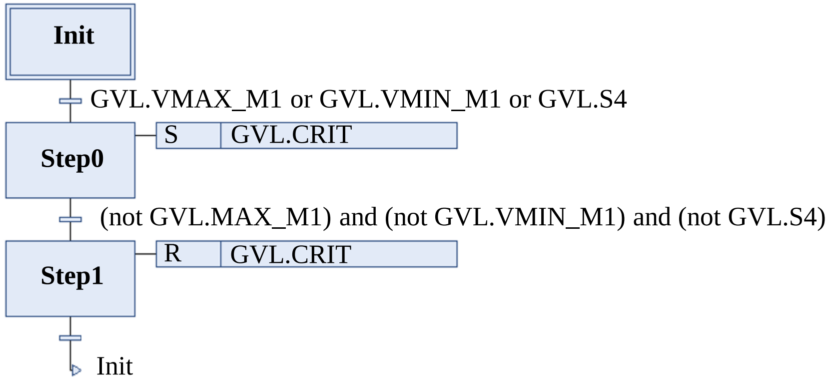


Figure 9 Visual alarm. *Source: Own elaboration.*

Appendix

Figure 10 shows the process of going to the HOME position. First, the motor M2 is sent back to the bottom position of the rail. Then the motor M1 is brought to the HOME position, where sensor SF is deactivated and sensor S0 is activated.

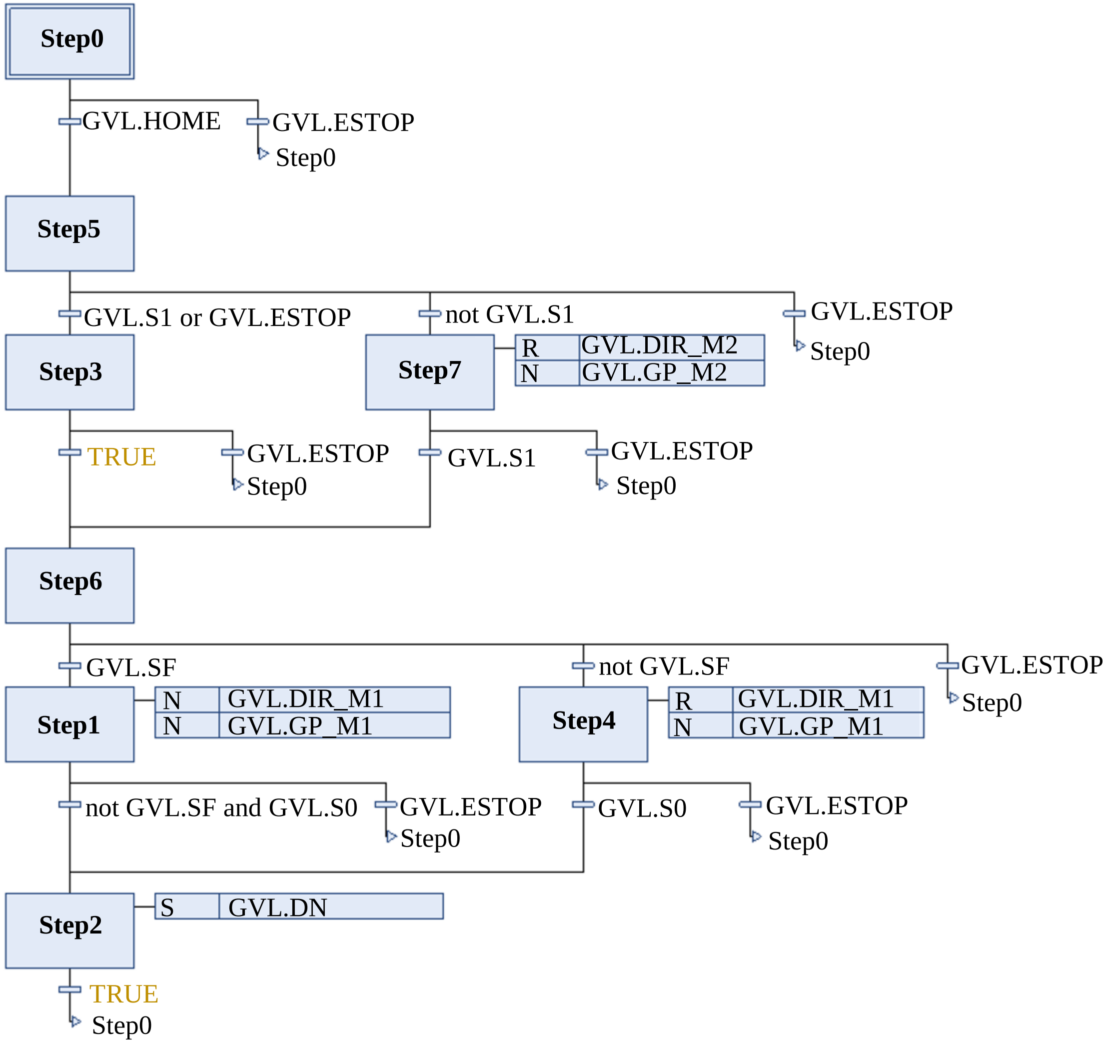


Figure 10 Return to initial position. *Source: Own elaboration.*

Appendix

Figure 11 shows the automatic control of the machine operation. From the HOME position, the table is rotated 360°. At the end of the rotation, the camera is raised until it reaches sensor S2. Then, the table is rotated 360°, and the process is repeated until the camera has risen to S3. At the end of the sequence, the machine is sent back to the HOME position and returns to the initial state waiting response of the INI start button.

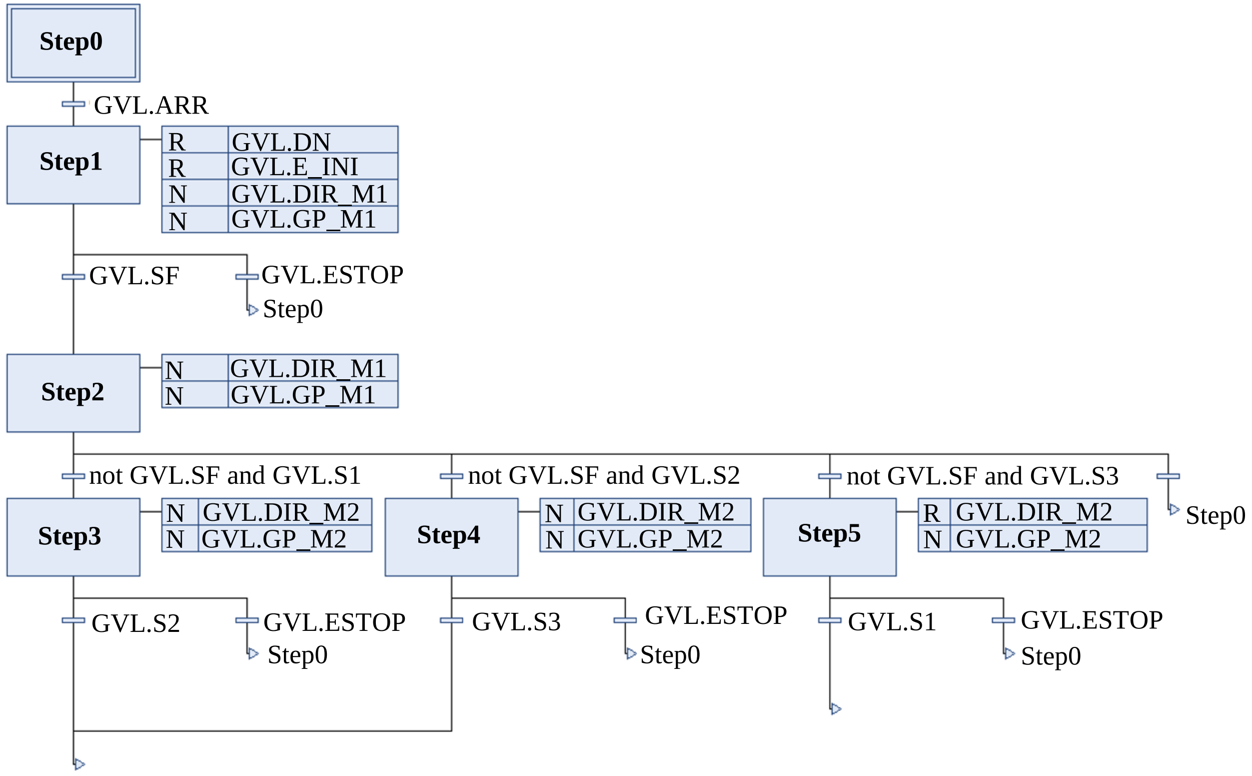
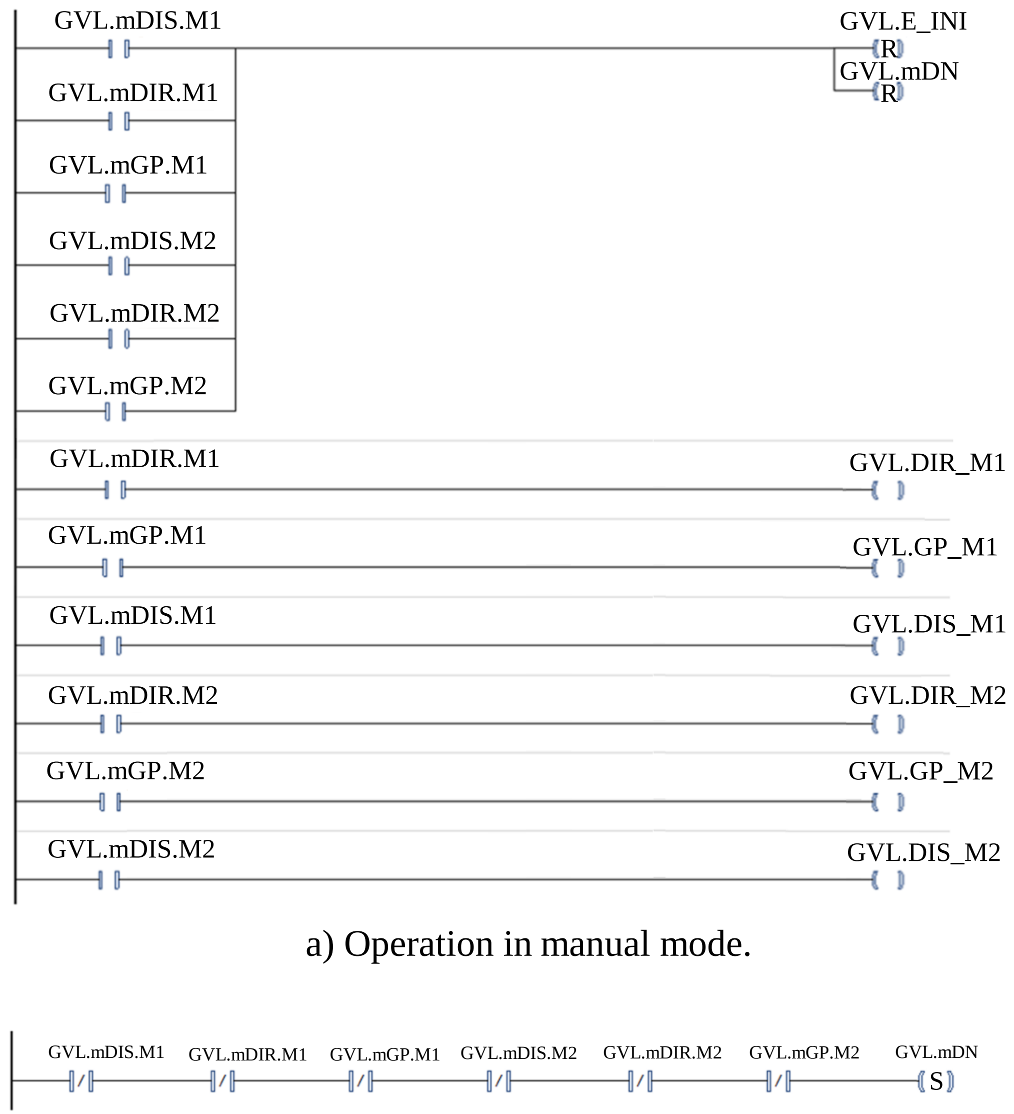


Figure 11 Operation in automatic mode. *Source: Own elaboration.*

Appendix

Figure 12 shows the manual mode of the machine. Figure 12a shows the operation logic in manual mode. Figure 12b shows the initial conditions that allow the execution of the manual mode.



b) Conditions for entering manual mode.

Figure 12 Manual mode. *Source: Own elaboration.*

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