FINAL SCRIPT: APPROVED FOR FILMING

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Title: Simulation of a Scaled Assembly Process with Collaboration of a Robotic Arm and Monitoring Through a Vision System for Quality Control

Authors and Affiliations:

Lisaura Walkiria Rodriguez Alvarado[1], Brenda Lorena Flores Hidalgo[1,2], Jesus Jaime Moreno Escobar[3], Jesus Loyo Quijada[1]

[1]Departamento de Sistemas, División de Ciencias Básicas e Ingeniería, Universidad Autónoma Metropolitana
[2]Escuela Superior de Ingeniería Mecánica y Eléctrica, Unidad Zacatenco, Instituto Politécnico Nacional
[3]Centro de Investigación en Computación, Instituto Politécnico Nacional

Corresponding Authors:
Jesus Jaime Moreno Escobar (jmorenoe@ipn.mx and jmorenoe@cic.ipn.mx)

Email Addresses for All Authors:

Lisaura Walkiria Rodriguez Alvarado (lwra@azc.uam.mx)
Brenda Lorena Flores Hidalgo (blfh@azc.uam.mx and blflores@ipn.mx)
Jesus Loyo Quijada (lqj@azc.uam.mx)
Jesus Jaime Moreno Escobar (jmorenoe@ipn.mx and jmorenoe@cic.ipn.mx)

Author Questionnaire

1. Microscopy: Does your protocol require the use of a dissecting or stereomicroscope for performing a complex dissection, microinjection technique, or something similar? **No**

2. Software: Does the part of your protocol being filmed include step-by-step descriptions of software usage? **Yes, done**

3. Filming location: Will the filming need to take place in multiple locations? **No**

Current Protocol Length
Number of Steps: 11
Number of Shots: 18

Introduction

Videographer: Obtain headshots for all authors available at the filming location.

1.1. **Jesus Jaime Moreno Escobar:** The research develops a scaled model of semi-automatic assembly using a cobot and a vision system, evaluating quality, process representativeness, and the advantages and limitations of this simulation.

1.1.1. INTERVIEW: Named talent says the statement above in an interview-style shot, looking slightly off-camera. *Suggested B roll: 2.2.2*

What are the most recent developments in your field of research?

1.2. **Brenda Lorena Flores Hidalgo:** Recent developments include semi-automatic assembly with cobots and vision systems, enabling real-time anomaly detection, improving quality, traceability, and efficiency in industrial processes.

1.2.1. INTERVIEW: Named talent says the statement above in an interview-style shot, looking slightly off-camera.

What significant findings have you established in your field?

1.3. **Jesus Jaime Moreno Escobar:** A scaled semi-automatic assembly model with cobots and vision demonstrates integration in a modern, educational manufacturing environment, enhancing efficiency, precision, and applicability in real industrial processes.

1.3.1. INTERVIEW: Named talent says the statement above in an interview-style shot, looking slightly off-camera.

What advantage does your protocol offer compared to other techniques?

1.4. **Jesus Jaime Moreno Escobar:** Our protocol combines cobots and vision in a scaled model, allowing practical, educational evaluation of efficiency, precision, and consistency, surpassing the limitations of traditional simulations or manual practice.

1.4.1. INTERVIEW: Named talent says the statement above in an interview-style shot, looking slightly off-camera. *Suggested B roll: 2.3*

What research questions will your laboratory focus on in the future?

1.5. **Brenda Lorena Flores Hidalgo:** Our laboratory will focus on optimizing cobot-human collaboration and developing a vision system with a neural network to address lighting issues, improving defect detection and scalability to industrial processes.

1.5.1. INTERVIEW: Named talent says the statement above in an interview-style shot, looking slightly off-camera.

Videographer: Obtain headshots for all authors available at the filming location.

Testimonial Questions (OPTIONAL):

How do you think publishing with JoVE will enhance the visibility and impact of your research?

1.6. **Jesus Jaime Moreno Escobar:** Publishing in JoVE will allow us to present our protocol visually and educationally, facilitating understanding of cobot and vision system integration, increasing visibility, reproducibility, and impact of our findings in the scientific and industrial community.

1.6.1. INTERVIEW: Named talent says the statement above in an interview-style shot, looking slightly off-camera.

Can you share a specific success story or benefit you've experienced—or expect to experience—after using or publishing with JoVE? (This could include increased collaborations, citations, funding opportunities, streamlined lab procedures, reduced training time, cost savings in the lab, or improved lab productivity.)

1.7. **Brenda Lorena Flores Hidalgo:** We expect that publishing our protocol in JoVE will facilitate the replication of our semi-automatic assembly model with cobots and vision, accelerating student training, streamlining lab procedures, and fostering collaborations with other institutions interested in advanced manufacturing.

1.7.1. INTERVIEW: Named talent says the statement above in an interview-style shot, looking slightly off-camera.

Protocol

2. Assembly of Worm Gear Set Using a Collaborative Robotic Arm

Demonstrator: Brenda Lorena Flores Hidalgo

2.1. To begin, organize all the necessary components for assembly on the replenishment tray **[1],** aligning them according to the designated layout **[2]**.

2.1.1. WIDE: Talent placing components neatly on the replenishment tray, matching the shown layout.

2.1.2. LAB MEDIA: FIGURE 3

2.2. Enter the programming sequence into the interface **[1]**. Then, wait for the collaborative robot to initiate the assembly sequence by picking up the bottom part of the box and transferring it to the assembly point **[2]**.

2.2.1. SCREEN: JoVE68888-2.2.1-1080p 00:10-00:20.

2.2.2. Shot of the robot arm picks up the base of the box and moves it into position on the assembly fixture. **Videographer's NOTE**: Shoots 2.2.2 to 2.6.1 were shot in a single video.

2.3. Allow the robot to pick up the worm and position it into the designated slot within the assembly **[1]**. Then, the robot picks up the worm gear and assembles it on top of the box **[2]**.

2.3.1. Robotic arm retrieving the worm and carefully placing it into the box.

2.3.2. Robotic arm aligning and placing the worm gear on top of the worm.

2.4. Once the robotic subassembly is completed, wait as the robotic arm transfers it to the manual assembly area for further processing by an operator **[1]**.

2.4.1. Robotic arm lifting the subassembled component and setting it down at the manual workstation.

2.5. In the manual assembly area, have the operator pick up the subassembly and continue the build by following the designated assembly order **[1 and 2]**.

2.5.1. Talent picking up the subassembly from the workstation and performing the steps according to the guided sequence.

2.5.2. LAB MEDIA: Figure 7

2.6. Upon completion of the manual assembly, place the fully assembled part vertically on the tray, ensuring that the worm is oriented toward the back **[1]**. Once secured, have the collaborative robot place the product near the sensor on the conveyor for camera inspection **[2]**.

2.6.1. Talent placing the assembled part upright on the tray with the worm facing the rear.

2.6.2. Robotic arm placing the assembled unit on the conveyor belt near the sensor, aligning it for visual inspection.

2.7. For worm shape evaluation, after selecting the inspection tool, register a reference image. Click on the **Ref. Image** *(Reference-Image)* icon in the top right corner, select **Register Image**, and click **Execute** to capture the image **[1]**. ~~Choose the **BMP** *(B-M-P)* format and click **Save** to store the reference image **[2]**~~.

2.7.1. SCREEN: JoVE68888-2.7.1-1080p.

2.7.2. ~~SCREEN: Show the user choosing the BMP format from the dropdown and clicking Save to finalize the reference image registration~~. **NOTE**: Delete

2.8. For worm gear parameter configuration, select the **Pattern Region** option to adjust the detection area. Choose the **Polygon** shape, outline the perimeter of the part, and click **Ok** to confirm **[1]**.

2.8.1. SCREEN: JoVE68888-2.8.1-1080p. 00:20-00:25 and 00:40-00:49

2.9. To detect colors, select the **Pattern Region** option to refine the area around the worm gear. Choose the **Circle** shape, mark the worm gear's perimeter, and click **Ok** to apply the changes **[1]**.

2.9.1. SCREEN: JoVE68888-2.9.1-1080p. 00:10-00:9

2.10. Then, select the **Mask Region** option to exclude unwanted areas from analysis. Choose the **Rectangle** shape, outline the red edge of the part, and click **Ok** to confirm **[1]**.

2.10.1. SCREEN: JoVE68888-2.10.1-1080p 00:01-00:05 and 00:20-00:27.

2.11. Now, enable the software interface from the computer and activate the **Switch to Run Mode** **[1]**. Then, select the **Utility** icon, click on the **Statistics** option, and choose the preferred graph type, such as a trend graph or histogram **[2]**, to support data-based quality analysis by the new process manager **[3]**. **NOTE**: VO adjusted for the extra shot

2.11.1. SCREEN: JoVE68888-2.11.1-1080p. 00:18-00:27

2.11.2. SCREEN: JoVE68888-2.11.2-1080p.

Added shot: 2.11.3. Talent in front of the computer screen making the actions

Results

3. Results

3.1. The shape histogram showed a normal distribution centered slightly above the nominal value, indicating the process was under statistical control **[1],** although most parts were closer to the upper specification limit **[2].**

3.1.1. LAB MEDIA: Figure 12A. *Video editor: Highlight the central cluster of green bars that form a bell curve.*

3.1.2. LAB MEDIA: Figure 12A. *Video editor: Highlight the taller green bars positioned closer to the "Upper" specification line on the right side of the graph.*

3.2. The process capability indices revealed a strong alignment with the lower specification limit **[1],** but a much lower capacity near the upper limit, leading to a low overall process capability **[2].**

3.2.1. LAB MEDIA: Figure 12B. *Video editor: Highlight the value "1.483" under the Cpl column in the table*.

3.2.2. LAB MEDIA: Figure 12B. *Video editor: Highlight the values "0.599" under both Cpu and Cpk in the table.*

3.3. The control chart showed that initial readings were unstable due to measurement system adjustments **[1],** followed by a mid-stage outlier likely caused by a defective part **[2],** and ended with a stable trend within upper control limits **[3].**

3.3.1. LAB MEDIA: Figure 12C. *Video editor: Highlight the first segment of the line chart where the graph shows fluctuations*

3.3.2. LAB MEDIA: Figure 12C. *Video editor: Highlight the sharp dip or spike in the middle portion of the line.*

3.3.3. LAB MEDIA: Figure 12C. *Video editor: Highlight the final portion of the line chart where the values flatten out near the upper control line.*

3.4. The color histogram revealed that measurements clustered near the tolerance limits, suggesting only marginal compliance with specifications **[1],** and the presence of two skewed distributions indicated process instability **[2].**

3.4.1. LAB MEDIA: Figure 12D.

3.4.2. LAB MEDIA: Figure 12D. *Video editor: Emphasize the two distinct clusters of green bars skewed toward both extremes of the distribution.*

3.5. Capability analysis for color showed the process was centered, as Cpu *(C-P-U)* and Cpl *(C-P-L)* values were similar **[1],** but high variability reduced overall capability to a Cpk *(C-P-K)* of 0.539 **[2].**

3.5.1. LAB MEDIA: Figure 12E. *Video editor: Highlight the similar values under the Cpl and Cpu columns in the table.*

3.5.2. LAB MEDIA: Figure 12E. *Video editor: Highlight the value "0.539" in the Cpk column of the table.*

3.6. The control chart for color showed extreme instability, with wide variation and frequent control failures throughout the production cycle **[1].**

3.6.1. LAB MEDIA: Figure 12F.

- replenishment

Pronunciation link: https://www.merriam-webster.com/dictionary/replenishment
IPA: /rɪˈplɛnɪʃmənt/
Phonetic Spelling: ri-PLEN-ish-ment

- collaborative (in "collaborative robot")

Pronunciation link: https://www.merriam-webster.com/dictionary/collaborative
IPA: /kəˈlæbəˌreɪtɪv/
Phonetic Spelling: kuh-LAB-uh-ray-tiv

- worm gear

(This is a compound term; both "worm" and "gear" are common. If you like, I can treat "worm gear" as one term.)
Pronunciation link: https://www.merriam-webster.com/dictionary/worm
(for "worm")
IPA for "worm": /wɜrm/
Phonetic Spelling: wurm
Pronunciation link: https://www.merriam-webster.com/dictionary/gear
(for "gear")
IPA for "gear": /ɡɪər/
Phonetic Spelling: geer
So "worm gear" = wurm-geer

- interface

Pronunciation link: https://www.merriam-webster.com/dictionary/interface
IPA: /ˈɪntərˌfeɪs/
Phonetic Spelling: IN-ter-fayss

- histogram

Pronunciation link: https://www.merriam-webster.com/dictionary/histogram
IPA: /ˈhɪstəˌɡræm/
Phonetic Spelling: HIS-tuh-gram

- specification

Pronunciation link: https://www.merriam-webster.com/dictionary/specification
IPA: /ˌspɛsɪfɪˈkeɪʃən/
Phonetic Spelling: spes-ih-fi-KAY-shun

- capability indices (treat "capability" and "indices" separately)

  - capability
    Pronunciation link: https://www.merriam-webster.com/dictionary/capability
    IPA: /ˌkeɪpəˈbɪlɪti/
    Phonetic Spelling: kay-puh-BIL-ih-tee
  - indices
    Pronunciation link: https://www.merriam-webster.com/dictionary/index
    (plural of index)
    IPA: /ˈɪndɪˌsiːz/
    Phonetic Spelling: IN-dih-seez