Autonomous Robotic Polishing and Determination of Tacit Knowledge in Manufacturing

A Major Qualifying Project (MQP) Report Submitted to the Faculty of
WORCESTER POLYTECHNIC INSTITUTE in partial fulfillment of the
requirements for the Degree of Bachelor of Science in

ROBOTICS ENGINEERING
BIOLOGY AND BIOTECHNOLOGY

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Abstract

The objectives of this project are to develop an autonomous polishing system using a 6 degree of freedom (DOF) robot arm, to quantify the neurocognitive basis of tacit knowledge in manufacturing, and to lay the groundwork for a human-like polishing system by combining the first two objectives. To do so we worked in parallel on a robotic polishing system and a functional near infrared spectroscopy (fNIRs) experiment on car body technicians. We were able to control the robot using a velocity controller and began creation of an impedance controller. We succeeded in determining that skill level at polishing results in differences in brain activity during the task, and we identified high level patterns in neurocognitive activity during a polishing task.

Acknowledgements

Special thanks to my advisors Professors Yihao Zheng and Benjamin Nephew for guiding and advising this project. I would also like to thank Jiaqi Yang, Rohit Dey, Ge Zhu, and Patrick Chernjavsky for their dedicated assistance on the project.

Finally, I would like to acknowledge the contributions of the Robotics Engineering, Mechanical Engineering, and Neuroscience departments. Thank you to everyone who assisted with the production of this project.

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1 Introduction

1.1 The Process of Auto Body Polishing

1.1.1 Importance of Automotive Polishing

Polishing is an important step in both the manufacturing and detailing of automotive vehicles. It is used to remove rough patches after filler work during the manufacturing process and to even out the surface of the vehicle before and after painting. Detailing is important because it helps maintain an even surface and protects the car's paint from wear. Automotive detailing is a multi-billion dollar industry so there is a large need for detailing (Govdysh, 2023).

The process we are attempting to automate is the polishing of car bodies, either during manufacturing or as part of the detailing process. Polishing typically involves sanding the body of the car with a dual-action sander. Throughout the whole process the grit of the sandpaper gets finer, resulting in a smooth finish (Sandpaper America).

Figure 1, a sander being used to polish the side of a car (freepik)

1.2 Advantages of Robotic Automation

At present, the majority of polishing jobs are done manually, which is time consuming and requires skilled labor and a high cost (Li et al, 2018). The polishing environment can also be hazardous due to the presence of particulates and noise, which is risky to the operator (Li et al, 2018). Collaborative robots are designed to work alongside humans, completing repetitive tasks and improving productivity in the workplace (Sherwani et al, 2022). Between decreasing the need for skilled workers and improving productivity there is a great benefit to automated polishing over manual work. Robots have a very high capacity for repetition and precision that allows them to potentially produce more consistent work than a manual technician. It also reduces the need for skilled workers and variance in results based upon skill level (Oba et al, 2015).

1.2 Current Technology

There are currently multiple solutions for robotic polishing, however most come with constraints like small workpieces, or use polishing tools that are not standard in industry. Multiple advancements have been made for polishing pieces with unusual surface geometry (Lin et al, 2009, Iuvshin et al, 2019, Zhou et al, 2019) but lack the flexibility and robustness necessary to polish a large and contoured piece like a car hood or require a fixed workpiece. Our aim is to create a polishing system that is robust enough to work on any surface regardless of size and also to be portable and easy to use alongside a technician, a need which has not yet been met.

1.3 Tacit Knowledge in Manufacturing

The other primary component of this research paper is determining a way to quantify tacit knowledge in manufacturing. Tacit knowledge refers to the skill, strategy, and technique used by technicians to perform their tasks (Nordin et al, 2019). Tacit knowledge is typically acquired through extensive training and is difficult to precisely quantify due to its nature as a skill based knowledge system. Understanding precisely how to quantify tacit knowledge is important as it will help improve manufacturing education and understanding. It will also allow us to better understand the neurocognitive processes involved in manufacturing expertise. Many prior studies have been performed to quantify the neurocognitive basis of technical knowledge but none have specifically targeted the automotive polishing process (Zhang et al, 2021, Marsh et al, 2010, Adamovich et al, 2009). In addition to improving the knowledge base of manufacturing, understanding neural activation related to the car polishing process can potentially help with the development of more human-like polishing behavior in a robotic system. m

1.4 Research Goals

The goals of this research are threefold. The first goal is to develop a robotic system capable of polishing a car's surface autonomously and in real time to a level of quality equal to or greater than that of a skilled technician. The second goal is to improve academic understanding of tacit knowledge in manufacturing through neuro-imaging techniques. Finally, the first two goals will be integrated to create an autonomous polishing system that mimics the behavior of human technicians.

1.5 Requirements Analysis

1.5.1 Safety and Human Collaboration

Polishing is a multi-step process, which may require moving the robot or changing the sandpaper on the tool, so the robot needs to be safe for use in the presence of human operators.

1.5.2 Adaptability to Generic Surfaces and Real Time Control

Since the robot will be working on a large variety of surfaces it needs to be able to navigate and polish any form. Thus, it needs some kind of force feedback to make sure it is anchored to the workspace. Since the intended application of the robotic system is to polish the surfaces of cars it also needs to have a very high workspace and be able to work on pieces that are not specially anchored. The robot also needs to be able to quickly adjust based upon the evolving needs of the workpiece so it must be a real time system.

1.5.3 Human-like Behavior

Ideally the robotic system would deliver results that are on par or greater than those of a manual technician. Polishing is not a singular procedure, and it depends heavily upon the surface of the car being polished, so mimicking human decision making in the robot is likely to improve its capabilities.

1.5.4 Portability

The system should be easy to transport so that it can be taken to any vehicle in an auto body shop and operated on with little effort. Thus, the system needs to be moveable and compact.

2 Background

2.1 Current Car Polishing Methods and Technology

Automobiles are painted with multiple layers to provide long lasting color and protection from the elements. Notably automotive paint consists of a primer layer, a color base, and a clear coating to protect the paint from UV radiation and other environmental hazards (nist).

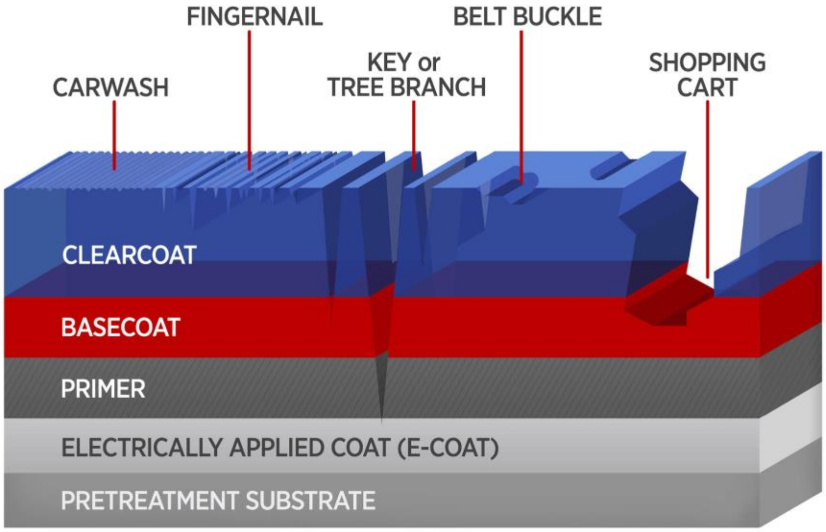


Figure 2, an example of the paint layers on a car and various scratch types (nist).

Car body detailing includes multiple abrasive manufacturing steps, wet sanding, compounding, and polishing. Wet sanding and compounding are used to remedy much rougher surfaces but leave behind an uneven surface (Auto Care HQ). Polishing is the last step in the abrasive manufacturing process and is meant to remove shallow scratches and even out surfaces that have just been compounded (Auto Care HQ). It is important to be precise with any form of abrasion on a car surface because too much grinding can remove the protective clear coat on the surface, leaving the base coat of paint exposed to UV radiation.

2.2 Evaluating Success in Grinding

In abrasive manufacturing, one of the primary methods for evaluating the success of a grinding or polishing procedure is by quantifying its surface roughness (Huang et al, 2018). A high surface roughness can in many cases reduce the life and durability of the material (Rautio, 2022).

3 Design

3.1 Robot Hardware

3.1.1 Dobot CR5

To develop the autonomous polishing system, the Dobot CR5 was chosen. There are multiple advantages to using a robotic arm system to polish. The first is that it is highly portable, so it can be used on a vehicle anywhere. The second advantage is that the robot has a large workspace which allows it to work in a wide range of areas without being moved. Additionally, the tool can be changed, allowing the system greater flexibility for a wide range of applications. The Dobot CR5 is a commercial six degree of freedom collaborative robot developed by Dobot. It was chosen due to its accuracy and use in industrial applications. The Dobot is also designed as a collaborative robot so it will respond automatically to potential collisions with the operator. It has a maximum load of 5kg which is more than sufficient to control a sander for polishing (Dobot CR5 Hardware User Guide, 2020).

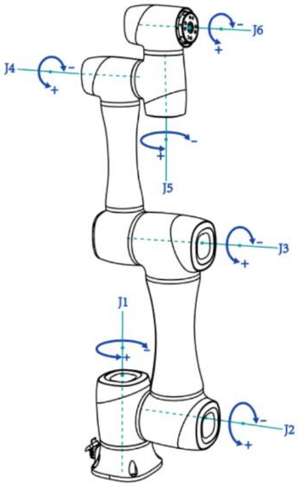


Figure 3, Joint Coordinates of the Dobot CR5 (Dobot CR5 Hardware User Guide, 2020)

3.1.2 Serial Axia 80

The Force-torque sensor used in this project was the Serial Axia 80 developed by ATI industrial automation. It features serial communication and force-torque measurements on the x,y, and z axes for a total of 6 measurements. The sensor has a toggleable ‘robot mode’ which optimizes the sensor for live collection of force-torque data. Reading this data in real time allows us to adapt to changes in force and torque in each of the three spatial directions. We decided to use a force-torque sensor for this application because we need feedback into the system to maintain regular surface pressure.

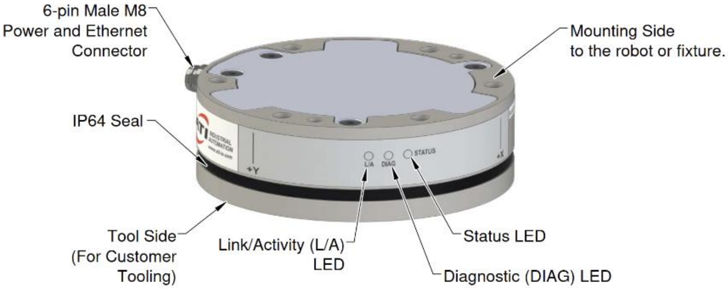
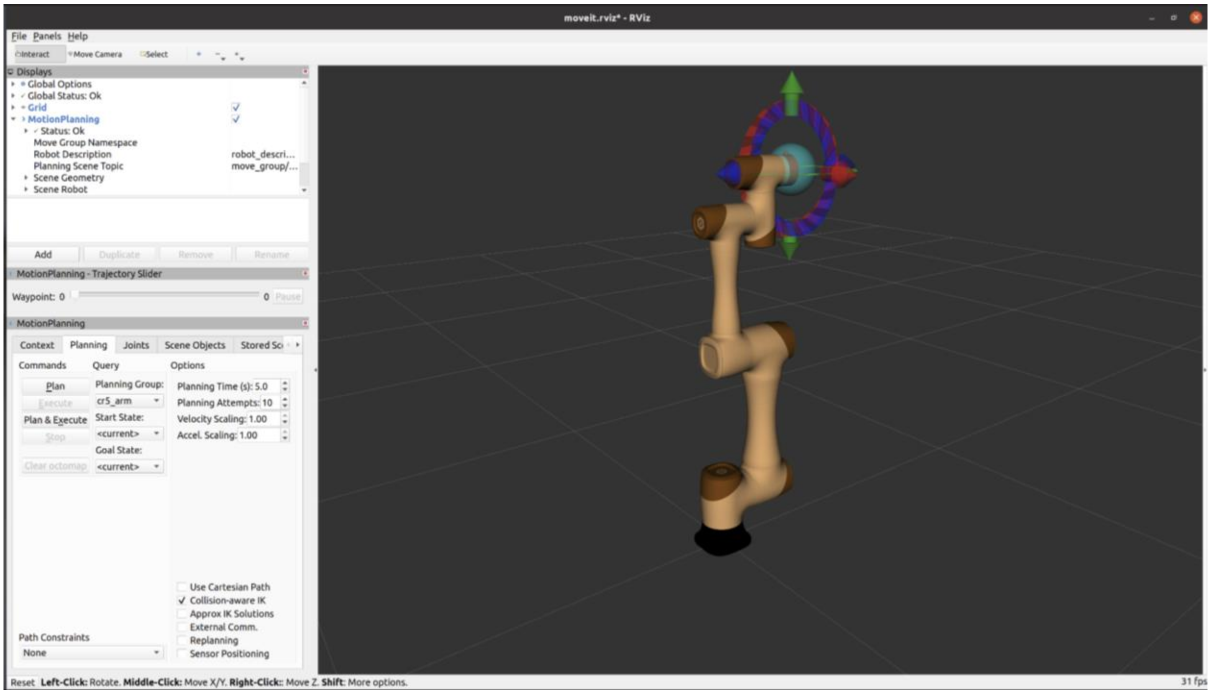


Figure 4, Seria Axia Force Torque Sensor (Serial Axia User Manual)

3.2 Robot Software

3.2.1 ROS Integration

Robot Operating System (ROS) is an open-source set of libraries and tools for programming robots that is commonly used for robotic applications. It consists of a variety of kinematic toolboxes, simulation software, and a flexible programming system based around running scripts in parallel with subsystems known as nodes (roswiki, 2021). Due to its advantages and ease of integration ROS Noetic was chosen for the project. The Dobot CR5 also already has an open-source kinematic toolbox built for ROS Melodic and Noetic which allows for basic control and simulation of the robot (Dobot-Arm, 2022). Since the robot needs to be controlled and receive measurements in real time, C++ was chosen as the control language for its speed.



Global Status: Ok

Status: Ok

Move Group Namespace

Robot Description: robot_descri...

Planning Scene Topic: move_group/...

Waypoint: 0 0

Planning Group: cr5_arm

Start State: <current>

Goal State: <current>

Planning Time (s): 5.0

Planning Attempts: 10

Velocity Scaling: 1.00

Accel. Scaling: 1.00

☐ Use Cartesian Path
☑ Collision-aware IK
☐ Approx IK Solutions
☐ External Comm.
☐ Replanning
☐ Sensor Positioning

Path Constraints: None

Left-Click: Rotate. **Middle-Click:** Move X/Y. **Right-Click:**: Move Z. **Shift**: More options.

Figure 5, Simulated model of CR5 robot in RViz.

3.2.3 Connecting to the Robot

To connect to the physical robot a launch file was run with the robot's IP address as its argument while connected by network to the robot. In future iterations it would be helpful to have all the code run locally on the robot rather than connecting via network.

3.2.4 Moveit Kinematic Solution

The first attempt at controlling the robot was to use the existing packages and the ROS Moveit framework to develop a velocity controller for the robot. While the robot was able to interpolate between points while controlling its velocity in both simulation and the real system, this was not sufficient for the polishing application as it had no way to maintain contact and directly control force on the polishing surface. As such, a variety of force-feedback controllers were considered.

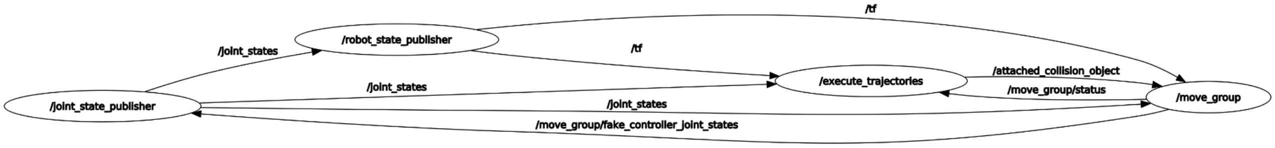


Figure 6, graph of nodes used in the robot simulation for velocity control. Generated using the rqt_graph ROS command.

3.2.5 Reading Force-Torque Sensor

To incorporate the force-torque sensor readings into the controller, a python script was written to communicate via serial port with the sensor measurements. The sensor was set to ‘robot mode’ which provides live force torque feedback sampled at 200 hertz in hexadecimal format. The data was then converted into force torque measurements and published on a ROS topic to be used by the motion controller.

3.2.6 Force-Torque Controller

One of the first solutions for force feedback control was a force-position hybrid controller. The controller operates by using a kinematic control solution such as velocity control to interpolate to the target surface, then switches to a PID controller with force feedback so that it can maintain contact with the surface and control its force to meet a target (Olah & Tevesz, 2006).

3.2.7 Impedance Controller

We also considered a dynamic impedance controller for the robotic system Due to its ability to compensate for gravity and robust force feedback response this is the ideal control algorithm for the application (Ochoa et al, 2022, Xue et al, 2022). We wrote a python script that calculates the Lagrange dynamic model necessary for the impedance controller given the robot’s dynamic parameters. Unfortunately, we have had trouble acquiring the dynamic model for the cobot so this is still in progress. The program to calculate the dynamic model was relatively slow but that is not an issue in our application because it only needs to be run once before operation to generate all of the necessary matrices for the dynamic control.

3.3 fNIRS Experimental Methodology

3.3.1 Description of fNIRs

The technology being used to measure brain activity is called Functional Near Infrared Spectroscopy (fNIRs). fNIRS operates by measuring the brain blood oxygenation levels, which can be used to estimate brain activity (Pinti et al, 2020). fNIRs was chosen for the study because it is non-invasive and resilient to noise from motion, making it ideal for a wearable system. fNIRS still suffers from noise due to physiological fluctuations, so to mitigate this issue, we are using a special device called a NINScan (described in Strangman et al, 2018), which uses ECG along with fNIRs to filter out all fluctuations. fNIRs has been used in multiple studies to investigate tacit knowledge (O'Neill et al, Zatorre et al) so it is demonstrated to be effective in measuring activity during mechanical tasks. NIRx was also considered as a potential strategy but during some preliminary tests, it was eliminated due to its bulkiness and susceptibility to errors from electrodes getting unplugged during motion.

3.3.1 Equipment

NIN Scan

The device being used to read the fNIRS data is a prototype developed by WPI’s Medical and Manufacturing Innovation (MEDMAIN) Laboratory. The prototype is based on methods from Strangman et al, 2018 called a NINScan. The device consists of a wearable velcro headset with infrared lasers positioned according to figure 1. The NINScan system consists of fNIRS to collect data and an ECG collection device, which is used in a post-processing algorithm to remove noise resulting from the subject’s physiological fluctuations.

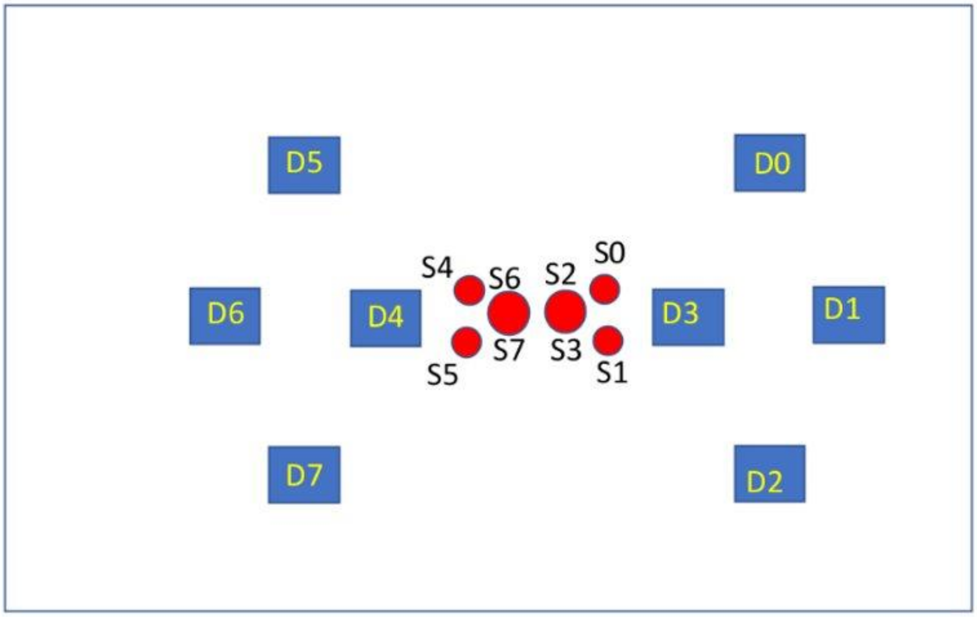


Figure 7, Relative Laser Positions on the fNIRS headset.

Recording Equipment

The grinding process will be recorded so that the NINscan data can be compared to the work completed by the subject. The process will be recorded from 2 different angles, a close up angle taken from a digital camera and an isometric angle recorded from a smartphone resting on a tripod.

Sander

The sander used in the experiment is a 3M Elite Non-Vacuum Random Orbital Sander (28497)

3.3.2 Experimental Design

Experimental Setup

To create a simulated car body for the polishing experiment the following procedure will be performed:

1. Sand the panel with 600 grit sandpaper.
2. Apply 2 heavy coats of sandable primer, with 10 minutes of wait time between coats.
3. Lightly sand the primer with 600 grit sandpaper
4. Apply 4 medium coats of base color, with 15 minutes in between each coat.
5. Very lightly sand the base coat with 1000 grit sandpaper
6. Apply three layers of clear coat (two light coats, one heavy coat)
7. Let the panel dry overnight.
8. Trace an 8-inch circle using a paint marker to define each test area and mark a cross in the center.
9. Use a key to scratch out the cross area on the panel.

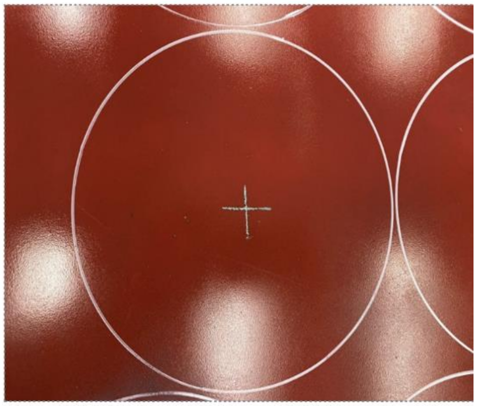


Figure 8, Example of a test area for polishing

Figure 9, Pre-experiment Setup

3.3.3 Recruiting Candidates

Participants for the experiment were identified by Patrick Chernjavsky through referral from a connection at a body shop. The condition for inclusion was a minimum of 2 years of non-apprenticeship work as a car body technician. Two technicians were selected for the experiment with differing levels of experience and invited to participate in the study. Once they accepted, the candidates were presented with an informed consent form and the experiment was verbally explained to them. In addition to the two body shop technicians, two of the student investigators involved in this project also performed the experiment to form a control group of individuals who have little to no experience with car polishing.

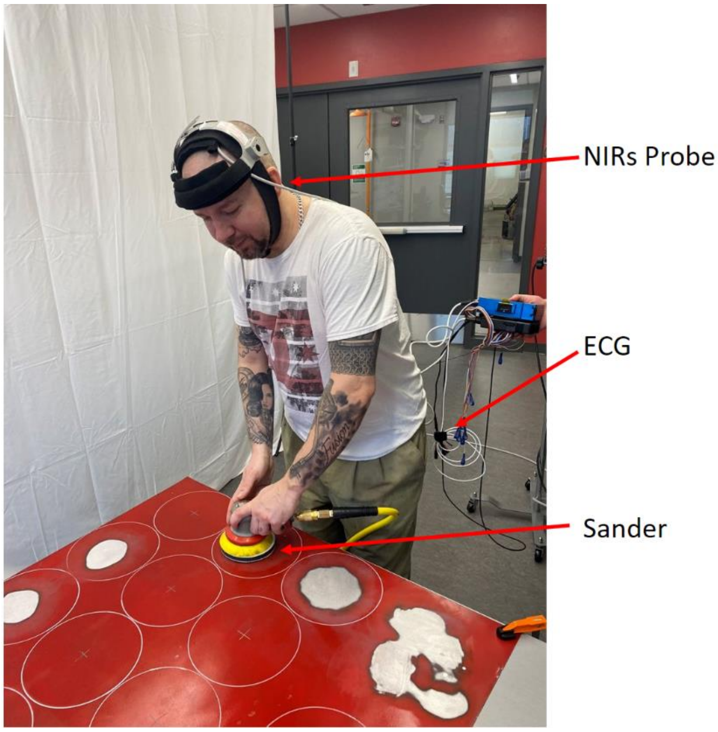


Figure 8, a skilled technician polishing a test surface while fitted with the NINScan device.

3.3.4 Experimental Procedure

1. The subject is fitted with a wearable NINScan device, which rests on the forehead.
2. The subject is handed a DA (dual action) sander and asked to grind a scratch off the aluminum test surface.
3. At the start of the test start recording NINScan data and signal the subject to begin polishing
4. Once the subject is satisfied with their polishing, wait for them to stop, and end the NINScan recording.
5. A thirty-second timed break will be taken between each test, after which the experiment will be repeated. The test will be repeated for a total of 4 grinding episodes.

Each grinding episode will take approximately 1 to 2 minutes, with a 30 second break between each test. The total estimated in-lab time will be approximately 15 minutes.

Safety Procedures

The experiment will be conducted in a well-lit room, and the subject will be offered safety glasses to protect their eyes from potential injury. All camera equipment and other potential obstacles were cleared from the grinding surface to prevent collisions.

3.3.5 Processing fNIRS data

Once the data is collected the multiple channels will be combined into one stream of filtered data using NIRS lab and MATLAB scripts from Massachusetts General Hospital (MGH). Each of the channels in the raw data corresponds to a probe on the fNIRs headset.

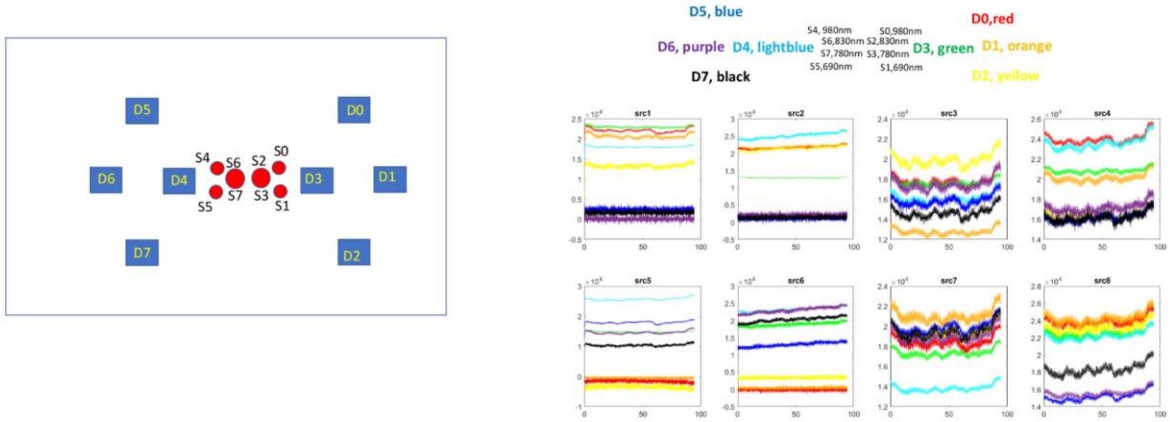


Figure 9, example unfiltered multi-channel fNIRs data. The labels on the probes in the left image correspond to different channels on the right image.

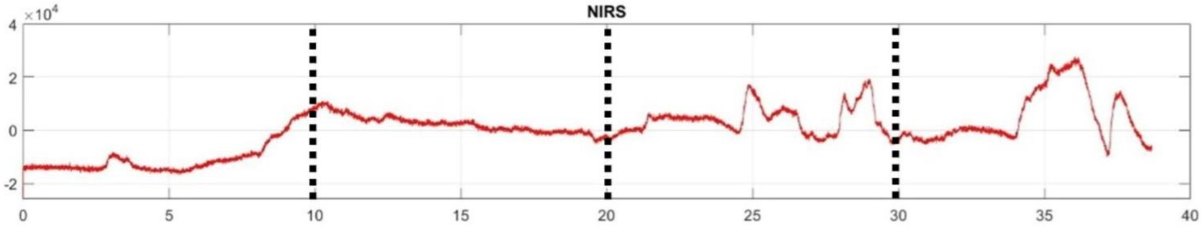


Figure 10, filtered data example.

The fNIRs data was then synchronized with the video using a MATLAB script and analyzed using the video editing software Kinovea to correlate changes in tool angle, pressure, and other movements with the fNIRs data.

4 Results

4.1 fNIRS Data Analysis

4.1.1 Preliminary Experimental Results - Advanced User

The fNIRS data was first examined on a macroscopic level, searching for general patterns in the data. In the first test, with an advanced technician clear pattern of activity were identified between each test. The process began with a major increase in activity upon starting the task. This was followed by a relatively consistent activation pattern that corresponded to the development of a consistent movement pattern in polishing the surface, with regular back and forth movements of the sander. Finally, there was a drop in fNIRs signal towards the end of the task when the technician began slowing down the process and making finer finishing touches.

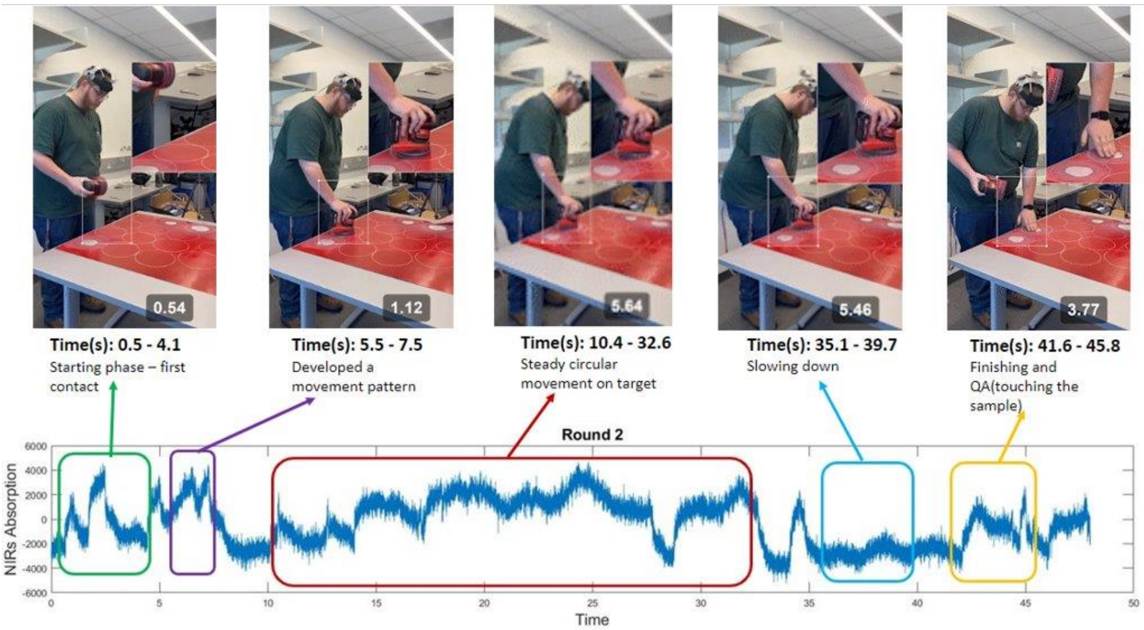


Figure 11, Annotated fNIRs data from a preliminary polishing test.

For the advanced subject, these patterns persisted across every test, indicating that there was a consistent process for polishing the sheet. The colored regions in the figures indicate the different phases we identified in the experiment. One interesting observation between tests is the valley towards the end of the consistent polishing phase. This anomaly was consistent across all trials with the advanced level subject but was not obviously present in the advanced technician. Further investigation is necessary to see whether this is an outlier or correlated to a particular skill level.

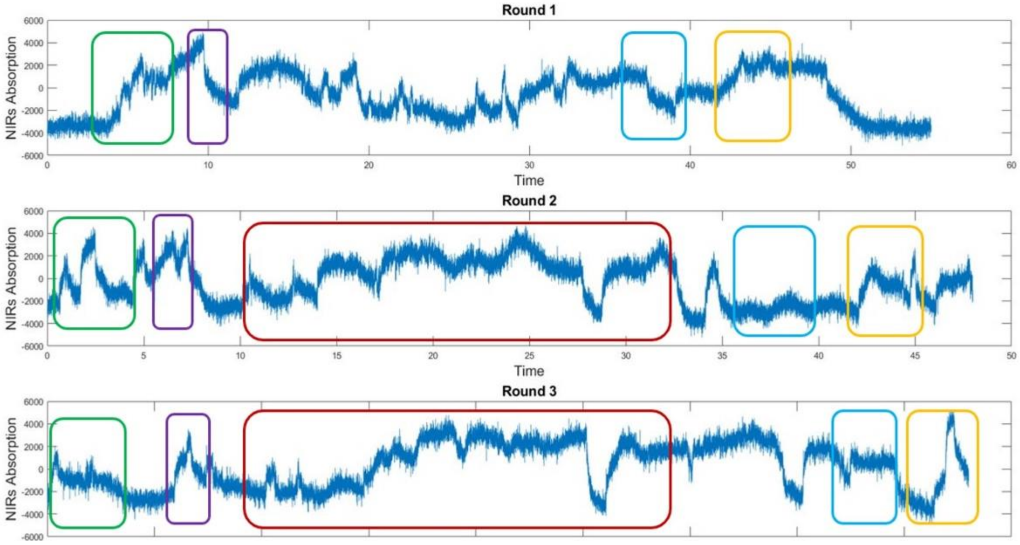


Figure 12, fNIRs data for tests 1-3 of the advanced subject.

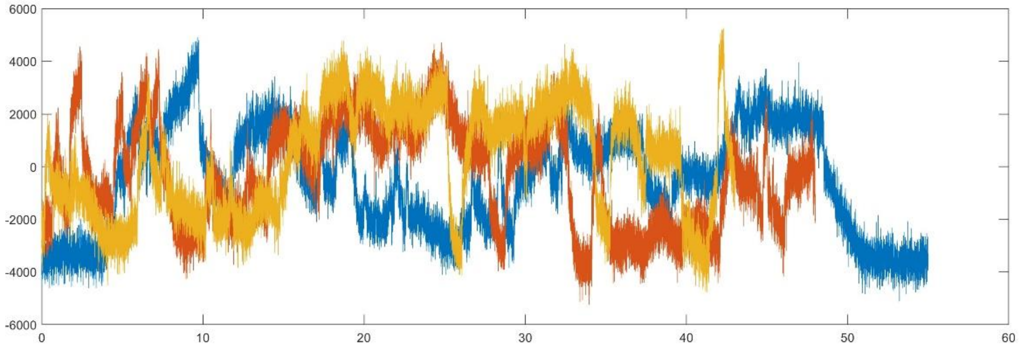


Figure 13, Intermediate fNIRs experiments overlaid.

Figure 15 shows all three trials overlaid on top of each other. The total peaks and valleys between each trial are relatively similar at happen at the same parts of the polishing process. The slight shifts in activity times are due to changes in the technician's timing between trials. These consistent results between trials indicate that behavior in polishing is potentially predictable using fNIRs data. This is perhaps unsurprising since the same relatively simple polishing task was performed in all trials. Trials on a surface with complex curved geometry may not show the same results and confirming whether fNIRs is consistent on more complex operations requires more experimentation.

4.1.2 Expert Technician Test

Based upon the results of this preliminary test, a second test was performed on an expert level technician with more years of experience. In addition to seeing how variance in skill alters fNIRs signal, we also wanted to determine whether the patterns we observed in the first experiment were generalizable to multiple different technicians.

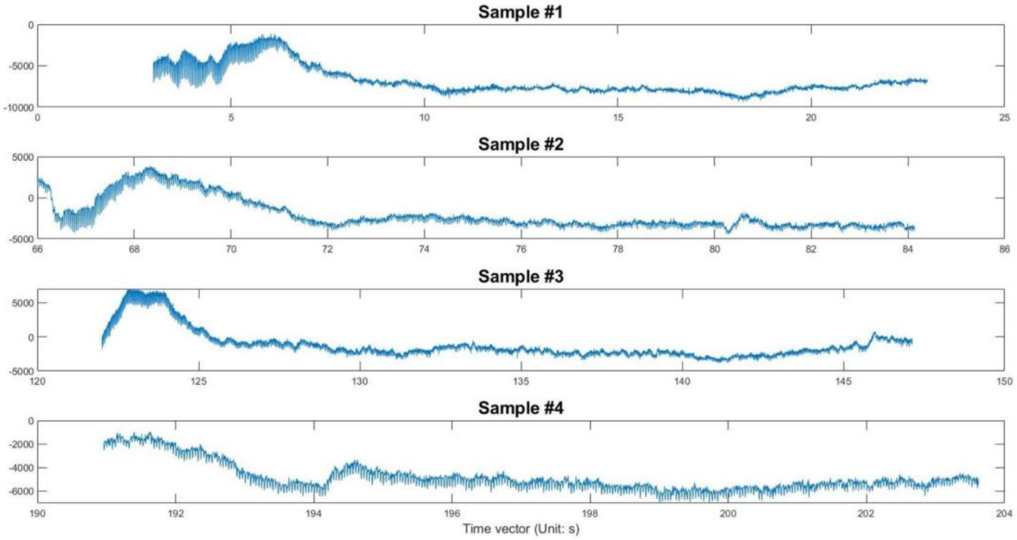
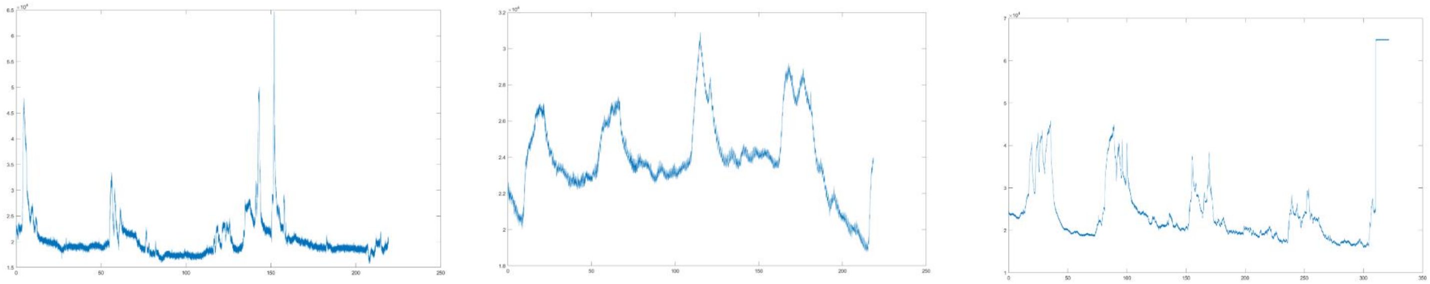


Figure 14, Expert level technician fNIRs samples.

In the experiment with the expert level technician there was a somewhat similar set of patterns. There was a peak in activity at the start, presumably as the techician was beginning the movement and considering how to approach the problem. There was interestingly a slight increase in activity towards the end of the task. This is similar to the increase in activity at the end of the advanced technician’s trials, in which they were inspecting their work for quality assurance. Another interesting result is that the base level of activation is much lower than the advanced technician’s data. This is consistent with prior research on surgeons and medical students, which indicates that more expert individuals have lower activation (Gao et al, 2021). While not as obvious as the advanced technician, the data shares some of the same patterns with a sharp increase at the beginning of the movement, followed by a steady phase and a slight dip in activation near the end of the movement.

4.1.3 Multi-level subject comparison

In order to test the differences in neural activation between different groups. The same test as above was performed with a novice, intermediate, and advanced subject to record their neural activation during the test.



Description
Level: Beginner – no experience in car body polishing
Average time for task: 41 seconds
Tool path: random and no specific pattern
Hand position: two hands on the sander

Description
Level: Intermediate
Average time for task: 29 seconds
Tool path: circular motion with slight tool angle at the beginning
Hand position: two hands on the sander

Description
Level: Advanced – prior work experience in the autobody shop
Average time for task: 33 seconds
Tool path: circular pattern with occasion up-down pattern
Hand position: one hand on tool one hand in pocket

Figure 15, fNIRS data comparison between novice, intermediate, and expert subjects. Each chart consists of continuous results across four different tests.

The novice subject had somewhat random movements and took significantly longer to complete the task than the other two groups. Similarly, their neural activation is much less consistent across tests with very high peaks and no noticeable patterns between each test. In the intermediate subject there are clear peaks and valleys in the test. For the intermediate and advanced subjects there is a similar amount of consistency between each trial as there was in the individual trials. The beginner group had inconsistent patterns of activity across each test as compared to the intermediate and advanced groups which developed a consistent procedure for each test. In the advanced subject there are many more subtle peaks and valleys during each test, potentially indicating more complex movements. Further analysis should be done in the future on larger test groups to verify these patterns.

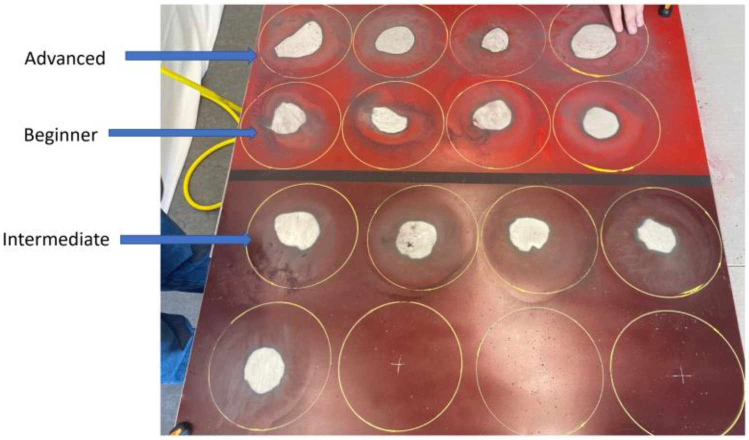


Figure 16, Comparison of polishing results between the three skill groups.

5 Discussion

5.1 Deliverables

- We conducted a preliminary study on fNIRs activation in polishing technicians, finding that there is a correlation between technician skill level and neural activation. This is grounds for numerous future studies investigating the neurocognitive basis of tact knowledge in manufacturing and future experiments in the WPI MedMain Laboratory.
- We developed a kinematic velocity controller for the Dobot CR5 in ROS using C++ as the control language.
- We created an interface for attaching the force-torque controller to the cobot end effector.
- We began developing a dynamic impedance controller in python but ran into difficulties acquiring the dynamic parameters.

5.2 Challenges

As mentioned previously we had a lot of difficulty acquiring the dynamic parameters of the Dobot CR5. On the experimental side, since there was a lack of funding for recruiting subjects, we were only able to experiment on a small set of body shop technicians.

5.3 Future Work

Using what we learned from the fNIRs experiment to modify control of the robot.

Conducting an experiment to further quantify technician’s polishing process by recording their force-torque inputs and tool angle using the Seria-Axia sensor in addition to fNIRs data would further both our understanding of tacit knowledge and also improve our ability to integrate human skill into a robotic polishing algorithm. If we can correlate tool angle and output force of the technician to NIRs data, it could be used to train a robotic control algorithm.

A study more directly comparing the fNIRs activity from experienced and inexperienced individuals.

This is a preliminary test with only a few subjects, future studies with a wider range of subjects will be necessary to verify that the results are generalizable. One of the interesting results that we found was that different polishing skill levels had different levels and patterns of activation. By comparing a larger range of subject across different skill levels and

fNIRs as a Skill Evaluation Tool in Manufacturing Training.

If polishing skill is potentially predictable via fNIRs data, then it could be interesting to explore fNIRs as a method for evaluating manufacturing skill or as an educational aide for technical training. It would also be interesting to study how an individual’s fNIRs signals change as their skill develops in a longer-term study.

Perform the fNIRs experiments on more realistic surfaces

The simulated car body we used for the fNIRs experiment is not very representative of an actual car body and is very uniform. This eliminates a lot of the decision making and skill necessary to polish an actual automobile. By performing the tests using actual car parts or curved parts with more complex geometry we could capture the decision-making processes involved in polishing much more accurately.

Incorporating a scratch detection computer vision algorithm

A previous MQP team developed a computer vision algorithm and calibration procedure for the Dobot CR5 that detects blemishes in a metal surface (Shi et al, 2022). By refining this algorithm and incorporating it into our future impedance controller, a basic autonomous polishing system could be created.

5.4 Ethics and Broader Impact

This project is still very much in the development phase but if completed could result in several positive benefits to the scientific and manufacturing communities. A further study on fNIRs as a tool in manufacturing could highlight important neurocognitive indicators of skill in polishing and provide a way to objectively measure skill in manufacturing. The proposed system of using fNIRs and a force torque sensor could also be used educationally to evaluate skill in technical schooling. At present the robotic impedance controller is still in development, but if it were to be successfully implemented, it would lessen the need for skilled work on polishing jobs and provide value to the automotive industry by allowing multiple jobs to be run in parallel with less workers. This would also free up time for currently employed technicians to do other work. Since the target application is only one step in the car finishing process and likely requires human supervision, it is unlikely that any future results of this project will prevent employment opportunities for current body shop technicians. The use of a collaborative robot ensures that the application is safe for work in the presence of humans, so risk related to deployment is minimal. The experiments conducted in this study involving human subjects were approved by the International Review Board at Worcester Polytechnic Institute and the subject filled out an informed consent form prior to the study. See the appendix for more information.

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Appendix: Informed Consent Form

Informed Consent Agreement for Participation in a Research Study

Primary Investigator: Yihao Zheng, Mechanical and Materials Engineering Department
Student Investigators: Patrick Chernjavsky, Alexander Breiling, Ge Zhu

Contact Information:

Higgins Labs 110, 100 Institute Road, Worcester MA, 01609

508-831-4649 yzheng8@wpi.edu

Title of Research Study: FNIRS Study on Manufacturing Tacit Knowledge

Introduction

You are being asked to participate in a research study. Before you agree, however, you must be fully informed about the purpose of the study, the procedures to be followed, and any benefits, risks or discomfort that you may experience as a result of your participation. This form presents information about the study so that you may make a fully informed decision regarding your participation.

Purpose of the study: The purpose of this study is to use a wearable fNIRS (functional near infrared spectroscopy) device to detect brain activity in simulated car body manufacturing task. This information, combined with subject feedback will be used for two main purposes. The first is to further understanding of the neural basis of polishing skill, and the second is to help develop an optimized car body polishing protocol for a robotic arm.

Additional Information

What is fNIRS?

fNIRS is a non-invasive brain imaging technique that uses infrared light to estimate blood

flow in the brain. This information is then used to estimate brain activity levels. fNIRS is a well-established method that has been used extensively in clinical settings and has no associated risks.

The quality of fNIRS data is highly susceptible to movement of the head. In order to remove this noise, we use an algorithm that combines the fNIRS data with electroencephalogram data (EEG).

What is EEG?

EEG stands for electroencephalogram and is a procedure that measures electrical activity, (commonly used to measure brain activity) by putting electrodes (small metal disks) over the area of interest.

Procedures to be followed:

All procedures carried out will be filmed from a close-up angle and an isometric angle to correlate the brain imaging data with your physical actions.

1. You will be fitted with a wearable fNIRS (Functional near-infrared spectroscopy) and EEG (electroencephalogram) device, which rests on the forehead. These collect information on brain-blood oxygen levels and electrical signals respectively.

2. You will be handed a DA (dual action) sander and asked to grind a scratch off a simulated car body made from spray-painted aluminum.

3. A thirty second timed break will be taken between each test, after which the experiment will be repeated. The test will be repeated for a total of 4 grinding episodes.

Each grinding episode will take approximately 1 minute, with a 30 second break between each test. The total estimated in-lab time will be approximately 15 minutes. This does not include transportation to the lab.

Safety Procedures

The experiment will be conducted in a well-lit room and you will be given safety glasses to protect your eyes from potential injury. All camera equipment and other potential obstacles will be cleared from the grinding surface to prevent collisions.

Equipment Details

The tool to be used by the participant is a dual-action sander, similar to the kind used in the auto shop industry.

The device used for EEG and fNIRS is a NINScan device. It includes wearable sensors for both fNIRS and EEG recording. The device is a prototype and as such it is not FDA approved but there are no known risks.

Risks to study participants: All risks associated with this study are related to the operation of a DA sander. For experienced individuals there should be little to no risk. Novice individuals will be advised upon the safe usage of the tool. If safety measures are not properly followed, there is a risk of personal injury.

You may decline to answer any or all questions and you may terminate your involvement at any time if you choose.

Benefits to research participants and others: There will likely be no direct benefit to the participant.

The project will contribute to further academic understanding of tacit knowledge in manufacturing that is not easy to explicitly study. If the second phase of the study is completed, it will result in an automated grinding system, which can help speed up the process and increase surface finish uniformity of the surface.

Records of your participation in this study will be held confidential so far as permitted by law. However, the study investigators, the sponsor or its designee and, under certain circumstances, the Worcester Polytechnic Institute Institutional Review Board (WPI IRB) will be able to inspect and have access to confidential data that identify you by name.

Any publication or presentation of the data will not identify you unless you explicitly permit it.

We will not disclose your name, image, or any identifiable private information to any party outside of the research team without your explicit permission. You may provide permission for us to do so at the bottom of the document.

Compensation or treatment in the event of injury: If you are injured during the experiment, the severity of the injury will be assessed. If the injury can be treated easily with first aid, it will be applied immediately. If the injury is more serious, or at your request, we will take you to the nearest hospital for immediate treatment. You or your guarantor will be responsible for any medical costs incurred. You do not give up any of your legal rights by signing this statement.

For more information about this research or about the rights of research participants, or in case of research-related injury, contact Yihao Zheng, whose contact information is on the first page. You may also contact IRB Manager Ruth McKeogh (Tel. 508 8316699, Email: irb@wpi.edu) and the Human Protection Administrator (Gabriel Johnson, Tel. 508-831-4989, Email: gjohnson@wpi.edu).

Your participation in this research is voluntary. Your refusal to participate will not result in any penalty to you or any loss of benefits to which you may otherwise be entitled. You may decide to stop participating in the research at any time without penalty or loss of other benefits. The project investigators retain the right to cancel or postpone the experimental procedures at any time they see fit.

By signing below, you acknowledge that you have been informed about and consent to be a participant in the study described above. Make sure that your questions are answered to your satisfaction before signing. You are entitled to retain a copy of this consent agreement.

______________________ Date: __________________

Study Participant Signature

____

Study Participant Name (Please print)

____________________________________ Date: __________________

Signature of Person who explained this study

I authorize the researchers involved in this study to use my photos and videos recorded during each experiment for the purpose of publishing a research paper related to the experiment. Initial "Yes" or "No" to agree or disagree to this statement. There are no consequences to disagreeing to this clause.

Yes: _________

No: _________

___________________________ Date: ___________________

Study Participant Signature