PORTABLE RADIO SIGNAL SOURCE LOCALIZATION DEVICE

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By

Sèzan Prudence Hessou

Electrical Engineering Intern

Pennsylvania State University/Capital College

Mentor: Benjamin Charrow, PhD Candidate

Advisor: Dr. Vijay Kumar, Pr. of MEAM

Sèzan Hessou, Benjamin Charrow, Vijay Kumar
GRASP Lab, University of Pennsylvania
e-mail: sph5125@psu.edu, {bcharrow, kumar}@seas.upenn.edu

ABSTRACT

In this paper we analyze the use of radio frequency (RF) technology applied to mobile robots and persons in their environment. In particular, we study the problem of localizing a person equipped with a mobile sensing device integrating a nanoPAN 5375. We researched, identified, designed, built, and implemented a light-weight, resilient, heat-refracting and wearable device powered with DC source to carry a computer, a hard drive, a nanoPAN 5375 RF module and a radio antenna. Once the device was successfully built, we collected and analyzed a range of data using the new box to validate our approach.

CONTENTS:

1. INTRODUCTION

Wireless sensor networks [1] have inspired tremendous research interest in recent decades with a wide variety of potential prospects [2]. Several researchers have proposed using embedded networks to support mobile robot applications. Batalin *et al.* [3], [4] used a sensor network to aid in coverage, navigation, and task allocation. In the network, robots will act as a team, sense, collect, and aggregate data that will be conveyed to a central source for processing. Each robot must accomplish these tasks by establishing point-to-point communication capabilities, and successfully processing and flowing data within the wireless network; this requires a computer, and not a mere microcontroller. Earlier studies have attained this goal and research is ongoing to broaden the application range of these results.

This project aims to apply the same principle to a portable radio signal source localization device for robots to locate and communicate with the person wearing the device. We are interested in human-worn sensors that allow robots to track them in a collaborative human-robot mapping. This will require a sensor device with a computer, a hard drive, a range sensing module and an RF radio antenna to allow the robots to track the human. Consequently, there is the need for a housing to carry all of the items within the sensor. The focus of this project is to develop a frame to house all the components of the sensor.

2. BACKGROUND

Because regular sensing devices have certain limitations such as wall crossing capability, their use becomes inappropriate for some applications. An effective and low cost alternative for sensing in those applications calls for radio based ranging methods. However, radio signal propagation is a complex, multi-scale process that occurs at a number of length scales [5].

It must be noted that our work is not a stand-alone research project, nor is it the continuation of previous studies. It is an integrative component of research being conducted in the General Robotics, Automation, Sensing and Perception (GRASP) lab at the University of Pennsylvania by Benjamin Charrow. He has previously developed "algorithms for estimation and control that allow a team of robots equipped with range sensors to localize an unknown target in a known but complex environment" [6]. In his study, he developed a model for radio-based time-of-flight range sensors. "Adopting a Bayesian approach for estimation," [6] Benjamin Charrow developed a control law that maximizes the mutual information between the robot's measurements and their current belief of the target position [6]. However, his work has been limited to inter-robots application so far. This study extends to human beings and calls for the need of a human-worn sensor.

There are three pieces to the human-worn sensor project: the mechanic, the electronics, and the software. The mechanical part involves researching, designing, and building a light-weight, resilient, heat-refracting and human-worn housing to hold all the electric and electronic components of the sensor. The electronics includes choosing proper electronic components based on their specification and their intended use while properly and safely connecting the devices. The software is developed in C++ and interfaced via Robot Operating System [6]. It must be noted that the software part was previously designed and is not described here.

3. METHODOLOGY, DESIGN AND ARCHITECTURE

The central idea of the methodology adopted in designing the portable radio signal source localization device consists in searching and accessing the available literature regarding the object of our research.

After collecting all the ideas and reading on what is already available in the industry, a thorough analysis follows. The analysis consists of deciding what is applicable and what is not and proceeding by elimination while keeping in mind the weight and cost effectiveness as well as the feasibility within the allotted time.

Once everything is built and assembled, a series of testing, adjusting, modifying and/or correcting the initial design follow to come up with a final design and a prototype.

Finally, once the prototype was built, another set of testing leading to data collection follows to validate our approach.

An important consideration for human-worn sensors is mobility and height, without forgetting the device must be clutter free to allow the human to perform other tasks while wearing the sensor. In the inter-robot application, the robots are custom differential-drive wheeled and all located on the ground level as illustrated in Figure 1.

The primary challenge in our approach is the design and physical implementation of a system to house the radio propagation device, the ranging module, and the computer for the point-to-point wireless network for humans to wear while keeping maintainability, durability and weight in mind. To overcome such a challenge, several skills and tools are needed. SolidWorks turns out to be a vital tool in our design. Ergonomic skills and space management are necessary as well to fit all parts inside and on the designed device.

A secondary challenge of this work is the choice of technology and materials used in the design. Initially, CNC machining was the technology we had intended to use while designing the housing for the sensor. As the research moves forward, it turns out there are several other technologies we could use for the manufacturing of the sensor's housing. The prototype is built with a combination of technologies –3D printing and laser cutting—to keep the manufacturing cost affordable. Based on the desired qualities (light-weight, resilience, heat-refraction) expected during the operation and use of the sensor, we choose to use Acrylonitrile Butadiene Styrene (ABS) material.

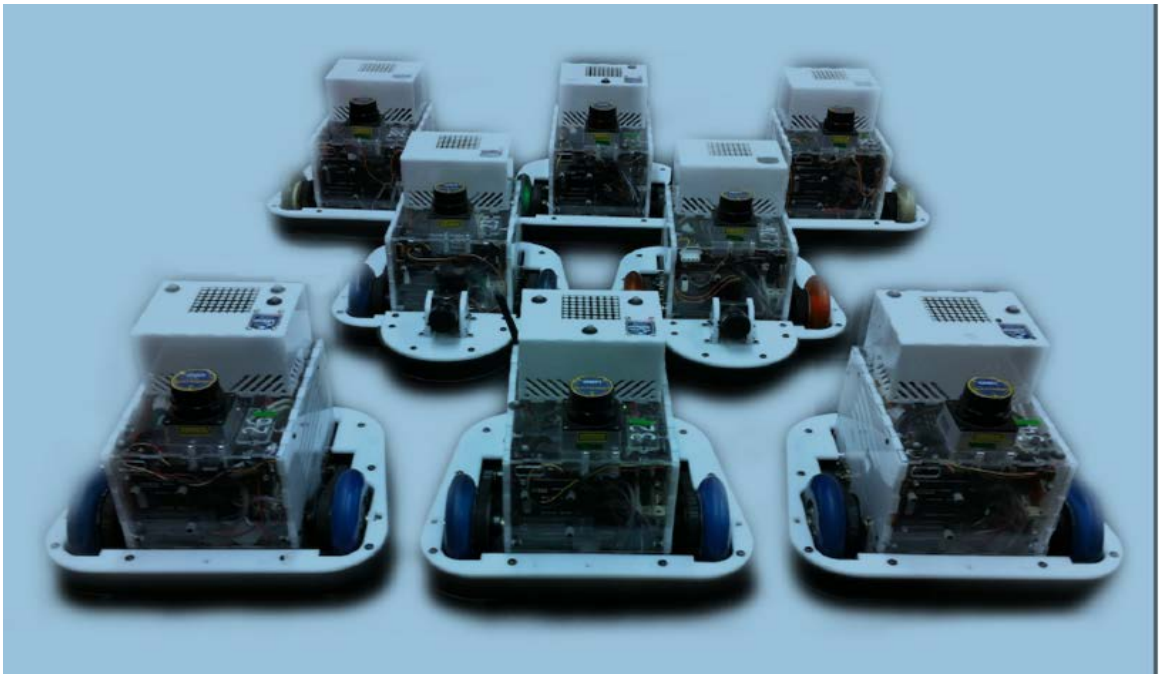


Figure 1: 0.23m x 0.27m x 0.28m Scarab platform on the ground

3.1 HARDWARE

The hardware used for the sensor must be light-weight, resilient, heat-refracting and wearable. The sensor itself is powered by a smart Lithium-Ion battery with 95Wh of capacity (NL2024). The battery provides between 3 to 4 hours of typical usage [5]. The hardware is composed of:

- A light-weight, resilient, heat-refracting and wearable case,
- A 2.5mm x 5.5mm female DC Power Jack Socket Panel-Mount Connector,
- A computer,
- A hard drive,
- A nanoPAN 5375 RF module
- And a radio antenna.

The portable device was designed using SolidWorks. To build the device, we consider several technologies. In the end, a combination of 3D printing and laser cutting technologies is adopted.

Since the sensor will be worn by humans, we strive to make the device light (958g). Considering the sensor will be worn at about 0.7 to 0.9m from the ground, it is most likely to fall and experience shocks to an extent, due to gravity. To protect the sensor from damage in case of a fall, it is made of resilient Acrylonitrile Butadiene Styrene (ABS). By creating ventilation slots in the frame, we ensure the heat from the working electronics and Joules effect are dissipated through aeration. To make the box portable, it must be congestion and clutter free to allow the human to perform other tasks while wearing it. The designed product that meets all those specifications is illustrated in Figure 2*.

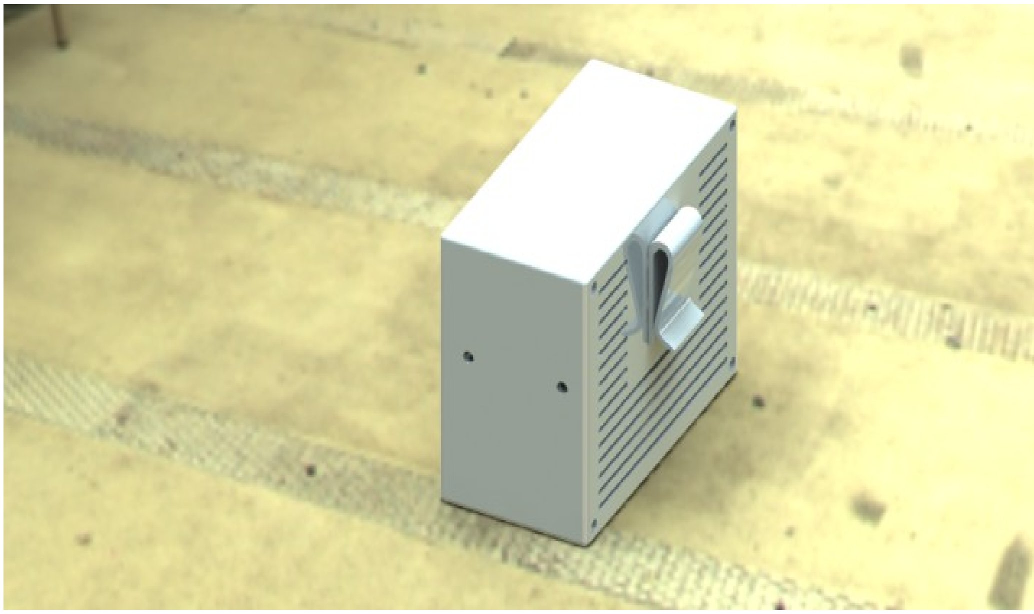


Figure 2: 0.090m x 0.140m x 0.175m Portable Sensor Housing Case

The 2.5mm x 5.5mm female DC Power Jack Socket Panel-Mount Connector is chosen to match the accessory available from the manufacture of the battery pack, *Inspired Energy*. Figure 3 displays the female DC Power Jack used in our design.

Figure 3: 2.5mm x 5.5mm female DC Power Jack Socket Panel-Mount Connector

*See appendix A for more technical drawings pertaining to the architecture of our design of the case.

The computer consists of a Nano-ITX motherboard with a 1.5GHz processor, 1GB of RAM and a 16GB solid-state drive for storage. Wireless communications are facilitated by an IEEE 802.11 wireless radio card operating in the 5GHz frequency range. Figure 4 shows the motherboard of the computer.

Figure 4: Nano ITX motherboard

The hard drive inside the computer is a 16GB SSD, 2.5 inch, with SATA II interface, with an Mlc flash chips inside. Figure 5 shows the hard drive.

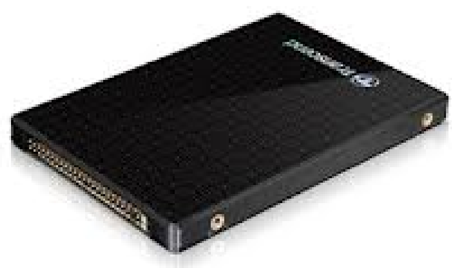


Figure 5: Hard drive

The nanoPAN 5375 RF module is a range sensing device. Figure 6 displays nanoPAN module.

Figure 6: nanoPAN 5375 RF module

The finished product fully assembled can be viewed in Figure 7.

Figure 7: Finished product

3.2 SIMULATIONS

To confirm our choice of material and ensure all desired features of the sensor are met, we have simulated drop tests due to gravity and fatigue tests on the belt clip to ensure this is robust and durable while keeping its flexibility. These simulations are not to be interpreted as the validation of the experiment, for they provide theoretical imitation of reality only. Simulations are a good tool in this project because they enable the theoretical prediction (with some probabilistic error) of different worst-case scenarios that will not physically be available. The results are not experimental and cannot be the basis for validation.

Figure 8 in the "Results and Discussion, Validation" section show the drop test simulated on the box, for this design.

4. TESTING

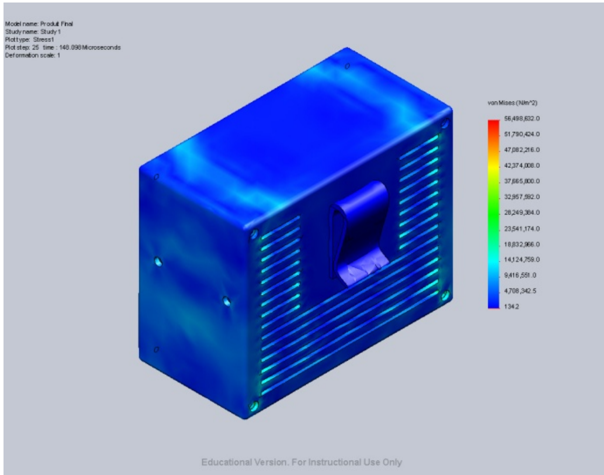
After assembling the final product, the sensor was powered on with the power push button. Before starting the experiment, the true distance of the experiment was measured to be 23.32m. Both the Scarab and the person wearing the sensor were placed at one end of the measured straight distance. After calibrating the sensor, the recording time was synchronized to match a theoretical zero starting, to the best of our estimation. On a "Go," the person wearing the device walked at a steady and regular pace from one end of the true distance to the other, in a round trip. Once the "walker" reached the point where he initially started (the same place where the Scarab remained throughout the experiment), the timer was then stopped. The data were recorded. This experiment was repeated three times and data were generated and collected each time, to compare the sensor's recordings (measured distance) to the true measurements.

The data generated are then imported to Excel for processing and analysis. We use MATLAB for further processing, analysis and interpretation. The graph are also drawn with MATLAB. The results are in "Results and Discussion, Validation" section.

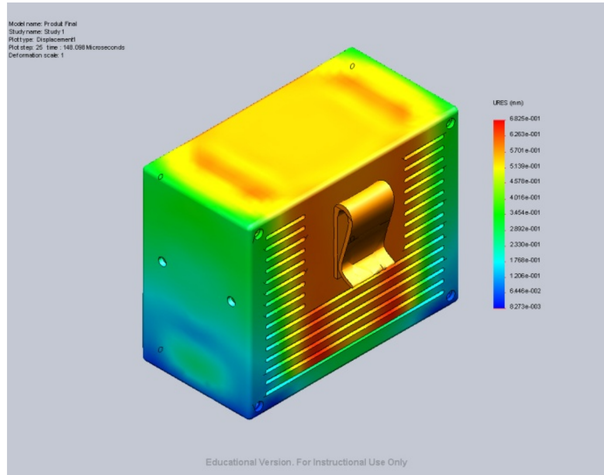
5. RESULTS AND DISCUSSION

5.1 RESULTS AND DISCUSSION

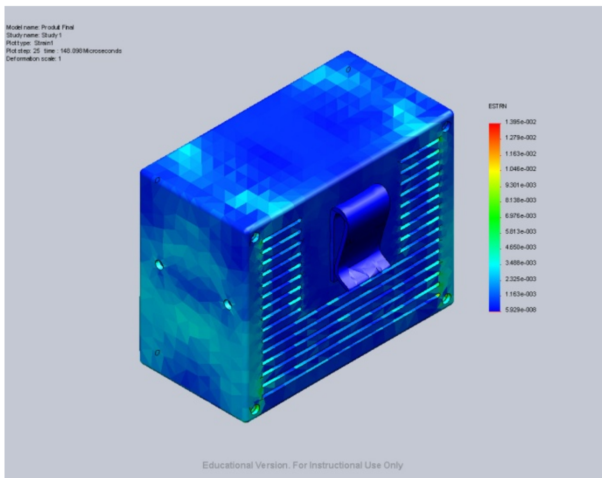
Figure 8 shows the simulation results for the drop test. Ic is observed, from simulation that the box handles stress, displacement and strain very well. None of the results approaches the critical zone (red color mark). The displacement after dropping the box is in the yellow zone however, on the top and the back of it specifically. This issue can be addressed in future work to improve the sensor's housing.



a. Stress Test from Drop



b. Displacement Test from Drop



c. Strain Test from Drop

d.

Figure 8: Drop test results (a, b and c)

A more comprehensive drop test results is appended to this paper as appendix G.

First, knowing the recorded time it took the person takes to walk the true distance back and forth along a straight line, we are able to determine the average speed of the "walker" wearing the sensor.

Second, knowing the propagation speed, the measured distance is calculated through an algorithm developed by Benjamin Charrow in his previous work [6] based on time it takes for the emitted signal to return to the emitting source after going through the stationary Scarab. These calculations are approximate because it takes the receiving Scarab a fraction of milliseconds to process the information and may cause some error in measurement. The extent and impact of this error, however, is not quantified at this moment.

Figures 9 shows the data collected from three consecutive trials, combined in one graph. To single out a trial and show the results, we have included Figure 10 to show the data collected during one of the trials. In Figure 10 (a singled out trial), it is clearly observed that the experimental data (actual data) does not match the theoretical expectation (Ideal expectation).

In all three cases, it is observed the distance measured by the sensor is smaller than the true distance; which is quite opposite to what one would expect, as the Scarab takes some time to process the signal emitted by the portable sensor. Various interferences could have also caused the signal to return with delay, which would make the sensor return longer measured distances by assuming the Scarab is located further than it actually is. It turns out this finding is consistent with previous work done by Benjamin Charrow. The reason for the difference is that the sensor is over-compensating for the amount of processing time, because there is less interference than the sensor expects. Specifically, the algorithm which calculates distance expects there has to be some interference. Consequently, when there is very little or no interference, the algorithm overestimates the amount of interference, which results in an underestimate of the true distance. This is true for all three trials.

The code used in MATLAB to generate the combined trials can be viewed in appendix as appendix E.

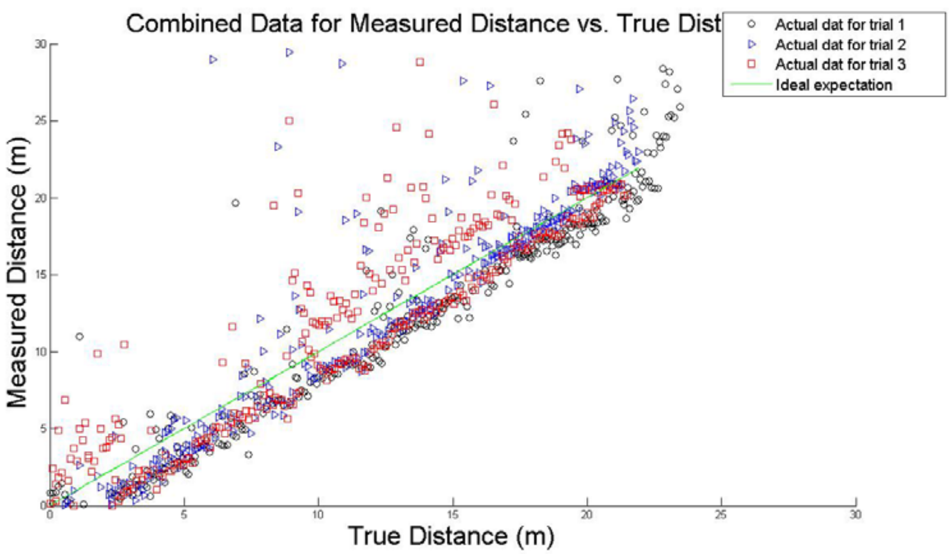
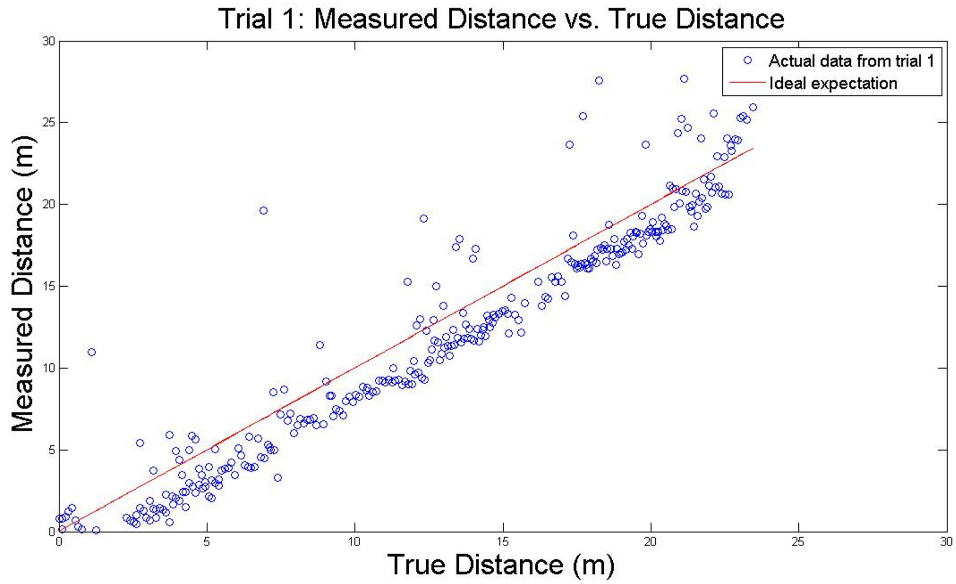


Figure 9: Combined trials



<u>Figure 10:</u> One of the Three Trials

The code used in MATLAB to generate the individual trial's graph can be viewed in appendix as appendix D.

It is observed that there is a discrepancy in measurement between 7 and 8m for all three trials. Figure 10 evidences such discrepancy. At this moment, there is no explanation as to why this occurs. Even though there is no data or theory to explain this fact, we can always speculate the sensor experiences some delay due to calibration and self initialization. Beside the 7 to 8m gap, the data seems closed to the ideal expectation in all three trials. The three trials above yield a percent error of less than 4. The average percent error is 3.54 precisely. This percent error is calculated with the following formula:

$$\textit{Percent error} = (|(\textit{True distance} - \textit{Measured distance})|/(\textit{True distance})) \times 100$$

The MATLAB code used to calculate the same percent error is in Appendix as appendix B.

To see how accurate our data is, we graph the variance curve to visualize the distribution. To proceed with graphing the variance, we divide the true distance in sub-groups of 1m each. Considering our experimental data is not continuous, we use the discrete data formula to calculate the variance of measurement:

$$\textit{variance} = (1/n)*\sum(x_i-\mu)^2$$

Where n is the number of data, x_i each individual value of the measured distance, and μ, the mean value of the data per unit of true distance.

Figure 11 shows the graphs of variance of measurements for all three trials combined.

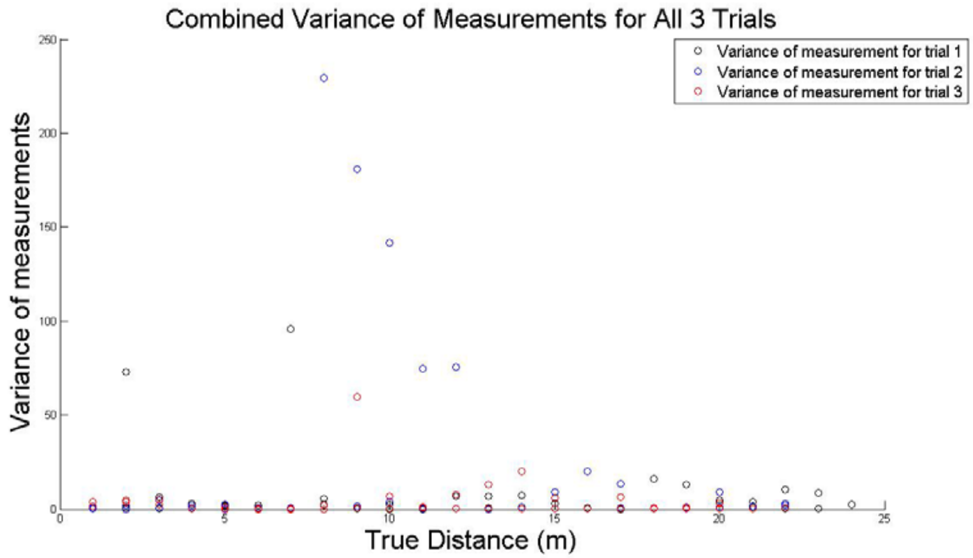


Figure 11: Combined variance of measurement graphs

See appendix D for MATLAB code to graph the variance of measurements for each trial individually.

Appendix F shows the MATLAB code to graph the variance of measurements for all three trials combined.

5.2 VALIDATION AND CHALLENGES

As the results in the previous section show, the data collected from the experiment shows some error. But altogether, it is clearly evidenced that we are able to sense. The sensor housed by our designed box was successful at emitting and receiving signals for the stationary Scarab. This validates our approach. More specifically, the fact that we are able to consistently reproduce a result found by previous studies conducted by Charrow when conducting the inter-robots experiment proves the box works.

Throughout the course of this experiment, we faced two main challenges:

- The design of the belt clip was time consuming as there were no geometrical shapes in SolidWorks to design it and using the spline feature on a remote desktop was not practical, especially when one is using SolidWorks remotely through the virtual lab.
- The never ending unit conversion war between metric and imperial as every time the design is taken to fabrication it appears too big and the

units had to be converted first; and finally, a few design errors that were corrected on the second prototype.

6. FUTURE WORK

For future work, I suggest reinforcing the material from the top and the back of the box to reduce the displacement impact after a drop. I also recommend adding a power LED to the box, at it has none at the moment. The only way one can tell it is powered on is by peaking inside the box to ensure the light is on, or by feeling the fan on the computer unit is turning once the power button is switched on. Adding a LED will be very helpful at solving this issue. I also recommend miniaturization, which improves the prototype. The miniaturization will prevent any eventual damages due to drop or cluster. The user can possibly carry the sensor in his/her pocket just like an iPod. Researching manufacturing the product at the nano-technologic level should be a venue to explore. Looking into the aesthetic aspect of the product should be part of the product's improvement. As to the material used, I suggest researching and finding more environment-friendly materials and possibly one that can adapt to the environment just like adaptive architecture. How variables such as the location of the device on the agent and mobility of the agent wearing the device may affect the performance will be the scope of future studies. To manufacture the sensor at a mass production level, I recommend injection molding, but that requires significant upfront costs and is only useful for very large-scale production (10,000 units).

7. CONCLUSION

We researched, identified, designed, built, and implemented a light-weight, resilient, heat-refracting and wearable device powered with DC source to carry all the components of our sensor. Once the device was successfully built, we showed the sensor was able to successfully locate the human wearing it repeatedly, through experimental testing. This evidences the successful communication between the sensor and the Scarab. Finally, we presented data collected during our experiment to prove our successful point-to-point wireless communication via RF-based range sensors. This validates our approach.

8. ACKNOWLEDGMENTS

I would like to thank everyone who, directly or indirectly, helped me in the accomplishment of this project. Special acknowledgements go to Dr. Van der Spiegel for giving me the opportunity to be part of the SUNFEST program this summer, to Dr. Vijay Kumar for granting me the privilege to work in the GRASP lab and under his supervision and advisement, Mary Westervelt for helping improve my writing and presentation skills altogether, to Benjamin Charrow for his mentorship, and to and the SUNFEST's staff for making the experience successful. I would also like to thank Dr. Sonia Gwak and Dr. Jorge Santiago and his family for adding fun and socialization during my time at UPenn. Furthermore, I would like to acknowledge Joe Pollin, senior student and expert in SolidWorks; Terry Kientz, lab fabrication specialist; Christian Moore, student and expert in plastic manufacturing technologies and Christine Kappeyne, 3D printing specialist for lending me their expertise in their respective field without equivoque. My gratitude goes on to thank the University of Pennsylvania for hosting and organizing the SUNFEST program, and the National Science Foundation for their continued financial support of the SUNFEST REU.

Finally, I would like to dedicate this paper to my son, Xander Tonan Hessou, as my profound gratitude for his smile and innocent understanding every day as I leave for my research lab or school. I hope he grows to learn, through my example that "the future is not a gift, but an achievement," as JFK once said.

9. REFERENCES

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[5] J. Fink, "Communication for teams of networked robots" (2011). *Dissertations available from ProQuest.* Paper AAI3485694. http://repository.upenn.edu/dissertations/AAI3485694

[6] B. Charrow, N. Michael, and V. Kumar. Cooperative Multi-Robot Estimation and Control for Radio Source Localization. in Proc. of the Intl. Sym. on Exp. Robot., Quebec City, Quebec, 2012.

10. APPENDIX

Appendix list:

Appendix A: Technical drawings of the box

Appendix B: MATLAB code for Percent Error Calculation

Appendix C: MATLAB code to graph individual trial’s data

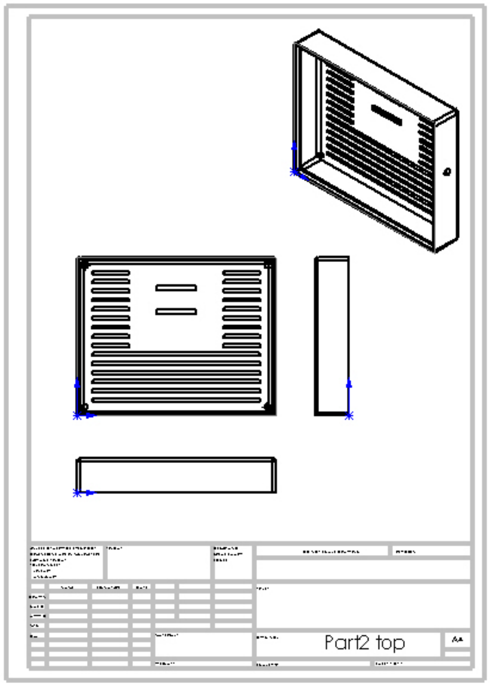
Appendix D: MATLAB code to graph individual trial’s variance of measurements vs. true distance

Appendix E: MATLAB code for combined data

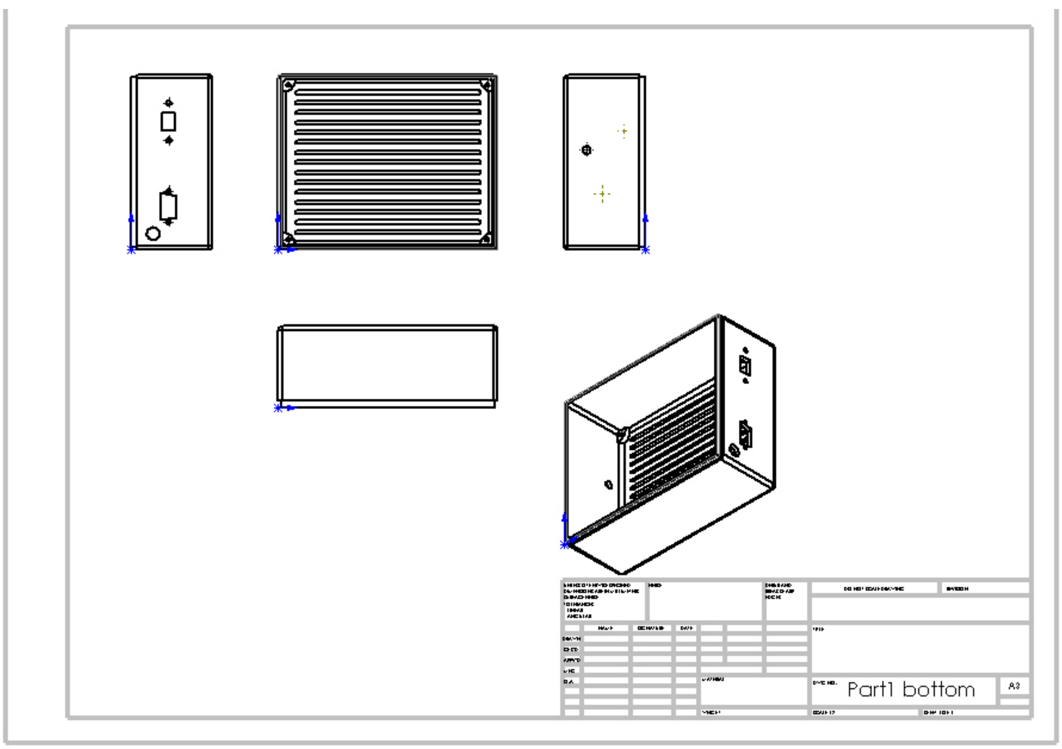
Appendix F: MATLAB Code for combined variance of measurements

Appendix G: Comprehensive drop test report

Appendix A: Technical drawings of the box



Top



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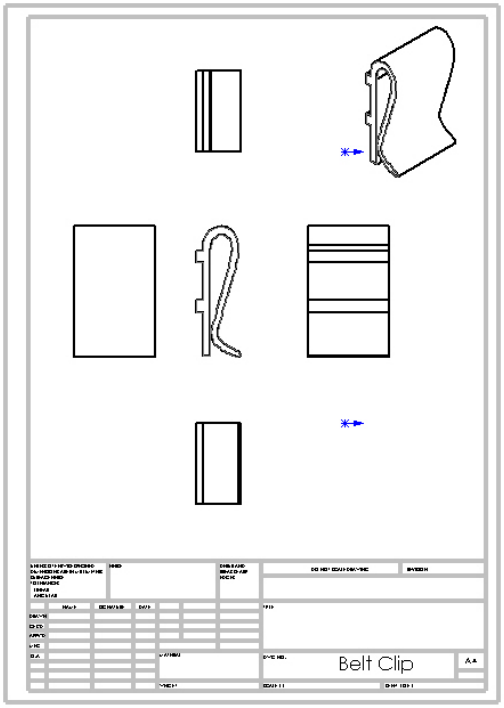
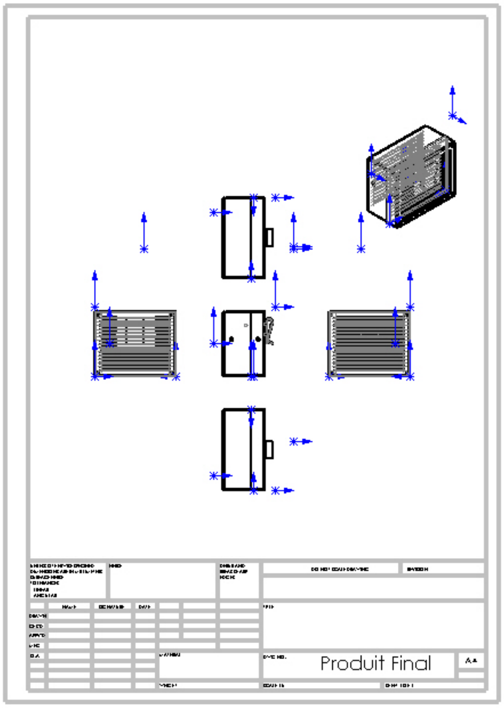


Belt Clip



Assembly

Appendix B: MATLAB code for Percent Error Calculation

```
>> measured_distance=xlsread('C:\Documents and Settings\sph5125\My Documents\Data\Trial
a.xls','sheet1','c2:c327');

>> true_distance1=xlsread('C:\Documents and Settings\sph5125\My Documents\Data\Trial a.xls','sheet1','j2:j327');

>> measured_distance1=xlsread('C:\Documents and Settings\sph5125\My Documents\Data\Trial
a.xls','sheet1','c2:c327');

>> true_distance2=xlsread('C:\Documents and Settings\sph5125\My Documents\Data\Trial b.xls','sheet1','j2:j327');

>> measured_distance2=xlsread('C:\Documents and Settings\sph5125\My Documents\Data\Trial
b.xls','sheet1','c2:c327');

>> true_distance3=xlsread('C:\Documents and Settings\sph5125\My Documents\Data\Trial c.xls','sheet1','j2:j323');

>> measured_distance3=xlsread('C:\Documents and Settings\sph5125\My Documents\Data\Trial
c.xls','sheet1','c2:c323');

>> error1=(((1/326)*(sum((true_distance1)-(measured_distance1))))/23.32)*100

error1 =

    3.7256

>> error2=(((1/326)*(sum((true_distance2)-(measured_distance2))))/21.84)*100

error2 =

   -3.8477

>> error3=(((1/322)*(sum((true_distance3)-(measured_distance3))))/21.49)*100

error3 =

   -3.0546

>> average_error=(3.7256+3.8477+3.0546)/3

average_error =

    3.5426
```

Appendix C: MATLAB code to graph individual trial’s data

```
>> measured_distance=xlsread('C:\Documents and Settings\sph5125\My Documents\Data\Trial a.xls','sheet1','c2:c327');

>> true_distance=xlsread('C:\Documents and Settings\sph5125\My Documents\Data\Trial a.xls','sheet1','j2:j327');

>> plot(true_distance,measured_distance,'o')

>> axis([0 30 0 30])

>> hold on

>> x=true_distance;

>> y=x;

>> plot(x,y,'r')

>>
```

Appendix D: MATLAB code to graph individual trial's variance of measurements vs. true distance

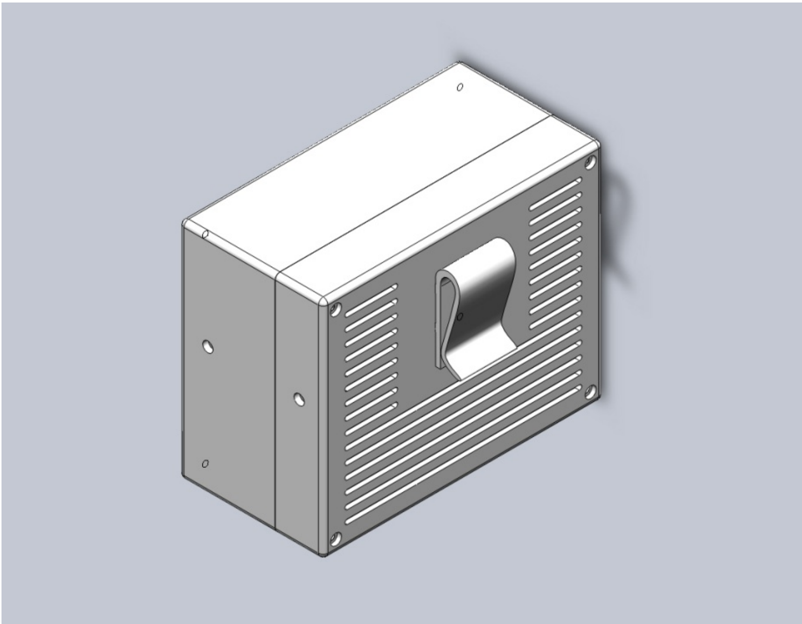
```
true_distance=xlsread('C:\Documents and Settings\sph5125\My Documents\Data\Trial a.xls','sheet1','h2:h327');

>> variance_of_measurements=xlsread('C:\Documents and Settings\sph5125\My Documents\Data\Trial a.xls','sheet1','b2:b327');

>> plot(true_distance,variance_of_measurements,'o');

>>
```

Appendix E: MATLAB code for combined data

```
>> measured_distance1=xlsread('C:\Documents and Settings\sph5125\My Documents\Data\Trial a.xls','sheet1','c2:c327');

>> true_distance1=xlsread('C:\Documents and Settings\sph5125\My Documents\Data\Trial a.xls','sheet1','j2:j327');

>> measured_distance2=xlsread('C:\Documents and Settings\sph5125\My Documents\Data\Trial b.xls','sheet1','c2:c327');

>> true_distance2=xlsread('C:\Documents and Settings\sph5125\My Documents\Data\Trial b.xls','sheet1','j2:j327');

>> measured_distance3=xlsread('C:\Documents and Settings\sph5125\My Documents\Data\Trial c.xls','sheet1','c2:c323');

>> true_distance3=xlsread('C:\Documents and Settings\sph5125\My Documents\Data\Trial c.xls','sheet1','j2:j323');

>> scatter(true_distance1,measured_distance1,'k')

>> axis([0 30 0 30])

>> hold on

> scatter(true_distance2,measured_distance2,'>','b')

>> scatter(true_distance3,measured_distance3,'square','r')

>> y=x;

>> plot(x,y,'g')

>>
```

Appendix F: MATLAB Code for combined variance of measurements

```
>> true_distance1=xlsread('C:\Documents and Settings\sph5125\My Documents\Data\Trial a.xls','sheet1','h2:h327');

>> true_distance2=xlsread('C:\Documents and Settings\sph5125\My Documents\Data\Trial b.xls','sheet1','h2:h327');

>> true_distance3=xlsread('C:\Documents and Settings\sph5125\My Documents\Data\Trial c.xls','sheet1','h2:h323');

>> variance_of_measurements1=xlsread('C:\Documents and Settings\sph5125\My Documents\Data\Trial a.xls','sheet1','b2:b327');

>> variance_of_measurements2=xlsread('C:\Documents and Settings\sph5125\My Documents\Data\Trial b.xls','sheet1','b2:b327');

>> variance_of_measurements3=xlsread('C:\Documents and Settings\sph5125\My Documents\Data\Trial c.xls','sheet1','b2:b323');

>> hold off

>> scatter(true_distance1,variance_of_measurements1,16,'k');

>> hold on

>> scatter(true_distance2,variance_of_measurements2,16,'b');

>> scatter(true_distance3,variance_of_measurements3,16,'r');
```



Simulation of Produit Final

Date: Wednesday, August 08, 2012
Designer: Sezan Prudence Hessou
Study name: Study 1
Analysis type: Drop Test

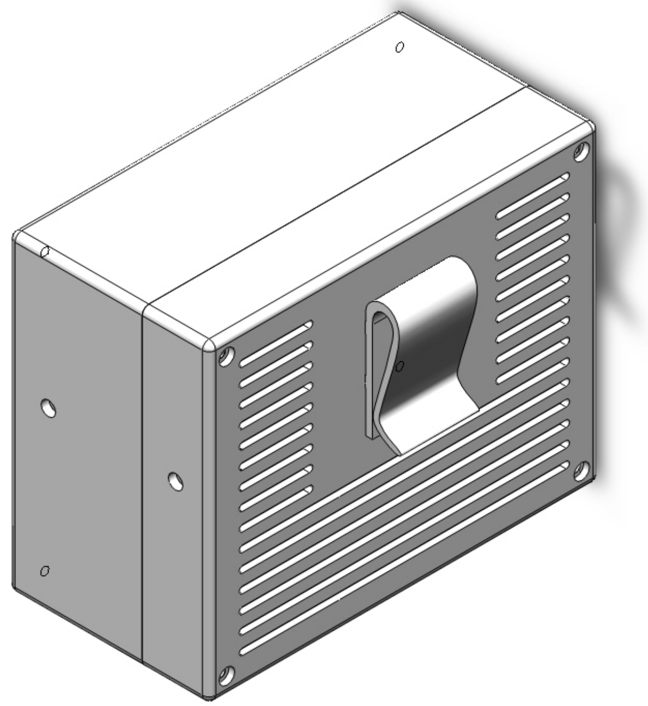
Table of Contents

Description

No Data

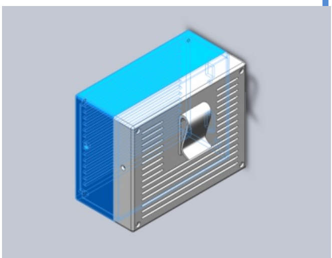
Assumptions

Model Information



Model name: Produit Final
Current Configuration: Default

Solid Bodies			
Document Name and Reference	**Treated As**	**Volumetric Properties**	**Document Path/Date Modified**
Boss-Extrude1	Solid Body	**Mass:0.0136243 kg** **Volume:1.33572e-005 m^3** **Density:1020 kg/m^3** **Weight:0.133518 N**	**E:\SUNFEST\SolidWorks\Belt Clip.SLDPRT** Jul 12 01:44:20 2012
Fillet4	Solid Body	**Mass:0.110406 kg** **Volume:0.000108241 m^3** **Density:1020 kg/m^3** **Weight:1.08198 N**	**E:\SUNFEST\SolidWorks\Part2.SLDPRT** Jul 12 01:57:01 2012

Fillet5 	Solid Body	**Mass:0.191946 kg** **Volume:0.000188182 m^3** **Density:1020 kg/m^3** **Weight:1.88107 N**	**E:\SUNFEST\SolidWorks\Part1.SLDPRT** Jul 12 01:44:29 2012

Study Properties

Study name	Study 1
Analysis type	Drop Test
Mesh type	Solid Mesh
Large displacement	On
Result folder	SolidWorks document (E:\SUNFEST\SolidWorks)

Setup Information

Type	Drop height
Drop Height from Centroid	0.9 m
Gravity	9.81 m/s^2
Gravity Reference	Face<1>
Friction Coefficient	0
Target Stiffness	Rigid target

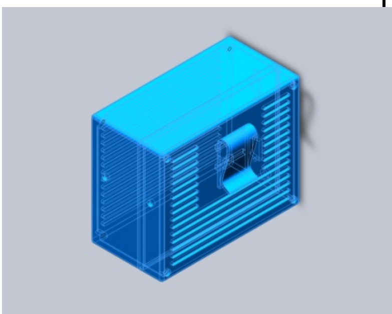
Result Options

Solution Time After Impact	148.1 microsec
Save Results Starting From	0 microsec
No. of Plots	25
No. of Graph Steps Per Plot	20
Number of vertex	0

Units

Unit system:	SI (MKS)
Length/Displacement	mm
Temperature	Kelvin
Angular velocity	Rad/sec
Pressure/Stress	N/m^2

Material Properties

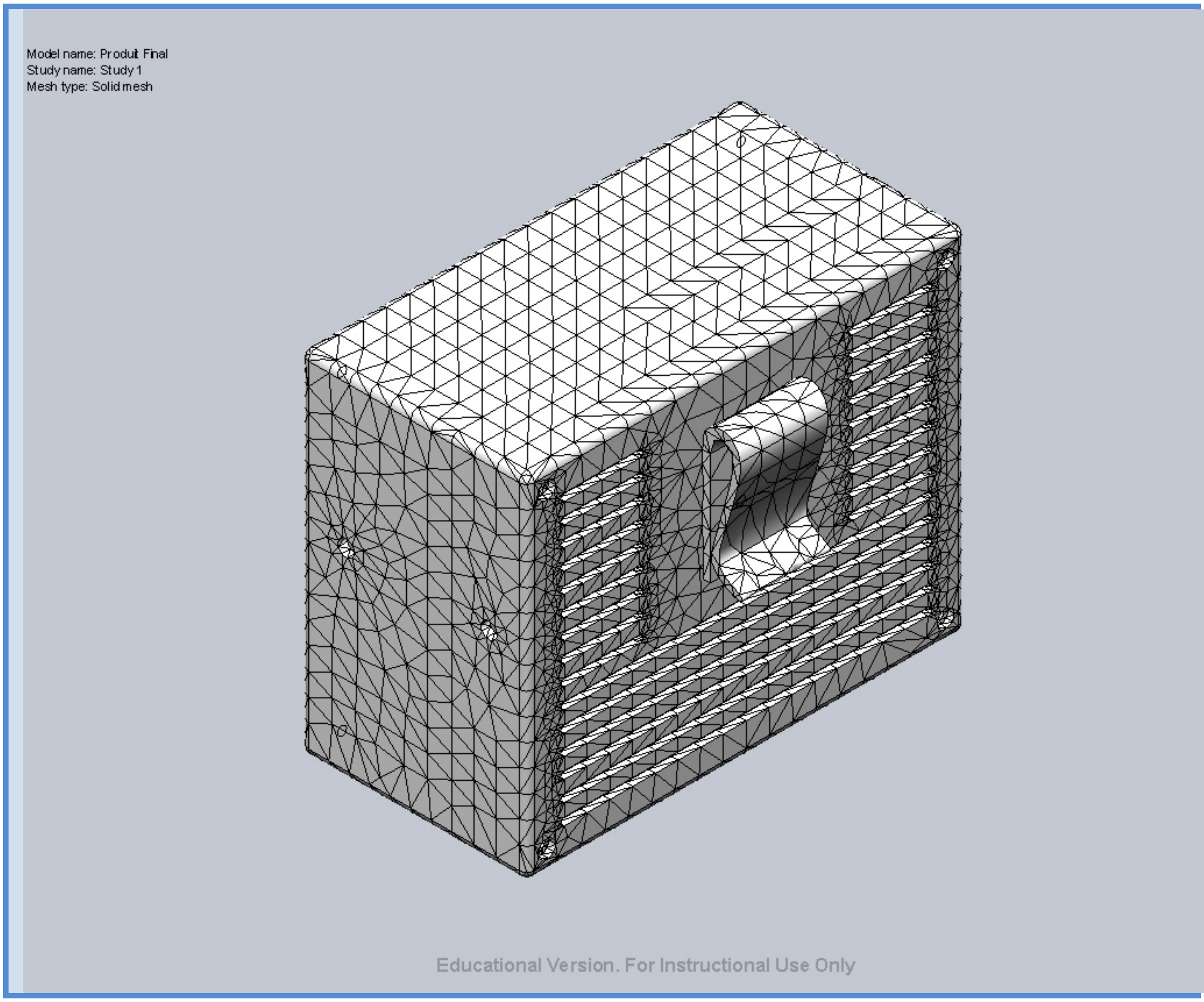
Model Reference	Properties	Components
	**Name:** ABS **Model type:** Linear Elastic Isotropic **Default failure criterion:** Unknown **Tensile strength:** 3e+007 N/m^2 **Elastic modulus:** 2e+009 N/m^2 **Poisson's ratio:** 0.394 **Mass density:** 1020 kg/m^3 **Shear modulus:** 3.189e+008 N/m^2	SolidBody 1(Boss-Extrude1)(Finished Designed Sub-Assembly1-1/Belt Clip-1), SolidBody 1(Fillet4)(Finished Designed Sub-Assembly1-1/Part2-1), SolidBody 1(Fillet5)(Part1-1)
Curve Data:N/A		

Mesh Information

Mesh type	Solid Mesh
Mesher Used:	Curvature based mesh
Jacobian points	4 Points
Maximum element size	0 mm
Minimum element size	0 mm
Mesh Quality	High
Remesh failed parts with incompatible mesh	Off

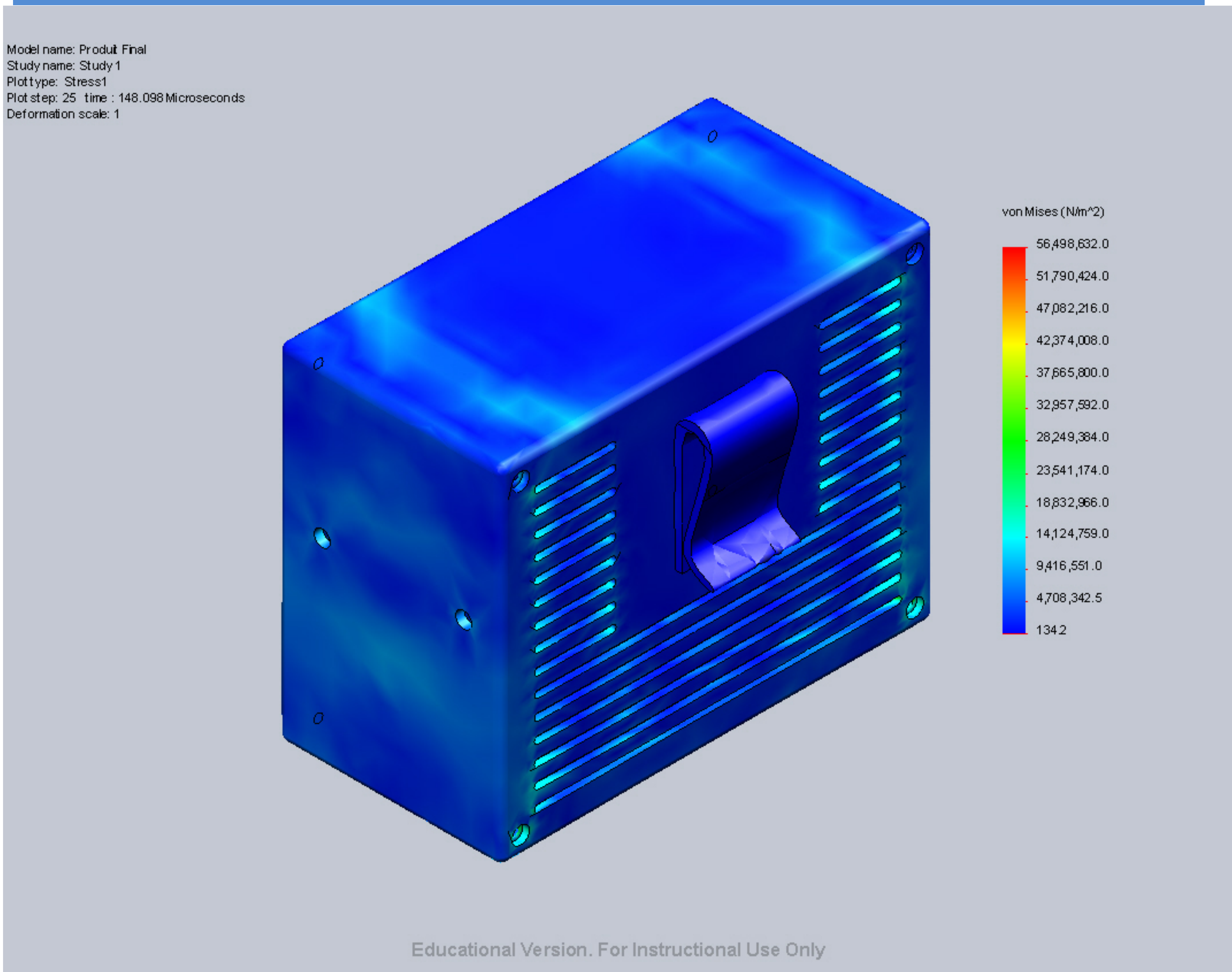
Mesh Information - Details

Total Nodes	37168
Total Elements	42396
Maximum Aspect Ratio	157.19
% of elements with Aspect Ratio < 3	51.9
% of elements with Aspect Ratio > 10	0.917
% of distorted elements(Jacobian)	0
Time to complete mesh(hh;mm;ss):	00:00:16
Computer name:	HBGOSW225-211


Model name: Produit Final
Study name: Study 1
Mesh type: Solid mesh
Educational Version. For Instructional Use Only

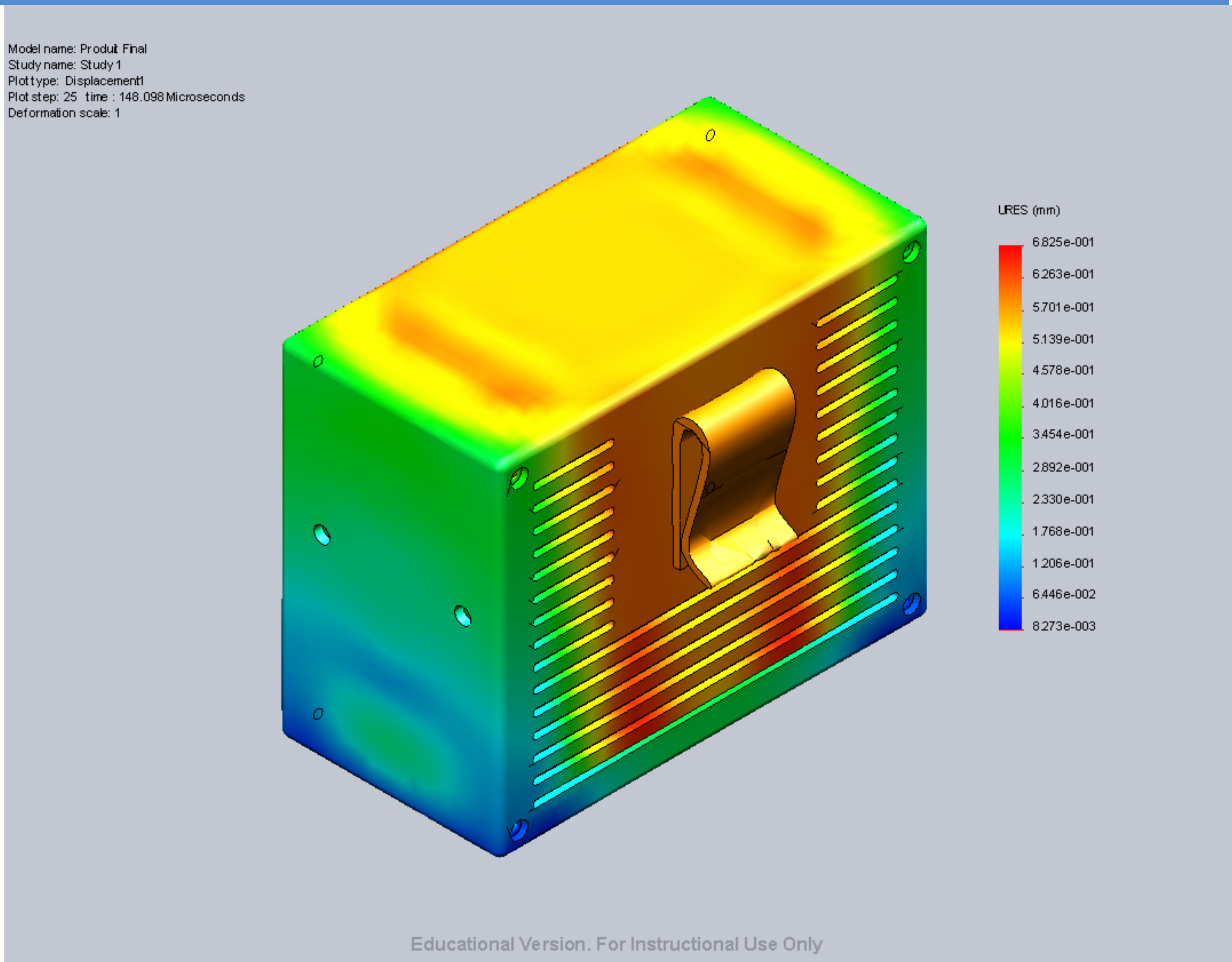
Study Results

lame	Type	Min	Max
tress1	VON: von Mises Stress	134.243 N/m^2 Node: 425	5.64986e+007 N/m^2 Node: 1181



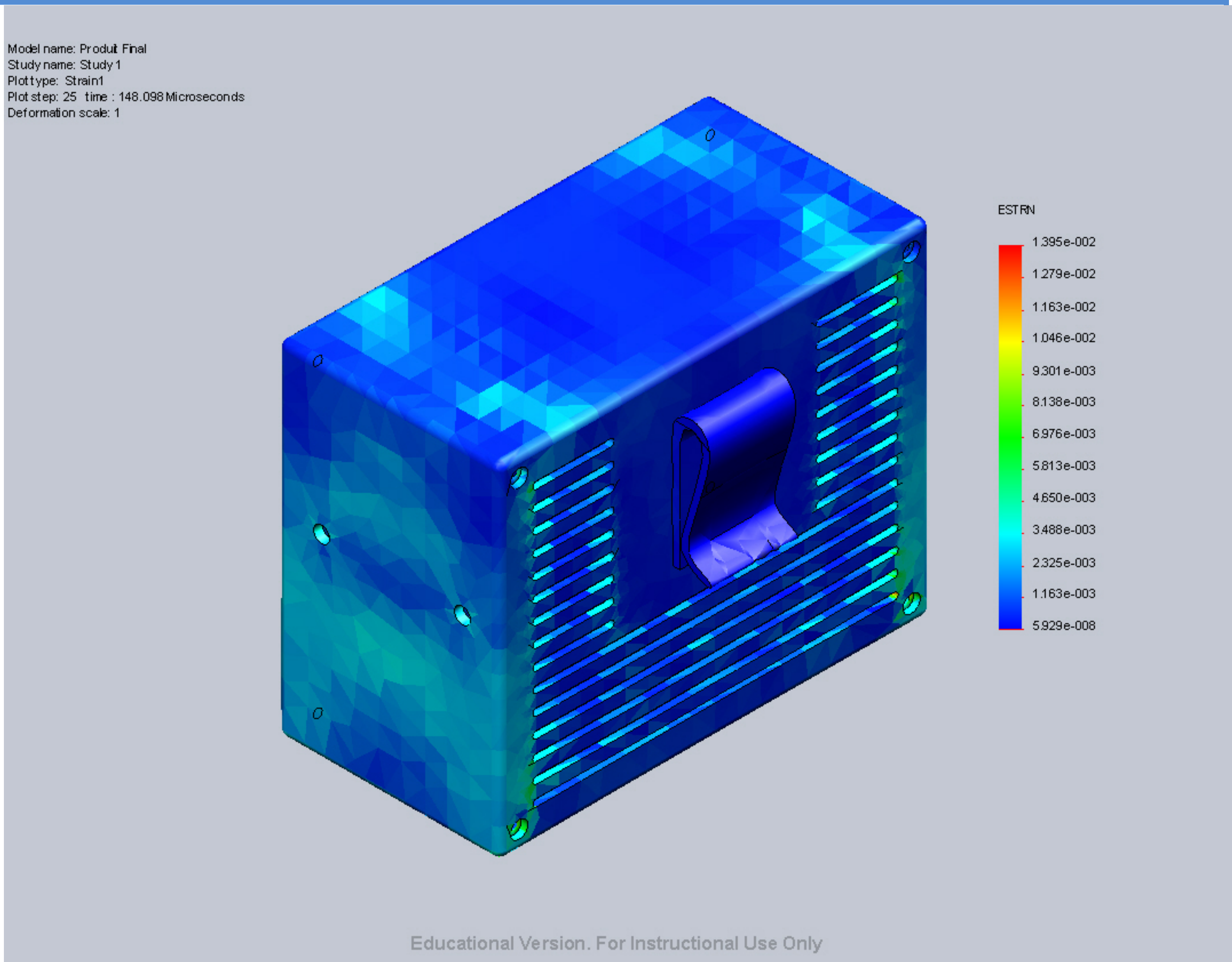
Produit Final-Study 1-Stress-Stress1

Name	Type	Min	Max
Displacement1	URES: Resultant Displacement	0.00827335 mm Node: 7676	0.682496 mm Node: 34032



Produit Final-Study 1-Displacement-Displacement1

Name	Type	Min	Max
Strain1	ESTRN: Equivalent Strain	0 Element: 18099	0.0139511 Element: 5149



Produit Final-Study 1-Strain-Strain1

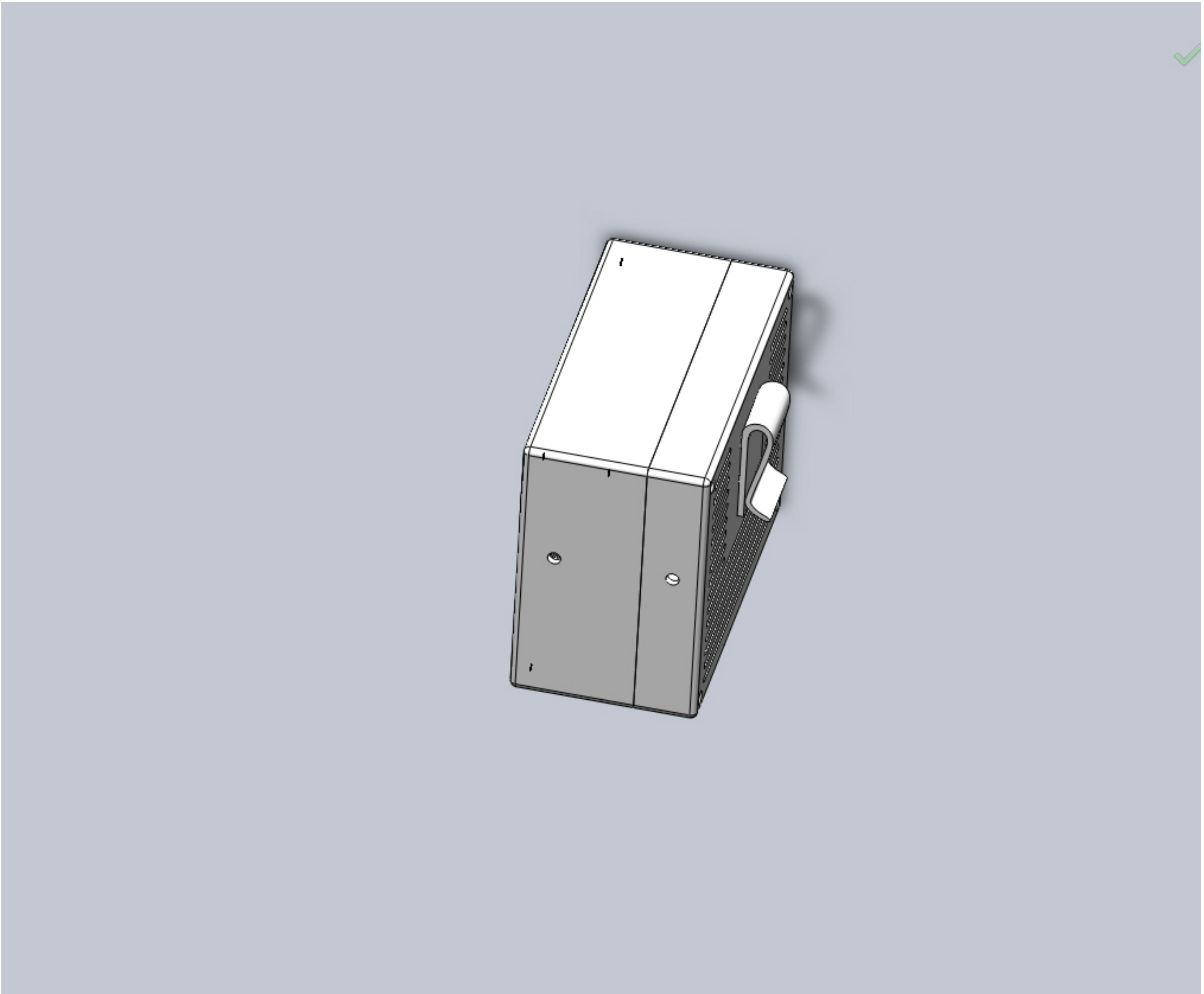


Image-1

Conclusion

Appendix