Steganography in Gcode Extruder Commands

Ann Tupek

University of Alaska Fairbanks

CS 680

Abstract

The objective of this experiment was to determine the validity of using extruder commands in gcode to hide a message. A message was hidden in the last two digits of the extruder commands and the modified gcode was printed. The dimensions of the modified prints were within the standard deviations of the objects printed using the original gcode, and the byte correlation histogram was identical to the original file. From these results, it would appear that hiding a message in gcode extruder commands is a viable method of steganography.

Introduction

Steganography is the practice of concealing data within other data. This experiment examined the validity of steganography in 3D printer gcode. A text message was hidden within the extruder commands of a gcode file.

The message was converted into modified ASCII decimal values. These values then replaced the last two digits of the extruder commands. The resulting modified gcode file was printed. The prints were compared to those printed from the original, unmodified gcode file to determine whether or not the modified gcode had any impact on the print.

Since the message was in the gcode, it is not possible to retrieve the message from the printed object. However, it can be retrieved from the modified gcode by removing the last two digits of the extruder commands and converting them into their un-modified ASCII values, and then printing out the corresponding characters.

Materials & Methods

The 20mm cube model was selected because the regularity of its dimensions facilitated the ease of taking measurements. The gcode for the 20mm cube contained 4,807 extruder commands, and the message contained 3,056 characters. The models were printed on a Prusa Mendel I3 3-D Printer with a 0.5mm nozzle diameter using Matter Hackers Pro PLA filament.

To prepare the message to be hidden within the gcode, each character was converted to its ASCII decimal value. This number was then modified to restrict the value to two digits. The modified value of a newline was -22, which was given the new value of 99. 98 was selected to be the sentinel value denoting the end of the message.

The gcode was produced by Slic3r from an .stl file with a layer height of 0.2mm and 20% rectilinear infill.

To ensure there is enough room to hide the message within the gcode, the program checks the number of extruder commands and compares this to the number of characters in the message. If there are not enough extruder commands, the program alerts the user to this.

The extruder commands are located via a regular expression: \\x45\\d+\\.\\d{5} This matches the format of a gcode extruder command: EX.XXXXX where E denotes the beginning of an extruder command and the X are digits 0-9.

The program reads through the gcode from the beginning copying the gcode to a new file. As the program reaches each extruder command, the last two digits of it are removed and the extruder command is written to the new file with the last two digits replaced by the modified ASCII value of corresponding character in the message. When

the last character of the message is placed in the gcode, the following extruder command is modified with an end of message sentinel value.

To retrieve the message from the gcode, the same regular expression is used to locate the extruder commands. The program reads through the modified gcode from the beginning, and as it reaches an extruder command, it gets the last two digits from it. It puts these digits into an array.

After the program has reached the end of the gcode, the array is processed. The digits represent the modified ASCII value of the characters. This is modified back to the original value, and the character that corresponds to that ASCII value is printed to a new file, until the sentinel value for the end of the message is located.

To determine if modifying the gcode in this way produced results that could be detected in the printed cube, three 20mm cubes were printed from the gcode that had been modified with the message, and three 20mm cubes were printed from the original, unmodified gcode.

Results

The histogram in Figure 1 shows the coincidence table of values of bytes occurring together in the original gcode file. The histogram in Figure 2 shows the coincidence table of values occurring together in the modified gcode file. The x-axis represents the first byte, and the y-axis represents the byte that follows it in the file. The origin (0,0) is at the top left corner, while (255, 255) is at the lower right corner.

Figure 3 is included to illustrate that not all gcode files produce the same byte coincidence pattern.
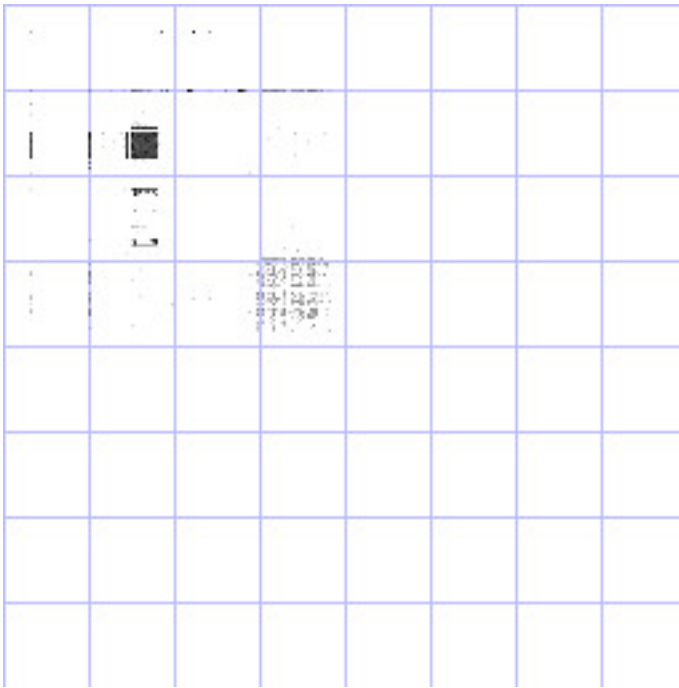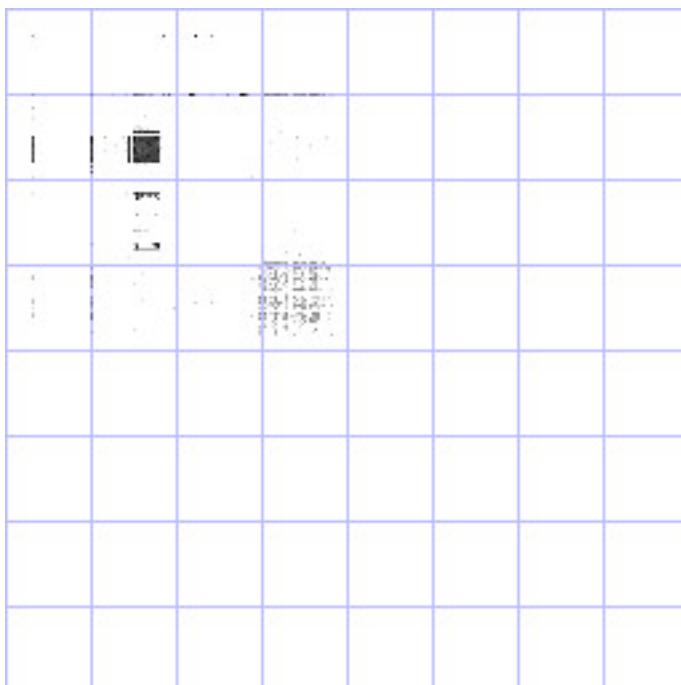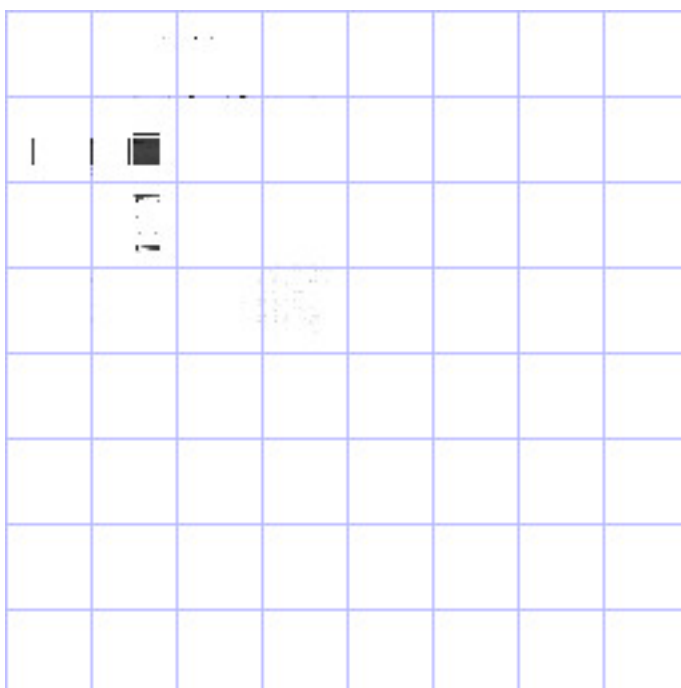

Figure 1

Figure 2

Figure 3

Table 1 shows the measurements of the 6 printed cubes. Cubes 1, 2, 5 were printed using the modified gcode, while cubes 3, 4, 6 were printed using the original gcode. The mean and standard deviation are also listed in the table. It also shows the weight of each cube.

	x	y	z	w
cube1*	20.16	20.02	20.32	6
cube2*	20.13	20.00	20.07	6
cube3	20.08	19.96	20.02	6
cube4	20.2	20.07	19.74	6
cube5*	20.31	20.07	19.86	6
cube6	20.14	19.93	20.8	6
mean (unmodified)	20.14	19.98667	20.18667	
mean (modified)	20.2	20.03	20.0833333	
standard deviation	0.06	0.07371	0.5493	

Table 1

* cubes printed with modified gcode

Discussion

From the measurements taken, it appears that the cubes printed with the modified gcode do not differ signficantly from the cubes printed from the original gcode. The mean measurements for the cubes printed with the modified gcode are within the standard deviation of the measurements for the cubes printed with the original message.

All of the cubes weighed the same amount. This measurement was expected to differ, due to the different amount of fillament being extruded. However, the scale used to measure the weight was not accurate to within fractions of a gram, so a more accurate scale should be used to determine whether or not a significant difference in the weights exists.

The byte coincidence histograms are identical for the two files. This shows that modifing the last two digits of the extruder commands has no effect on this visual representation of the bytes of the file.

Given the measurements collected and the histograms, it appears that this steganography method of hiding a message in gcode is not detectable, and therefore a valid method of hiding data. However, more testing should be done to validate this claim.

The extruder commands in gcode use absolute measurements, so they are always increasing in value. I did not conduct an exhaustive search to determine whether or not this is the case in the modified gcode, but a quick glance through the code showed that the modified extruder commands also appeared to always increase in value. An exhaustive search should be undertaken to prove that this is the case.

In addition to needing a more accurate measurement of the cube weights, more samples should be printed to obtain additional data points. Also, the number of characters in the message replaced 63.57% of the extruder commands in the gcode. It would be beneficial to use a longer message that replaced all of the extruder commands.

The 3-D printer used has been tuned using various calibration prints (including the 20mm cube). However it is not a precision machine, as can be seen from the variations in the control cubes. Printing mulitple copies of the two gcode files on a more precise machine, or multiple machines, would provide more information as to the validity of steganography in gcode extruder commands.

The extruder commands in gcode use absolute measurements, so they are always increasing in value. I did not conduct an exhaustive search to determine whether or not this is the case in the modified gcode, but a quick glance through the code showed that the modified extruder commands also appeared to always increase in value.

A future experiment would be to replace the last three digits of the extruder commands and see if that changes the measurements of the cubes and the byte correlation histogram. Replacing the last three digits of the extruder commands would also obviate the need to modify the ASCII values. However, since the extruder commands use absolute measurements and are always increasing in value, replacing the last three digits would probably cause the commands to decrease in value. This would alert anyone familiar with gcode to the notion that the file had been modified.

This preliminary experiment presents hiding a message in gcode extruder commands as a viable method of steganography. However, more research should be undertaken to for confirmation.

Sources

20mm calibration cube: http://www.thingiverse.com/thing:547339

Histogram Code: Lawlor, Orion Sky:

https://www.cs.uaf.edu/2015/spring/cs463/lecture/01_23_correlation.html

Information on gcode: http://reprap.org/wiki/G-code