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A Safe G-Code Subset for 3D Printing

Status: Interim

Abstract: This white paper defines a "safe" subset of G-code for use in 3D printing with IPP along with the capabilities and parameters needed to allow a client to generate G-code compatible with the printer.

This is a PWG [Working Draft](#). For a definition of a "PWG [Working Draft](#)", see:

<https://ftp.pwg.org/pub/pwg/general/pwg-process30.pdf>

This white paper is available electronically at:

<https://ftp.pwg.org/pub/ipp/wd/wd-pwgsafegcode10-20180426.docx>

<https://ftp.pwg.org/pub/ipp/wd/wd-pwgsafegcode10-20180426.pdf>

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Deleted: <https://ftp.pwg.org/pub/ipp/wd/wd-sweet-safe-gcode-20180416.pdf>

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31 Title: [PWG Safe G-Code Subset for 3D Printing](#)

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80 **1. Introduction**

81 G-Code [\[ISO6893-1\]](#)[\[RS274D\]](#)[\[REPRAP\]](#) is a commonly-used format for 3D printing with so-
82 called Fused Deposition Modeling (FDM) printers. Besides the commands used to move the
83 print head and/or platform and to extrude material, G-Code includes a variety of device
84 control (e.g., set extruder temperature) and hardware access (e.g., write file to SD card)
85 commands that pose serious safety and security concerns. To make matters worse, such
86 commands are often printer-specific or have printer-specific variations in syntax, requiring
87 the equivalent of printer driver software to produce G-Code suitable for a particular model or
88 firmware version. Finally, differences in filament and extruder nozzle diameters mean that
89 G-Code created for one print job may not work on the same printer due to changes to the
90 material or extruder.

91 The IPP 3D Printing Extensions v1.0 [\[PWG5100.21\]](#) define the model and semantics for
92 networked 3D printing, along with a required high-level 3D file format. However, the
93 processing requirements of such a format require either improved printer controllers with
94 greater memory, storage, and CPU capacity or the use of Cloud services to offload that
95 processing.

96 The IPP Shared Infrastructure Extensions (INFRA) [\[PWG5100.18\]](#) define the model and
97 semantics for Cloud printing, however it does not specify an intermediate format suitable for
98 3D printing.

99 This document defines a "safe" subset of G-Code that can be used for direct and Cloud
100 printing configurations, along with a description of the capabilities and parameters that will
101 be needed to generate suitable layers for printing to the target printer.

102 The goal of this document is to enable the use of IPP with existing entry-level FDM printers
103 that are not able to perform their own slicing and to enable generic Cloud and local
104 infrastructure services to provide slicing services to existing FDM printers. Support for other
105 kinds of 3D printers will likely require an intermediate format such as the 3MF Slice Extension
106 [\[3MF-SLICE\]](#).

107

108 **2. Terminology**

109 **2.1 Terms Used in This Document**

110 *Cloud*: the environment supporting services such as Cloud Computing.

111 *Cloud Computing*: "... a model for enabling ubiquitous, convenient, on demand network
112 access to a shared pool of configurable computing resources (e.g., networks, servers,
113 storage, applications, and services) that can be rapidly provisioned and released with
114 minimal management effort or service provider interaction." The NIST Definition of Cloud
115 Computing [NISTSP800-145].

116 *Fused Deposition Modeling*: A 3D printing process that extrudes a molten material to draw
117 layers, sometimes also called material extrusion.

118 **2.2 Acronyms and Organizations**

119 *IANA*: Internet Assigned Numbers Authority, <https://www.iana.org/>

120 *IETF*: Internet Engineering Task Force, <https://www.ietf.org/>

121 *ISO*: International Organization for Standardization, <https://www.iso.org/>

122 *PWG*: Printer Working Group, <https://www.pwg.org/>

123

124 **3. PWG Safe G-Code Subset**

125 This document defines a safe G-Code subset with the MIME Media Type
126 "application/vnd.pwg-safe-gcode". Safe G-Code files consist solely of the following
127 commands which represent the common subset of commands supported by most FDM
128 printers:

129 G0: Rapid Linear Move

130 G1: Controlled Linear Move

131 G4: Dwell

132 G21: Set Units to Millimeters

133 G28: Move to Origin (Home)

134 G90: Set Absolute Positioning

135 G91: Set Relative Positioning

136 G92: Set Position

137 M82: Set Absolute Extrusion

138 M83: Set Relative Extrusion

139 Tnnn: Set Tool

140 Machine ("M") commands are not allowed since they directly control or access the machine
141 hardware. Temperature control and other machine settings are the responsibility of the IPP
142 Printer, which will likely use the IPP Job Template attribute values to send the corresponding
143 printer-specific G-code commands to a lower-level controller.

144 The line number command ("N") and checksum ("*") are similarly not allowed because they
145 are used for direct communications with the controller - IPP provides the necessary
146 infrastructure for reliable communication of the G-Code file to the IPP Printer.

147 Comments starting with the ";" character are allowed and continue to the end of the current
148 line.

149 For simplicity, safe G-Code always uses millimeters for the units (the default).

150 **3.1 G0 and G1: (Rapid/Controlled) Linear Move**

151 These commands move the current tool (extruder) and/or extrude material for printing.
152 Parameters for this command are:

- 153 Xnnn: Set X position in millimeters
- 154 Ynnn: Set Y position in millimeters
- 155 Znnn: Set Z position in millimeters
- 156 Ennn: Extrude the specified number of millimeters of material
- 157 Fnnn: Set the feed rate in millimeters/minute
- 158 Note: The "S" parameter is not allowed in safe G-Code.

159 **3.2 G4: Dwell**

160 This command pauses printing for a specifies amount of time. The "Pnnn" parameter
161 specifies the time interval in milliseconds.

162 **3.3 G21: Set Units to Millimeters**

163 This command explicitly specifies that coordinates are in millimeters (the default).

164 Note: This command is only provided for completeness - there is no support in safe G-Code
165 for any other units.

166 **3.4 G28: Move to Origin (Home)**

167 This command moves the current tool to the home position (end stops). The "X", "Y", and
168 "Z" parameters may optionally be specified to move the tool on the specified axes - if not
169 supplied the tool is moved on all axes.

170 **3.5 G90: Set Absolute Positioning**

171 This command specifies that all coordinates are relative to the origin of the machine.

172 **3.6 G91: Set Relative Positioning**

173 This command specifies that all coordinates are relative to the current position of the tool.

174 **3.7 G92: Set Position**

175 This command sets the current tool positions without moving or extruding material.
176 Parameters for this command are:

- 177 Xnnn: Set X position in millimeters

178 Ynnn: Set Y position in millimeters

179 Znnn: Set Z position in millimeters

180 Ennn: Set extrusion to the specified number of millimeters of material

181 All positions are set to 0 if no parameters are specified.

182 **3.8 M82: Set Absolute Extrusion**

183 This command specifies that the extrusion ("E") coordinates in move commands are
184 absolute.

185 **3.9 M83: Set Relative Extrusion**

186 This command specifies that the extrusion ("E") coordinates in move commands are relative.

187 **3.10 Tnnn: Set Tool**

188 This command sets the current tool (extruder) to use, starting at 0.

189 Editor's Note: Discuss how client maps tool numbers to materials.

190

4. Generating Safe G-Code

IPP Clients [RFC8011] and Infrastructure Printers [PWG5100.18] can generate safe G-Code using the values of Printer Description attributes reported by the IPP Printer or Proxy. Table 1 shows the information that is needed to generate safe G-Code for a printer. [The "materials-col" values are obtained from the "materials-col-database" and/or "materials-col-ready" Printer Description attributes which provide a list of all possible materials and those that are loaded in the Printer, respectively.](#)

Table 1 - Information Needed to Generate Safe G-Code

Description	Current IPP Attribute
Accuracy limits/minimum layer height	print-accuracy-supported (collection)
Build platform dimensions	printer-volume-supported (collection)
Build platform shape	platform-shape (type2 keyword)
Extruder nozzle size/maximum layer height	See section 4.1
Filament diameter	materials-col.material-diameter (integer)
Retraction support	See section 4.1

4.1 Material Extrusion Parameters

IPP 3D v1.0 [PWG5100.21] does not define attributes or values for the extruder nozzle size, nor does it define a way to specify whether retraction is used. These can be added to the "materials-col" collection as:

"material-nozzle-diameter (integer(0:MAX))": Specifies the required extruder diameter in nanometers, with the value 0 indicating the nozzle diameter is less than 1 nanometer.

"material-retraction (boolean)": Specifies whether retraction should be used with the material.

A corresponding "material-nozzle-diameter-supported (1setOf (integer(0:MAX) | rangeOfInteger(0:MAX)))" Printer Description attribute can provide the supported nozzle diameter values. [The presence of 'material-retraction' in the "materials-col-supported" Printer Description attribute indicates that the Printer supports material retraction.](#)

4.2 Support for Additional "Safe" G-Code Commands

In addition to the common subset of G-Code commands listed in the previous sections, newer FDM printers support additional "safe" commands such as mixing of extruded material ("M163", "M164", and "M165"), controlled arc ("G2" and "G3") and Bézier cubic spline ("G5"). In order for a generic slicer to support these commands, a printer needs to advertise its support for them. The usual method employed for IPP is a PDL-specific capability attribute, such as "safe-gcode-supported (1setOf text(MAX))" with each value corresponding to a named command.

Deleted: Extruder Nozzle Size

Deleted: Currently

Deleted: only

Deleted: and

Deleted: support

Deleted: have not been defined but

Commented [MS1]: DISCUSS: Pause (M226), Display (M70), Sound (M72), Set Build Percentage (M73) commands. Also "printer-state-reasons" keyword for when pause command is active?

226 **5. Printing Safe G-Code**

227 Printers that support safe G-Code can largely pass the print file to the controller - typically
 228 all that is required is to add printer-specific commands to initialize the printer to set
 229 temperatures and other machine settings, send the print file, and then add printer-specific
 230 commands to return the printer to an idle state.

231 Status information returned by the printer can be used to set the values of the various IPP
 232 Printer Status attributes.

233 **5.1 Adding Printer-Specific Machine Commands**

234 IPP Job Template attributes provide the values for extruder and build platform temperatures,
 235 as well as the list of materials used in the print job. Table 2 lists the standard attributes a
 236 FDM printer can use to configure the machine prior to printing.

237 **Table 2 - IPP Job Template Attributes**

Description	IPP Attribute(s)	Typical G-Code
Build platform temperature	platform-temperature	M140/M190
Chamber humidity	printer-volume-humidity	M146
Chamber temperature	printer-volume-temperature	M141/M191
Extruder nozzle size	materials-col/material-nozzle-diameter	
Extruder temperature	materials-col/material-temperature	M104/M109
Filament color	materials-col/material-color	
Filament diameter	materials-col/material-diameter materials-col/material-diameter-tolerance	M200
Filament type	materials-col/material-type	
Flow rate	materials-col/material-rate materials-col/material-rate-units	M203
Job Name	job-name	M531
Print accuracy	print-accuracy	M201/M202/ M222/M223
Print quality/speed	print-quality	

238 When an IPP Client does not specify one or more of these attributes, the corresponding
 239 default attribute values are used - "materials-col-default", "platform-temperature-default",
 240 "print-accuracy-default", "print-quality-default", "printer-volume-humidity-default", and
 241 "printer-volume-temperature-default" for the attributes in Table 2.

Deleted: and

242 **5.2 Printer-Specific Attributes and Values**

243 IPP allows implementors to add printer-specific attributes and values as defined in section 7
 244 of [RFC8011]. However, printers cannot depend on IPP Clients or Infrastructure Printers to
 245 support such attributes or values, particularly for generation of safe G-Code. Default values
 246 should be used as a backup when necessary.

Formatted: IEEEStd Paragraph

248 **6. IANA Considerations**

249 **6.1 Attribute Registrations**

250 The attributes defined in this white paper will be published by IANA according to the
 251 procedures in IPP/1.1 Model and Semantics [RFC8011] section 7.2 in the following file:

252 <https://www.iana.org/assignments/ipp-registrations>

253 The registry entries will contain the following information:

254	Job Template attributes:	Reference
255	-----	-----
256	materials-col (1setOf collection)	[PWG5100.21]
257	material-extruder-diameter (integer(0:MAX))	[SAFEGCODE]
258	material-retraction (boolean)	[SAFEGCODE]
259		
260	Printer Description attributes:	Reference
261	-----	-----
262	material-extruder-diameter-supported (1setOf (integer(0:MAX)	
263	rangeOfInteger(0:MAX))	[SAFEGCODE]
264	safe-gcode-supported (1setOf text(MAX))	[SAFEGCODE]

265 **6.2 MIME Media Type Registration**

266 The MIME media type defined in this white paper will be published by IANA according to the
 267 procedures in the Media Type Specifications and Registration Procedures [BCP13] in the
 268 following file:

269 <https://www.iana.org/assignments/media-types>

270 The registry will contain the following information:

271 Type name: application
 272
 273 Subtype name: vnd.pwg-safe-gcode
 274
 275 Required parameters: N/A
 276
 277 Optional parameters: N/A
 278
 279 Encoding considerations: US ASCII
 280
 281 Security considerations: Safe G-code prohibits machine control commands,
 282 however it is up to the consumer to verify that such commands are not part
 283 of the print file.
 284
 285 Interoperability considerations: While the format is interoperable, the
 286 contents of each file are still specific to the combination of material
 287 parameters and printer capabilities used for the G-code.
 288

Commented [MS2]: DISCUSS: Make this standards-track or leave a vendor extension?

289 Published specification: [this white paper]
290
291 Applications that use this media type: IPP 3D
292
293 Fragment identifier considerations: N/A
294
295 Additional information:
296
297 Deprecated alias names for this type: N/A
298 Magic number(s): N/A
299 File extension(s): gcode
300 Macintosh file type code(s): N/A
301
302 Person & email address to contact for further information: Michael Sweet,
303 msweet@apple.com
304
305 Intended usage: COMMON
306
307 Restrictions on usage: N/A
308
309 Author/Change controller: The Printer Working Group, c/o The IEEE Industry
310 Standards and Technology Organization, 445 Hoes Lane, Piscataway, NJ
311 08854, USA
312
313 Provisional registration? (standards tree only): No

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340 Semantics", RFC 8011, January 2017,
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351 white paper:

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353 **9. Change History**

354 **[9.1 April 26, 2018](#)**

- 355 [1. Made a PWG Best Practice working draft.](#)
- 356 [2. Added reference to RepRapWiki for G-Code](#)
- 357 [3. Added reference to ISO 6983-1 for current official G-Code specification](#)
- 358 [4. Section 4: Mention materials-col-database and materials-col-ready](#)
- 359 [5. Section 4.1: Retitle as "Material Extrusion Parameters"](#)
- 360 [6.](#)

361 **9.2 April 16, 2018**

- 362 1. Status: Interim
- 363 2. Introduction: Added discussion of nozzle and filament diameter influencing
- 364 portability of G-code, and why we want this.
- 365 3. Added G21, M82, and M83 commands, and hooks for other printer-specific
- 366 commands (safe-gcode-supported)
- 367 4. Updated T command (set tool) to use 0 as the first index.
- 368 5. Added sections on generating and printing safe G-code
- 369 6. Added IANA registration of new attributes and the MIME media type
- 370 7. Added references to 3MF slicing and RFC 8011.

371 **9.3 April 12, 2018**

372 Initial revision.