Next Generation 3D Printer

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Concept Generation and Selection
Document

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Contents

1. Introduction

The engineering design program at Northern Arizona University (NAU) is striving to assist in the collaboration of its students with fellow organizations to help instill the necessary qualities and experience needed in future careers. As a realization of this ideal, the Novakinetics team (NT) has been organized through a senior-level capstone course to work with their client, Novakinetics, to conceptualize and design a more efficient and cost effective large scale 3D printer.

Through state of the art research, the NT realizes the limitations and potential of the 3D printing process. Such limitations include print speed, print volume, cost and accuracy. To address such limitations, the NT has established the objectives to increase the print speed, maximize accuracy, reduce maintenance, make it safe to operate and easy to use, and as well be economical. With a design that can meet such limitations, the NT will be able to produce a finished product which will ultimately optimize Novakinetics current manufacturing process. However, in order to produce such a product, the NT must first identify the components required to achieve the various functions of a 3D printer.

The following report will discuss the NT's conceptualization and selection process of individual components which make up a 3D printer. The first step of this process is to identify the functions of a 3D printer. In the following section, a functional diagram will be established to organize such functions in relation to each other. The second step is to establish criteria of each function along with their corresponding relative weights. With an established functional diagram and relative weights, a concept generation process will be conducted. In this section, individual concepts will be discussed in relation to the functions of a 3D printer. These concepts will then be ranked by means of decision matrices, which will lead to the selection process of individual components. Lastly, an updated project plan will be discussed to clarify what the Novakinetics team has done, and still needs to do in regards to the overall project.

2. Functional Diagram

2.1 Introduction

A 3D printer has many different functions that need to be identified. To do this, a functional diagram must be made. This diagram is useful for identifying the main functional properties of a complex machine. In this case, a function is something that accomplishes a certain task in a process. The different functions all work together to accomplish the ultimate goal. Once the different functions are identified, the criterion of each function can be established to determine relative importance. The next section will show the functional diagram for a 3D printer.

2.2 Functional Diagram

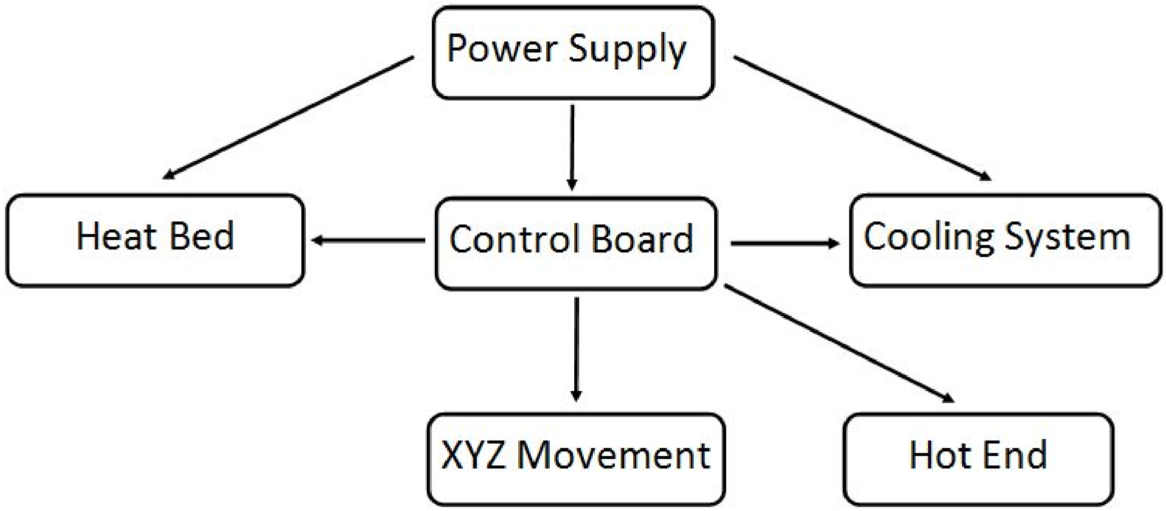

Figure 1: Functional Diagram

Figure 1 shows the basic functional diagram for a 3D printer. Computer Programs, CAM and CAD tools, and firmware are more discrete sub functions of a 3D printer, but in regards to this functional diagram, the team decided to focus on the general functions of a 3D printer. These general functions include the power supply, the heat bed, the control board, the cooling system, XYZ movement, and the hot end.

The power supply is the energy source of the 3D printer. In the United States, the voltage of a standard wall electricity output in a home is 120V. The main power supplies that 3D printers use are standard universal power supplies, ATX power supplies from computers, or any kind of power supply available that can support the proper wattage of the 3D printer system.

The heat bed is the platform in which the part is made. Some 3D printers utilize glass as the print surface. In larger scale models, a heated print bed is desired. The purpose of a heated print bed is to prevent the layers of the print from warping. This problem is prevalent in large print areas. For the bed to function, power must be supplied in order to generate heat.

The control board is what translates commands from the computer into movement of the printer, which is why XYZ movement branches off of the control board. The computer will communicate with the control board through various programs. These programs break a 3D model down into many layers and translate it into machine code called "G-Code". The control board interprets the G-Code commands into movement of the various stepper motors, which in turn coordinates movement of the 3D printer extruder in the XYZ directions.

The cooling system is what keeps the 3D printer from getting too hot. Computer fans are often selected for the cooling process. These fans generate enough airflow to the hot end and prevent warping. Liquid cooling is also utilized in some 3D printers. The power supply also requires cooling often, but most power supplies include a fan pre-installed.

Finally, the hot end is the nozzle that melts the plastic filament in order to create each layer. These hot ends can often have up to 4 different nozzles that extrude different color filament. They can also have a single nozzle for a basic design. The control board will also communicate with the hot end to regulate heating temperature and extrusion rate. The client has specific requirements that the 3D printer must meet. The team must build and evaluate criteria for each function so that the 3D printer will meet the client's specifications.

3. Criteria of Functions

3.1 Introduction

In order to create relative weights for the criteria, each team member did a piecewise comparison of the criteria for each function. The scale used can be seen in Table 3.1. Our team's six piecewise comparisons were then averaged to create our final weights for each criteria. These weights were then used in our decision matrix in section 4.3, to select the components for each function. Section 3.2 contains all of the piecewise comparisons, along with descriptions of the criterion.

Judgement	Numbering
Extremely Preferred	9
Very Strongly Preferred	7
Strongly Preferred	5
Moderately Preferred	3
Equally Preferred	1

Table 3.1

3.2 Relative Weights of Criteria

In Table 3.2, the team established the criteria for the power supply as ease of implementation, power output, and cost. Ease of implementation is rated in terms of how much work needs to be done before it is ready to be implemented into the 3D printer and received a weight of 0.288. The power output was based upon how much power the power supply can output, and was weighted the heaviest at 0.462. Lastly, the cost was rated on how low the cost is and received a weight of 0.250.

Power Supply

Criteria	Ease of Implementation	Power Output	Cost	Overal l
Ease of implementation	0.167	0.432	0.26 3	0.288
Power Output	0.480	0.370	0.53 6	0.462
Cost	0.353	0.197	0.20 1	0.250

Table 3.2

In Table 3.3, the team established the criteria for the control system as open source, multiple motor drivers, and modular. Open source is based on the availability of code for the control board and whether we can modify existing code to fill our needs. This criteria was determined to be the most important and had a weight of 0.359. Next the multiple motor drivers was simply rated on how many stepper motors the control board can control and was weighted at 0.350. Lastly, modularity was based on how the control board was built, and whether individual components can be replaced or upgraded, and was weighted the lowest at 0.291.

Control System				
Criteria	**Open Source**	**Multiple Motor Drivers**	**Modula r**	**Overal l**
Open Source	0.156	0.378	0.542	0.359
Multiple Motor Drivers	0.579	0.153	0.318	0.350
Modular	0.265	0.468	0.141	0.291

Table 3.3

In Table 3.4, the team established the criteria for the hot end as temperature, nozzle size, and reliability. Temperature is rated on how high of a temperature the hot end can reach, and was weighted at 0.301. Nozzle size is based on how large of a diameter the hot end has, in our case a larger nozzle diameter is preferred. The nozzle size was determined to be the most important criteria and weighted at 0.365. Lastly, reliability was based on how consistent the hot end is and how resistant to clogging it is. This criteria was weighted at 0.334.

Hot End				
Criteria	**Temperature**	**Nozzle Size**	**Reliability**	**Overall**
Temperature	0.204	0.255	0.444	0.301
Nozzle Size	0.448	0.219	0.430	0.365
Reliability	0.348	0.526	0.126	0.334

Table 3.4

In Table 3.5, the team established the criteria for the heat bed as temperature, cost, and speed. Temperature was based on how hot the heat bed can get and was given a weight of 0.236. Cost was based on how low the price of each heat bed is and was weighted the highest at 0.432. Lastly, the size was rated on the heat bed area, where a larger heat bed is preferred. The heat bed size was given a weight of 0.332.

Heat Bed				
Criteria	**Temperature**	**Cost**	**Speed**	**Overall**
Temperature	0.118	0.196	0.394	0.236
Cost	0.537	0.286	0.472	0.432
Size	0.345	0.518	0.134	0.332

Table 3.5

In Table 3.6, the team established the criteria for the XYZ movement, which is comprised of the stepper motors. The criteria are torque, step angle, and revolutions per minute (RPM). These criteria were all based on the specifications for each stepper motor where torque and RPM are desired to be maximized, and the step angle is desired to be minimized. Torque was given the highest weight at 0.434, step angle was given a weight of 0.366, and RPM was given a weight of 0.200.

XYZ Movement				
Criteria	**Torque**	**Step Angle**	**RPM**	**Overall**
Torque	0.199	0.629	0.474	0.434
Step Angle	0.513	0.174	0.410	0.366
RPM	0.288	0.197	0.116	0.200

Table 3.6

In Table 3.7, the team established the criteria for the cooling system to be efficiency, power consumption, and cost. Efficiency is based on how fast the cooling system can remove heat, and was given the highest weight at 0.381. Power consumption was based on the amount of power required for the cooling system and was given a weight of 0.272. Lastly, the cost was based on the price for each cooling system and given a weight of 0.347.

Cooling System				
Criteria	**Efficiency**	**Power Consumption**	**Cost**	**Overall**
Efficiency	0.195	0.445	0.502	0.381
Power Consumption	0.307	0.121	0.389	0.272

Cost	0.498	0.434	0.10 9	0.347

Table 3.7

4. Concept Generation

4.1 Introduction

The concept generation section takes the information from the criteria of functions and finds products on the current market to fulfill such needs. This is called concept generation and is helpful in determining different types of solutions. Multiple products are chosen in order to have a diverse pool to choose from. These products are then ranked by means of decision matrices, which in all will pertain to the team's selection process of individual components.

4.2 Concept Generation

To begin the concept generation process, it is important to start at the heart of the project, the power supply. The power supply is critical in a 3D printer because it is what powers the whole system. The power supply needs to be able to have a wide range of input voltages, a high Watts power output, and finally a high Amp output. Keeping this criteria in mind, three power supplies have been chosen. The chosen power supplies are the ATX Power Supply, LED Strip Power Supply, and Universal Power Supply. Listed in Table 4.1 below is each one of these power supplies as well as the common features. These common features include the power output, amps, and input voltage.

Table 4.1: Power Supply

Power Supply	Power Output	Amperage	Input V
ATX Power Supply	500W	16	115-2
LED Strip Power Supply	480W	10	115-2
Universal Power Supply	350W	29	110-2

The next decision to take a look at are control boards that are able to run the large scale 3D printer that Novakinetics needs. With many control boards on the market, the only boards to be considered are those that afford the most flexibility and expandability. These boards include the Azteeg X3 Pro, Smoothieboard, FastBot BBP, and finally an Arduino Mega. Table 4.2 below list these control board as well as comparing specifications between the possible choices including the supported firmware, max number of stepper motors, and max number of thermistors.

Table 4.2: Control Board

Control Board	Max # of Stepper Motor	Max # of Endstops	Max # of Thermistors	Firmware
Azteeg X3 Pro	8	6	3	Arduino IDE
Smoothieboard	5	6	4	Smoothie Firmware
FastBot BBP	6	5	3	Fastbot Firmware
Arduino Mega	4	6	3	Arduino IDE

Table 4.3 contains three different steeper motors that can be used to build a large scale 3D printer. These motors include the RepRAP, Kysan 1124090, and Nema-17. Criteria for comparing the stepper motors are the running voltage, torque, and degree of step angle.

Table 4.3: XYZ Movement

XYZ Movement	Running Voltage	Degree Step Angle	Max Speed	Torque
RepRAP	12V DC	1.8	200 RPM	0.48
Kysan 1124090	4.2V DC	1.8	400RPM	0.54
Nema-17	12V DC	0.9	600RPM	0.48

The hot end is important in determining both the resolution of a printed part as well as how long it will take to print. With this in mind three hot ends were selected for their reliability in other proven 3D printers. These hot ends include E3D Cyclops, E3D Volcano, and the MICRON3DP. Important specifications about each of these hot ends is listed below in Table 4.4 and include the nozzle size and maximum temperature.

Table 4.4: Hot End

Hot End	Nozzle Size	Max Temp.	Other Info
E3D Cyclops	.4mm	290 C	Multiple Material Feed
E3D Volcano	Multiple Sizes	290 C	up to +/-0.1mm accuracy
MICRON3DP	.35mm or .5mm	400 C	All Metal Hot End

The cooling systems main job is to keep the extruder cool in order to prevent clogging. Its secondary job is keep both the control board and stepper motors cool in order to extend their life-cycle. Three different and unique types of cooling systems were chosen as possible solutions. These included the EK-Water Cooling, Corsair AF140 fan, and the Addicore Heatsink. Corresponding specifications of the cooling method and unit cost can be found in Table 4.5.

Table 4.5: Cooling System

Cooling System	Cooling Method	Unit Cost
EK - Water Cooling	Forced Convection	$224.99
Corsair AF140 Fan	Forced Convection	$20.99
Addicore Heatsink	Natural Convection	$4.55

In order to keep printed parts from warping during the printing process multiple heated print beds will be used in order to create one large heated print bead. The options include the MK2A, MK2B, and the PiBot Heatbed. Their specifications of size and power input can be found bellow in Table 4.6.

Table 4.6: Heat Bed

Heat Bed	Size	Power Input
PiBot Heatbed	250mm x 250mm	12V or 24V
MK2B Heatbed	214mm x 214mm	12V or 24V
MK2A Heatbed	214mm x 214mm	12V or 24V

4.3 Decision Matrices

The following section contains all the decision matrices and the reasoning behind why a single products is a better choice when compared to its competition. Starting with the selection of the power supply, the ATX power supply was given the highest weighted total and therefore is the best choice for this particular application. All of the power supplies were compared based on the criteria of ease of implementation, power output, and the cost. The ATX power supply received high ratings in cost because one of our team mates is able to get them for free. The power output also received high marks because it has the highest output of 500W. Ease of implementation is low because the ATX power supply is not plug-and-play. It will have to be modified in order to work for this particular application.

Table 4.7 Power Supply Decision Matrix

Power Supply	LED Strip PSU		Universal Power Supply		ATX Po
	Unweighted Score	Weighted Score	Unweighted Score	Weighted Score	Unweighte Score
Ease of Implementation (0.288)	7	2.02	9	2.59	6
Power Output (0.462)	8	3.70	6	2.77	10
Cost (0.250)	6	1.50	7	1.75	10
Weighted Totals:	7.212		7.114		

When comparing the control boards the clear winner is the Azteeg X3 Pro. By reference of Table 4.8 it scored high in modularity and having multiple motor drivers. This is extremely important in being able to expand the printer later if changes need to be made. The Azteeg scored moderately in being open source because the board is only able to run basic firmware such as the Arduino IDE.

Table 4.8 Control Board Decision Matrix

Control Board	Azteeg X3 Pro		Smoothie		Fastbot BBP		Ardu
	Unweighted Score	Weighted Score	Unweighted Score	Weighted Score	Unweighted Score	Weighted Score	Unwei Sc
Open Source (0.359)	8	2.87	7	2.51	9	3.23	8
Multiple Motor Drivers (0.350)	10	3.50	6	2.10	7	2.45	5
Modular (0.291)	10	2.91	7	2.04	8	2.33	5
Weighted Totals:	9.282		6.650		8.009		

For the XYZ movement of the 3D printer the best suited stepper motor is the Nema 17-42BYGHM809. By having the lowest step angle this means that the Nema 17 will have a higher resolution and therefor the highest score. The RPM of the Nema 17 received the highest score due to it being the fastest. Torque was moderate and the score reflects this.

Table 4.9: XYZ Movement Decision Matrix

XYZ Movement	RepRap Stepper Motor		Kysan 1124090		Nema 17-
	Unweighted Score	Weighted Score	Unweighted Score	Weighted Score	Unweighte Score
Torque (0.434)	8	3.47	10	4.34	8
Step Angle (0.366)	5	1.83	5	1.83	10
RPM (0.200)	4	0.80	6	1.20	10
Weighted Totals:	6.102		7.370		

The hot end was a difficult decision. It came down to the Volcano having the highest scores in nozzle size as well as having good reliability. While the Volcano is not able to reach high temperature like the Micron 3DP it is still able to reach high enough temperatures to melt both PLA and ABS.

Table 4.10: Hot End

Hot End	Cyclops		Volcano		Mic
	Unweighted Score	Weighted Score	Unweighted Score	Weighted Score	Unweighte Score
Temperature (0.301)	7	2.11	7	2.11	10
Nozzle Size (0.365)	6	2.19	10	3.65	5
Reliability (0.334)	8	2.67	8	2.67	7
Weighted Totals:	6.969		8.429		

The cooling system was very close across the board. Overall the Corsair AF 140 fan is the winner because of receiving good rating in all categories of efficiency, power consumption, and cost.

Table 4.11: Cooling System

Cooling System	EK - Water Cooling		Corsair AF140 Fan		Addico
	Unweighted Score	Weighted Score	Unweighted Score	Weighted Score	Unweighte Score
Efficiency (0.381)	10	3.81	8	3.05	5
Power Consumption (0.272)	9	2.45	8	2.18	10
Cost (0.347)	5	1.74	9	3.12	10
Weighted Totals:	7.993		8.347		

When choosing the heat bed the MK2b heatbed is overall the best choice. It has very similar ratings compared to the PiBot. The deciding factor came down to how the weighted scores affected the unweighted scores.

Table 4.12: Heat Bed

Heat Bed	PiBot Heatbed		MK2B Heatbed		MK2/
	Unweighted Score	Weighted Score	Unweighted Score	Weighted Score	Unweighte Score
Temperature (0.236)	8	1.89	9	2.12	7
Cost (0.432)	9	3.89	10	4.32	8
Size (0.332)	10	3.32	8	2.66	8
Weighted Totals:	9.096		9.100		

5. Updated Project Plan

5.1 Completed Tasks

The team has completed approximately seven weeks of their thirteen week plan. In week one, the project objectives and constraints were defined and decision matrices were developed to aid in selection of crucial design components. In weeks two and three, the team focused on researching existing printing and coding techniques. From this, they were able to create a functional diagram and select a final design in weeks four and five. Once a final design was selected, basic CAD drawings were created to assist in further development of the design as well as estimating the total cost.

5.1 In-Progress and Upcoming Tasks

At the start of week eight, the team began selecting specific materials and components to be used in the final design. This task will be completed toward the end of week nine, at which point the team will begin construction of the prototype and the compilation of the code to be used. In weeks nine through thirteen, the focus will be to build and test the prototype and adjust the design as necessary. After completion of the prototype, the design and construction of the final product will begin.

Figure 2: Updated Project Plan

6. Conclusion

The team's client, Novakinetics, is in need of a more efficient manufacturing process in order to reduce the lead time for aerospace composite molds and tooling. This can be achieved using 3D printing by optimizing the process for large scale 3D printers while maintaining affordability. Through state of the art research, the team established objectives that their 3D printer design must meet. To create such a design, the team identified key operating functions using a functional diagram. For each function, criteria was established which were given relative weights using a piecewise comparison. With established relative weights for each criteria, the team then researched individual components in relation to each function. Decision matrices were then formed to rank and compare the individual components based on how well they met each weighted criteria. Using these decision matrices, the individual component selection process began.

In consideration to the power supply, the team decided to use an ATX power supply due to it being the most affordable and having the highest power output. For the control board, the Azteeg X3 Pro was selected due to being the most modular and being able to run the most stepper motors. For the hot end, the Volcano was selected due to it being to have the largest nozzle. To address the general XYZ movement of the printer, the Nema 17-42BYGHM809 stepper motor was selected due to possessing the smallest step angle and being able to run at highest speed. The team's cooling system will consist of multiple Corsair AF140 fans due to their low cost. Finally, the printer's heat bed will be custom built using multiple MK2B heat beds due to their ability to reach high temperatures and being the most affordable. With selected parts chosen, the next step as seen in the team's project plan is to design and build a prototype of certain portions of the 3D printer in order to prove the design validity and functionality.

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