EML 4501 Summer 2020 – Group 5
Anthony Restrepo, Brady Walter, Derek Teodoro, Josiah Bray, and Lucas Michels

String and Spring Precision Extraction and Extrusion Device (SSPEED)

Department of Mechanical & Aerospace Engineering
UNIVERSITY of FLORIDA

Abstract

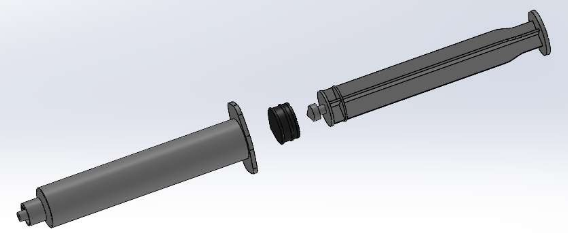
The objective of this summer 2020 Mechanical Engineering Design course was to design a 3D bioprinter capable of printing and extracting cells in a gel medium on top of a Nikon Eclipse Ti confocal microscope. Thus, a group of engineering students designed their own unique solution through an engineering design process wherein different concepts were generated, scored, and compared for selection for the final design. Based on a hedgehog concept where the design does not rely on microscope mounting turret to reduce vibrations and ease assembly, the String and Spring Precision Extraction and Extrusion Device (SSPEED) was conceived. SSPEED is a bioprinter unique in its design due to actuation of the printer head movements through a spring and string mechanisms. While tension springs forces movement in one direction, the control on the tension of a string with a stepper motor provides a precise actuation for printing. Therefore, this design allows for motors to be mounted outside the printer head fulfilling customer requirements. The height of the printer head is controlled through a string connected to a stepper motor and spool that compensates horizontal movement through a controls algorithm to maintain constant height. The extrusion and extraction flow rate are actuated through a lead screw mechanism that controls a disposable syringe for easy sterilization. Ultimately, due to its design simplicity, SSPEED is an affordable precision bioprinter.

Rendered image of full assembly

Product Functionality

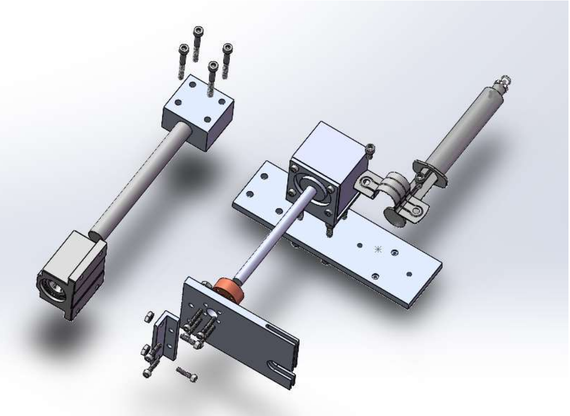
A motor with lead screw allows for an accurate actuation of **0.0552 µL** of cell deposition per motor step. The horizontal positioning of the printer head occurs with help of a string-spring system with accuracy of **8 µm** per motor step due to the presence of a 1 to 100 ratio planetary gear. Similarly, the height actuation possess the same planetary gear offering accuracy of **8 µm**. A disposable syringe is used as cell storage subsystem and a 25-gauge needle for nozzle subsystem due to ease on sterilization process as required. A software algorithm is programmed to compensate the change in length of the strings as the printer moves. It also utilizes the 3D mapping feature of the Nikon Eclipse Ti confocal microscope to orientate positioning of nozzle tip, so printing of multiple features is possible independent of human input.

Cell Storage subsystem



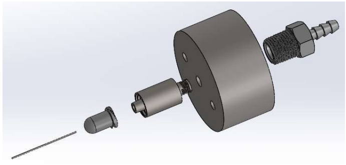
Exploded view of disposable syringe used as cell storage subsystem.

Cell Delivery subsystem



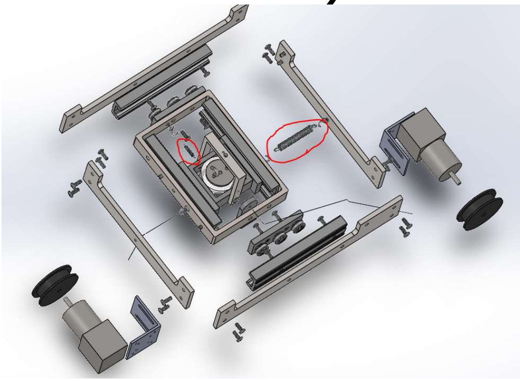
Exploded view of cell delivery subsystem illustrating lead screw motor, syringe, syringe plunger holder, guide shaft to prevent rotation and attachments.

Nozzle subsystem



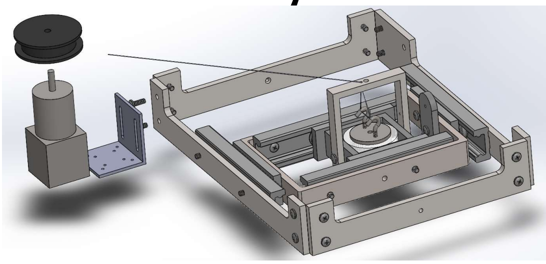
Exploded view of disposable needle nozzle subsystem showing all parts that goes through sterilization.

X and Y subsystem



Exploded view of X and Y subsystem. Springs are highlighted and dark spools holds wire and are attached to motor for X-Y actuation.

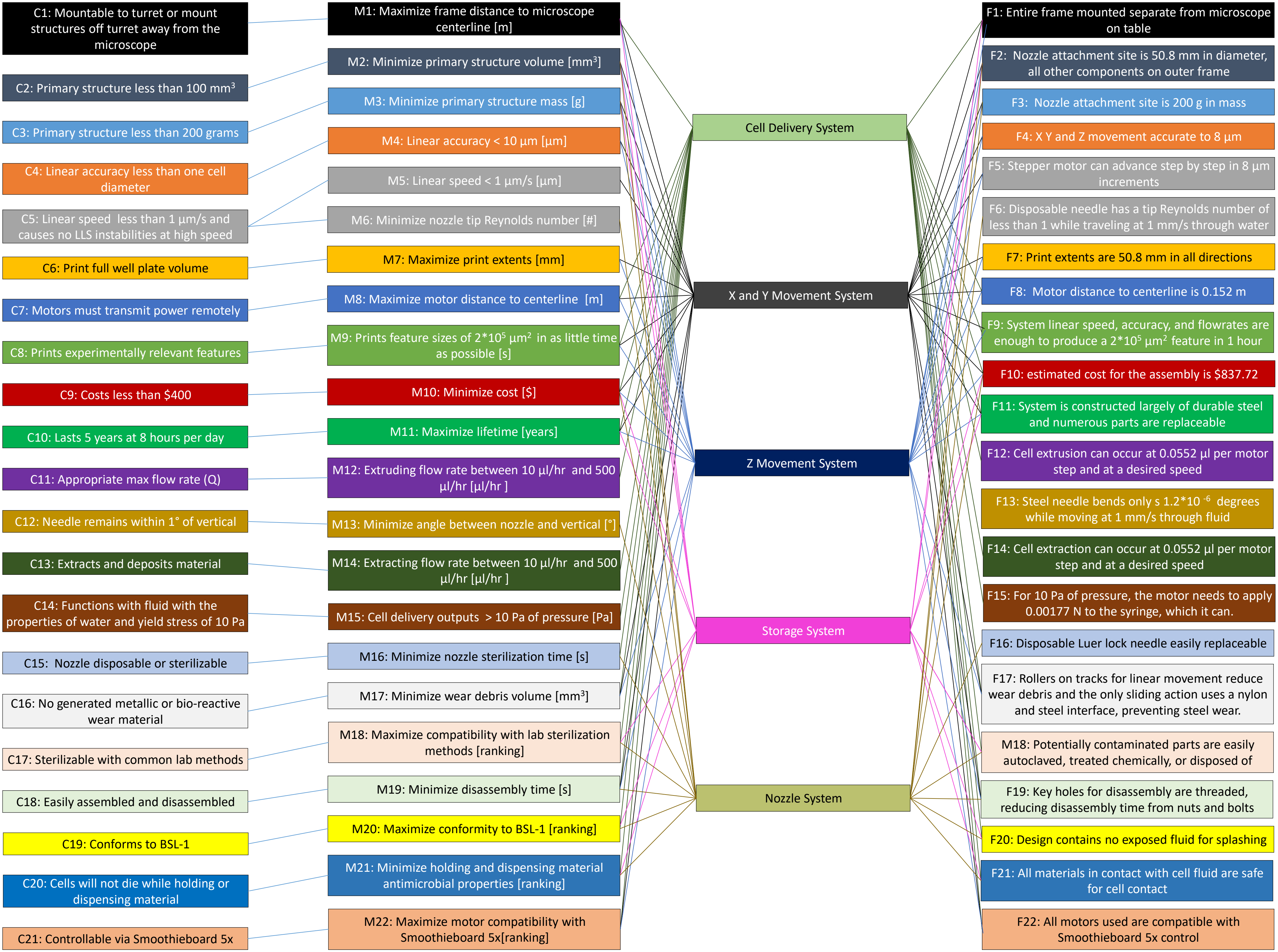
Z subsystem



Exploded view Z subsystem. A string length is controlled with a motor making nozzle subsystem move up and down.

Cost Overview

Subsystem	OTS	Raw material	Manufacturing (labor & energy)	Subsystem total
Cell delivery	149.44	33.45	0.43	183.32
X and Y	482.09	23.72	5.51	511.32
Z	16.77	2.81	2.7	22.28
Nozzle	0.09	0	0	0.09
Frame	0	11.99	12.48	24.47
			Assembly cost	96.24
			Total	**837.72**


C1: Mountable to turret or mount structures off turret away from the microscope
C2: Primary structure less than 100 mm³
C3: Primary structure less than 200 grams
C4: Linear accuracy less than one cell diameter
C5: Linear speed less than 1 μm/s and causes no LLS instabilities at high speed
C6: Print full well plate volume
C7: Motors must transmit power remotely
C8: Prints experimentally relevant features
C9: Costs less than $400
C10: Lasts 5 years at 8 hours per day
C11: Appropriate max flow rate (Q)
C12: Needle remains within 1° of vertical
C13: Extracts and deposits material
C14: Functions with fluid with the properties of water and yield stress of 10 Pa
C15: Nozzle disposable or sterilizable
C16: No generated metallic or bio-reactive wear material
C17: Sterilizable with common lab methods
C18: Easily assembled and disassembled
C19: Conforms to BSL-1
C20: Cells will not die while holding or dispensing material
C21: Controllable via Smoothieboard 5x
M1: Maximize frame distance to microscope centerline [m]
M2: Minimize primary structure volume [mm³]
M3: Minimize primary structure mass [g]
M4: Linear accuracy < 10 μm [μm]
M5: Linear speed < 1 μm/s [μm]
M6: Minimize nozzle tip Reynolds number [#]
M7: Maximize print extents [mm]
M8: Maximize motor distance to centerline [m]
M9: Prints feature sizes of 2*10⁵ μm² in as little time as possible [s]
M10: Minimize cost [$]
M11: Maximize lifetime [years]
M12: Extruding flow rate between 10 μl/hr and 500 μl/hr [μl/hr]
M13: Minimize angle between nozzle and vertical [°]
M14: Extracting flow rate between 10 μl/hr and 500 μl/hr [μl/hr]
M15: Cell delivery outputs > 10 Pa of pressure [Pa]
M16: Minimize nozzle sterilization time [s]
M17: Minimize wear debris volume [mm³]
M18: Maximize compatibility with lab sterilization methods [ranking]
M19: Minimize disassembly time [s]
M20: Maximize conformity to BSL-1 [ranking]
M21: Minimize holding and dispensing material antimicrobial properties [ranking]
M22: Maximize motor compatibility with Smoothieboard 5x[ranking]
Cell Delivery System
X and Y Movement System
Z Movement System
Storage System
Nozzle System
F1: Entire frame mounted separate from microscope on table
F2: Nozzle attachment site is 50.8 mm in diameter, all other components on outer frame
F3: Nozzle attachment site is 200 g in mass
F4: X Y and Z movement accurate to 8 μm
F5: Stepper motor can advance step by step in 8 μm increments
F6: Disposable needle has a tip Reynolds number of less than 1 while traveling at 1 mm/s through water
F7: Print extents are 50.8 mm in all directions
F8: Motor distance to centerline is 0.152 m
F9: System linear speed, accuracy, and flowrates are enough to produce a 2*10⁵ μm² feature in 1 hour
F10: estimated cost for the assembly is $837.72
F11: System is constructed largely of durable steel and numerous parts are replaceable
F12: Cell extrusion can occur at 0.0552 μl per motor step and at a desired speed
F13: Steel needle bends only s 1.2*10⁻⁶ degrees while moving at 1 mm/s through fluid
F14: Cell extraction can occur at 0.0552 μl per motor step and at a desired speed
F15: For 10 Pa of pressure, the motor needs to apply 0.00177 N to the syringe, which it can.
F16: Disposable Luer lock needle easily replaceable
F17: Rollers on tracks for linear movement reduce wear debris and the only sliding action uses a nylon and steel interface, preventing steel wear.
M18: Potentially contaminated parts are easily autoclaved, treated chemically, or disposed of
F19: Key holes for disassembly are threaded, reducing disassembly time from nuts and bolts
F20: Design contains no exposed fluid for splashing
F21: All materials in contact with cell fluid are safe for cell contact
F22: All motors used are compatible with Smoothieboard 5x control