DX Demo – Mechatronics Bio-Tech Diagnostics Testbed

San Diego State University

Simplexity Product Development

Abstract

The purpose of the DX Demo – Mechatronics Bio-Tech Diagnostics Testbed is to be able to demonstrate bio-tech and diagnostic processes that are being researched and used in today's medical field. The DX Demo - Testbed is a device that combines innovative biological processes to demonstrate the ability to rapidly decrease the time of accurate diagnosis. In the future, this product would be used to analyze blood samples to assist medical professionals to diagnose and choose successful treatment plans. Currently, the goal of this project is to demonstrate how combining standard biology lab practices with automation can advance the medical field and improve the quality of healthcare. In order to achieve this, the design includes a collaboration of both mechanical and electrical based subsystems that will aid in demonstrating multiple complex bio-tech and diagnostic subprocesses. The DX-Demo Testbed is a steppingstone towards what could be a game changer in the bio-medical field in years to come.

Project Description

Through the combination of electronical and mechanical integration, known as mechatronics, a Testbed was created to demonstrate innovative bio-tech within the diagnostic field. The project includes 4 biological processes:

I. Thermocycling
II. Sonication
III. Magnetic Separation
IV. Optical Examination

These biological processes have the potential to be incorporated in the diagnosis and examination of a biological fluid, like blood. The fluid would be injected into the flow path of a cartridge, experience each subprocess, and analyzed leading to a diagnosis. The diagram below explains in depth each process and their goals.

Biological Processes Explained

Thermocycling

I. The heating and cooling of a fluid is utilized for a biomedical process called Polymerase Chain Reaction (PCR).

II. DNA sections can be quantified (or amplified) without degradation of RNA.

III. Aids in detecting the presence or absence of a gene to help identify pathogens during infections.

Sonication

I. Ultrasonic frequencies are used for a process called Cell Lysis.

II. The intensity of the waves increase the permeability of biomass cell walls by generating cavitation events.

III. Aids in rupturing the cell wall, allowing for the release of intracellular constituents such a DNA.

Magnetic Separation

I. Magnetism is utilized in microfluidic technologies to locate desired molecular targets.

II. Magnetic nanoparticles are created to bind to targets, so when an external magnetic field is applied separation of the molecular targets occur.

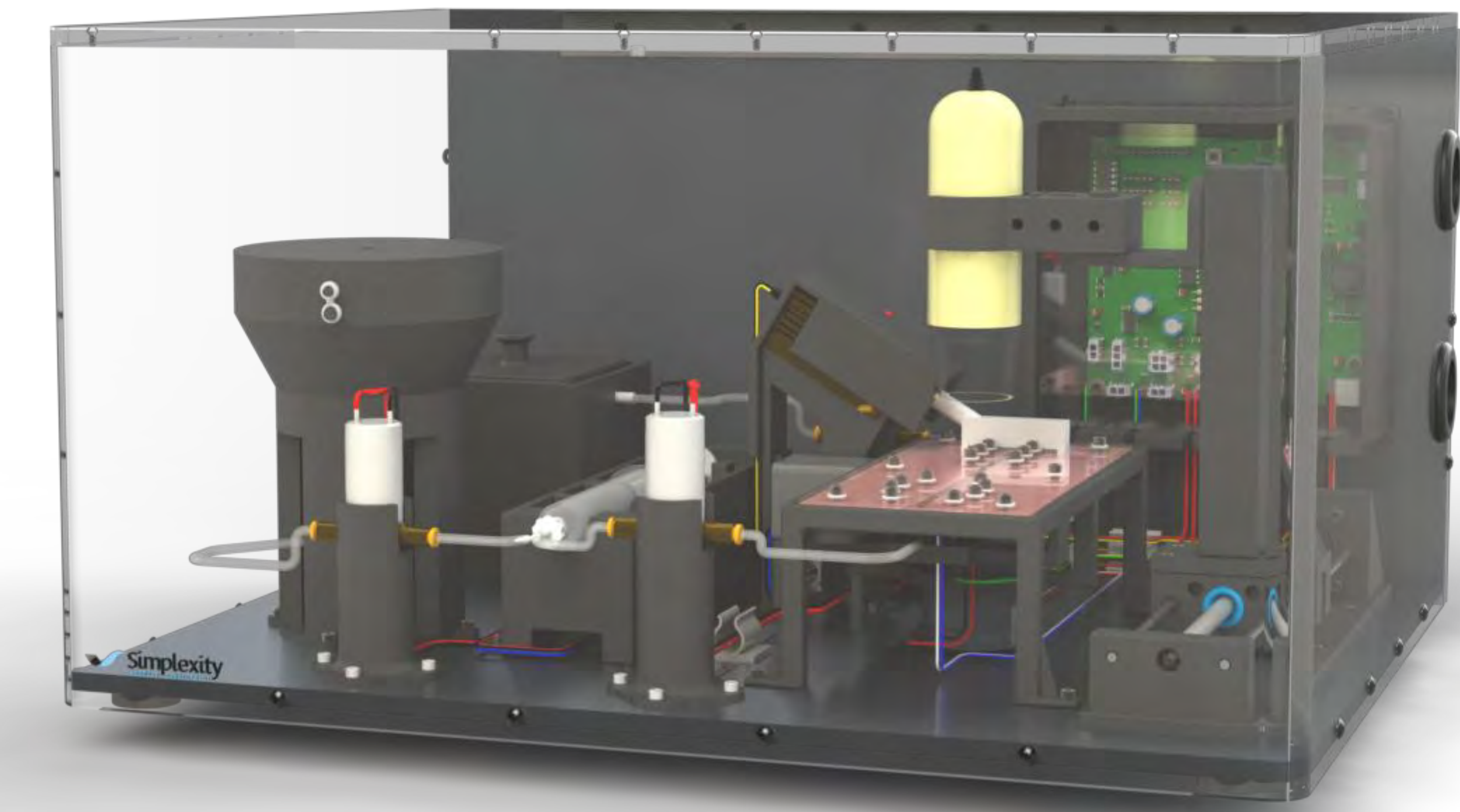
III. Aids in separation of small molecules, proteins, tissues, organisms, and inorganic materials, therefore having the potential to detect and monitor bacterial, viral, and other pathogenic contamination.

Optical Examination

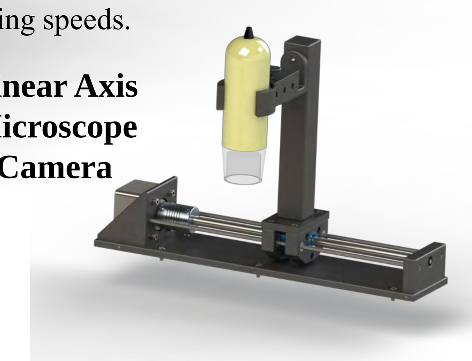
I. Optical photonics is used to examine the way light interacts with biological substances.

II. When conditions of pathology (disease) are present, the absorption, scattering fluorescence, amplitude, wavelength, and polarization properties of light passing through a biological sample often undergo significant changes that are measurable through optical examination.

III. Aids in non- or minimally-invasive, high resolution, rapid-real-time measurements differentiating healthy and diseased conditions at their earliest stages.



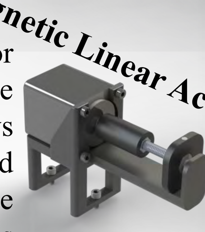
The DX Demo – Testbed was designed to demonstrate innovative bio-tech and diagnostic subsystems surrounded by a portable outer casing. The outer casing was designed to be transparent which allows for a clear view into the testbed. The bio-tech and diagnostic subsystems themselves are focused around a working fluid. The fluid is inserted into the device and as it moves through the system, the fluid is observed using a microscope camera. Designed for an enhanced perspective of the cartridge and the diagnostic subsystems, the microscope camera moves with the fluid. This is accomplished by attaching the microscope camera to a linear axis stage that can move in both directions at varying speeds.


Linear Axis Microscope Camera

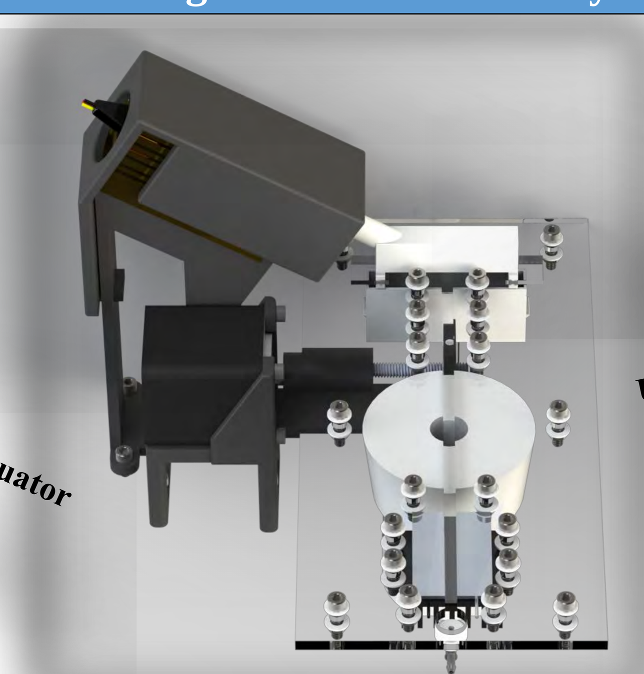
The Cartridge and Bio-Tech Subsystems

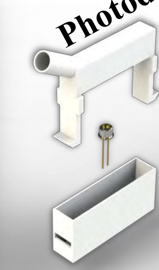

Laser Diode

The laser diode is a green Class II laser oriented to pass through the flow path within the cartridge. This subsystem corresponds with the photodiode system and plays a role in the optical examination of the biological fluid that would pass through the cartridge.


Magnetic Linear Actuator

The magnetic linear actuator osolates a magnet underneath the flow path of the cartridge. This allows for the separation of the magnetic and targeted particles within the biological fluid that would pass through the cartridge.



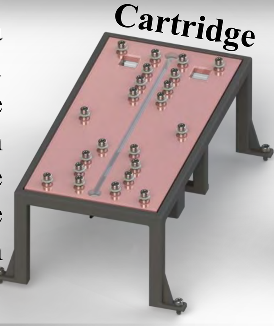

Photodiode

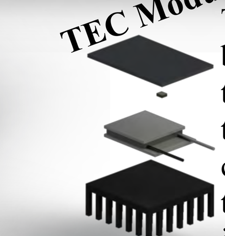
The photodiode is a sensor that interprets light and is integrated with the laser diode system. As the laser light passes through biological fluid within the flow path, the photodiode measures the change in the light and allows for the optical examination of the fluid.


Ultrasonic Transducer

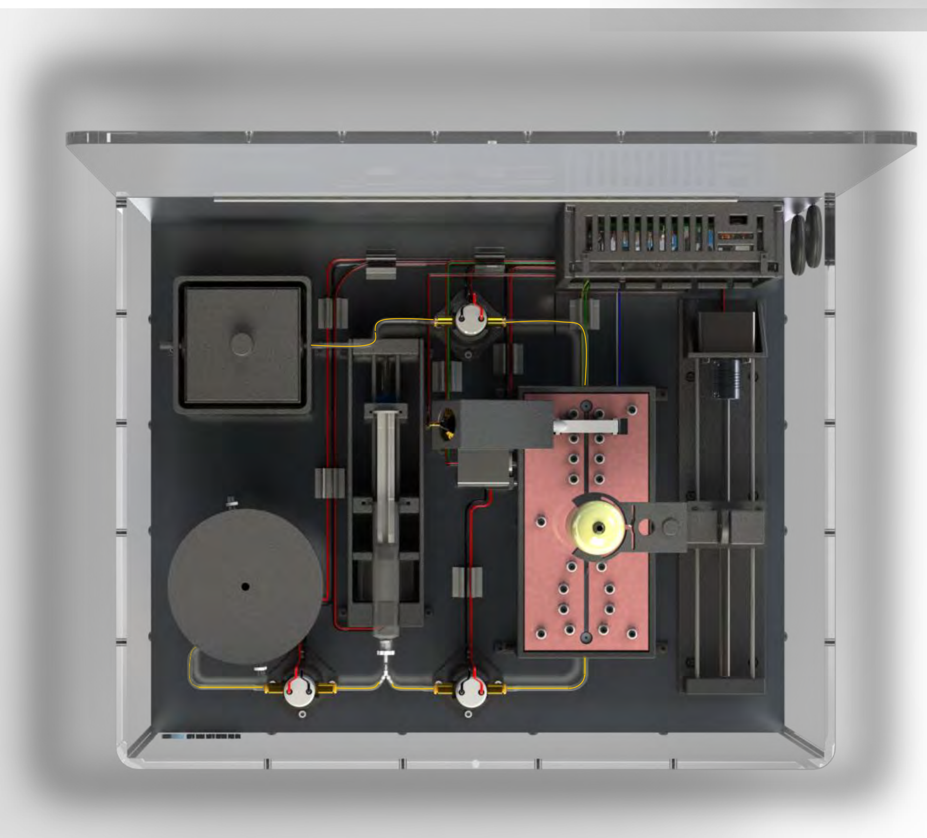
The ultrasonic transducer is a device that can resonate at an ultrasonic frequency. The face of the transducer is flush against the cartridge, allowing the frequency to penetrate the cartridge layers into the biological fluid in the flow path. This subsystem allows for the biological process of cell lysis to take place.

The cartridge allows the flow of the biological fluid to be in a compact environment for the biomedical process to occur. The flow path runs down the middle of the cartridge while the biological processes are placed in line with the flow path as seen in the center photo. The cartridge is made of five layers, two acrylic, two polycarbonate film, and one silicone layer, allowing for sealing as well as heat and vibration resilience.


Cartridge


TEC Module

The TEC module is a Thermo-Electric Cooler, that is in between a plate of aluminum, that aids in dispersing heat into the cartridge. A heat sink aids in the dissipation of heat from the assembly. The TEC assembly allows for cyclic heating and cooling of the biological liquid in the cartridge and conducts the biological process of thermocycling. This assembly also includes an RTD sensor that measures the changing temperature of the system.



The Fluid Flow

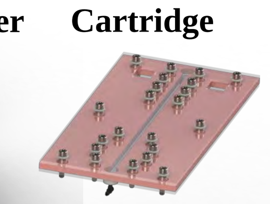
The fluid flow in the DX Demo – Testbed is the heart of the system and allows for the testbed to demonstrate and run the biological processes. To achieve this innovative way of fluid flow, a fill container (beginning point) and an emptying container (end point) were designed. These allow the system to run multiple demonstrations before the fluid needs to be refilled. To move the fluid about the system, a syringe pump was designed to suction the water from the fill container and pump it through the cartridge into the emptying container. Lastly, in order to control the flow of the fluid from these points and though the tubing, solenoid valves were place along the tubing, which close off sections of the flow path when needed. The top view of the testbed (left) displays all the fluid flow components (right) and the tubing pathway (highlighted yellow) the fluid passes through.

Fill Container

Syringe Pump

Empty Container

Cartridge



Solenoid Valve

The Electronics

The electronics board commands each of the functions on the testbed. Using the 100-Pin ATSAME51 Microcontroller, each of the subsystems is directed and sequenced. A 19.8V power adapter is used to provide power to each of the subsystems of the board. To meet the demands of all the devices, the voltage is stepped down to 12V, 5V, and 3.3V's. Codes and operations are written and stored directly onto the microcontroller. Commands are sent from a laptop computer which is directly connected to the board via USB.

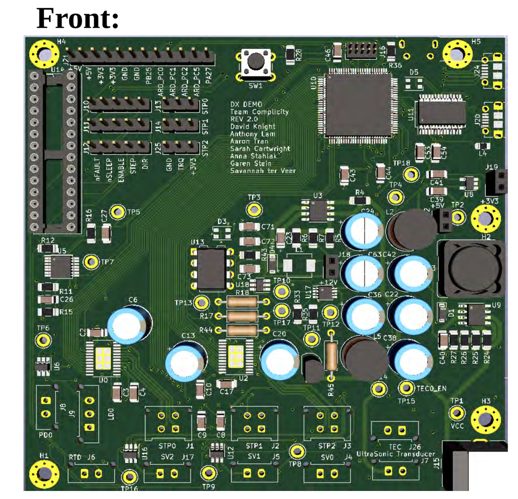

ATSAME51

To meet the demands of each of the subsystems, the ATSAME51 uses 100 pins in order to effectively operate the entire testbed. Every command from the computer is sent to the microcontroller which dictates which sequence or process is needed to start.

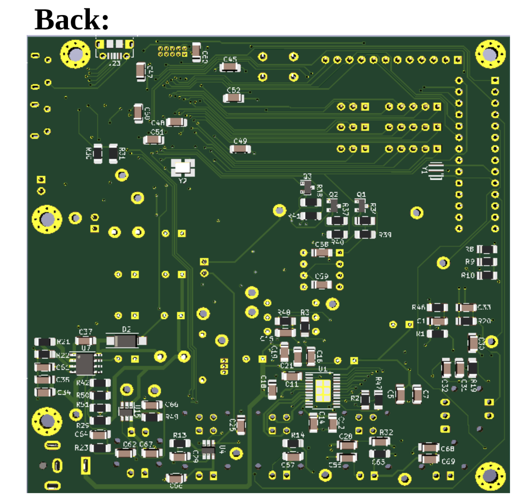
The FT232RL allows the microcontroller to communicate via Universal Asynchronous Receiver/Transmitter (UART) with the windows computer. Connected by a Micro-USB, the two devices communicate and update one another. The laptop sends commands, while the microcontroller replies with data.


FT232RL

Front:



Back:

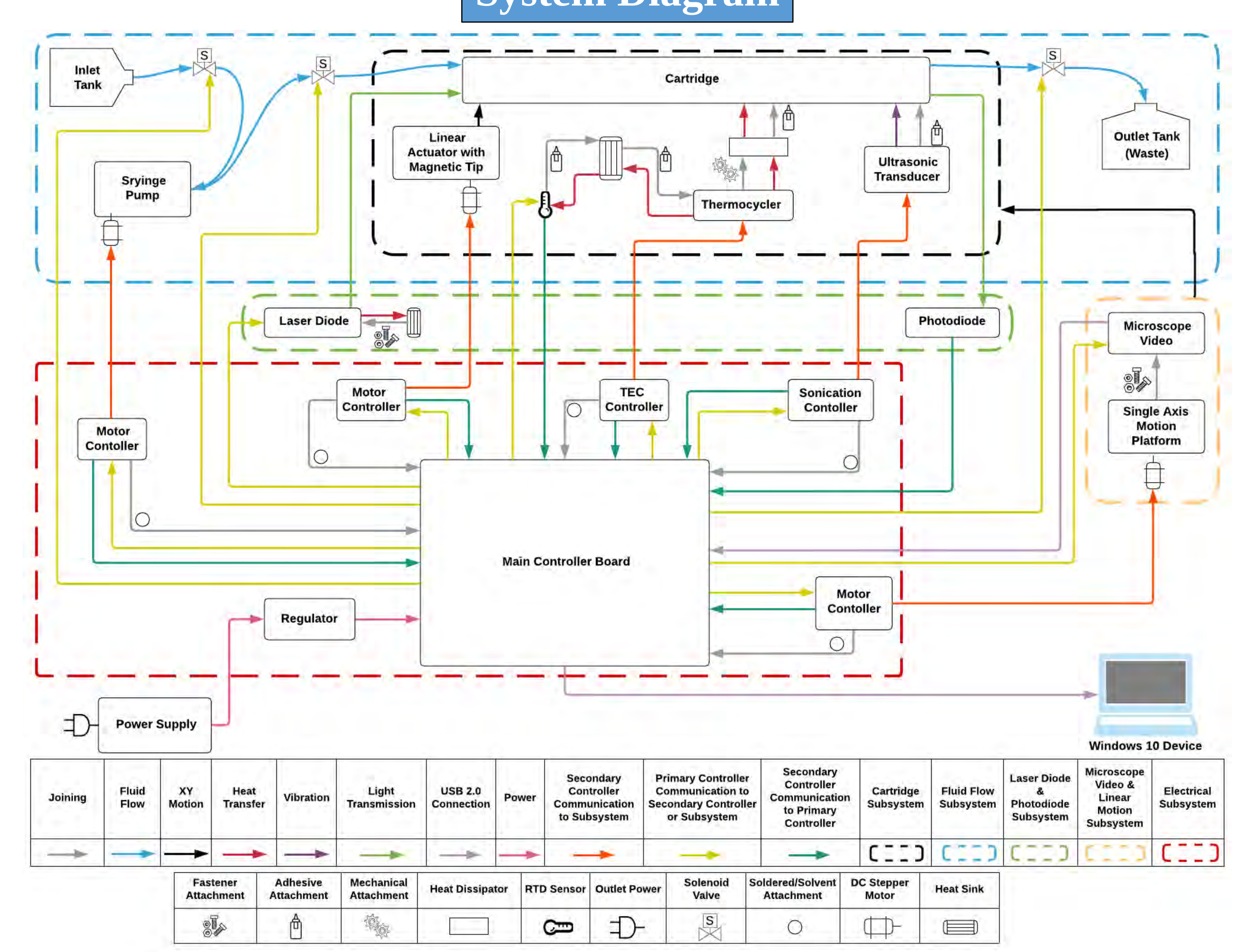


The Printed Circuit Board

The PCB makes use of both sides of the board, using both through hole and surface mount components. The use of both allow for a reduced size as well as the capability to handle higher voltages and currents where necessary. Using vertical Molex connectors, which are all positioned at the bottom of the board, allows for easy access and adjustment as well as a quick disassembly.

The board is powered by a 19.8V laptop power adapter which is convenient for transport and user friendly. The middle two layers are for 3.3V and GND, allowing for cleaner tracing across the entire board and giving room for a compact design. In the case of failure, an ATmega is placed on the board to allow for testing and running the subsystems, independent of the main controller.

System Diagram



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Spring 2020