The Ultimate Bionic Arm (T.U.B.A.)

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***Abstract* — T.U.B.A. was designed in partnership with Limbitless Solutions to investigate improvements to their current electronics in their low cost bionic limbs for children. Specifically, T.U.B.A. was built to demonstrate multiple Electromyography sensor input, multiple servo output, haptic feedback, wireless charging, and wireless re-programmability hardware while maintaining low weight and long battery life. This was accomplished by consulting with Texas Instruments about what chipsets were available and choosing the lowest power/ smallest packages that were available. T.U.B.A. was successful in demonstrating all of the aforementioned goals. While this exact implementation may not be used by Limbitless Solutions in the future, T.U.B.A. lays a foundation for Limbitless Solutions to build off of in the future.**

***Index Terms* — Haptic Feedback, Electromyography, Bionics, Limbitless Solutions, Texas Instruments**

I. INTRODUCTION

Begun by Albert Manero in the spring of 2014, Limbitless Solutions started as a small collective of individuals with the ethos that “no one should profit from a child in need”. Two years later, the nonprofit organization has advanced by leaps and bounds, with four directors overseeing five different teams looking to tackle the world of modern, low-cost 3D printed bionics. As they rise to meet the ever growing demand and need for their product, they struggle to maintain their product individuality, with each bionic limb being custom built and programmed to the interests of each of their clients.

Given that the majority of the Limbitless leadership find their specializations in the field of mechanical engineering, they rely greatly on the expertise and dedication of the Electrical Engineering student body to continue to push the electronics of their product to its next stages of evolution, with varying degrees of success: the problem has been solved, but the solution is crude, lacking elegance, and is prone to failure. Wanting to contribute beyond the normal boundaries of volunteering, the authors recommended that their capstone project be dedicated to helping Limbitless Solutions advance their electronics package to a more mass reproducible and reliable form, as this would allow the production team to focus their efforts in the future on individualizing the aesthetics of their products, rather than troubleshooting electrical problems.

Limbitless Solutions has a current electronics solution for their bionic arms that is built using different boards bought from various vendors and assembled on prototyping board. This is non-ideal from multiple standpoints, including price, footprint, reliability, and expandability. The current design has only basic functionality, as well as stability issues, as a result of lack of power regulation and voltage incompatibilities. As such, Limbitless Solutions has asked this team to design a new set of integrated electronics that will solve problems as well as increase functionality in these areas.

The electronics as they exist now are functional, but unstable. The package created serves two primary purposes. First, the team has created a more stable design. The second purpose is to examine additional desired functionalities, as well as analyzing components that are not being utilized on the boards. To eliminate these issues, the main electronics will be unified into a single printed circuit board that can be easily replicated for future product fabrications. Second, the additional research components will serve as a collection of various “plug and play” technologies that can be utilized in future designs. Care will be taken to ensure modularization of each section, such that if certain elements are not wanted for a specific arm, they can be easily truncated from the board. This will ensure that the solution can be used in a variety of different situations as needed by each individual client. Future compatibility will also be kept in mind during design. The team will ensure that future goals will be able to be implemented using this board. This includes having multiple EMG inputs, multiple servo outputs, and multiple haptic feedback sensors and mechanisms. In terms of future usage, the design will be updateable through plug-and-play expandability for the hardware components, in the case of additional units or more efficient hardware. Having a reliable hardware set will allow Limbitless Solutions to implement most of their future changes by only changing the software.

II. GOALS AND OBJECTIVES

For the execution of this project, Limbitless Solutions set forth specific criterion that they desired in their future builds, and, based off of these parameters, specific goals and objectives for the project were set. By setting these goals, the team ensured that an overall quality product was designed that improved upon the current solution. Each of these goals dictated the efforts and defined the general course of research. The goals and objectives of the T.U.B.A. were as follows:

A. Maintain Design Features - Ensure that the new set of electronics has all the same functionality as the current set up and more. At a minimum, the electronics should allow the user to control the hand by flexing a muscle on the limb with the bionic attachment.

B. Unify the Electronics - Create a PCB, or a series of PCBs, to optimize the electronic footprint and eliminate unused board space or unused functionality.

C. Update the Microcontroller - Switch to a different microcontroller that allows for expandability. The board must also not be mounted to an evaluation board. The main motivation behind this was that the current solution utilizes an Adafruit evaluation board for its processing needs. This results in several unutilized components, but that Limbitless were forced to purchase for each arm due to presence on the evaluation module. The new solution will seek to eliminate this wastage and only utilize components necessary for a successful solution.

D. Software Improvements and Customization - Upgrade the code and develop a calibration subroutine. This will allow the arm to be programmed for the individual.

E. Integrate Feedback System - Install a system of haptic feedback for the design. This will include a way for the user to get some sort of feedback, so that they are aware that the hand is actually closed on an object. This will add a feature that is included in much more expensive prosthetics, but at a lower cost.

F. Environmental Protection for Electronics – Methods of waterproofing and dust proofing were demonstrated in this project. Waterproofing the electronics built for T.U.B.A. was a stretch goal for the team if time allotted.

G. Protection from User Tampering - Create housing for the electronics that will prevent users from tampering. User interaction with the electronics can cause potential harm and cause system malfunctioning.

H. Improve Charging System - Add charging capabilities that does not expose the charging port to environmental hazards.

I. Wireless Software Updates – Add the hardware required for wireless programming capability so that the electronics can be programmed without the necessity to remove the electronics from the housing. Implementing the software for the wireless software updates was a stretch goal for this team.

J. Expandability and Future Improvements - Add the ability to include multiple electromyography inputs, as well as multiple haptic feedback inputs and outputs for future expansion of the design.

K. Affordability - Ensure the overall cost of the electronics solution is optimized, and remains affordable. Improve power efficiency to reduce the cost charging the battery.

L. Lightweight - Keep the weight of the electronics to a minimum, to ensure that arm does not feel uncomfortable.

III. SPECIFICATIONS

Limbitless Solutions provided the team with a set list of specifications to be integrated into the design.

Description	**Quantifiable Specification**
Electronics Weight	Less than 1.4 kg
Battery Life	10 Hours Standard Usage
Price (wholesale)	Under $350 for the overall electronics design
Environmental Protection	Demonstrate At least IP27
Wireless Programmable Range	Minimum of 3 meters
Charge Time From Entirely Drained Battery	Less than 10 Hours

Note: IP27 – "Protection against fingers or other object not greater than 80mm in length and 12mm in diameter. Protection against temporary immersion in water."

For the design, the team set the weight limit of the electronics to be under 1.4 kg, to keep the design lightweight. The battery life was requested to be 10 hours or longer. Hardware for over-the-air-download (OAD) was requested, and the wireless connection range was set to be within 3 meters. Since the team is made up of all Electrical Engineers with no Computer Engineers or Computer Scientists, Limbitless required the team to build in the hardware for OAD, but left the software as a stretch goal. As the battery would most likely be charged while the user is a sleep, the charge time from full drain was set to be less than 8 hours. With all of the specifications in mind, a higher cost could easily meet the specifications of the design. The goal of the Limbitless was to create an affordable bionic arm for children in need. To keep this aspect, the cost of the electronics was set to be under $300.

IV. MICROCONTROLLER OF CHOICE

Proper choice of an MCU lies at the heart of this project, as the choice needed to reflect not only the current build design, but also take into account all of the additional functionality that Limbitless hopes to include in the near future. When deciding on the microcontroller there were areas of importance to the project including, but not limited to communication protocols, wireless interface capabilities, pin quantities, timers, power requirements and dissipation, and most importantly, price.

The CC2640 is a dual mode Bluetooth microcontroller made by Texas Instruments that can implement Bluetooth 4.0, specifically the Bluetooth Low Energy (BLE) standard. The device comes pre-integrated with an ARM M3 Cortex processor, an extremely powerful processor with off the shelf OS capabilities. A lower ARM M0 separately handles all Bluetooth functionality. This device was an optimal choice from multiple standpoints including price, footprint and power requirements, ultimately leading to the means of communication via Bluetooth through a single chip solution.

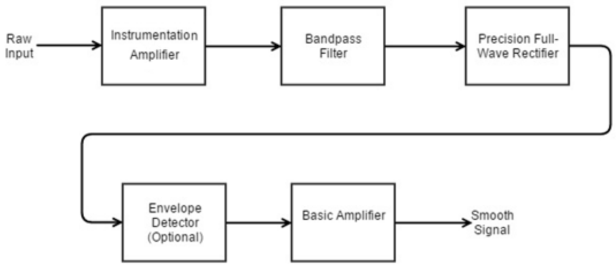
The CC2640 sports low power consumption, drawing only 61 μA/MHz during active mode calculations, and 1 μA/MHz while in standby mode. It is capable of a 48 MHz maximum clock speed via an external crystal. It comes embedded with 20 KB of low leakage SRAM, 128 KB flash, and 8KB of SRAM at the cache level. The CC2640 has four 32-bit timers, which can be divided further into eight 16-bit timers, each being able to be pulse width modulated. It also features an 8-channel, 12-bit ADC, capable of up to 200k samples per second. This MCU also has the unique feature of a programmable current source if required. A small downfall of this chip is the lack of a proper floating point unit. However, as there is no emphasis on calculation in the programming, this was only a minor inconvenience, with emulated floating point instructions still being capable on the chip

The final choice of this device led to the implementation of the LSR Sable-X, a CC2640 commercial off the shelf module that has pre-integrated clock crystals and radio traces. This choice greatly eased the burden of required effort on the Limbitless Solutions production team in regards to the tedium of RF trace integration, as well as simultaneously eliminating the hassle of FCC registration fees, as the product will now operate under LSR's umbrella for the module. Cost savings analysis was performed to examine the potential savings of the component solution against the increased cost of the module, and analysis showed that the component level design was not economically feasible given the current business model of Limbitless.

V. ELECTROMYOGRAPHY

Electromyography is reading the voltage produced by motor neurons when they are activated by the brain. In medicine, this can be used to ascertain the health of muscles and the neurons that control them. For this project, electromyography is only used to read whether or not a muscle is flexed.

Other techniques exist that allow the act of a muscle flexing to be transduced into an electric signal that could be used such as electrocardiographic and electroencephalographic sensors. Electromyography is the least intrusive of these methods (meaning that the other technologies can be uncomfortable to the user) and is the best researched for our application. Electromyography is usually used to measure minute changes in muscle health so the sensors have very high resolution and precision.



The signal coming from the muscles is roughly 1-10 mV, and 50-400 Hertz. This is a very small signal to start, but taking into account the large amount of noise that will come from the electrodes and the skin (if surface electrodes are used), this signal can be extremely difficult to detect. Detection requires the use of very sensitive amplifiers that have high Common Mode Rejection Ratio (CMRR).

After the signal is properly amplified and filtered, it needs to be rectified. With the analog to digital converters that are being investigated for use, the input voltage needs to be positive. As such, a full wave rectifier needs to be used to preserve the entire signal. Precision full wave rectifiers are suggested as they have the lowest noise and attenuation of the original signal. Often times, after the signal is fully rectified, a low-pass filter is used as an "envelope detector" to smooth out the signal. This low pass filter typically has a cutoff frequency of 100-200 Hertz. This will make the signal much closer to being a true DC signal.

Finally, a simple amplifier is used to compensate for any attenuation in the filtering or to invert the signal if needed (depending on the types of filters used, the signal can be inverted at the end of processing). This is typically a basic inverting or non-inverting amplifier with a potentiometer used for adjustable gain. The potentiometer allows the user to compensate for any day-to-day changes in muscle or skin conditions.

For the final solution, the MyoWare Muscle Sensor from Advancer Technologies was chosen. This Sensor follows the same filter design outlined above. The MyoWare gives the team a pre-built module that is small form factor, low power, and high reliability. It has been used by Limbitless Solutions for some time now with few issues and comes with high praise. The MyoWare Sensor requires the use of disposable EMG electrodes (the same kind used in hospitals for electrocardiograms) rather than reusable electrodes. This is not ideal as it pushes a recurring cost on the user, but for the purposes of demonstrating the capability in T.U.B.A. this was decided to be a nonissue.

VI. HAPTIC FEEDBACK

For the new Limbitless Solutions Bionic Arm, the group had been tasked with enabling a feature that will allow the user to have a sense of feeling when the arm is being utilized. This feature is important in order to let the user feel the arm as it operates. The current bionic arm allows the customer to pick up an object based on the flex of their muscle, but provides no form of feedback to show that the arm has been closed after it performs its task. Feedback for this purpose provides the user with the ability to feel the arm in action, and make the interface more realistic for the user. This type of feedback will ensure the user that the arm is functionally operating through a real-time response.

a) Haptic Sensor

In order to enable haptic feedback on the system, the arm must be able to sense when the hand is being closed or touching an object. The sensors that were chosen to interpret this input are force sensitive resistors (FSR).

Force-sensitive resistors are accurate enough to determine when pressure is applied. The sensing is not exact, but the specified range of the expected result from holding an object was coded to be recognized by the microcontroller. This range was determined after testing varying amounts of pressure and programming the ADC of the microcontroller to respond to this range. Since the hand will not be directly touching the palm of the hand at all times, the FSR was mounted onto the finger where the most contact with the object will be. The sensor was mounted to the surface of the thumb, as indicated by Limbitless as the location of the most contact. For the purposes of demonstrating the concept, one FSR was used for this design. Multiple of these resistors can be wired in parallel and placed at several locations on the hand. This configuration would achieve the same output as well.

b) Haptic Driver

The T.U.B.A. project utilizes a haptic driver in order to generate a feedback response to the user. Drivers are required for haptic systems as the processor, or microcontroller, cannot provide enough current to drive the physical actuator when the output is controlled by a microcontroller rather than a direct voltage. Common issues with actuators include the duration that the motor takes to start and stop its response. Drivers are programmed with protocols called Overdrive and Active Braking. These two techniques are essential in creating an effective system, and are only possible through the use of a driver. The driver also allows for the design to be programmable and have a wide variety of functionality. The DRV2605L is an Eccentric Rotating Mass (ERM) and Linear Resonant Actuator (LRA) Driver. The communication for this device is over an I2C bus or PWM input signal. This device allows for high flexibility over control of ERM and LRA actuators.

The DRV2605L has an embedded library of 123 different waveform effects for the output PWM signal. This allows the user to control the input that the actuator is receiving. The arm can be customized to the extent where if the child is grabbing an object with the arm, the child can receive a haptic motor feedback in the form of any of the programmable waveforms.

c) Actuator Feedback

For haptic feedback applications the actuator variant of choice is the ERM device. The device uses an unbalanced weight attached to the motor shaft, which rotates when current is supplied to the motor. The force created by the shifting weight about an axis causes the vibration sensation used in haptic systems. The ERM typically has a larger response compared to LRA devices, and with the customizations to the driver, the response can be modified to fit the individual. The LRA was originally chosen to be the actuator, as the ERM devices typically have an exposed motor. The ERM used in this design was a variation that was completely enclosed making it the ideal choice.

VII. FINGER ACTUATION METHOD

For the design of the T.U.B.A, the torque of the motor pulls on cables tied to the 3D printed finger mechanisms. The resulting pulling of cables causes each finger to curl towards the palm of the hand, forcing the hand to close. This actuation is possible through varying types of servos, but for the project the Tower Pro MG995 Servo was chosen.

The Tower Pro MG995 is a strong servo for its size although it is heavier than other servos in its class. It is also the only servo in its price range with metal gears. A standard angular servo was chosen versus a continuous rotation servo, as this gives better control for the application. For the price, rotational acceleration, current draw, and controllability, this is one of the best servos on the market. Without a significant increase in price, this servo cannot be beat in performance.

Since the project requires multiple servo outputs, a servo driver was chosen to control the servos. Specifically, the PCA9685 PWM driver was implemented. The PCA9685 is controlled via I2C and allows the microcontroller to control up to 16 servos utilizing only the I2C bus. This was chosen to allow for future expansion if multiple servos are required in future designs, without placing further strain on the dwindling number of available GPIO. Finally, the device has the capability to control further devices, including RGB LEDs, or any other expansion where PWM signals with a 20 ms period are required.

VIII. POWER AND BATTERY CHARGING

The current electronics are powered by a 3.7 volt, 2000 milliamp-hour Lithium Ion battery. Feedback from users indicates that this gives around 5-8 hours of usage. The client desired an increased battery life in addition to increased power provided to the servo to produce a more user friendly hand. The current hand uses a single cell 3.7 volt battery providing unregulated voltage to the integrated circuitry as well as to the single servo. With unregulated power the performance varies as the battery is depleted from normal use. Also the servo is severely lacking in holding power and takes an inordinate amount of time to close.

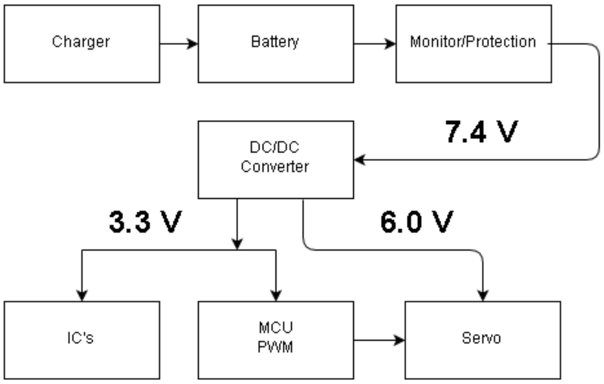
Upgrading to a two cell 7.4 volt battery addresses both issues for the performance of the servo. Application of 6 volts regulated to the servo improves both the holding power as well as drastically decreasing the time to close the hand.

The Tenergy Li-Ion 18650 battery has been chosen for its size, weight, and high energy density. The batteries' 5200mAh capacity provides the arm with eight to ten hours of run time provided that 85% of the operational time the hand is in the open position. The increased output voltage of 7.4V and current rating, allows for six volts with maximum current to be sent to the servo(s). The current design powers this servo at a maximum of 3.7V. This change is a significant improvement, and is what the servo is typically rated for. The battery has a built-in PCB to provide protection against overcharging.

To provide safe charging to the Li-Ion battery, a specific circuit was required. The BQ24123 chip provided by Texas Instruments was chosen. This allows for protection against over-heating, as well as, overcharging while allowing for cell load balancing and conditioning if the battery is excessively discharged.

One of the driving factors from the team's client is full isolation from the end user as well as the environment. To that end, induction charging was chosen as a proof of concept. The BQ500215 wireless transmitter and the BQ510215 wireless receiver provided by Texas Instruments were chosen for the induction charging pair. Evaluation boards are being used for the proof of concept of the design. From Texas Instruments the BQ51025 receiver came with the output limited to 7 volts. Modifying a resistor value on the receiver evaluation module allowed the team to increase the output to 10 volts in order to meet the requirements of the battery charging circuit design, which requires a range from 9 to 16V.

The project required several voltages in order to run the electronics. All of the integrated circuits, as well as the MCU, for the T.U.B.A. required a 3.3V source. The servo required a larger voltage than 3.3V to run the servo on its proper operating voltage. Using the 7.4V battery source, the TPS65257 Triple Buck Converter, was used for regulating these voltages from the battery source. Below is the block diagram showing the power flow from the charging unit to the battery to the circuitry and the servo(s).



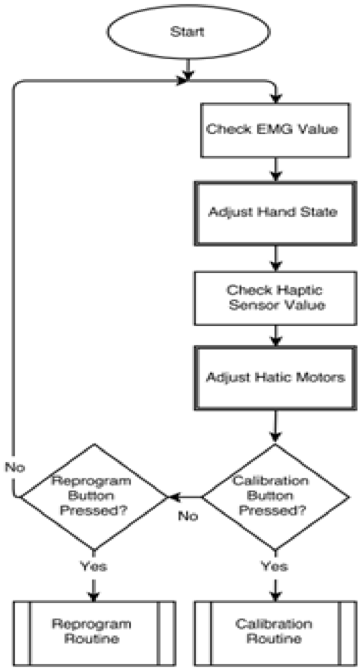
The TPS65257 takes a large portion of board space, approximately fifty percent. The footprint for a two voltage rail output would have been vastly smaller, but to allow for future expansion an additional voltage rail was necessary to provide power to future components that could require a 5V source.

Utilizing the six volt rail of the TPS65257 allowed for the servo to be operating at its rated voltage. Due to design constraints, the original arm was under powering the servo at 3.7 volts. The increase in voltage greatly improved the speed of the servos actuation. At 6 volts the time for the servo to open and close the hand was reduced down to approximately 2 seconds. This was an extremely large improvement to the original time of 0.5 seconds.

IX. CODE

Texas Instruments Real Time Operating System (hereinafter referred to as TI-RTOS) was used as a backbone for the final code. This comes with a host of built in libraries and Application Program Interface (hereinafter referred to as API) to control all of the onboard peripherals and communication protocols. Specifically, the Analog to Digital conversion (ADC), GPIO (General Purpose Input/Output), I2C (Inter-Integrated Circuit), and SPI (Serial Peripheral Interface) APIs were used extensively.

The main T.U.B.A. code that interacts with the servos, haptic sensors, haptic feedback drivers, and EMG sensors was written from scratch using the aforementioned APIs from TI. To attempt to integrate the Over the Air Download (OAD) functionality, software from TI was used. Specifically, the SensorTag source code present in TI's proprietary BLE stack software was modified to only contain Bluetooth communication and OAD functionality. The main T.U.B.A. code was then integrated into this modified SensorTag code, allowing for use of the OAD capabilities of the SensorTag software which comes complete with a mobile application (available on both Apple and Android phones). The software was structured such that the T.U.B.A. code runs on its own to start, and when a button is pressed, the T.U.B.A. code quits execution, and the SensorTag code runs alone. Once this is complete, firmware updates would be installed wirelessly through the simple press of a button on the mobile application, provided the desired .bin file is present on the connected device. This code flow is demonstrated in the figure below. The team was able to successfully communicate with the SensorTag Mobile Application using BLE, but was not able to meet the stretch goal of getting OAD to work with the T.U.B.A. code.



X. ENVIRONMENTAL PROTECTION

The electronics housing of the current Limbitless Solutions Arm is an open package design. The hand is connected to the electronics housing and this structure can be taken out of the forearm that encases it. One of the aims of this project was to demonstrate how to environmentally protect the electronics to ensure that they are not exposed to factors such as dirt, water, and ESD. The current Limbitless design does not prevent these possible stresses from affecting the electronics. With the current arm being used by a child, the possibility of debris entering the electronics is rather high.

The team investigated multiple methods of protecting the board, but conformal coating the board provided the best performance. To demonstrate that this is a viable method to protect electronics, an Arduino-style board was waterproofed in this manner and programmed with a simple LED blinking program. The board was then momentarily dropped in water and then dirt and shown to still work. The thought is that Limbitless Solutions will be able to use this method to protect the PCBs and therefore improve reliability of the final design.

Using the above design features, along with wireless programmability and induction charging, the team has outlined a robust design that satisfies the requirements set by Limbitless Solutions.

XI. ARM INTEGRATION

This section discusses the overall method followed for prototype creation, with focus placed on easily reproducible results for Limbitless Solutions to recreate as needed in the future. The goal of the design was to create a set of electronics that serve as improvements to the current design, while meeting the specifications that Limbitless required. This design was intended to be a proof of concept for the future design of the Limbitless arm.

a) Protected Electronics Enclosure

To incorporate the desired design changes set forth by the client, several engineering tradeoffs were forced to be made. Most notably, the size of the electronics housing was increased to include all of the features. This was mainly due to the size of the battery required to meet the desired specifications of life in the product. If Limbitless is willing to sacrifice an hour of life, the original housing may still be utilized. This increase in battery life is paramount, however, due to the needed current increase discovered during prototyping to enable a usable product; the arm to date was proven to be incapable of holding a 1 lb object.

With the new housing created, all applicable components were then attached to the main PCB. The PCB was mounted inside of the new enclosure, with all connections running out of the housing. The housing will be fully sealed using epoxy in the final implementation of the design.

b) PCB Fabrication

Once the schematics and design were finalized, the board was contracted to OSHPark for fabrication. Considering the optimized sizing of the board, which was only 1.5” x 2”, Limbitless may have these manufactured for a relatively cheap cost of about $5 per board.

All components on the board were chosen to SMD technology, which helped in the optimization process mentioned above. The challenge to the use of these components, however, is their correct mounting onto the boards. For prototyping, mounting was performed through the use of solder paste stenciling using a focused heat gun purchased relatively cheap from Amazon by one of the authors. Once all components were sourced from the bill of materials, a fine gauge syringe was utilized to apply solder paste to all pads on the PCB, and each surface mount component was placed onto the board via a magnifying glass and fine tooth tweezers.

For the purposes of replication, a streamlined option was sourced in Quality Manufacturing Services, a local, readily available PCB fabrication service that offers quick, cheap, next-day mounting of components. It was the author’s recommendation that it may be entrusted to a company such as this to handle the mounting of the finer component packages, such as VQFN footprint of the TPS65257, and the solder paste method may be used to affix the easier surface mount components in house by a Limbitless technician.

XII. CONCLUSION

The research executed for this project has laid the framework for the authors to develop a full working solution of the electronics for Limbitless Solutions. The fruits of this labor are a full set of working schematics, complete bill of materials, working prototypes, and a plan of action on how to execute, test, and integrate future iterations of the prototype. In addition to the electronics choices made, a full analytical process has now been presented to Limbitless for their future research, providing them with insight on the parts explored by this team as to their strengths and weaknesses for the given areas of implementation. In addition, while meant as an evaluation board in its own right, the prototype may be directly used as its own evolved form of electronics in Limbitless hands to help them evolve their model to a more consistent form.

From an overall standpoint, the design of the T.U.B.A. has left Limbitless with the ability to control multiple servos and EMG to further their future designs. The changes to the battery and voltage regulation, has increased power efficiency and overall performance. Using the CC2640 module, the team has included the hardware to update the software wirelessly. By adding sensors to the fingertips of the hand and mounting actuators to the design, the team has incorporated haptic feedback to improve user experience. The team has also increased the reliability of the design by unifying the electronics and adding capabilities for environmental protection. These milestones met for Limbitless will provide them with enhanced capabilities, including better inventory management, a more consistent method of product fabrication, and a more modular approach to future iterations of design as the design evolves into more elegant solutions, including additions as additional degrees of freedom in the elbow or fingers.

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THE ENGINEERS

Carolus Andrews:

Carolus Andrews is an Electrical Engineering student focused on analog systems, control theory, and analog filter applications. He also received a Minor in Intelligent Robotic Systems. For the T.U.B.A. project, he was in charge of embedded hardware, and schematic/PCB design. From graduation, he will eagerly be joining Texas Instruments as an applications engineer.

Ray Brunkow:

Raymond Brunkow is an electrical engineer focused on power. For the T.U.B.A. project he was in charge of the power management, induction charging, and the servo. His future goals are to work in the power industry as a power system engineer.

Wesley Mullins:

Wesley Mullins is an Electrical Engineer focused on Control Theory and Embedded Systems. For the T.U.B.A project, he was in charge of the EMG sensor and the software. He will be working for Lockheed Martin as a Test Engineer.

Blake Steiner:

Blake Steiner is an Electrical Engineer focused on analog and digital design. For the T.U.B.A project he was in charge of the Haptic Feedback System and assisted in the schematic design for the board. In the future he will be working as an Electrical Engineer at Lockheed Martin.