Developing a Portable 3D Vision-Guided Medical Robot for Autonomous Venipuncture

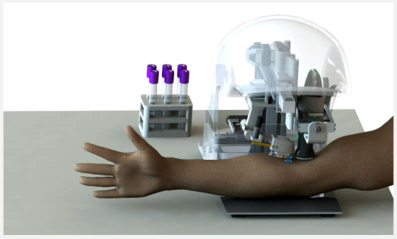

Figure 1. A computer-aided design rendering of an automated blood draw procedure using VenousPro.

"The NI platform provided our start-up the flexibility to pursue cutting-edge engineering research as well as the reliability to hit time-critical development milestones. NI products empowered our company to rapidly develop and test a disruptive medical technology."
- Alvin Chen , VascuLogic

The Challenge:
Developing a portable, image-guided, medical robot that autonomously performs blood draws and other IV procedures when medical professionals are unable to successfully access veins.

The Solution:
Combining the performance of NI CompactRIO hardware, the flexibility of NI LabVIEW system design software, and the extensive NI robotics and machine vision libraries to deliver a safe portable medical device for initial human testing.

Author(s):
Alvin Chen - VascuLogic

VascuLogic is a hybrid medical device start-up and research lab based in New Jersey. Founded in 2010, our mission is to develop and commercialize novel image-guided medical technologies that significantly improve clinical care. Our featured device, the VenousPro, improves the accuracy and safety of the venipuncture procedure by autonomously performing blood draws and other IV procedures with close to 100 percent first-stick accuracy in less than two minutes (Figure 1).

The Engineering Problem

Performed over 1.4 billion times each year, venipuncture is the most ubiquitous invasive clinical procedure in the United States. The success rate varies significantly across hospitals, especially in challenging settings in which first-stick accuracy depends heavily on the patient's physiology and the practitioner's experience. These challenges have recently driven the development of commercial imaging devices aimed at enhancing vein visibility; however, these devices still leave the needle insertion to the clinician. VascuLogic's VenousPro addresses these limitations by ensuring rapid, single-stick venous access and completely removing practitioner contact with the needle.

Addressing Design Challenges With NI Technology

VenousPro operates by imaging and mapping in real time the 3D spatial coordinates of peripheral forearm veins to robotically direct a needle into the designated vein. To develop an advanced prototype for initial human testing, we needed to address three main challenges. First, our device needed to be safe, which meant we needed repeatability and deterministic execution. Second, the device had to be highly portable to work in a plethora of clinical environments. Finally, the system had to meet the rigor of FDA evaluation. Before selecting NI technology, we considered several different programming environments and hardware interfaces.

As the complexity of our design and the size of our engineering team increased, we realized we needed a reliable integrated development platform. We applied for, and received, support from the NI Medical Device Innovation Grant, which provided us with custom NI hardware solutions, LabVIEW, and the NI Training and Certification Program. We built our second-generation prototype using CompactRIO for a rugged, embedded, high-performance platform to control the robotic device. We converted our The MathWorks, Inc. MATLAB® code into LabVIEW, and developed an intuitive user interface. We thought the process would take three months, but it only took three weeks because of the flexibility and modular design of the LabVIEW environment. As a result, we completed our prehuman in vitro proof-of-concept testing ahead of schedule.

The core of the device (Figure 2) comprises five I/O modules on the NI cRIO-9025 real-time controllers, including four NI 9514 C Series modules that direct a four DoF miniature robotic arm and one NI 9401 C Series digital I/O module that provides eight channels of bidirectional communication. Also central to the CompactRIO system are three linear stages that connect to the RS232 port to provide XYZ positioning, two GigE Vision cameras with enhanced near infrared sensitivity that connect through an Ethernet hub, and one handheld ultrasound probe that connects a USB. We built the "brains" of the VenousPro from the extensive library of mathematics, robotics, and machine vision tools available in LabVIEW. We used a queued state machine architecture to deterministically control the sensors/effectors on the CompactRIO controller, as well as the user interface (Figure 3) on the host machine.

During real-time execution, images are acquired from the GigE Vision cameras and the ultrasound probe. The processing pipeline employs advanced algorithms from the NI Vision Development Module and the 3D position and velocity information extracted from the images is communicated to the CompactRIO motion control modules at 20 frames per second. The CompactRIO system then directs the robotic needle manipulator. The device uses kinematics, PID, and path planning VIs in the NI LabVIEW Robotics Module for functions such as correlating joint angles in the robotic arm with the 3D Cartesian coordinates of the needle tip. It also uses the NI LabVIEW Control Design and Simulation Module to predict future positions based on current velocity profiles through a Kalman filter. Complex mathematical operations on large arrays are accelerated using the NI LabVIEW Multicore Analysis and Sparse Matrix Toolkit.

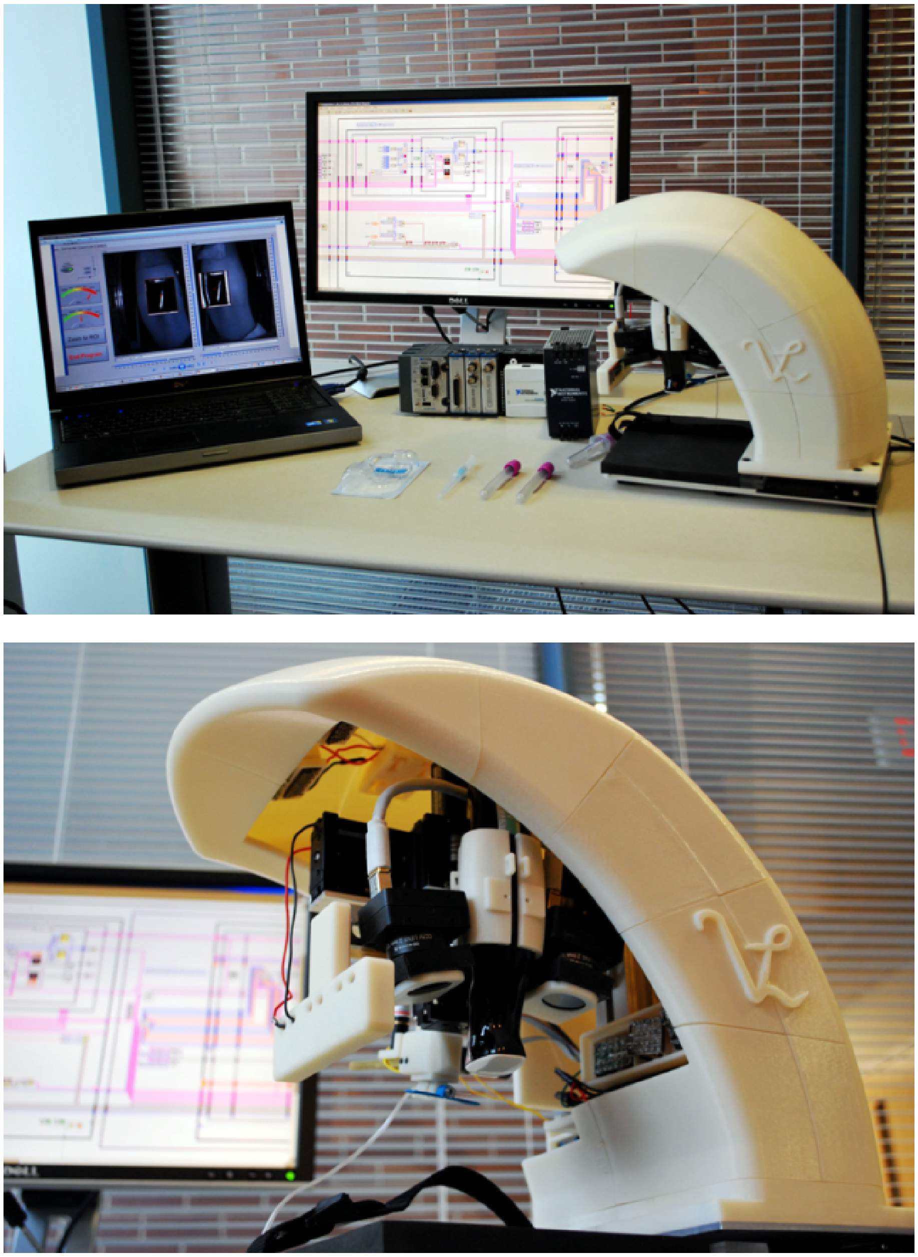

Figure 2. *The VenousPro system driven with CompactRIO hardware and LabVIEW software.*

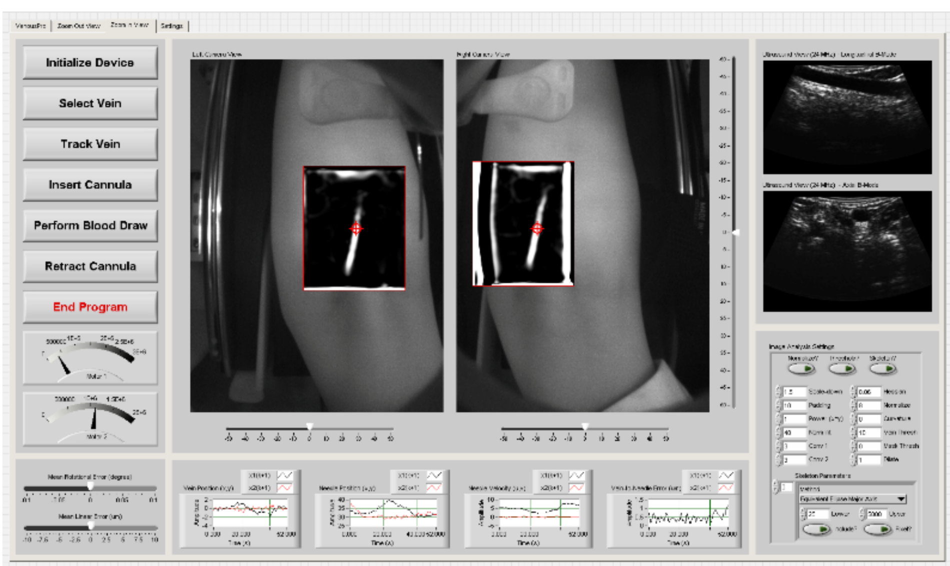

__Figure 3.__ The LabVIEW front panel graphical user interface.

Results

To date, we have demonstrated more than 98 percent first-stick accuracy in multiple in vitro studies. We plan to upgrade to new multicore CompactRIO hardware and develop the user interface on an NI touch panel, so we can remove the host machine. Once these final design changes are implemented, we can commence with Institutional Review Board-approved human clinical testing in preparation for the initial FDA filing. By developing on the NI platform, we delivered a device ready for clinical testing at $50,000 below budget and five months ahead of schedule.

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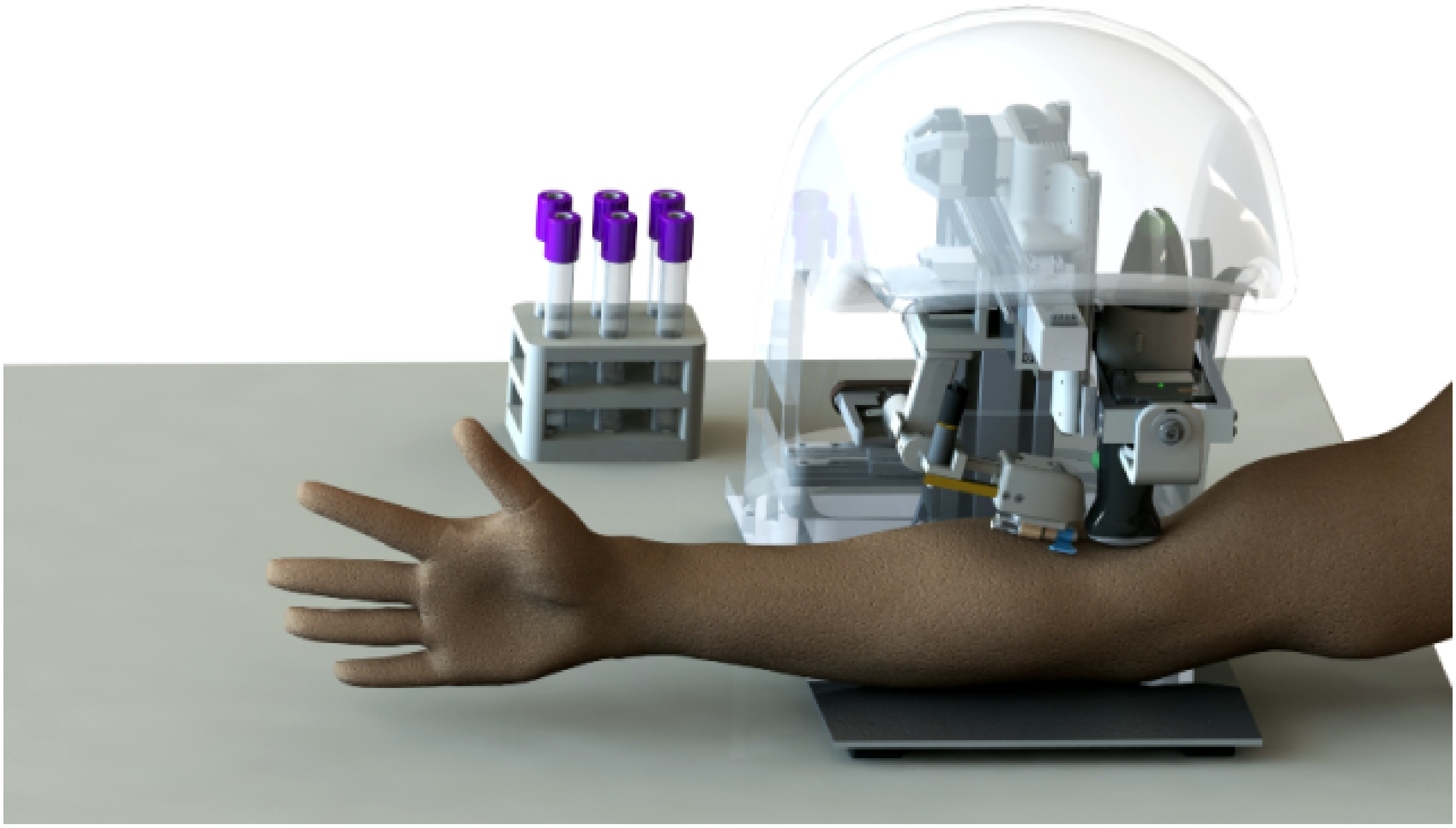

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