A project intended to develop advanced prosthetics for military amputees may ultimately eliminate the need to put military personnel at risk to begin with, if engineers at Telefactor Robotics have their way. The company specializes in advanced robotic vision systems and dexterous manipulation solutions that provide human-like capabilities in remote or otherwise hazardous areas. “Robotic arms typically terminate in rigid two-fingered pinchers,” says Matt Kozlowski, vice-president of engineering at Telefactor. “We're replacing that with a conformal finger system that can basically pick up an amorphous object with little or no additional cognitive load on the user.” They offer more than just hands, however. The full Contineo Dexterity Solutions product line includes wrist, elbow, and shoulder joints with degrees of freedom that mimic those of the human body, effectively performing “hands-on” tasks as if a human were physically there (see figure 1). With the aid of innovative architectures and small DC motors from MICROMO, Telefactor subsystems bring new capabilities to robotics in applications ranging from security and defense to industrial manufacturing, mining, and even agriculture.

In 2005, Kozlowski and Telefactor chief technology officer Stuart Harshbarger were working at the John’s Hopkins University Applied Physics Laboratory on a Defense Advanced Research Projects Agency (DARPA) program aimed at prosthetic development. As the effort progressed, it became apparent that the technology had much broader promise to not only restore lost function, but to actually prevent injuries and to project human capability into remote or potentially hazardous areas. Robot arms that might ordinarily terminate in a standard end effector or a dedicated tool such as a screwdriver, wrench, or welding fixture could be fitted with a conformal finger system that would in turn allow them to pick up that screwdriver, wrench, or welding fixture on command. This upgrade would not only create a...
multifunction arm, it could eventually enable that same robot arm to be programmed to pick up tools one by one at the appropriate time and perform a different sequence of movements with each. The approach could take bomb-disposal robots and other hazardous applications to a whole new level.

It was easier said than done, of course. “It’s a challenging task,” says Harshbarger. “The human hand is an incredibly complex structure, with 20 or more degrees of freedom, depending on how you count, all packed into an extremely small package. It simply isn’t feasible from a size, weight, or cost perspective to replicate that architecture in a purely electromechanical system.” The Telefactor team had to find an easier way.

Under actuation
For starters, they stripped the design down to three digits: two “fingers” and an opposable “thumb” (see figure 2). Each digit has three joints; in addition, the thumb has the ability to adduct/abduct for opposition. Even this simplified structure nominally requires 10 degrees of freedom. Here, too, one motor per axis simply wasn’t feasible. Beyond size and weight considerations, every additional gear motor adds a point of failure, and if there’s one product that needs to be reliable, it’s a bomb-disposal robot.

To reduce the complexity, the design team used a technique called passive actuation. Passive actuation takes advantage of the interactive forces between the axis and environment, for example using linkages and ratcheting non-global sections to harvest potential energy and allow part of the structure to move without active power. Kozlowski calls it under actuation.

The human finger includes three joints. Starting from the base of the finger at the palm, they are the metacarpal interphalangeal joint (MCP), the proximal interphalangeal joint (PIP), and the distal interphalangeal joint (DIP). Although humans can actuate two and often three of the joints independently, Kozlowski and his team realize that was unnecessary for robotic hand. Instead, they placed the motor at the MCP and fit it with a spur gear. The gear interacts with an actuator through a device they call a captured tendon mechanism, a cable “tendon” that connects to the PIP and the DIP. When the gear turns in one direction, tendon tightens to flex the finger; when it reverses, the tendon drives in the opposite direction to actively extend the finger mechanism. That same gear also delivers torque directly to the MCP. “With a single under-actuated drive, we get effectively three degrees of freedom that are differential to each other,” says Kozlowski. By modifying the spring values and damping ratios at the various joints, they can tune a robotic hand to deliver the desired human-like motion.
Figure 4: The actuator required a thin cylindrical motor from MICRO-MO that supplied significant torque in a high-aspect-ratio form factor. (Courtesy of Telefactor Robotics)

The approach allows them to build a functional three-fingered robotic hand with 10 total degrees of freedom, only four of which need to be directly actuated by motors (see figure 3). The four independent motors operate in a coordinated fashion off of a single control bus. The resulting device is smaller, lighter, and consumes less power. Strategically locating the drives, coupled with the reduced overall mass lowers the effective inertia, improving responsiveness and speeding motion.

Design for manufacturability
The strategy of using passive techniques to streamline the design process is representative of the engineering team’s entire philosophy. Rather than developing every element of the system from scratch, they used commercial off-the-shelf components where possible, saving their in-house engineering hours for their core value proposition.

“What has really enabled us to move forward at much faster intervals is to outsource primary drive systems and not reinvent the wheel,” Kozlowski says. “We were able to expand the product line beyond our means because we don’t have this huge engineering team to support.” They chose MICRO-MO as their motor supplier, in part because the right combination of torque per unit volume was available in a long, thin gear motor rather than a disk-shaped version that would not fit well in the actuators (see figure 4). “We’re leveraging the tens of thousands man-hours that went into the research and development of these systems,” says Kozlowski. “There’s not one system in the Contineo Dexterity Solutions product line that would work without a good motor. It’s so often under recognized yet it is the absolute pinnacle of importance for our stuff.”

Another key part of their approach was to go with a modular design platform, a move intended to tame the complexity of the system. The integrated solution consists of a fully anthropomorphic system capable of the range of motion delivered by a human arm/body system. Each part the shoulder and elbow, for example presents different requirements for torque and range of motion. Using a different gear motor for each joint and degree of freedom would have required separate drives and controls, which would add size, weight, cost, and complexity. Instead, the team developed a modular design based on a well-defined and understood architecture. The same motor can be paired with different gearheads for reduction ratios ranging from 66:1 to 143:1, for example.

“The fact that we’ve been able to parameterize our designs effectively with these transmission elements is really key because that means that we don’t have to size an entire new motor and then an entirely new controller and controller architecture,” says Kozlowski. “We just have to understand our speed and torque differential.” The team uses the same controller electronics for multiple motors; even the controls are multifunctional. “We just released a custom board designed specifically to control the 6-mm, 8-mm, 12-mm, and 16-mm variants of the MICRO-MO line,” he notes. “Because of similarity with regard to drive currents and motor coefficients, we were able to design a board that would control a vast section of the family of motors. It just really is a testament to the MICRO-MO line.”

In keeping with their philosophy of saving their efforts for tasks that add product differentiation, Telefactor purchases fully packaged, fully integrated gearheads, motors, and transmission units with wiring harnesses already soldered on and terminated with specialized connectors.
The company then interfaces these modules to its proprietary linkages, conformal device mechanisms, and the structures around them. The approach streamlines assembly and ensures consistency, which translates to monetary savings. Overall, Kozlowski feels the combination of modularity and outsourcing has paid off big. “It’s allowed us to use our architecture and cherry pick the properties that we want for a given instance of a technology, whether it’s speed or torque or quiet operation, or whatever,” he says. “It’s not just the engineering hours that we save but the learning curve. MICROMO’s varied array of products allows us to do it all while retaining the same base architecture. And with the support that we have received to date, there is no doubt that MICROMO is far more than just a supplier. The company has helped make Telefactor what it is today.”

For over 50 years, MICROMO (FAULHABER Group) has brought together the widest range of high quality, high performance linear and rotary motion solutions, decades of micro motion expertise based on dc motor technology and full service design, sourcing and manufacturing capability on a global basis to deliver benchmark motion solutions.

For more information on the Contineo Dexterity Solutions line visit: http://contineo-robotics.com/
For more information on the DC Motors used in this application visit MICROMO at: www.micromo.com