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MICRO MOTION SOLUTIONS

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Defense and Aerospace

MICROMO, Founded in 1961 , MICROMO is a member of the FAULHABER Group and a full service, value added partner to the defense and aerospace markets for micro motion solutions. The leader in DC micro motor and encoder technology and design customization, MICROMO has provided benchmark solutions for a wide range of applications, including extensive work with unmanned systems. MICROMO brings together value-added services and cutting-edge technologies from around the world through high efficiency, high performance offerings, including brushed, brushless, stepper, thin-profile, piezoelectric and linear motors for diverse applications.

MICROMO's LEADING CONTRIBUTIONS WITH UNMANNED GROUND, AERIAL AND MARINE SYSTEMS INCLUDE APPLICATIONS SUCH AS:

Gyro-feedback stabilized sensor turrets
Camera systems
Steering vanes
Flight surface control actuators
Payload manipulation actuators
Propulsion devices
Telescopic modules
Valve actuators
Control throttle
Waste gate
Engine cooling flap
Weapon targeting devices

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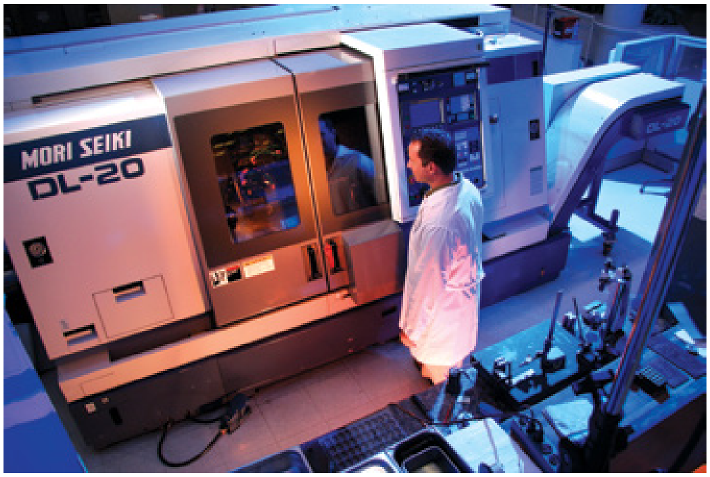
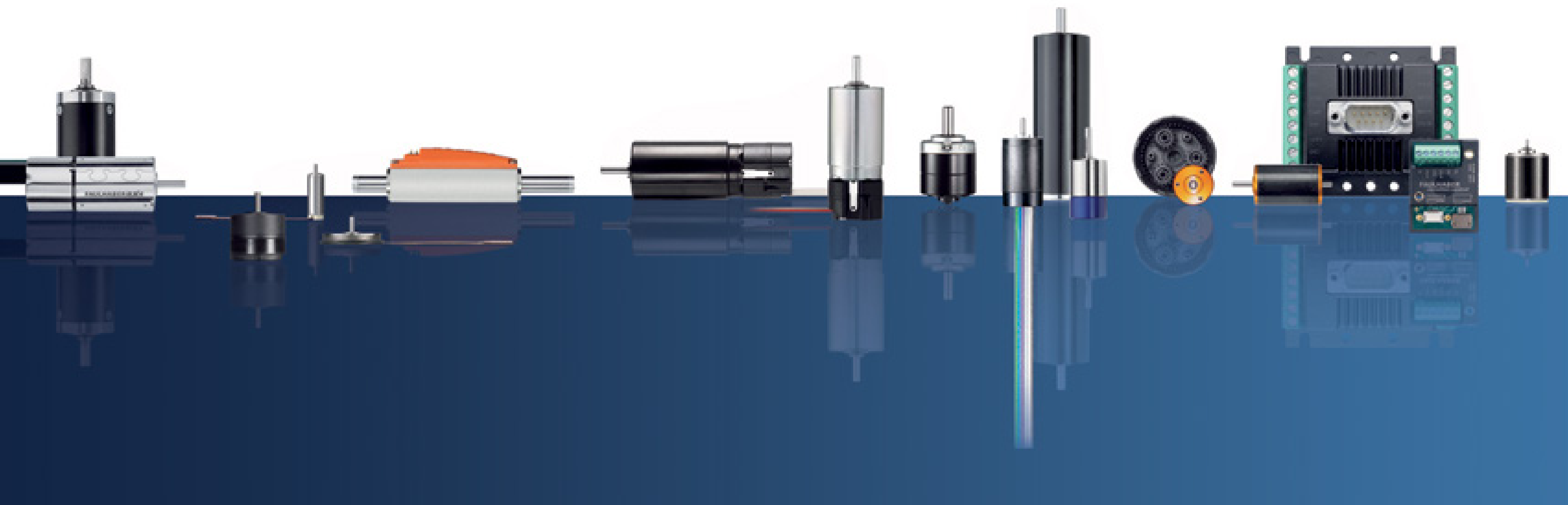




Gyro-Stabilized Turrets Provide Real Time Imaging

Lightweight, high-efficiency servomotors stabilize and position sensor turrets on unmanned aerial vehicles.

There was a time when reconnaissance meant either multi-million dollar satellites snapping a few shots per orbit or pilots risking their necks to fly over hostile territory. Today, recon is dominated by unmanned aerial vehicles (UAVs), a much more cost effective approach that presents no risk to the operators, who are not only on the ground but frequently on the other side of the globe.

Of course, imagery is only useful if it's crisp and clear, which requires both focusing and stabilization. That's where Alticam Vision™ Corporation comes in. In 2001, Alticam Vision developed the first 700-gram gyro-feedback-stabilized sensor turret. This enabled a new class of lightweight UAVs weighing 15 kg and offering 24 hrs of endurance. Central to the success of these systems is a collection of compact motors from MICROMO.

"We're trying to squeeze as much as we can into this class of UAV, keep them small and light and affordable," said Alticam Vision Tech President Dr. Andy von Flotow, noting that larger, more sophisticated UAVs can run around $10 million, compared to $100,000 to $200,000 for small light designs. "People have to make reservations days and weeks in advance for the big UAVs, while they can afford to distribute the smaller, more economical design widely so everyone can use them."

Alticam Vision currently uses several classes of imagers: an Electro-Optical Daylight camera and a selection of Infrared (IR) cameras that image primarily in the mid wave and long wave IR spectral bands. The cameras produce NTSC video with fields of view on the order of 10 to 30 feet for a 1000 feet to 3000 feet altitude. Objecttracking feedback based on optical control loops allow the cameras to lock onto objects. For example, they can automatically track a truck driving along a road.

Dust in the Wind

An Alticam Vision turret keeps the sensor payload and electronics steady and aimed while countering vibration, thermal loading, wind forces and more. The 500-gram gyro-controlled gimbal mechanism consists of a coarse/fine design, with the outer coarse stage powered by MICROMO motors.

Ultralight UAVs are launched by catapult, suffering 35 Gs of force. (COURTESY OF INSITU INC.)

The turret controls both coarse axes using micro-stepping stepper motors as rate actuators, closing the loop with an absolute encoder. Why not just use a torquer, you ask? Simple, says Dr. von Flotow. "With a stepper motor, when you command a step you get one, when you command a step rate, you get that velocity. When you command a torquer, you don't get any motion until the torque you command overcomes the friction and then it jumps, so you have to do clever friction compensation. Most people think of steppers as doing a discrete number of steps but we step these things at tens of thousands of times per second." At such rates, friction and striation are almost irrelevant Ultralight UAVs are launched by catapult, suffering 35 Gs of force. (Courtesy of Insitu Inc.) and the motion becomes nearly smooth. "It's basically then an angular velocity actuator," Dr. von Flotow said. The motors are teamed with dual-path spur gearboxes to produce a 200:1 reduction ratio. That yields an angular velocity of up to 90 deg/s for the axis of rotation.

In a precision pointing application like aerial reconnaissance, backlash can introduce unacceptable error. To eliminate the issue, Alticam Vision turned to MICROMO zero-backlash gearboxes. The components essentially incorporate two parallel gear trains that are wound elastically against each other. "When you use such a gearbox, it's always a compromise between winding it too tight, generating so much friction that usable actuation torque is reduced to being useless, or winding it not quite tight enough, to where you still have a little bit of backlash," says Dr. von Flotow. "We had to work with MICROMO to get that right. We had to develop the process together."

The coarse stage features a large articulation, endless pan with slip rings to eliminate cable windup, and hence the need for unwind maneuvers. While the visible-wavelength imagers come equipped with motorized focus and zoom, the IR turrets also incorporate brushed DC motors from MICROMO for their focus mechanism. Some of the IR imagers also incorporate motorized zoom.

Stabilization and Control

The stabilization and control specs would be difficult to meet on the ground, but UAVs impose additional challenges. One obvious constraint is weight, but power is also an important issue. Minimizing power consumption for the turret prolongs battery life, lengthening the vehicle's range. The cameras draw about 3 watts, and the team worked to restrict the platform requirements to the minimum, in part by using high-efficiency motors. A typical stabilizing/pointing turret draws about 4 watts, so that the entire package demands only 7 watts from the aircraft. Since the propulsion system itself demands only a few hundred watts, 7 watts is a good number for camera-system power a 200-watts camera payload would be about as unwelcome on these small aircraft as a 5-kg payload.

Of course, even the lowest-power unit isn't much good if it only operates in the lab. The theater of operations for UAV presents a relentlessly hostile environment. "They can get unbelievably dusty over there in Iraq or Afghanistan," said Dr. von Flotow. "You should see some of the stuff that comes back." It's not just dust, either. The U.S. Navy operates a number of the lightweight UAVs, and there the issue is less dust than the salt and humidity of sea conditions. Corrosion damage is rare, though, Dr. von Flotow says. A far bigger problem is temperature.

The sensor turret (left) on the ultralight UAVs weighs 700 g. (COURTESY OF INSITU INC.)

"We have to watch for effects of thermal overload, first detectable in its effects upon the imagers," he notes. "This has been an issue especially in high elevation, hot situations like Afghanistan in the heat of the summer." The aircraft are often operated at 14,000 ft density altitude. The IR imagers require thermal stabilization, which adds weight and power demands to the system, putting more pressure on the stabilization motors to deliver motion in a small, efficient, economical package.

Of course, the challenges aren't just restricted to the environment. The UAVs are catapulted into flight, a process that imposes 35 Gs of force on the aircraft and turrets. Even more interesting is the landing or rather, the capture. The planes are snared in flight when they fly into a vertical rope, catching one of their wing tips. It is a method that would likely rip the wing right off a jumbo jet, but due to the advantages of scale, it simply whirls the UAV around—while subjecting it to 20 Gs of force. The turret must undergo stringent shock and vibration testing before the product is shipped, then extreme shock every mission once deployed. "We've had no G issues," said Dr. von Flotow. "We've made them tough enough to survive."

Indeed, the UAVs are tough right down to the motors. "We have very few, maybe even zero problems with motor failures," says Dr. von Flotow. "The most common way for our turrets to end their lives is not being worn out. The airplanes don't always make it home." ■

For capture, the UAV snags a wingtip on a vertical rope, for a rapid deceleration that exerts 20 Gs of applied force. (COURTESY OF INSITU INC.)

Miniature unmanned ground vehicles reliably perform reconnaissance in the harshest environments, with the help of compact, high-torque servo motors

Imagine the scene: A trio of terrorists are holed up in a hotel room, holding a group of terrified staff hostage. Outside, the SWAT team gathers. One of the members pulls a pin from an object and tosses it onto the room's balcony, where it rolls to the sliding glass door. Moments later, chaos erupts. Commandos burst into the room through a side door, surprising the terrorists and freeing their captives. No, the object on the balcony wasn't a grenade, it was a miniature unmanned ground vehicle (UGV), and the images it transmits have the power to save lives.

When it comes to search and rescue robots, the philosophy today is the smaller, the better. It's unlikely that even the most sophisticated robot can do a more effective job than a person at pulling victims from rubble or picking up a downed soldier. A UGV like the Recon Scout IR from ReconRobotics Inc. (Edina, MN) can easily and unobtrusively slip into a collapsed building or a hostage situation where a person can't, however, and send back real-time images that allow responders to identify a tactical response. Although it looks for all the world like a small dumbbell, the Scout can climb uneven terrain, navigate a path as commanded, and send back a steady stream of images, all while operating untethered). Using sophisticated design, robust materials, and compact, high-torque servomotors from MICROMO to build the device, ReconRobotics has positioned itself as a major player in the search and rescue robot market.

The Recon Scout IR can be thrown into a scene and operate untethered, sending back images and navigating on command for 1 hr or more per charge. (PHOTO COURTESY RECONROBOTICS INC.)

Tiny But Mighty

The UGV may be small but designing it was a tall order. The engineering team faced conflicting performance demands at every turn: The unit had to be powerful but small, high torque but with long lifetime on a single charge. It took tradeoffs, optimizing components, and prioritizing specifications, but the resultant robot can do nearly everything well.

The primary order of business was motive power—a search and rescue UGV isn't much good if it can't reach the target area. Traveling over rubble or uneven ground requires an appreciable amount of torque. Normally, an engineer would just choose a motor large enough to provide the power required, but the Scout's compact form factor presented limitations. The second obvious approach, adding a high-reduction-ratio gearhead to convert motor speed to torque wasn't an option—not only would it increase size beyond the available space, but it would only increase torque at the expense of reducing speed, which is unacceptable in a search and rescue robot.

What the project required was high-power-density motors the diameter of a cigarette. MICROMO provided the answer with 8- and 10-mm DC motors. "They had the best available solution in the size range we were looking for," says Patrick McKinney, chief operating officer of ReconRobotics. "They do small really well." The motors were more typically used for medical applications, which brought the added benefit of a dependable solution. "They have to operate in an environment where lives depend on their function," he adds. "We've had these motors running continuously in tests for well over 168 hours at a 50% load. They're very impressive." An additional planetary gearbox provides a 64:1 reduction ratio to raise the torque even further with a modest size increase.

The original Recon Scout IR was designed for tactical law enforcement applications in relatively clean urban environments. (PHOTO COURTESY RECONROBOTICS INC.)

The Recon Scout IR features a visible/IR sensor mounted in the crossbar and a handheld control unit. (PHOTO COURTESY RECONROBOTICS INC.)

The crossbar of the UGV contains a visible imager with IR sensitivity, an IR illuminator, the motors, drives, and controller, as well as the radio transceiver that provides wireless operation.

Each of the Recon Scout's two wheels is driven independently, with the aid of a closed-loop control system that balances the drive signals. A gyroscope provides the z-axis feedback (yaw) to ensure that the wheels are driven evenly so the Scout can move in a straight line. To allow the UGV to be steered on the desired path, an accelerometer monitors x- and z-axis motion. A weighted stabilizing tail stabilizes the rotational position of the crossbar so that the camera aperture remains in the correct spot for image capture.

Tough Stuff

Forget about driving to the region of interest; the Recon Scout IR is designed to be cast or dropped directly into the surveillance location. As a result, the ReconRobotics team had to design the unit to survive an impact on concrete from 30 vertical feet. They began with a chassis of aircraft-grade aluminum, which also helps dissipate heat. A titanium housing on the crossbar protects the contents. The wheels consist of proprietary polyethylene that doubles as a shock absorber.

When the device lands after a throw, the wheels hit the ground with enough force to potentially strip the gears.

To protect against this possibility, the team designed a patented mechanical clutch that disengages the gears on impact and re-engages after the Scout has landed. With imager, illuminator, and wheels running constantly, the Scout has a per-charge runtime of 1 hr, thanks to the high-efficiency operation of MICROMO's motors.

The original Scout was a surveillance robot designed for military and tactical law enforcement applications in a relatively clean urban environment (see figure 3). When the ReconRobotics group set out to develop the search and rescue version, they faced a new requirement of operation amid rubble, dirt, and heat. The customer specified that the 4-in-tall Scout be able to lift itself over 2-in-high objects unaided. Meeting that spec was a challenge for such a small machine, especially since the other requirements remained as strict as ever. They solved the problem by using a more powerful 10-mm-diameter motor, widening the wheels slightly, and adding fearsome inch-long spikes for traction.

The ruggedized search and rescue version of the Scout features spiked wheels for climbing over obstacles. (PHOTO COURTESY RECONROBOTICS INC.)

For efficient, economical production, the ReconRobotics philosophy is to outsource whenever possible and save the inhouse engineering efforts for value-added aspects like controls. To assist, MICROMO delivers an integrated package of motor, gearhead, and leads. In addition, their dedicated machine shop [link to machine shop page] adds a pinion designed by ReconRobotics. "What we're buying from MICROMO is a solution that allows us to drop it into our robot, plug it into the boards and be up and running very quickly," says McKinney.

"MICROMO has done an excellent job for us over the years. They bend over backward to help us out."

The walkie-talkie style operator control unit for the Scout features a single joy stick and can be operated onehanded. McKinney points to the intuitive nature of the device operation as a big part of its value proposition.

"Law enforcement agencies are under severe budget constraints. Training is a luxury. I think that as you look at reconnaissance and rescue robots going forward, intuitiveness and ease of use is really going to drive their acceptance in the marketplace."

In tests with the New York Port Authority, a response team was able to deploy the Scout, capture images, and rescue a downed victim in 12 minutes, compared to 45 minutes for a competing device. ReconRobotics isn't done yet, though. They've got big plans for the future and MICROMO will be there with them. "We've staked out this miniature unmanned ground vehicle market and will be looking to MICROMO for solutions to some ideas we have in the future," McKinney says. "We can't speak to those yet but we're certainly looking forward to it." ■

Hot Wheels

High-torque, compact motors and rugged design create economical, light-weight bomb-disposal robot.

By: Kristin Lewotsky, Technical Writer, MICROMO

In a world in which an abandoned suitcase, a box, or even a pile of rubble can conceal an improvised explosive device (IED), bomb-disposal robots have become essential. Many units in the field bristle with cameras, feedback devices, and processors. Such sophisticated robots offer a significant amount of capability and autonomy but increasing complexity also drives up weight, size, and cost. Instead of organizations buying one device per platoon or police department, such systems have to be shared across several companies or counties. Enter the Mechanical Mobile Platforms (MMPs), a family of simplified, man-portable robots from the Machine Lab Inc. (Fort Collins, CO) that can perform a range of surveillance and bomb disposal tasks at a price point low enough for wide deployment (see figure 1). For the cost of a high-end system, which can exceed several hundred thousand dollars, users can purchase nine or 10 MMPs. Powered by compact, economical, high-torque motors from the Faulhaber group's value-added reseller MICROMO (Clearwater, FL), the Machine Lab's robots are making a difference around the world.

The Machine Lab engineering team started out with one over arching principle: keep it simple. This required an immediate trade-off. Instead of a robot that can perform 95% of what is needed, an MMP might only handle 60% of the tasks. Then again, as all engineers know, a solution doesn't need to be perfect, it just needs to be adequate to the application at hand.

Rather than focusing on building a single product, they took the big picture approach and developed a modular design platform that can be applied to a wide range of implementations. The basic line includes a quartet of direct-drive MMPs ranging from a four-wheel model that can carry a 4 lb. payload to a six-wheel model that can handle up to 30 lb. For loose terrain, the company also offers two track-driven versions: a four-wheeled version and a six-wheeled version (see figure 2). Here, too, the focus on simplicity came into play. Instead of driving with all wheels, each of the track-driven MMPs sports two passive wheels, providing savings in cost and weight without compromising performance.

The team avoided onboard processors and feedback devices, opting instead for direct user control via wirelessly linked joysticks or switches. The operator determines the path of the robot based on images transmitted by the unit's wide-angle IR camera. The mobile platforms provide a 0° turning radius and linear speeds as high as 6.0 ft/s. They range in size from 5 lb. and 11.5 in. × 11.2 in. to 40 lb. and 29 in. × 19 in., although custom versions can be larger, such as the 1500-lb unit built for clearing vegetation in mine fields.

The mechanical mobility platform provides a significant degree of agility and manipulation in an economical, lightweight design. To control costs, the base unit does not incorporate feedback or processors but leverages direct operator control over a wireless link. (PHOTO COURTESY THE MACHINE LAB)

Although cost control was important, a low price point would be meaningless if a unit couldn't perform or failed after a few weeks in the field. The team chose every component with an eye toward delivering a robust, lightweight product. The foundation of each MMP consists of a rugged aluminum chassis mounted on nylon wheels with rubber tires. Steel gears and IPrated motors help ensure survival (see figure 4). "The robots we send to Afghanistan have to be pretty much IP-62 weather proof," says company president Zack Bieber. "They need to be able to be washed down, they need to be able to resist the very fine, abrasive dust that you find out there."

The tracked version of the MMP operates like a tank to easily travel over loose terrain. Compact, hightorque motors allow the robot arm to safely handle improvised explosive devices. (PHOTO COURTESY THE MACHINE LAB)

Getting A Grip

Perhaps most critical aspect of a bombdisposal robot is the robot arm. Here, the engineering team faced a number of challenges, particularly in the gripper and wrist-rotation elements. To maximize the amount of payload a robot could handle while ensuring stability, they had to minimize the weight of the arm. That meant working with the lightest possible components. At the same time, those components had to power the arm so that it could grip a wide variety of materials and not only lift but rotate payloads as high as 40 lb.

One obvious way to get the torque required was to gear down a high-speed motor, but that approach adds size and weight, as well as complexity and cost. In keeping with the company's philosophy of simplicity, the Machine Lab team decided to skip additional gearing in the wrist rotator and look for a motor that provided enough muscle to do the job on its own.

Size presented another constraint. The design required a motor that would supply the required torque and still fit inside the 30-mm-diameter tube of the robot arm. "It was a very tight physical dimensional requirement," says Bieber. "We picked the MICROMO motor because of the power-to-weight ratio. It was really the only one we could find that would fit our application."

The gripper design was a little more tricky. The device needs to operate slowly to provide operators with the precision movement they need to handle explosive devices. At the same time, the grip needs to be fail-safe. Once an arm picks up an IED, it cannot drop it. For starters, the design incorporates a gearmotor fitted with a planetary gearhead that provides a 246:1 reduction ratio. An additional worm-drive gearbox supplies an additional 15:1 reduction ratio for a total of 3690:1, providing the degree of safety and reliability that bombdisposal squads require. "We couldn't have any kind of back drive in the system because once you pinch onto something with the gripper, you need to hold it," says Bieber. "Worm drives are very difficult to back drive."

Efficiency was another important design constraint. Running out of power in a cell phone is merely annoying. Running out of power during the disposal of an IED can cost lives. At every step, the team focused on specifying components for the most efficient possible design. Here, too, MICROMO helped. “What the operators are doing requires as long a run time as possible, and a very simple solution to swapping out a dead battery for a freshly charged one.” says Bieber. “Getting a lot of torque from the motor for a low input current allows us to save on battery use.” With the high-efficiency design, the units can deliver as much as an hour and a half of constant operation on a single charge from a 25-V lithium ferrous phosphate battery pack that weighs just 1.5 lb.

The most challenging aspect of the design was duty cycle, Bieber says. The motors for the wrist and gripper are specified to run 24 hours a day, but their actual duty cycle is closer to five or ten percent. During that time, however, they must routinely perform to their limits—and sometimes beyond. “We had to find that balance of maxing out the motors’ capabilities for a very short period of time without damaging them,” says Bieber. “The types of tasks these robots have to do are all over the place, and it’s all dependent on the operator. If we say this can only lift and rotate 5 lb., they’re going to grab 20 lb.” To eliminate over driving or stalling the motors, the design includes adjustable slip clutches on both gripper and wrist rotator. Add to that a robust monitoring you’ve got a recipe for ruggedness. “We haven’t returned a single motor that I know of,” Bieber says.

The wireless control scheme for the robots makes controlling electrical noise a particular concern. The team followed best practices in the design of the wiring harness. MICROMO made their job even easier. “MICROMO motors are extraordinarily clean as far as RF noise is concerned,” says Bieber. “With some of the cheaper motors, [RF noise] can be an issue and we have to integrate some cleanup electronics [to compensate]. With MICROMO, we get very low electrical noise and that’s definitely a benefit because we run wireless video as well as wireless control signals.”

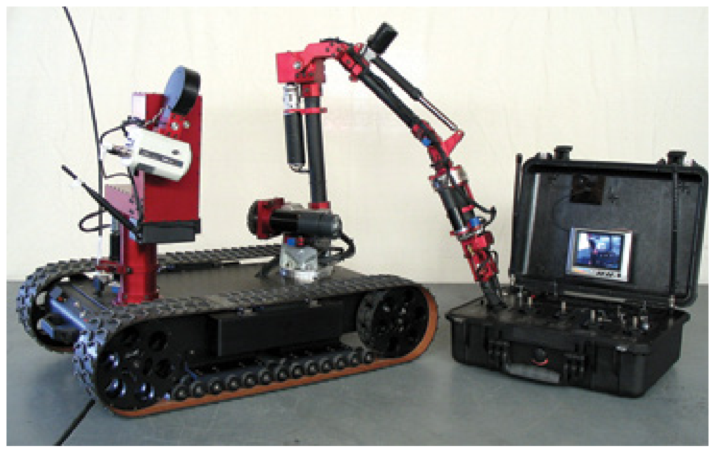
With the aid of its dedicated machine shop, MICROMO also applied an aluminum sleeve to some of the motors, retrofitting them to be compatible with a set of clamps that the Machine Lab had already manufactured. The modification allowed the company to leverage existing inventory while freeing up its staff to focus on more value-added activities.

It all came down to supporting the Machine Lab’s fundamental goal of keeping the price low. “Cost control is a high priority for us because we want a lot of our robots out there,” says Bieber. “The more guys who can use our robots without having to depend on larger, less-available machines, the better off we all are.” So far, their attention to detail has paid off. “We’ve got over 200 robots out in Afghanistan and surrounding countries, and probably another 50 to 80 out in law enforcement here in the US,” says Bieber. The company also recently secured another U.S. Navy contract for 250 more robots.

And as far as MICROMO goes, they couldn’t be happier. “We chose MICROMO, number one, because of reputation,” Bieber says. “You can get a very strong motor in a very tight, dense, small package. The bang for your buck is really good. MICROMO motors are exceptional.”

And when it comes to disposing of IEDs, exceptional is exactly what you need.

the MMP platform was designed from the ground up for operations in harsh environments, beginning with a rugged aluminum chassis, nylon wheels, steel gears, and IP-rated motors.
(PHOTO COURTESY THE MACHINE LAB)



MMPs can be customized, like this unit, fitted with a load cell to allow it to provide mechanical assistance to solo researchers operating in remote locations. (PHOTO COURTESY THE MACHINE LAB)

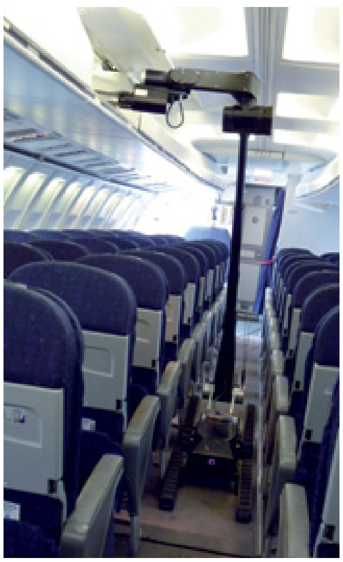
The robots range in size from 5-lb. models that can carry 4lb. payloads to significantly larger models that can carry up to 40 lb. while remaining man portable. No word on whether they are dog portable.
(PHOTO COURTESY THE MACHINE LAB)

Tactical robot features a 4-axis arm on a platform that provides higher speeds and the ability to climb stairs of featuring more battery power for a factor of four increased in run time.
(PHOTO COURTESY THE MACHINE LAB)

Detect, Secure, Defuse

Microdrives excel in hazardous terrain

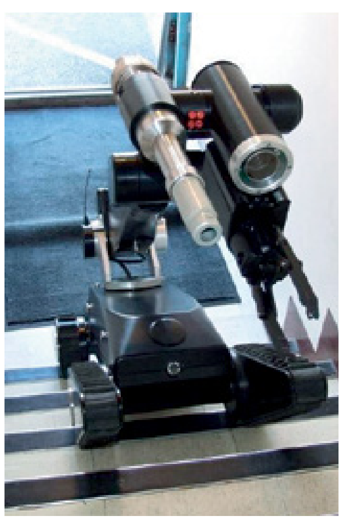
The timely tracking down and disarming of bombs, IEDs, booby traps and other dangerous munitions from the extremist arsenal is most definitely a job for the professionals. Prior reconnaissance to avoid calling in the specialists unnecessarily and to ensure a confirmed threat is handled as safely as possible is an essential element of this process. In this scenario special remotely operated devices can drastically reduce the risk to the human beings involved in such activities, with



high-precision micromotors replacing manpower to undertake the necessary hazardous operations at the bomb scene. AB Precision (Poole) Ltd., a UK company based in Dorset, has been supplying the British Ministry of Defense since the mid-1960s. To respond to the currently heightened risks in tracing and defusing explosive devices, the experts from Dorset developed the latest generation of their Guardian MROV (Miniature Remotely Operated Vehicles). The modular miniature vehicle is designed to carry additional equipment as required. Universal deployment capability also means that it has to cope with any terrain.

Compact design in demand.

Equally important is the compact design, so that it can be maneuvered in narrow passages, e.g. in trains, aircraft or underground rail carriages. With a view to accommodating as many different functions as possible in a slim line design, including a powerful four-wheel-drive transmission, ABP's security experts collaborated with microdrive specialist Faulhaber. In the basic Guardian module, fifteen different microdrives accurately execute the control commands. The entire procedure is managed from a control station in a carrying case. A 17" LCD monitor shows the images captured by the cameras, while a 10.5" touch screen with soft buttons and 3D imaging of the vehicle offers intuitive control of the device and any additional modules installed. The command center" is rounded off by two joysticks for the drive and manipulator arm. As reconnaissance often has to be performed in confined spaces, a compact design is essential. The dimensions of the device 417 mm (tracks), maximum length 1280 mm (extended) and height 504 mm are designed to facilitate navigation in narrow passages. In addition, the reconnaissance radius has to be as large as possible. Therefore a telescopic arm extends the reach of the pan and tilt head up to 2.10 m. At the same time the head can also be lowered so that it can inspect vehicle underbodies. A low center of gravity and sturdy caterpillar tracks provide a stable base for sharp, shudder-free images as well as curate manipulation using the cantilever head. Depending on the terrain involved, the chassis can also be fitted with wheels,



2.10 m reach gives the operator a comprehensive overview (photo: AB Precision)

allowing it to move faster on solid ground and thus enhancing mobility. Highly flexible thanks to modular design.

The complete vehicle can be quickly assembled at a safe distance from readily portable modules. This makes it easier to transport and allows the experts to deploy the right tool for each individual situation by choosing a particular module. Apart from the four on-board cameras providing color images, there are numerous other modules available such as various hardware devices (e.g. lock pick gun), X-ray unit, water jet and many more. Additional equipment can be transported in an optional trailer.

Customized solutions from the modular drive set.

The drives used in this system are just as diverse as the range of applications. However, all of them must meet certain general requirements such as absolute reliability, compact design, high performance combined with high precision handling, and the greatest degree of efficiency for long battery life. In a nutshell, the product philosophies of the Guardian and the Faulhaber drive motors are very similar. Both rely on a modular product to ensure the widest possible range of applications. This similarity is also reflected in the deployment of the fifteen drives. Motors and gearheads are selected depending on the task in hand and combined to meet the required performance. For example, each of the four drive modules is powered by a 38 mm diameter motor with matching diameter planetary gear. With over 200 W and around 150 mNm at the motor shaft, the combined motor output of 1 metric HP is more than sufficient to move the vehicle and its equipment through terrain or over inclines. Two structurally identical motors with different reduction ratios are also responsible for raising and lowering the telescopic arm. The wide range of gear ratios therefore allows the ideal output torque and speed to be selected for both operations. Smaller 32 mm motors with an output of around 80 W extend and retract the telescopic arm. To keep the weight of the head low, light 26 mm diameter, 44 W drives perform the "turn and tilt" function. The camera and optional weapons, on the other hand, are actuated by two identical drives 23 mm in diameter and with around 20 W output. Depending on the function required, the manipulator works with a 23 and 26 mm drive. All motors come in rugged DC brush design and are therefore capable of starting even at very low voltages. The comparatively simple yet robust drive control system using pulse-width modulation is also ideal for this application. ■

Higher performance with lower consumption

Electronic fuel injection in UAVs

Small and miniature aircraft, also known as UAVs (unmanned aerial vehicles), require reliable propulsion systems in order to achieve extended flight times with minimal quantities of fuel. Previously, the only option available for fuel delivery to the engine was a carburetor. The latter, however, is not able to provide an optimum fuel mix for all of the various phases of flight. A newly developed miniaturized electronic fuel injection (EFI) system designed especially for small combustion engines now provides the benefits of fuel injection, long enjoyed in larger engines, for small UAVs. The most striking characteristics of this system are higher performance combined with reduced consumption and considerably increased reliability. Microdrives are used to power the fuel pump to ensure the correct pressure in the fuel system. The properties required include high performance density together with low weight and superior reliability.

The compact injection system with electronic control unit (ECU), pump and pressure accumulator, all weighing just 200 g

Research, military and increasingly industry, media and emergency services are using miniature aircraft, known as unmanned aerial vehicles (UAVs), for reconnaissance flights and measurements. They are considerably cheaper to purchase and maintain than manned flights. Because they are so compact, they need small internal combustion engines for power, but to date these have virtually always been fitted with carburetors for the purpose of fuel delivery. Currawong Engineering Pty Ltd from Kingston, Tasmania, Australia, is now coming to the rescue by producing miniature electronic fuel injection (EFI) systems. This guarantees an optimum fuel mix at all stages of flight, even for miniature aircraft. The fuel, which is under pressure within the system, is injected into the intake manifold using specialist fuel injectors and the fuel/air ratio is electronically controlled by a multi-function electronic control unit (ECU). Auxiliary energy is required to build up the necessary fuel pressure. A high-performance, low-weight DCMicromotor ensures consistent fuel pressure, irrespective of height, fuel levels and flight maneuvers. Research, military and increasingly industry, media and emergency services are using miniature aircraft, known as unmanned aerial vehicles (UAVs), for reconnaissance flights and measurements. They are considerably cheaper to purchase and maintain than manned flights. Because they are so compact, they need small internal combustion engines for power, but to date these have virtually always been fitted with carburetors for the purpose of fuel delivery. Currawong Engineering Pty Ltd from Kingston, Tasmania, Australia, is now coming to the rescue by producing miniature electronic fuel injection (EFI) systems. This guarantees an optimum fuel mix at all stages of flight, even for miniature aircraft. The fuel, which is under pressure within the system, is injected into the intake manifold using specialist fuel injectors and the fuel/air ratio is electronically controlled by a multi-function electronic control unit (ECU). Auxiliary energy is required to build up the necessary fuel pressure. A high-performance, low-weight DCMicromotor ensures consistent fuel pressure, irrespective of height, fuel levels and flight maneuvers.

In-flight mixing.

Engines used in aircraft are particularly demanding when it comes to controlling the fuel/air ratio. Fuel and air will only ignite within specific limits, and the window is even smaller if the engine needs to run with optimized performance and minimum specific consumption at all times. Efficient consumption is especially important in small aircraft; every gram saved extends flight time or increases the usable load. As most miniature aircraft have only a single engine, any problems automatically result in a crash, so extreme reliability is required of all components. The problem of aircraft engines with carburetors is the fact that the mixture is too rich at

altitude if the carburetor is perfectly tuned at sea level. If the mixture is ideal at altitude, it is too weak on the ground. A compromise is always required and this reduces performance and increases fuel consumption. The only solution is electronic fuel injection. As the fuel is under several bar of pressure, the vaporization of fuel is ruled out even at high altitudes. Injectors spray the fuel into the inlet pipe. This allows a free, aerodynamic inlet path with no Venturi nozzles. The engine can “breathe” freely and unleash more performance. This is most noticeable at greater altitudes where the air is thinner. The amount injected is constantly recalculated electronically based on engine data such as inlet temperature, air pressure and performance required. The injection point and duration are coordinated with the crankshaft angle. In conjunction with the shape of the injectors, the pressure in the fuel system ensures extremely fine vaporization of the fuel; very small drops vaporize more easily than large ones to give a more consistent mixture. This guarantees an optimum mixture not only on ignition where there is practically no flow at all but also in thin air at high altitudes and at full power on the ground in thick air. Overall, use of an injection system translates into 15 to 30 percent better consumption, increased performance and improved engine reliability.

Injection in practice.

Although the principle is very simple, designing an injection system for miniature engines is incredibly complex. The specialists from Australia have managed to supply engines of be-tween 10 and 250 ccm with their compact system. The entire system consists of a number of components that can be tailored to the relevant engines.

As well as the controller, the sensors for crankshaft position, and inlet and cylinder head temperature, the system also incorporates an ignition module, the injector, a fuel pressure accumulator and the fuel pump. The high-precision mechanical components weigh a total of less than 200 g and take up just 74 x 58 x 39 mm (h x w x d). The area of application of the certified components covers a temperature range of - 30 to + 50 °C and an altitude of up to 6000 m. Non-stop test runs over 1500 h and 700 h confirm the components are extremely reliable. There is a piston pump to ensure the essential pressure build-up and a downstream pressure accumulator with pressure controller to guarantee a constant pressure of 2.9 to 3.2 bar in the system. In the fuel pump, a microdrive works with a bevel gear system on a crankshaft which powers the actual pump pistons. The 90° force transfer in the gearheads means the 27 g precious-metal commuted DCMicromotor can be positioned behind the pump cylinder to save space. The entire pump unit measures just 65 mm in height and 22 and 34 mm respectively in width and depth. The pump is controlled by means of pulse width modulation, with the service life being more than sufficient for this application. In order to increase torque and enable optimum transfer of the 2.5 W output to the pump crankshaft, there are planetary gearheads connected downstream of the engine. The input ratio reduces 19 : 1 for a 15 mm diameter. It works in a temperature range of – 30 to + 65 °C, which is more than adequate for UAV flights anywhere in the world. The torque for the two-speed plastic gear weighing just 5 g can be up to 200 mNm.

Servo Motors Help Rockets Blast Off

Robust servo motors survive launch conditions to optimize fuel burn in rockets

Amid tightening budgets, space agencies are increasingly looking to the commercial space sector to provide the launch vehicles of the future, and Space Exploration Technologies (SpaceX) is right there to help. The company builds high-reliability, economical launch vehicles like the Falcon 9 to carry a range of payloads into orbit (see figure 1). One way to control cost is by optimizing fuel burned during launch to minimize waste. The SpaceX team ensures top performance with the help of a special fuel-trim valve, powered by robust, reliable servomotors from MICROMO, the North American value-added reseller for the FAULHABER Group.

Rockets like the Falcon 9 and Falcon 1 at SpaceX burn a fuel known as RP-1, a highly refined form of kerosene that must be mixed with oxygen in order to burn. On the launch vehicle, 4-in pipes run from tanks of RP-1 and liquid oxygen (LOX) to combine prior to entering the combustion chamber.

The combustion chemistry of RP-1 is forgiving. The fuel won't burn without oxygen, but as long as oxygen is present, the two do not need to be combined in a precise ratio. "If the mixture is slightly lean, it is still going to burn decently," says Juerg Frefel, Avionics Engineer at SpaceX. The problem is that if the ratio of LOX to RP-1 varies from the optimum mix, either the oxygen will run out before the fuel or the fuel before the oxygen. Once combustion stops, the material left becomes dead weight, turning from propellant to liability. To ensure this doesn't happen, the fuel-trim valve adjusts the mixture in real time.

The fuel-trim device consists of a servo-motor-controlled butterfly valve. To achieve the proper speed and torque, the design incorporates a planetary gearbox for a roughly 151:1 reduction ratio, plus additional gearing internal to the unit. The team qualified the components with a significant safety margin to protect against common-mode failure. The shaft of the motor interfaces with the valve directly to make fine adjustments. "The basic mixture ratio is given by the sizing of the tubes, and a small amount of the flow of each one gets trimmed out," explains Frefel. "We only adjust a fraction of the whole fuel flow."

FIGURE 1
The Falcon 9 launch vehicle consists of a payload nacell atop two stages. Stage one consists of nine engines (lower black band) fed by a fuel tank above it. Stage two consists of one engine (upper black band) and a corresponding fuel tank. (PHOTO: SPACE EXPLORATION TECHNOLOGIES)

The Falcon 9 launch vehicle is a two-stage vehicle with a total of ten engines, each with its own fuel-trim valve. To ensure the proper mix, the valve operates in a double closed loop based on feedback from a triplicate feedback mechanism. The first stage features nine engines that burn for approximately three minutes, and the second stage includes one engine that burns for approximately seven minutes (see figure 2). Because of the duration of the burn for each stages, the control loops can actually run relatively slowly. "The whole valve doesn't necessarily need to be fast," says Frefel. "It's a closed-loop system, which means that the command to the valve is to go to a certain angle. The outer loop adjusts the angle of the valve and the inner loop keeps the position steady in case it gets pushed around [by shock/vibration]."

FIGURE 2
The first stage of the rocket includes nine engines, each of which features a servo-motor-driven fuel-trim valve to guarantee even fuel burn. (PHOTO: SPACE EXPLORATION TECHNOLOGIES)

Tough Enough

Accuracy aside, the characteristics most applications require from servo motors tend to be high torque, high speed, or small size. In the case of the fuel-trim valve, the chief motor requirement was simple: They had to survive launch. The shock and vibration produced in the first stage, in particular, are extreme (see figure 3). "For the three minutes of the first stage, the engine is producing 100,000 lb. of thrust," says Frefel. "It's quite a violent event and [the fuel-trim valve] is right next to the engine."

When the engineering team set out to qualify components for the fuel-trim valve, vibration testing caused motor after motor to fail. "We have vibration fixtures and tables here where we can simulate the engine environment," says Frefel. "We basically went through a whole bunch of motors from different vendors to see which one would hold up." To minimize points of failure, they switched from brushed to brushless motors. "The main performance issue for us was could it survive the environment? That meant that the gearbox stayed on, the Hall-effect sensors weren't damaged, that nothing bad happened in the extreme environment. We just [kept looking] until we found the manufacturer of motors that survived." In the end, that manufacturer was MICROMO.

Rocket engines produce heat as well as vibration, but contrary to what a person might think, thermal management does not pose a significant challenge in this application. Much of the heat is radiated and is reflected away. In addition, given the relatively brief duration of the stages, the unit's thermal mass makes it resistant to rapid temperature swings. "The actuator still has three to four pounds of mass, which means that in three minutes it doesn't heat up that dramatically," Frefel says.

Interestingly, the thermal issue he does mention is low, not high temperatures. During the second stage, for example, the engines may fire only briefly. The vehicle can then coast for as long as 45 min before a second burn takes place. By this point, the rocket is outside of the atmosphere, where temperatures can be quite low.

FIGURE 3
The fuel trim valve sits just above the engine, where the inflow pipes from the tanks of RP-1 fuel and liquid oxygen combine, to ensure that the two tanks empty evenly. (PHOTO: SPACE EXPLORATION TECHNOLOGIES)

FIGURE 4
The servo motors that drive the fuel-trim valve must be able to survive punishing launch conditions. (PHOTO: SPACE EXPLORATION TECHNOLOGIES)

To control cost and production timelines, the SpaceX philosophy is to try to work with stock components whenever possible. Nothing special was done to the MICROMO motors to ruggedize them for the application; the design team simply ordered standard products. Leveraging MICROMO's express prototyping program, the SpaceX team was able to obtain samples in very short time frames. "They were either in stock in the United States or they had them within a few days," said Frefel. "They do a good job of having small volumes that can allow you to try out different gear ratios for different topologies. I was quite impressed by how easy it was."

As schedule and budgetary pressures cause NASA to increasingly lean toward commercial orbital transportation services, opportunity in this sector is on the rise. With the help of MICROMO, SpaceX delivers robust, reliable technology at an appealing price point (see figure 4).

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