SENSORS

The forgotten spectrum: Reviving ultrasound for robust autonomy

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Seemingly outdated ultrasound combined with edge-AI denoising can make autonomy more robust when vision fails.

Robots are increasingly required to operate under conditions where standard sensing assumptions do not hold. Examples include smoke-filled buildings during search and rescue, dark utility tunnels for inspection, environments with glass or other transparent structures, and outdoor environments with snow, fog, or strong glare. In mobile autonomy, commonly used cameras and LIDAR (light detection and ranging) can provide both geometric and appearance information about the environment. However, these sensors can still degrade under real-world, nonideal conditions (*1*). As a result, many robots remain vulnerable in situations where reliability is most important. In this issue of *Science Robotics*, Velmurugan *et al.* introduce Saranga (*2*), a perception and navigation stack for palm-sized aerial robots that uses ultrasound as a low-power sensing modality for navigation in visually degraded environments.

WHY ULTRASOUND WAS SIDELINED

Acoustic sensors, such as ultrasonic ranging or microphone arrays, have seen widespread adoption across diverse fields. However, in robotics, ultrasound sensors are often associated with short range, coarse resolution, and susceptibility to interference (*3*). On aerial robots, propeller noise can further reduce echo quality. Under these constraints, ultrasound is often viewed as suitable only for simple proximity sensing rather than reliable autonomy.

However, this conclusion is mainly based on how ultrasound has been used in many robotic systems in the past. In nature, the bumble bee bat, which weighs about 2 g, uses ultrasound echolocation to fly safely and to detect objects as small as 8 mm (*4*). Ultrasound interacts with the environment through pressure waves rather than photons. Therefore, it can operate under visually degraded conditions and can detect thin or transparent obstacles that are challenging for optical sensors. The main difficulty is noisy echoes, where multipath returns, attenuation, and interference can reduce signal quality. On aerial robots, propeller-induced noise further masks the signal.

MODERN ULTRASOUND IN VISUALLY DEGRADED SETTINGS

Saranga addresses the problems above by combining modern computation with careful hardware design for low-power ultrasound sensing (*2*). It uses a dual low-power ultrasound sensor suite and tackles the extremely low peak signal-to-noise ratio of ultrasound returns. The method uses two complementary steps: physical noise reduction that blocks propeller-induced ultrasound noise and a deep learning denoising model that uses long-horizon echo time histories, trained with a synthetic data pipeline plus limited real noise data.

As a result, a palm-sized quadrotor measuring 0.16 m, costing about $400, and using only 1.2 mW of sensing power can navigate cluttered environments in dense fog, darkness, and snow and around thin and transparent obstacles using only onboard sensing and computation, with no reliance on external infrastructure. Optical and electromagnetic sensors struggle to operate reliably under the full range of conditions above. These results suggest that ultrasound can be an effective sensing modality for autonomy in visually degraded environments, provided that the hardware and computation stack is designed around its noise characteristics.

More broadly, ultrasound is not only a backup range sensor; it can also feed directly into the autonomy pipeline. Using echo sequences over time, the system can estimate when it is unsure, for example, distinguishing open space from smooth reflective surfaces that can confuse vision. For small robots with limited compute and power, this can guide system design. Instead of adding heavier sensors for rare edge cases, adding a low-power modality plus simple inference can improve robustness. This also suggests that benchmarks should report not only average accuracy but also performance under controlled degradations, such as fog density, illumination, propeller rotational speed, and multipath severity, where failures may be sudden and safety critical.

REVISITING LEGACY SENSING MODALITIES

Many other sensing modalities have been used in robotics. Examples include sonar, infrared proximity sensors, time-of-flight sensors, tactile and force sensors, thermal cameras, event cameras, optical-flow sensors, microphone arrays, Wi-Fi or other radio-based sensors, barometers, magnetometers, and chemical or gas sensors, among others. These sensors were common in earlier systems or niche applications. Later, as computer vision and LIDAR improved, they became less prominent in mainstream autonomy, especially for drones, humanoid robots, and autonomous driving.

Of course, these modalities have drawbacks, so many were replaced in mainstream systems (*5*). Infrared sensing is often short range and sensitive to materials and geometry. Thermal cameras work in darkness but can have low detail and weak contrast. Microphone arrays suffer from noise and reverberation. In

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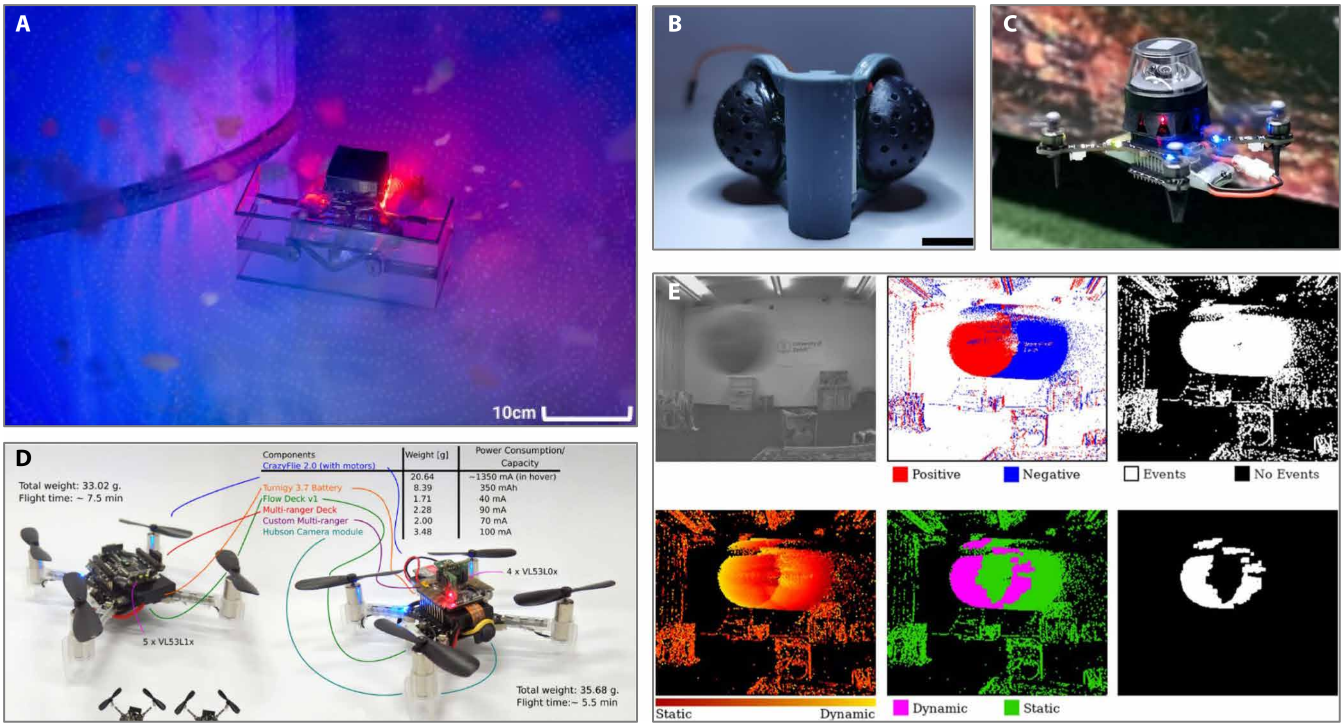

Components	Weight [g]	Power Consumption/ Capacity
CrazyFlie 2.0 (with motors)	20.64	~1350 mA (in hover)
Turnigy 3.7 Battery	8.39	350 mAh
Flow Deck v1	1.71	40 mA
Multi-ranger Deck	2.28	90 mA
Custom Multi-ranger	2.00	70 mA
Hubson Camera module	3.48	100 mA

Fig. 1. Diverse and innovative sensing modalities for autonomous robots. (**A**) Ultrasound echoes and denoising for navigation under visually degraded conditions (*2*). (**B**) Lens-free compound eye for motion tracking (*6*). (**C**) Highly compressed panoramic images for visual route following (*7*). (**D**) Signal strength information and single-point range sensors for exploration and return (*8*). (**E**) Event cameras for dynamic obstacle detection and avoidance (*9*).

radio-based sensing, received signal strength varies with occlusion, multipath, and local structures. Barometers drift, magnetometers are disturbed by nearby materials, and gas sensors can be slow and cross-sensitive. Nevertheless, each modality has strengths that are often obscured by practical limitations.

One practical lesson, as illustrated by Saranga (*2*), is that sensor choice can be more principle driven: Select sensor modalities according to which physical signals remain reliable under the target conditions rather than defaulting to vision or LIDAR and then patching failures. Making these modalities usable may require modern computation and enabling technologies. For example, temporal models can use multimodal histories rather than single snapshots, and learning-based denoising can extract weak structure from noisy measurements. Data-driven calibration can also reduce sensor-to-sensor variation and drift. As shown in Fig. 1 (B to E), artificial compound eyes can achieve an ultrawide field of view and outstanding angular selectivity (*6*); highly compressed panoramic images (*7*) and sparse range measurements (*8*) can enable miniature autonomous flight; and event cameras can help avoid fast-moving obstacles (*9*).

To make such hybrid systems more widely explored and used, we need better algorithms and practical tools. These include simple calibration, open datasets that align these modalities with standard vision and LIDAR, and clear evaluation that better measures the quality of sensor fusion. Packaging is also difficult. Acoustic, thermal, and radio-based sensors interact with platform hardware, including motors, enclosures, and shielding against electromagnetic interference, but this is often ignored in idealized perception research. If we treat these interactions as design constraints rather than mere noise, older sensors could become reliable parts of modern autonomy.

CREDITS: *SCIENCE ROBOTICS* (*2*, *6–9*).

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