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Engineering

Heat signals enable day-like visibility at night

Manish Bhattarai & Sophia Thompson

An imaging technique that uses a neural-network model to obtain physical information from infrared radiation improves on existing techniques in low-visibility situations, and could be deployed immediately in autonomous vehicles. **See p.743**

Image detection and classification techniques are indispensable for technologies such as autonomous vehicles, which are set to make an indelible mark on the twenty-first century. But these methods still face considerable challenges when visibility is low – either because of weather conditions such as fog and smoke, or as a result of something as commonplace as the natural hours of darkness. On page 743, Bao *et al.*[1] present heat-assisted detection and ranging (HADAR) technology, a groundbreaking approach that uses thermal imaging, physics and machine learning to shine light on the problem of low-visibility detection.

Bao and colleagues' HADAR system uses a commercial infrared camera to capture thermal images, from which it extracts the material properties of each object in its field of view, thus overcoming the visibility issues encountered by conventional navigation and imaging systems (Fig. 1). The analysis performed by the HADAR system reveals the temperature of an object, as well as its material composition and the unique patterns of thermal radiation that it emits. In this way, HADAR technology can unveil texture and depth in darkness, just as the human eye does in daylight. And by deducing more-detailed physical attributes than can conventional thermal imaging, the technique provides a comprehensive 'picture' of each object and its surroundings.

But although heat signals from thermal-imaging systems offer a way to 'see' through the darkness, they come with their own set of problems. A big roadblock for most thermal-imaging systems is the ghosting effect, which occurs when heat signals from various objects blend together, resulting in hazy, indistinct images[2]. HADAR's ability to overcome this limitation forms the foundation of its novelty and potential – and it does so with the help of artificial intelligence (AI).

The ghosting effect arises because it is difficult to distinguish between physical attributes of an object using thermal radiation alone. Thermal images contain information about how hot an object is, but also about the object's texture and its ability to emit infrared energy (its emissivity). Direct thermal emission from an object conveys no information about its texture: this information can be gleaned from environmental emission that enters the camera after scattering off the object. To disentangle these two types of emission, Bao *et al.* developed a custom library that catalogues the emissivity of every material that could possibly appear in a scene.

The authors trained a neural-network model with data from this material library. The model is designed to process intricate heat signals from the infrared camera to calculate the temperature, emissivity and texture of each object in a scene, and to learn from its own data; in effect, teaching itself to map the world through heat signals. With this model, the authors were able to mitigate the ghosting effect, and to obtain clearer and more-detailed

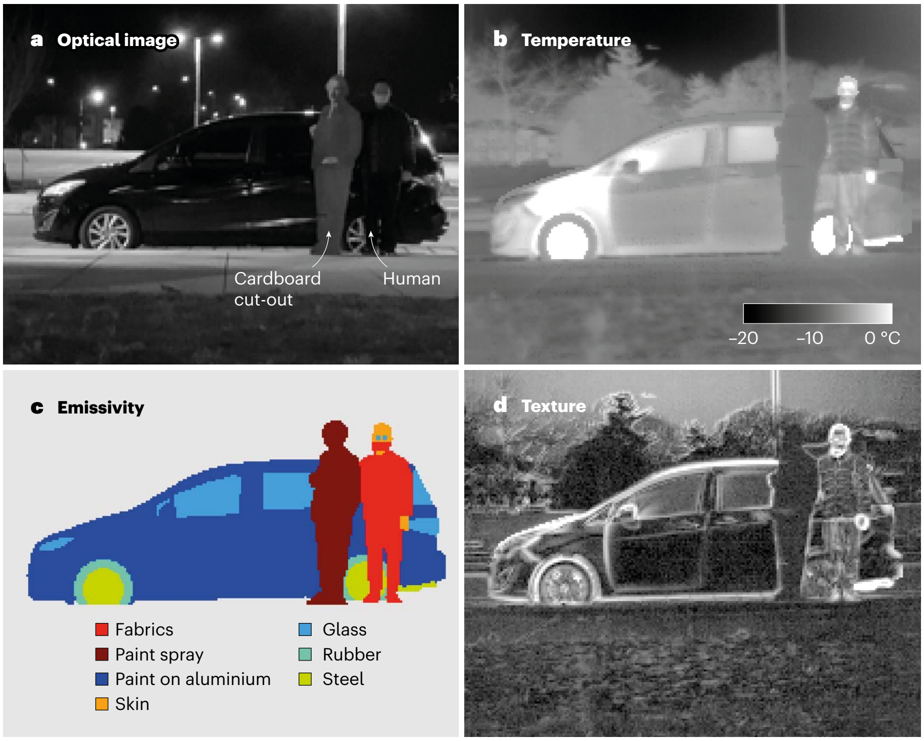

Figure 1 | Discerning objects under low-light conditions. Thermal imaging can be used in low-visibility situations, but it is difficult to distinguish between an object's temperature, emissivity (its ability to emit infrared energy) and texture on the basis of thermal radiation, and this makes it challenging to identify objects correctly. Bao *et al.*[1] devised a technique called heat-assisted detection and ranging (HADAR), which uses artificial intelligence to separate these three attributes. They used the technique to image a night-time scene involving a human, a life-size cardboard cut-out of Albert Einstein and a black car. Whereas optical imaging (**a**) struggles to distinguish between the human-shaped objects, HADAR can identify all objects in the scene correctly by deducing their temperature (**b**), emissivity (**c**) and texture (**d**). (Adapted from Fig. 5 of ref. 1.)

thermal images than those acquired with existing AI-enhanced thermal-imaging techniques[3,4]. HADAR therefore redefines machine perception in low-visibility environments.

Although HADAR is a nascent technology, its potential applications are many and varied. It seems clear that the system will find immediate applications in the autonomous driving and robotics sectors. But it could also be applied in national security and emergency-response settings, in which the success of a mission can hinge on the responder's ability to navigate under conditions of near-zero visibility (see go.nature.com/3cwan9c).

HADAR's ability to detect temperature accurately, despite the confounding factors of emissivity and texture, holds great promise for industries such as smart health care. For instance, it could be used in real-time, contactless systems for monitoring body temperature, providing an efficient means to screen people at airports or public events. The technology could also be used in agricultural settings, in wildlife monitoring and in geoscience research. And the scalability and passive nature of HADAR will no doubt inspire future imaging and vision technologies.

However, the system is not without its challenges. The greatest barriers lie in the cost of the equipment, and in hardware-level issues, including the fact that the system must be calibrated on the fly. Another stumbling block is the fact that a variety of environmental conditions can affect the temperature, emissivity and texture of an object, and so impair the model's ability to identify it correctly. This problem could be solved by modifying the material library to account for these factors. Integrating the technology with cutting-edge devices is yet another challenge in this list of formidable obstacles.

All these difficulties must be overcome if HADAR is to become widely accessible, but Bao and colleagues' proof-of-principle demonstration is sufficient to show that the approach is poised to revolutionize computer vision and imaging technology in low-visibility conditions. HADAR will no doubt improve autonomous driving and other machine-assisted technologies and, as it continues to evolve, it could pave the way for fully passive machine-perception technology that has an acute sense of its physical surroundings. It therefore has the potential to reshape our future – pushing us closer to a world in which machines can provide key safety information by assessing their surroundings with ever greater accuracy.

Manish Bhattarai is in the Theoretical Division, Los Alamos National Laboratory, Los Alamos, New Mexico 87545, USA.
Sophia Thompson is in the Department of Biology, University of New Mexico, Albuquerque, New Mexico 87106, USA.
e-mails: ceodspspectrum@lanl.gov; sophiat4@unm.edu

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Biophysics

Dynamics of protein droplets at multiple scales

Marina G. Guenza

Many biological processes rely on proteins that aggregate into droplets governed by dynamics that span myriad scales. A clever combination of spectroscopy and simulation offers a way to probe these diverse dynamics. **See p.876**

Coacervates are dense protein droplets that form spontaneously in cells through a process called phase separation[1]. These droplets have key roles in various biological phenomena, but an understanding of the molecular-scale mechanisms through which they perform their functions remains largely elusive. This is because their macroscopic properties are intricately linked to their structure on an atomic scale. Revealing these molecular mechanisms therefore requires the investigation of properties across a wide range of time and length scales. On page 876, Galvanetto *et al.*[2] address this challenge by combining several spectroscopic techniques with computer simulations to capture the dynamics of proteins in coacervates – from their atomic movements all the way up to the fusion of phase-separated molecular droplets.

One reason that coacervates have piqued the interest of so many scientists is that they are implicated in such varied phenomena, including cell replication and the dynamic compartmentalization of living cells. Protein aggregation has also been linked to the development of neurodegenerative diseases. In marine organisms, coacervates have a crucial role in providing robust adhesion, allowing organisms to withstand strong tides and waves. Finally, the presence of dense liquid droplets is thought to have been important during early evolution, because prebiotic aggregates can readily form from protein and polysaccharide mixtures.

But coacervates are intriguing for another reason: they form without the need for an enclosing membrane. The aggregation process is simpler than that for structures that are covered in membranes – it is driven by thermodynamics, and leads to the formation of protein-rich droplets that are dispersed in a low-concentration protein environment. Coacervates therefore have the advantage that their molecules can diffuse more freely between the condensed and dispersed phases than they would with a membrane. At the same time, the physical proximity of molecules in the condensed phase still gives rise to intermolecular interactions.

Most of the proteins that are involved in the formation of coacervates belong to a class known as intrinsically disordered proteins (IDPs)[3]. Unlike other protein classes, IDPs exist mainly in an unfolded state when they are in solution. However, when IDPs bind to other molecules, they can adopt distinct folded structures that have special functions. Despite decades of dedicated research[4], scientists do not have a full understanding of IDPs. Galvanetto *et al.* investigated the behaviour of two IDPs: a protein known as histone H1, which helps to package DNA in human cell nuclei, and its nuclear chaperone, prothymosin α. In doing so, the researchers combined topics that sit at two of the most exciting frontiers in modern molecular biology: IDPs and coacervates.

So far, investigations of coacervates have focused mainly on scales larger than that of the molecules in the droplets[5], leaving the underlying molecular mechanisms that govern coacervates' biological functions largely unexplored. This is because it is challenging to probe these systems on multiple scales of interest, given that each experimental and simulation technique can explore only a well-defined and small range of timescales (Fig. 1).

Macroscopic phase separation is known to be guided by a delicate balance of attractive and repulsive molecular forces at the atomic scale. Therefore, although these forces operate at sub-nanometre scales, they have an