The Contact Problem

About free-space demos, the last centimeter, and why robots still struggle when the world pushes back.

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ROBOTICS · MANIPULATION · CONTROL

Perception and planning got fast. Physical contact did not. When we imagine the machines of the future, we often picture them moving cleanly through air. The harder question is what happens when they have to touch us, and the rest of the world, and come away unbroken.

Most robotics demos that look like the future are free-space problems with a hardware costume on. An arm tracks a path through empty air. A drone holds a pose. A learned policy looks competent until a fingertip meets an edge it did not model. Watching a robot move is impressive. Watching it press, grip, dock, or lean into something uncertain is usually where the performance thins out.

When we consider these machines, it helps to ask what kind of progress we are celebrating. Seeing and planning have improved quickly. Cameras got cheaper, models got better, and free-space motion started to look solved enough for a demo reel. Contact did not keep the same pace. Force, friction, and compliance are still the unfinished parts of the stack, because they are where the world stops being a picture and starts pushing back.

Contact is awkward in a way that planning rarely is. Friction does not behave smoothly. Stiffness can jump by orders of magnitude between foam, metal, and skin. A millimeter of misalignment that would never spoil a render can jam a joint, slip a grasp, or crack a housing. In free space, small error is often cheap. In contact, the same error becomes energy, heat, and failure modes that compound before anyone has time to narrate them.

Think of it as a last-centimeter problem. Not the last mile of autonomy as a slogan, but the last centimeter of a grasp, a dock, a mating surface, or a wheel on ground that is not quite what the map promised. That is where a clean kinematic plan meets unilateral constraints, where friction refuses to be polite, and where the difference between success and damage is a few newtons over a few milliseconds.

It is tempting to answer the gap with more intelligence alone. Better models and richer simulation help, but they do not cancel the physics sitting underneath. A stiff, overconstrained mechanism will not become gentle because the policy got smarter. Softness in the wrong place will chatter under force control. And if the robot can see a surface without feeling how hard it is pressing, the controller is still guessing about the thing that decides whether contact went well.

Classical robotics already named pieces of this. Hybrid force and position control, impedance and admittance architectures, and soft robotics all treat contact as something worth designing for rather than discovering at the end. The gap is not that the ideas are unknown. It is that they remain unevenly used. Many systems still optimize for free-space metrics, then meet contact late in integration, when changing the mechanism is most expensive and least romantic.

What needs solving is a stack, not a single invention. Mechanisms that encode compliance instead of fighting it. Tactile and force sensing that is cheap, durable, and fast enough for closed loop. Controllers that treat contact events as state, not as faults. Simulation that is honest about friction and deformation instead of optimistic about them. Requirements that specify contact cases with the same seriousness as free-space accuracy.

Our future will be full of machines, and they will have to touch the world we live in. Fluency in description is useful. Fluency in contact is what keeps those machines in good company with us. Progress will come from teams that treat the last centimeter as the product, not as leftover error after planning.
