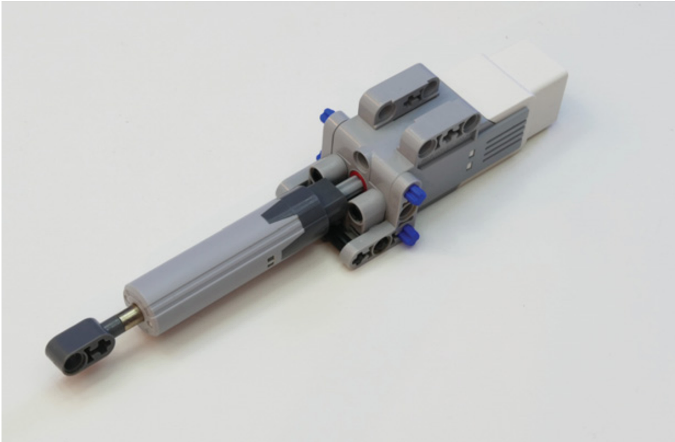
Technic movements on a miniature scale

By Oton Ribic

Images by Oton Ribic

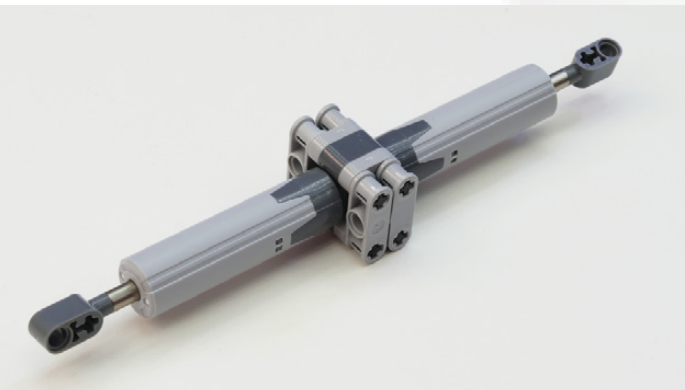


[Fig_1] In this configuration, the actuator extension can be controlled down to 1/16th of a millimeter, under optimal conditions.

It's not a common problem for every LEGO builder, but anyone who has attempted to perform very precise Technic movements will be well acquainted with it. The problem is also well known amongst MINDSTORMS builders when attempting to build accurate robots and controlled mechanisms, particularly if they need to interact with objects outside of LEGO.
Basically, due to the mechanical tolerances of LEGO parts, the resulting movements often tend to have a bit of unpredictable slack. This slack or 'looseness' is hardly noticeable or important if driving an off-road car through your backyard, but it quickly surfaces once one begins hunting for fine micromovements. It should be said that the tolerances in question are not carelessness on LEGO's part – on the contrary, they are necessary in order to allow for easy building and disassembly.

Since these tolerances and the inaccuracy they incur tend to accumulate, as a general rule the simplest mechanisms are often the most accurate. In the perfect case, there is only one moving part involved in the action you want to perform. In other words, if you can avoid transmitting the movement through a few axles, U-joints, rack and pinion, or further linkages, then do so, and restrict the movements to only the bare minimum of parts.

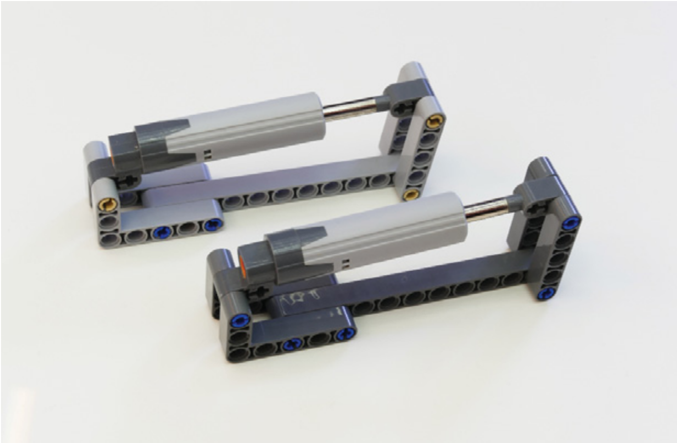
However, this reductionist approach is not always possible, and there are ways around the problem in such cases [Fig_1]. Sometimes, if the number of involved linkages is not too high (i.e. not over six), it is worth replacing the frictionless pins or axles around which the parts rotate with friction pins. They fit snugly into the holes and leave no tolerance, or backlash, as long as the forces involved are not too large.



[Fig_2] By rotating one end and keeping the other one static, these back-to-back actuators function as a single long one.

Using friction pins in large quantities, however, introduces the problem of requiring a lot of force to move the desired parts, thereby slightly bending the parts themselves and introducing even further inaccuracies. Or, for the more technical-minded, the proper term for this is that in such cases we start facing unwanted mechanical hysteresis.

A mechanically more complex approach, but one that yields better results, is to design the entire mechanism so that the critical parts are always directly affected by gravity. This is often an interesting approach for precise plotting or engraving mechanisms: if the drawing or engraving surface is horizontal, the pen or the drill bit will necessarily show some slack in its movements. However, if the entire mechanism is vertical, it will always be pushed into one direction by the gravity and precisely respond to the movement of its axle, chain, control rod, or something similar.



[Fig_3] These structures should behave identically in theory, but the darker one is more precise because of using friction pins at the rotation points that allow less slack movement, but at the cost of more resistance.

In any case, keep in mind that achieving excellent accuracy usually requires some tuning once the basic mechanism is finished. Try a friction pin here, observe the change, add a weight there, vary the angle of the baseplate – these adjustments are just as important as the underlying design.

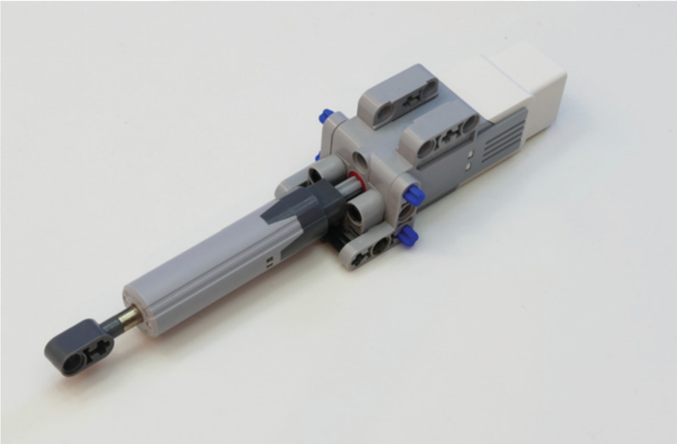
As for the maximum accuracy one can realistically strive for using LEGO parts, this depends on many factors, but we can provide a few ballpark figures for reference [Fig_2]. A generally good idea, if it suits your project, is to connect a MINDSTORMS motor directly to a large linear actuator. These actuators are sturdy, reliable (particularly the redesigned version), fairly accurate and ubiquitous.

The pitch of the actuator's inner screw makes one millimeter of linear movement per 240º rotation at the input. Taking into account that about 15º is the smallest angle the MINDSTORMS motor can reliably make, it is easy to calculate that the smallest controllable actuator movement amounts to 1/16 of a millimeter, or about 63 µm. This is a tiny movement, on the order of magnitude of a hair's width, yet perfectly achievable with standard parts, if all the prerequisites mentioned earlier (tension, tight pins, etc.) are satisfied.

The author has attempted to downgear the motor output and thus provide even finer movements of the linear actuators, or connect it to various triangular linkages which reduce motion, but it turned out that, if looking for accuracies ranging below 50 µm, secondary effects surface. Tension of the actuator screw, flexibility of its supporting structure, bending of its arm, etc. start getting in the way, and although there are ways to reinforce and minimize even those effects, their complexity soon outweighs the entire mechanism alone. Still, the aforementioned resolution of a 1/16 of a millimeter, under optimal circumstances, should be more than enough.

This is based upon the assumption that the total range of five studs, i.e. 40 mm, which the large linear actuators offer, is enough [Fig_3]. If it isn't, another option is to use rack & pinion systems, among which the new parts introduced in the Arocs Truck, designed for just this purpose, are very practical (part numbers 18940 and 18942). Their range is about 10.5 reliable studs, more if some underlying rails are provided, amounting to at least 84 mm. With some proper gearing down and tensioning, it is possible to control its movement accurately down to a tenth of a millimeter, but it incurs more friction than the actuators, particularly if large forces are involved, and also allows for some slack movement of the rack once fully extended.

An interesting third option is to use two large linear actuators connected back-to-back and rotate one end [Fig_4]. This has some drawbacks, such as being impractically long even when fully retracted, and will probably require an additional mechanism to allow rotating it freely. But these are compensated for by having an actuator accuracy over double the range, i.e. 80 mm. Even more actuators can be cascaded this way, though after the third one this construction itself begins losing stability, offsetting any particular advantage in the accuracy itself. Still, if you have plenty of actuators at hand, this is definitely worth considering.



[Fig_4] The recently introduced rack and pinion parts allow good precision at longer range, though not as good as the linear actuators.

And finally, whichever of the solutions you go for, make sure you are using parts in good condition. Worn-out parts increase the tolerances and thus slack space, while the old, worn and dry linear actuators, often recognized by their squeaking, cause more friction among the inner parts, thereby making the linear motion more skippy than smooth. Fortunately, they are not difficult to disassemble and relubricate if no other option is at hand.
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