# Ratchair: Furniture learns to move itself with vibration

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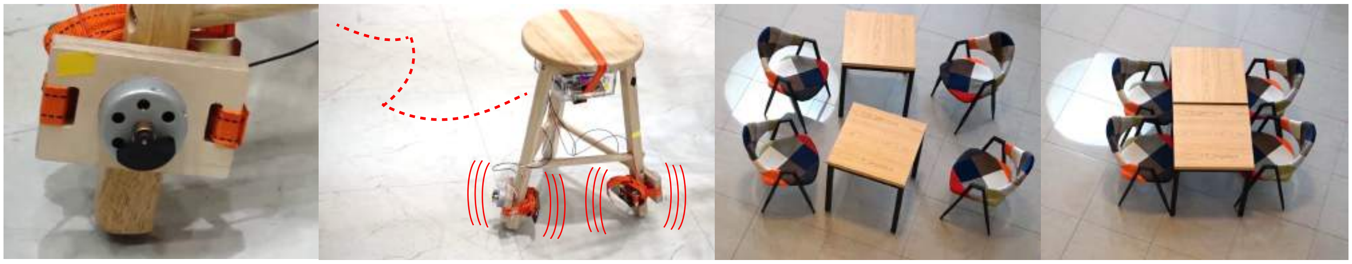

**Figure 1:** *The running and gathering of ratchairs. The chair on the left moves through vibration induced by strapped-on motors.*

**Keywords:** robot locomotion, tracking, vibration, optimization

**Concepts:** •**Computer systems organization** → **Robotic control;**

## 1 Introduction

An Egyptian statue on display at the Manchester Museum mysteriously spins on its axis every day; it is eventually discovered that this is due to anisotropic friction forces, and that the motile power comes from imperceptible mechanical waves caused by visitors' footsteps and nearby traffic. This phenomena involves *microscopic ratchets*, and is pervasive in the microscopic world - this is basically how muscles contract. It was the source of inspiration to think about everyday objects that move by harvesting *external* vibration rather than using mechanical traction and steering wheels. We propose here a strategy for displacing objects by attaching relatively small vibration sources. After learning how several random bursts of vibration affect its pose, an optimization algorithm discovers the optimal sequence of vibration patterns required to (slowly but surely) move the object to a *very* different specified position. We describe and demonstrate two application scenarios, namely assisted transportation of heavy objects with little effort on the part of the human and self arranging furniture, useful for instance to clean classrooms or restaurants during vacant hours.

## 2 Principle

Vibration as a principle for directed locomotion has been previously applied in micro-robots. For instance, Vibrobots such as the Bristlebot mount a pager vibration motor and a coin cell battery on a toothbrush head. The motion is not random: the unbalanced weight transforms the brush into a ratchet and forces the heading. The three-legged Kilobots [Rubenstein et al. 2012] move thanks to centrifugal forces alternatively generated by a pair of vibration on two of its legs [Vartholomeos et al. 2013]. Again, the resulting motion is deterministic with respect to the input vibration. As far as we know, adding vibratory actuators to deterministically steer large object regardless of their structural properties has not been demonstrated. Large displacements of big objects induced by vibration is a common occurrence but the result is generally unpredictable - think an unbalanced front-loading washing machine. Indeed, for controlled movement, wheels or legs are generally preferred. For instance, the actuated furniture demonstrated by Lassy in Ikea Robotics [Lassy, Adam 2010] and the robotic office chairs concept [Nissan 2016] by Nissan use wheels. Roombots [Sproewitz et al. 2009] are transforming and actuated furniture. Another approach to arrange furniture involves pushing it *by* robots [Lau et al. 2011]. The perturbation resulting from a particular pattern of vibration depends on a myriad of parameters including but not limited to the microscopic properties of the contact surfaces. The key challenge is to *empirically* discover and select the sequence of vibration patterns to bring the object to the target pose. The idea is as following: in a first step we systematically explore the object response by manipulating the amplitudes of the motors. This generates a pool of available moves (translations and rotations). We then calculate from this pool the most efficient way (either in terms of length or number of moves) to go from pose A to pose B using optimization strategies, such as genetic algorithms. The learning process may be repeated from time to time to account for changes on the mechanical response, at least for the patterns of vibration that contribute more to the change.

## 3 Prototype

We experimented with eccentric rotating motors (type 345-002 precision microdrive) with a nominal force of 115g which proved sufficient to shake (and eventually locomote) both a 4 legged IKEA chair and a 3 legged IKEA stool, in a configuration similar to that of the Kilobot. The motors are driven by a Arduino Nano though a motor shield, all powered by a LIPO pack. All the hardware is externally attached using straps (Fig.1). In our prototype, the Arduino does not compute the optimal vibration sequence, but receive commands wirelessly from a PC over a IEEE 802.15.4 (Zigbee).

We first confirmed that activating one motor made the chair pivot on the opposite leg, and alternating between the vibrators effectively made the chair walk in a straight line. The object can be steered to any position using this gait (although the motion is non-holonomic). That being said, the case studied here is just an example and we aim at a *general* method that can be used when there is no obvious dynamic response - and indeed, as can be seen in Fig.2 the optimal trajectory involves several other patterns of vibration.


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We employed both an embedded compass (LSM303) and external tracking (overhead camera) for absolute pose estimation. This helped populating a large 100x100 matrix of possible transformations (rows and columns corresponds to different powers for each motor, and each entry is the resulting translation/rotation matrix) - a time consuming process. The duration of the stimuli (2 sec) was decided after observing that it was long enough to significative change the pose, but not too long as to rotate the object by a full turn for instance. After discarding a significant amount of entries that did not generate either a significant translation or angle change, we ended up with about 170 entries that were taken as candidate moves. Still, for a large displacement, hundreds of moves are needed and an exhaustive search is not possible. A genetic algorithm could solve the problem, but given that it is also difficult to estimate the length of the solution, we opted for a simple breadth-first search, limiting the look-ahead to a maximum of four levels on the solution tree. The cost function used basically measures the proximity to the target for each final branch. After storing this four-moves path, the search algorithm is restarted from the corresponding leaf.

## 4 Results

As shown in the video, using only the compass and a Myo armband we can easily direct objects in specified directions with simple gestures without requiring any optimization (again, this is possible because of the particular Kilobot-like configuration). To study the general method and to see if it can discover automatically the pivot-gait (or better solutions), we use the overhead camera and fit the chair with color markers and proceed to learn the table of moves. In this case we use the overhead camera and the computer as the interface to select the target position in room space - Fig.2:(b).

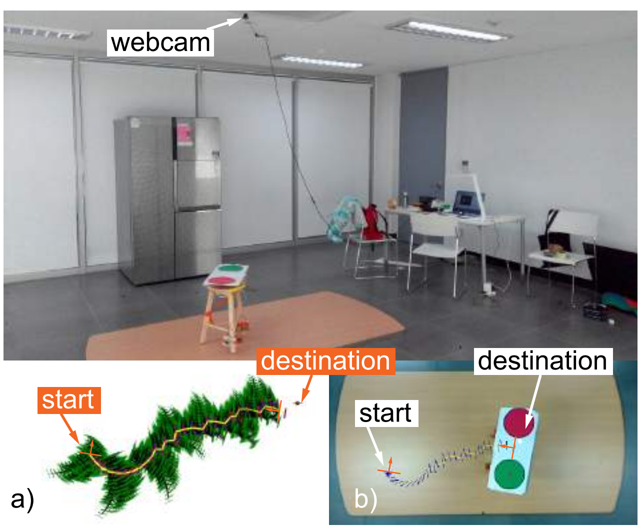


**Figure 2:** *(a) offline breadth-first optimised path; (b) resulting real path after applying the sequence of vibration patterns*

Fig.2:(a) shows the results of the optimization before actually commanding the motors. As can be seen, the system discovered pivot-like gaits - and more. However, as one can imagine, using the pre-computed sequence does not end up perfectly matching the target pose. This is because the contact properties vary with location. Although this can be considered a secondary disturbance, it may in certain cases be mandatory to recompute the matrix of moves every now and then (the chair could for instance move into a wet area, or over plastic carpet, etc). This is in principle possible, as we assume time is not a constraint. What is required in this case, is to have absolute tracking of the object at all times. Indoor, precise localization of everyday objects is evolving fast; in the meanwhile, contactless odometry methods - for instance using mouse optical tracking technology or upgrading the compass to a full IMU system is an interesting and cheap alternative.

## 5 Discussion and Future Work

We demonstrated how to deterministically steer large objects by attaching small sources of vibration. Alternating path optimization and self-tracking, allows the object to steer itself to the desired target with relative ease. Our first prototype consisted of two strap-on vibration motors, but the principle described here is agnostic with respect to the number, type, or relative position of the actuators. This principle may be useful for moving large objects in situations where attaching wheels or complete lifting is impossible - assuming the speed of the process is not a concern. A product that can be easily attached to small furniture to make it obedient to effortless gestures could be a welcomed creation for people with low mobility, including the elderly (for approaching things, closing blinds, etc). Embedding vibration modules as parts of mass-produced objects would provide a low-cost way to make almost anything mobile. One drawback of the approach may be the noise that it produces. Designing inaudible actuators is possible, for instance using contact ultrasonic transducers. It may still be possible to move the object albeit extremely slowly - or not at all. This is something that needs further study. More intriguing perhaps is the possibility of doing away with the actuators, and instead use a clever mechanism to exploit natural sources of noise, for instance by hardening or softening the contact surface so as to anisotropically filter the vibrating, whatever its origin. There exists a number of interesting materials today that can change the elastic properties almost instantly by applying electricity, such as conductive polymers. These could be adapted to furniture as smart shock-pads capable of differently adjusting their shock-absorbing properties on each leg.

## 6 Acknowledgements

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