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Height Adjustable Kitchen Work and Dining Surface

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Senior Design Project

By Jay Van Voorhis

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Introduction

Motivation

Food keeps us alive, and it is a source of great joy, in the making and in partaking. More so if that food is shared. However, especially for many there are barriers to these joys. Many people live in apartments where space is at a premium, especially in kitchens. Smaller kitchen spaces means less room for equipment, less room for prepping, and ultimately less room for cooking. One solution to small kitchen spaces is to add a kitchen counter as a standalone piece of furniture, but this can be difficult because, correlated with small kitchen spaces are small dining spaces, even spaces that are collapsed into the kitchen space (Open concept). Small dining spaces make it harder to share the meals prepared in small kitchens. Even if space is not at a premium, most kitchens are not designed for people with height differences, either because of stature, or the use of a mobility aid such as a wheelchair.

In some circumstances these difficulties can be partially overcome by combining a dining surface and a work surface. This can theoretically be done by simply working seated at a kitchen table, but is not ergonomic or efficient for many tasks. The alternative is to get tall chairs to sit at counter/bar height, but this poses its own issues, people with limited mobility can have difficulty reaching the seat, and it can be uncomfortable to have feet dangling above the floor for the course of a meal. An ideal would be to have a surface that can be counter height for meal prep, and dining height while enjoying the meal.

The top of a standard dining table is between 28” and 30” from the floor. Standard counter height in the US is 36” which is idealized for a 5’7” user. The majority of people in the world are not 5’7” and a principle in inclusive design that designing for the average results in a functional, but uncomfortable option for just about everyone. An adjustable work surface is more inclusive of people of different heights and of different abilities.

Perhaps because of its superiority, accessible and customizable furniture is expensive. Furniture that moves poses unique challenges to stability, constructability, and repairability rendering it costly to design and produce. The goal of my project is to do the design work so that an inclusive kitchen work surface can be available for people to produce for themselves and/or loved-ones.

Goals & Constraints

Goals

The broad goals for this project were ultimately stability and aesthetics.

In order for this design to actually be useful it has to stand up to the demands of a kitchen work surface. There are two main tasks I considered as limiting tasks for a kitchen surface. It must be able to dampen some vibration from chopping motions, and it must be able to resist lateral forces from kneading. Any other movements can be characterized as related to or less impactful than these two motions.

Secondly, in terms of aesthetics, the design must not be so over-built that it no longer seems at home in the dining area of a home. The legs must not be so large, nor the joints so obvious that it looks more like an engineering project than a kitchen table.

Constraints

The main constraints placed on the design were, budget, capacity for movement, simplicity of construction, repairability and transportability.

Budget

The constraints on budget were both practical, I only had access to 400$ of department funds to work on the project, and in line with my project motivations. In order for this to be a viable alternative to commercial alternatives, the cost of materials had to be low enough to off-set construction time and potentially specialty tools for a hypothetical individual interested in replicating my design. Since most commercial options are over $1,000 [cite/appendix?], it makes sense to set the ceiling of material costs at 40% of breaking even. With that, if the design is able to be built so that it does not take too much time or skill, then the 'labor' cost is unlikely to surpass the commercial alternative.

Movement

This is the most critical constraint and is the feature that makes the table unique. To fill the various purposes laid out in the motivations, the table ought to move 12" vertically, and with minimal effort. Additionally any movement system should be capable of moving 400lbs to account for a heavy countertop and possible kitchen equipment.

Simplicity

The design should be simple enough to be built with a small selection of tools and few complex cuts. To me this means mostly square cuts (no miters), and no or few cuts that require cutting only partially through the material such as dados or lap joints. Keeping material square is enough of a challenge even in a shop setting that this issue does not need to be compounded over complicated cuts in a home workshop setting.[1]

Repairability & Transportability

Another way that I could have phrased this constraint was sustainability. Since that is the essential motivation behind these constraints. This should be an object that lasts a long time. In order for this to be the case it should be repairable, if the motors burn out they should be easily accessible for repair or replacement. Additionally, the whole thing should be able to come apart in sections for transport to a new home without loss of structural integrity.[2]

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[1] In my design one concession I make to complication is using dowel joints instead of screws for the legs, because their aesthetic value is so much higher than screws. With a good jig they are ultimately not that complicated to execute.

[2] Thinking of specific Swedish commercial furniture here – it packs flat initially, but almost never holds up well when moved from one living space to another.

Methods

The following methods are presented linearly, though under no circumstances was the following process linear. The design process and build process are presented separately though they were deeply entwined.

Design Process

Defining Parameters

Professional Guidelines

Initial parameters for the design were informed by Americans with Disabilities Act (ADA) standards for publicly accessible dining tables. In order to be ADA compliant a table must have 19” of knee room from the edge of the table to any barrier, and a minimum of 27” from the floor to the bottom of the table. This combined with industry standard 36” counter tops (floor to top of surface) became the basis of the starting parameters for the design. A 12” movement allows for a 39” floor to bottom of surface height, which results in a minimum of 40” of working height at the top of the range of movement.

Experience

Going into this project with a fair amount of experience working with wood and even on table designs I was aware of the constraints of the machines I was working with and the general behavior of the material. A certain degree of intuition based on experience was employed in the design process.

Structural Analysis

Structural analysis was used early in the design process once a form had been conceived to determine whether tipping forces would be determinative in the design. It was concluded that with sufficient weight and a broad base of support, these concerns would not be as design restrictive as the strength of the joints or the footprint of the linear actuators.

Design Decisions

This section covers different aspects of the design and how they were decided on.

Tension in Movement and Form

These aspects were perhaps some of the most co-dependent in the design. The form of movement dictated what structural forms were possible, and the forms constrained the movement.

Movement

This part of the process was the longest and most twisting. Essentially three different methods of lift were considered, pulleys, manual screw jacks, and motorized screw jacks (linear actuators).

Pulleys

Initial designs centered around pulley systems that lifted a pedestal base. These designs consistently failed on two fronts. One, there was never a convincing locking strategy, and two, there was never a good way to take tension off of the cables between the pulleys. One option that was considered was using pegs to support the table when it was not moving. This solution was rejected because pegs would require simultaneously keeping the table in position and fitting the pegs. The easier fitting the pegs would be the more holes would have to be in the table leg. This would not have removed the locking requirement either since the table would have to be capable of locking while the peg was being fitted. Ultimately this was an unviable design path.

Screw Jacks

This idea took inspiration from the precise movement capabilities of machines in the engineering shop. With an easy turn of a wheel heavy machinery can be positioned and will stay there as long as the wheel stays in position. These are morphologically similar to screw jacks, both use a precisely machined lead screw, a worm gear, and a threaded collar to move along an axis. The self locking component and the ease of use were very compelling answers to the problems presented by the pulley system. However this solution posed its own difficulties, it would have needed an essentially bespoke gearing design and needed to contain multiple spinning parts in at least three different parts of the table. The screws themselves operate based on rotation and would need to be fully housed in both legs in addition to whatever rod and gearing system connected them. If these components were exposed they might pose a pinching safety risk, especially for small children. The costs of purchasing precisely machined parts is prohibitive on a small scale.

Motorized Linear Actuators

These are the key parts of many commonplace heavy adjustables, some examples include dentist chairs, hospital beds, and standing desks. However, in their precise applications they are incredibly expensive. Stepper motors are perhaps the most precise option, but the cheapest with a 12" stroke length that I was able to find were $113[3] which meant that for two actuators, more than 50% of the budget would be spent on the actuators themselves, not counting the controller they need. These also would not be capable of meeting the 400lb moving minimum I set. There is a similar issue when using servo motors. DC motors with feedback are much more capable of holding higher weights but are also expensive themselves while requiring a controller system. This leaves us with direct DC motors, they are simple and can carry large weights compared to cost. However they are much less precise because no two motors behave exactly the same when exposed to the same voltage, opening the user up to an increasingly lopsided table as the differences grow over time. This is combatted however with the use of limit switches at the bottom and top of motion that prevent actuation when at the extremes of its movement even if a current is still being applied. This allows any potential differences to effectively reset at the top and bottom of its movement. This is the solution that guided the rest of the design. The size of the

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3 https://www.automationdirect.com/adc/shopping/catalog/motion_control/stepper_motor_linear_actuators/stepper_motor_linear_actuators/stp-le17-2a12ann

actuators ended up determining the sizing of the legs because the legs had to be large enough to hold them.

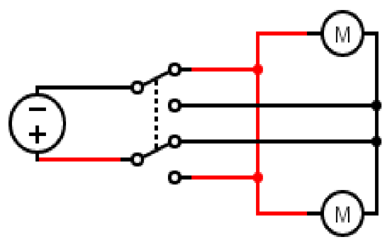

Figure 1. The linear actuators and a 12-volt power source are wired to a 6-pin momentary switch. The leads from the power source are reversed between two of the sets of pins. Reversing the voltage across the motors in this way changes their direction of travel. This diagram is reversed. The wires from the motors are crossed instead of the power source leads.

Form

With the pulley concept it made the most sense to design for a pedestal base so they were all enclosed and there were no cables with the potential to move exposed and criss-crossing the base of the table. However, with the linear actuators and screw jacks it made more sense for them to be in separate legs so there was a larger base of support. This eventually led to a trestle table design, which is characterized by two large legs and a beam connecting them at some point below the table top. This design has been in use for centuries, as seen in figure 2.

Figure 2. 1600s table listed on antiques auction site.

This design is well regarded for its stability and robustness. Perhaps because legs are far enough apart and wide enough to resist tipping and the beam resists twisting. Unfortunately there is a dearth of literature studying the structural properties of heritage designs and joints such as this.

Since the table needed to adjust in height, the legs needed to telescope. To encourage stability when extended the legs were designed to have as much overlap as possible. The design that ended up being tested and built was nested boxes, the outer lined with felt to facilitate movement between the two of them, and reduce the effect of imperfect tolerances.

Figure 3. The boxes were left open to showcase both inner and outer legs, the felt lining, and the support system for the linear actuator. Since the inner leg was made longer than the compressed actuator the actuator was given a free floating lift to act against. The L-brackets for this design were made from wood. This is not recommended for future designs. The block at the bottom was a test beam made to test the housings.

Trouble Connecting

One of the weaknesses of my design ended up being its joints. This caused the greatest lack of stability. The following are discussed in order of most to least stable.

Actuators to Legs

This connection was greatly dictated by future accessibility of the actuators for repairs. The actuators selected had nubs with eyes at either end to connect brackets to. The L-brackets were then connected to a cap for the inner leg. A band around the cap was screwed into the leg so that the actuator pulled the leg up with it, but when removing the screws the cap could be lifted off and the actuator serviced. The connection between the actuator to the legs was relatively stable, but there was trouble with the actuator pivoting in the leg, and the collars around the top of the leg could have been taller to create a more stable friction connection.

Legs to Beam and Floor

The legs needed to be slightly wider at the floor to act against tipping. A square piece of plywood acts as a foot for the legs, and on top of it needed some structure capable of accepting the leg. Creating an opening in the bottom of the legs for the beam to connect them was challenging. The inner legs needed to be supported inside the bottom of the outer leg and the actuators needed something to push against. The structure connecting the leg to the foot was able to serve a triple purpose in this way. It acts to hold the leg and beam with a friction fit, while the beam and roof of the structure give the actuator something to act against. The result is below in figure 4.

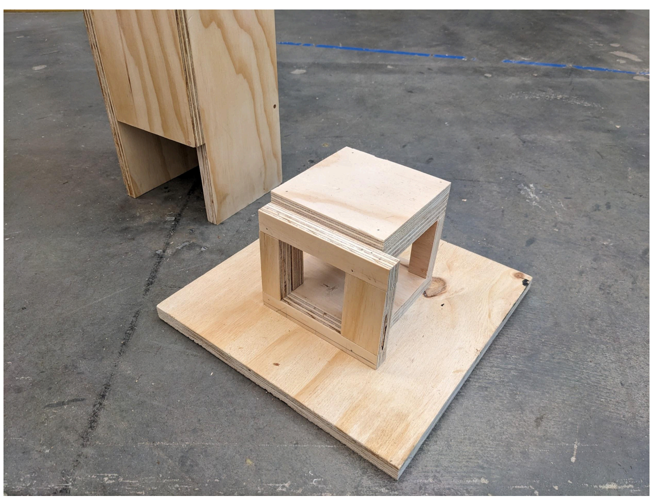

Figure 4. This "house" as I came to call it was nailed to the "foot" (large square) with a facing piece matching the space cut from the bottom of the leg. The opening is 3" x 3" to accept the 3" x 3" beam that connects the legs. These had a tight friction fit to the legs, but did not stop the legs from pivoting when forces were applied perpendicular to the open face.

Table to Legs

This is the most unstable joint requiring the most future work. At the time of presentation the joint was simply an extrusion from the top of the leg fit between two guide rails on the underside of the table top. After some reconsideration a T-joint was created to provide more surface area for the connection between the legs and the top.

Figure 5. Two strips of plywood were attached to the initial set-up with screws to create a T-channel. A matching connector was made to fit and the legs were slid into the top. Not pictured are gaps where the tops of the legs are not adequately flush and the rails are not adequately square. They were cut on the bandsaw when the table saw would have been more appropriate but was unavailable.
This design change also allows for better concealment of the wiring. Not pictured is a notch that allows the power source adapter to sit concealed within the lower channel.

Build Process

The build process and the design process were entangled, especially for more finicky aspects of the design. Since this process' aim was to be replicated in a less well equipped space, it was as much of an additive process as possible. Complex shapes were built out of smaller pieces rather than being cut out of larger ones.

Material

Early on wood was decided as the main material for the project. In addition to being cost effective on its own, it is also more cost effective to work, with less of a skill barrier to entry than metal working. While aesthetically and durability wise hardwoods would be an ideal choice for the project they can be exceptionally expensive depending on species and finish quality (whether they come planed and jointed or not). Since most people do not have jointers and planers in house, material that did not need additional processing was prioritized. Hardwood plywoods are some of the best value for money. As composites they react to changes in humidity less than their solid wood counterparts and they are consistently sized. Thinking about robustness and needing weight to stabilize the legs, ¾" birch plywood was selected over smaller thicknesses.

⅛" Industrial felt was used as an additional material to ease the movement between the legs. Industrial felt is created to more precise thicknesses than crafting felt. In addition to easing movement, it also allowed for some ease in tolerances since it is a more compressible material than wood. This way the inner leg could fit tighter in the outer leg than would have been possible with wood on wood movement.

Tools

Many different tools were used in construction. Several cutting tools, band saw, table saw, panel saw, track saw, and the drill press. The panel saw was used for cutting the plywood to workable dimensions from the 4' x 8' sheets. The table saw was used for making batch cuts of consistent widths. Since this is a shop table saw with a long fence and extended table it's ideal for making long repeat cuts. The track saw was used for rip cuts that were too long for the panel saw when the table saw was unavailable. A track saw is a relatively reasonably priced option when a table saw is unavailable. It is very versatile and capable of much longer cuts than a worksite table saw. However, like any other piece of shop equipment, being balanced and level is very important for both safety and precision. The drill press was used with the assistance of a custom built jig to support and align the butt joints so the legs were connected squarely.

Final Design

Images – Figures [6 - 11]


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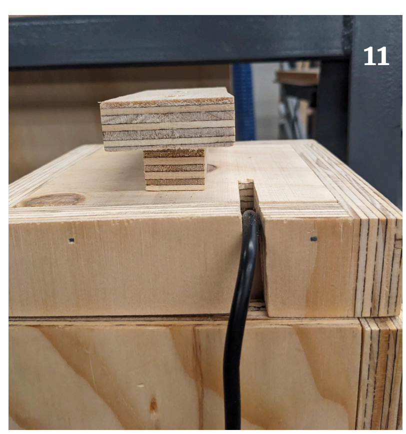
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Figures 6, 7, 9, show the surface in its constructed form, figure 6 is partially raised, figure 9 is fully lowered, and figure 7 is fully raised. This is a smaller version of the design than originally conceived, the legs are close together and the top is smaller. However this is an excellent proof of concept design. The legs themselves are incredibly stable, the majority of the movement in the design comes from the connection between the legs and the table top, with some additional movement coming from the connection between the legs and the floor. In initial tipping tests went very well, considerable force was applied to the edges of the table and concern over the strength of the joints between the table top and legs was an issue before the legs lifted off the floor. Furthering the point that those connections will be fruitful sites of future work.

Figure 10 is a close-up of the dowel pin connections in the table leg. These were half glued and in future it may be wise to fully glue them as there was some splitting as the legs were maneuvered. This was corrected for in figure 7 with clamps prior to a tipping test. The clamps simulated a tighter fit around the foot structure.

Figure 8 shows the table disassembled with no damage to the constituent parts. Earlier issues with the wiring regarding disassembly have been addressed temporarily and a long-term solution with removable connections is being considered.

Finally figure 11 shows the top of an inner leg with the T-bracket that sits in the channel under the table top. Also clear is the notch that allows the wire from the linear actuator to exit the table leg into the T-channel on its way to the switch.

Evaluation

Item	Price
Felt	$32.00
Linear Actuators	$132.99
Switch	$7.00
Power Source	$35.00
Plywood	*$160.00*
Total	**$366.99 (206.99)**

The project was broadly a success. For less than $400 in materials a height adjustable, deconstructable, repairable, reproducible work surface of albeit middling stability was designed and built. There are a couple major take-aways, the first is that many of these long straight cuts are difficult to execute well without the proper equipment. Many of the cuts that I made could be reproduced with a track saw, but while these are a cheaper option than the myriad of different saws I used they are still not cheap, approximately $900 not cheap. So in order for this to be truly worthwhile as a personal project, a builder must already have access to appropriate tools either themselves or within their networks of friends, family and neighbors. Some portions may also be accomplishable with the equipment available for rent or free use at big hardware stores.

However, one of the major goals of the project was not met satisfactorily. The surface is not stable enough to do most cooking tasks or have a comfortable dining experience. This is an area rich for future work. In terms of the connection between the legs and the top there are a few clear steps to take first. One step is to add a true table top with enough weight to add to the friction in the joints and reduce their movement. Another is to square and surface the faces already in contact with each other, the more precise the tolerances the less room for movement there is. A bigger change would be to move the design closer to the heritage design and make the foot and the connection with the table more symmetrical, increasing the contact area. The next major area for improvement is the connection between the foot and the lower leg.

There is certainly room for improving the design of the "house," perhaps closing in the sides and removing the top part of the facing to keep the leg panel longer so it slides over more of the "house" giving it less room to pivot. Especially if this area is adapted so the beam travels through the leg instead of stopping inside. This could allow the leg system to support a broader range of table top sizes without having to be rebuilt as the legs are repositioned along the beam and table-top supports.