# Design of a Kickstand-Integrated Bicycle Lock for a Bike Share Program



by

Jacob A. Sanchez

Submitted to the
Department of Mechanical Engineering
in Partial Fulfillment of the Requirements for the Degree of

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**ABSTRACT**

A retrofittable, electronically-operated lock integrated into a bicycle kickstand was developed for the MIT Media Lab's Social Computing group as part of a peer-to-peer bike-share program currently in development. Connecting to the rear axle, the system consists of two modules, each constructed of many planar parts cut on the waterjet from aluminum. The first of these is a lock, which uses a servo-driven double rack and pinion that locks into keyways within the ring of the rho-shaped kickstand. The second is a mechanical retainer mechanism that uses a latching spring-loaded bar actuated by the user's foot via a push-button to retain the kickstand in the upright position while riding. With the alpha prototype complete, Social Computing can now begin system-wide testing of their program while easily iterating on the modular lock design to resolve any issues that arise.

Thesis Supervisor: Sepandar Kamvar
Title: LG Career Development Professor of Media Arts and Sciences

## ACKNOWLEDGEMENTS

I would like to thank Professor Kamvar for freedom he allotted me during the project, as well as Nazmus Saquib and Yonatan Cohen, my collaborators in designing the lock. Also I would like to thank the staff of both the MIT Hobby Shop and the Center for Bits and Atoms Digital Fabrication Facility: Ken, Brian, Hayami, John, and Tom, for all of their technical expertise and support during the fabrication process.

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## SECTION I: INTRODUCTION

This lock was developed in conjunction with the MIT Media Lab's Social Computing Group, under the direction of Professor Sepandar Kamvar, as part of a project to develop a peer-to-peer bicycle sharing service. For this it was necessary to develop a lock which did not rely on static structures like street signs and bike racks, and was also operated electronically. This thesis covers the mechanical design of this locking system, and was developed alongside the electronics system designed by Nazmus Saquib, a Ph.D. student in the lab.

### 1.1: Motivation for Bicycle Share Program

The Social Computing Group (SC) was founded on the idea of utilizing data mining and analysis to inform projects dedicated to improving quality of life in urban communities. During the "You Are Here" project, which involves creating digital maps of major cities that display data geographically, for example showing the age distribution of neighborhoods or the density of coffee shops in an area. One of these maps showed transportation efficiency in Cambridge, where users could select a neighborhood and see sections of the city highlighted in varying colors, depending on the method of transportation that would take a user from the initially selected point to that section of the city in the least amount of time. It was discovered that no matter which point in Cambridge was selected, cycling was the most efficient method of transportation, with up to 80% of the city being reachable fastest by bike. This prompted the students of SC to examine the use of bicycles in urban environments, ultimately leading to the founding of the bike share project.

### 1.2: Description of Bicycle Share Program

SC has developed a model for a bicycle-sharing program that differs from competitors such as Citibike and Hubway in that there is very little physical infrastructure associated with it. There are no stations that the bikes must be ridden to, as the bikes are intended to lock while freestanding, are self-recharging, and bike rental is handled from the user's cellphone. In addition, the bikes that comprise the program are intended to be donations from the city and the citizens themselves, that are retrofit via an open-source kit that can be installed on the majority of bikes easily with included tools.

It is intended that using the system be as simple as operating one's own bike. Users can use a mobile application to locate nearby bikes and reserve them, and then use unique visual identifiers on the bike itself once in the vicinity to find their bike. The user then moves the bike to wake up the microprocessor onboard, so that Bluetooth authentication can be performed between the bike and the user's phone, the bike then unlocks and the user is on their way. Progress is monitored intermittently via the phone's GPS, and then the bike is locked at the end of a ride and the server is updated with the bike's availability and new location.

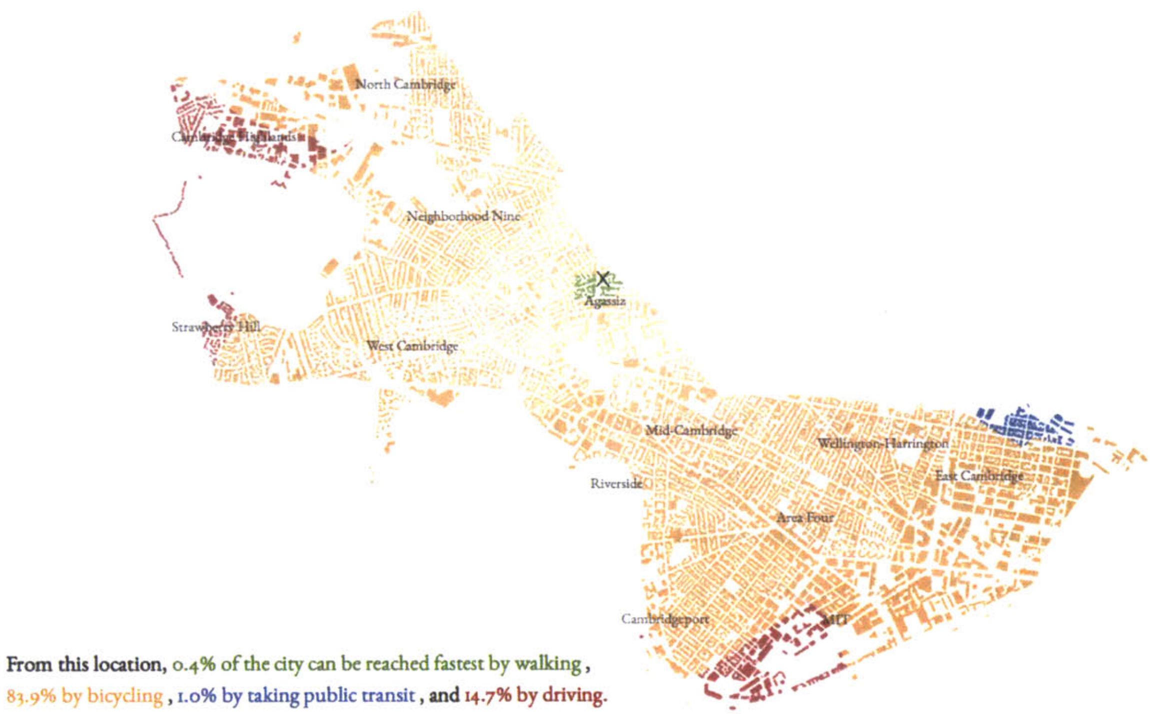


**Figure 1-1: A map of Cambridge from the "You Are Here" project, showing the fastest mode of transportation from the black "X" to other areas of the city. Areas reachable fastest by cycling are shown in orange.**

## SECTION II: DESIGN CONSIDERATIONS

As described above, the hallmark of this system is simplicity of the user experience. SC actually requested a form factor for the lock at the onset of the project that had been devised during early conceptual talks: a kickstand-integrated lock. The rationale was that lifting the kickstand was an action already undertaken by bike riders, so if it could be incorporated into locking/unlocking the bike then using a shared bike would be just as easy as using a personal bike. The kickstand lock also stood out as being unique and brand-able, which appealed to the members of SC.

### 2.1: Mechanical Requirements

As stated above, the lock needed to be incorporated into a kickstand retrofitted to existing bicycles, and needs to provide a reasonable amount of security as well as unlock when an electronic signal was sent. The mechanical movement should be robust and resist attempts to move the kickstand by force, it should be safe to operate and to ride with without interfering with the bike's operation, it should be nearly universal in its attachment to the bike, and it should be able to be prototyped given the equipment in the Center for Bits and Atoms Digital Fabrication Facility in the Media Lab.

### 2.2: Durability Requirements

Since the lock is to operate outdoors continuously, it needs to resist the intrusion of water and dust, and resist corrosion. It also needs to deter vandalism and theft. Low power consumption is another requirement that will work in tandem with power regeneration to keep the system operational continuously. Overall a high degree of robustness is desirable because having to perform regular maintenance would undercut the easy-to-use and infrastructure-light properties of the program.

### 2.3: Open Source and Prototyping Considerations

It has been known since the outset that the design of this lock would be made public upon its completion, and that the entire project was to be well-documented and open source. Additionally since SC plans to test these bikes within the Media Lab initially, it is important that prototyping can take place in-house. The Center for Bits and Atoms (CBA)

Digital Fabrication Center contains all the tools of a standard machine shop, but not all parties who might be interested in the design of the lock have machining knowledge or access to heavy equipment. This constrains fabrication methods available, but allows for more rapid iteration.

## SECTION III: DESIGN OVERVIEW

The current prototype consists of two cylindrical modules, which mount to the bicycle via the rear axle. Each module is constructed of layered planar aluminum parts with axial screws tying the assembly together. The first module is the lock mechanism, which houses the onboard electronics and contains a servomotor that locks the kickstand in the downward position. The second module is the retainer, which holds the kickstand securely in the retracted position while riding and allows the user to lower the kickstand by pressing a spring-loaded button with their foot. The kickstand itself has a U-shaped profile and surrounds the rear wheel, attaching to the modules on either end of the rear axle.


**Figure 3-1: The alpha prototype installed on a bicycle.**

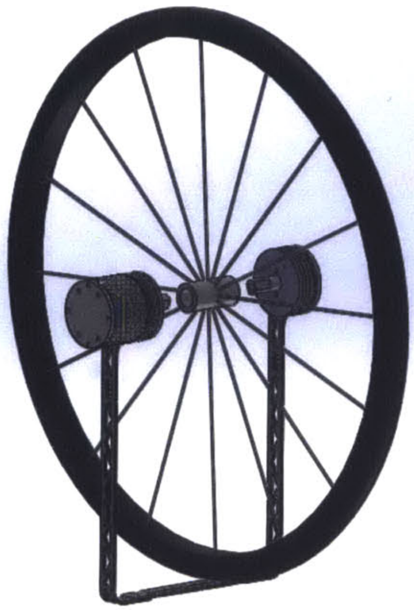

**Figure 3-2: A CAD representation of the system in relation to a bicycle wheel.**

3.1: Connection to the Bicycle

In order to attach the device to the bicycle, a custom castellated coupling nut was machined from 6061 aluminum rod. The first design relied on the use of standard coupling nuts, but the thread used by bicycle manufacturers in China is known as the British Standard Cycle thread, which is equivalent to 3/8"-26 TPI, unlike the modern fine thread standard of 3/8" – 24 TPI. This outdated standard forced the machining of custom parts, and it was discovered that in order to prevent the rotation of the lock about the axle it was necessary to provide splines or castellation on the nut. The connector screws onto the bicycle axle, and the ten protrusions fit into a feature on the baseplate of both the lock and retainer modules, and then a standard fine-thread 3/8" cap head screw is fastened into the connector on the outboard side to complete the connection. The other parts of the lock fasten to this baseplate.

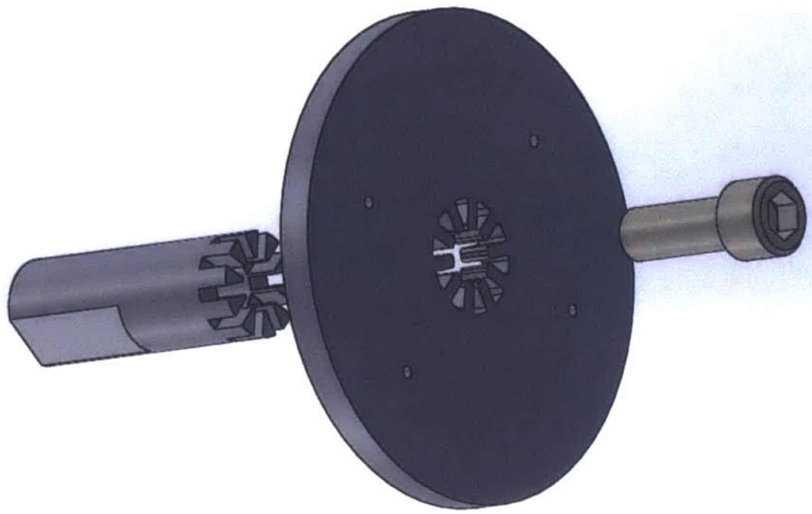

**Figure 3-3: The connector assembly. The machined piece on the left is threaded onto the bicycle axle, and the bolt is then threaded into the other side, locking the assembly in place.**

### 3.2: Lock Mechanism

The basis for the locking mechanism is a servomotor driving a double rack and pinion that engages with keyways on the inner ring of the kickstand. This system was developed after the switch to a cylindrical architecture, built around the kickstand being shaped like the Greek letter rho. The first prototype consisted of a simple bar shaped kickstand that rotated about a point near its end, with the long end going to the ground and the short end terminating in a shackle that could be locked into a box containing a servo-operated bolt. The new design functions on the same principle of a bolt lock, but internalizes the workings by having the kickstand rotate around the mechanism itself, thus aligning all of the axes of rotation in the system.

The load-bearing surfaces of the lock mechanism are two 0.25" square bolts, which slide 0.25" into the kickstand's keyways across the diameter of the ring. These bolts are in turn supported by the walls of the lock cylinder by a split aluminum ring with increased thickness that forms a channel that supports and aligns the bolts as they engage the kickstand. The bolts are the racks of the rack and pinion system, with the pinion gear being directly linked to the servomotor. The racks are held in place and aligned by screws running through them that slide in a track cut into a layer further outboard in the assembly.

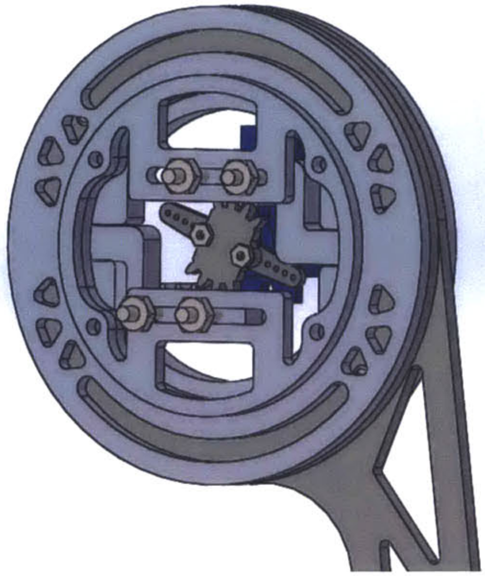

**Figure 3-4: The locking mechanism with supporting components.**

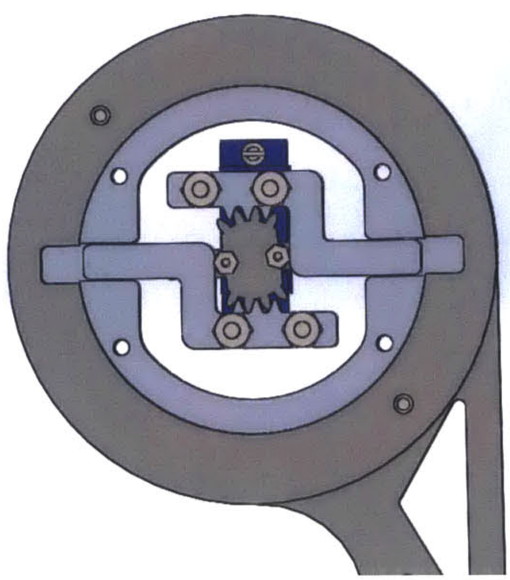

**Figure 3-5: A simplified plan view of the mechanism, showing clearly the double rack and pinion.**

3.3: The Retainer Mechanism

In order to save power, it was decided that the lock should not engage to hold the kickstand in the retracted position while riding. This allows the microcontroller to sleep for the duration of the trip. For this purpose a separate retainer mechanism was developed that would sit opposite the lock. At the heart of this mechanism is the second half of the kickstand, which is identical to the first except bent in the opposite direction, and a spring-loaded bar that rides on two rails. This bar is connected to a button that protrudes outside of the lock so that it is accessible to the user. When the kickstand is retracted by the user and reaches a position parallel to the ground, the spring-loaded bar will align with the keyways in the kickstand and engage them from the inboard side of the mechanism. When the user wishes to deploy the kickstand, pressing the button with ones foot will force the bar inboard again, allowing the kickstand to fall under the influence of gravity. The bar then presses against the kickstand, but will not engage it in the downward position, as this is the task that the lock module accomplishes.

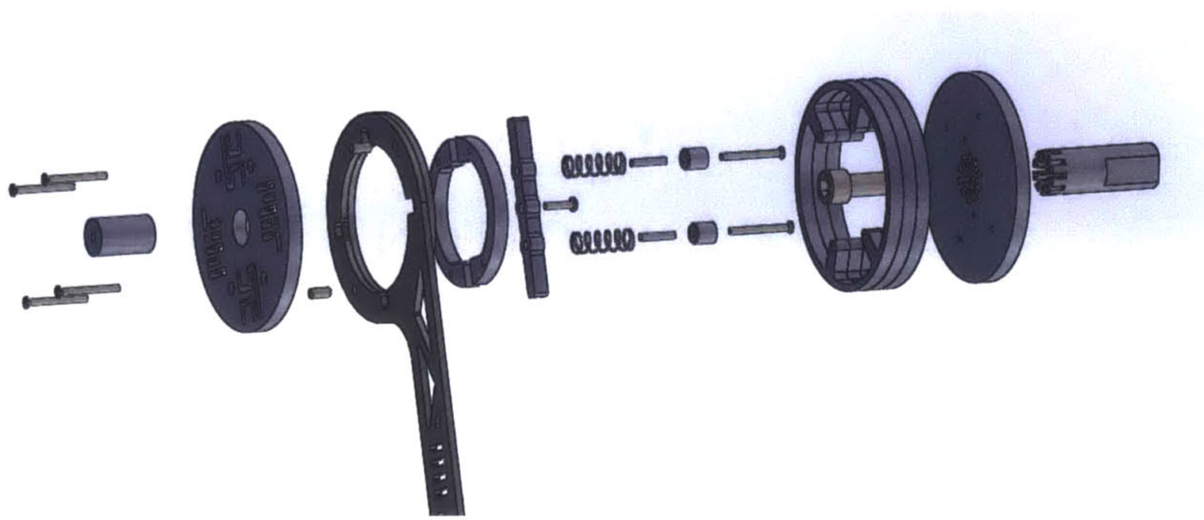

**Figure 3-6: An exploded view of the retainer module.**

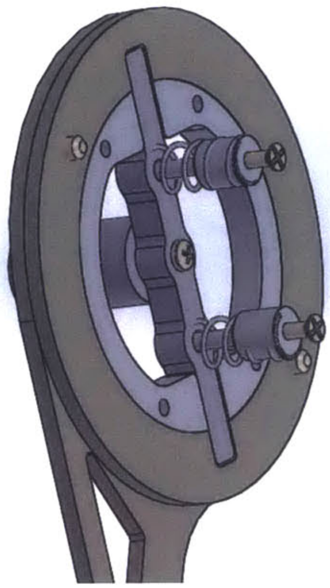

**Figure 3-7: The retainer mechanism. The screws on the right are held fixed in a plate (not pictured) and the vertical bar rides along them. Pressing the foot button compresses the springs and frees the kickstand to rotate.**

## 3.4: Electronics Integration

Integration with the electronic components is very simple, as the lock only needs power and a signal to the servo to function. The electronics, which will consist of a single custom PCB and a battery, sit outboard the lock mechanism, all contained in a lightweight acrylic shell. Polycarbonate would be a better material selection for its shock resistance, but acrylic was easier to acquire in the necessary size for prototyping purposes.

During the project it became clear that it is not necessary to power the microcontroller while the kickstand is up and the bicycle is in motion, as all tasks regarding tracking the user's progress are handled by the user's phone and the accompanying mobile application. Thus it was resolved to make the kickstand also function as an on/off switch connecting the battery to the rest of the electronics. For this purpose a magnetic reed switch was selected, which will read the passing of a magnetic field when the kickstand is engaged. This will wake the microcontroller, authenticate the user, and toggle the lock state. This system takes advantage of the fact that incorporated into the design already are two set screws holding together the kickstand and its shim, which ride in grooves cut into the layers alongside the kickstand to limit its rotational movement and ensure that the keyways on the kickstand line up with the lock's bolts. To one of these set screws a small neodymium magnet can be affixed with epoxy, and then the reed switch can be placed alongside the body of the lock (again with an adhesive) such that when the kickstand is down the magnet lies beside the reed switch, causing the contacts to touch and completing the circuit.

### 3.5: Development of the Layered Architecture

Early on in the development cycle, a "lock box" was designed which used a servo-driven cam and a sliding bolt to create a versatile locking mechanism that would accept a rectangular shackle and hold it fast. This was designed before the rest of the first prototype, and then was altered to better fit the device as it became further resolved. The method of fabrication for this box, which soon contained many small and complex features, was to be CNC milling out of a single block of aluminum. This process proved to be incredibly difficult considering the constraints of the machinery and challenges of the design, and the part ultimately produced for the prototype was of low quality and could not be modified. The process was time-consuming and uneconomical, and therefore made iteration of the design difficult.

It seemed that the design would require a series of complex features in three dimensions, with not all features accessible from one side. Such features are difficult to cut into a single part, and would require multiple machining operations on advanced CNC machinery. This led to the question of whether the device need be made from a single part, or whether it could be divided somehow to simultaneously make fabrication easier and allow for more flexibility in the design. The answer lay in slicing up the box like a loaf of bread, which made a collection of simpler planar parts that could be fabricated on the waterjet. These parts could then be stacked to create the three dimensional architecture necessary. This design principle was first applied to re-designing the initial prototype, and then was used from the beginning to create the alpha prototype using the cylindrical architecture.

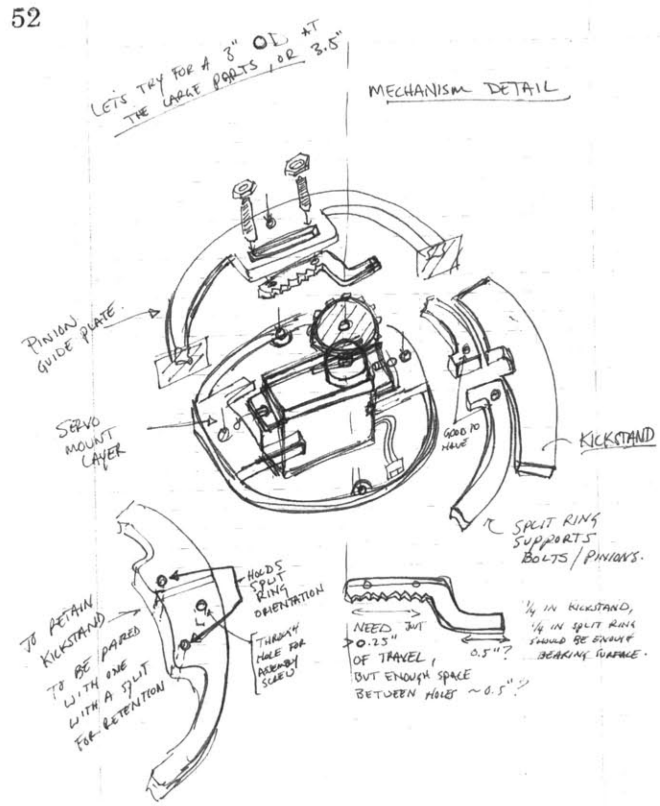


**Figure 3-8: A sketch of the initial conception of the mechanism, showing the layered construction.**

The advantages of this fabrication method have become evident during the process of creating the alpha prototype. First, it was possible to create working mockups in acrylic of parts using a laser cutter. This allowed for extensive debugging and tweaking of parts with much lower time and material costs than using the waterjet to cut aluminum. Also, when one feature is found to be defective or needs to be re-designed, it is simple to alter the solid models of those particular layers and cut them on the laser cutter before swapping them into the mockup. This allowed for efficient refinement of the design before the switch to the final materials.

The only disadvantage of this method is that assembly of the layers becomes more difficult, and if serviced by the user it could become confusing. Additionally the presence of seams along the device presents an issue with intrusion of dust, water, and debris, but this is to an extent mitigated by the presence of plastic coverings over much of the lock. Finally, it is likely that the overall strength of the lock is somewhat compromised as compared to a seamless design, but the layered architecture allows for a compactness and variety of features that would not have been possible with other manufacturing methods.

### 3.6: The Open-Source Conscious Design

As this is an open-source project, it is necessary to attempt to keep the device accessible to those without full access to the resources of an institution like MIT. Thus all of the electronics can be assembled from commercially available boards like the Arduino Nano. This principle carries over to the mechanical design as well. Waterjet machines are by no means ubiquitous, but laser cutter machines are becoming staples of makerspaces worldwide. Thus with this design and its layered architecture it is possible to create a version of the design in plastic that is fully functional except for the ability to carry loads. Machining operations are kept to an absolute minimum, with only the coupler to the bike axle requiring mill and lathe operations. Thus it is possible not only to understand the device's function, but also to alter layers and offer improvements on the design simply by using a laser cutter.

### 3.7: Use of the Device

The users will first encounter the device on a bike parked with the kickstand lock deployed and the electronics in hibernation. Waking the bike by triggering the accelerometer will cause the bike to authenticate with the user's phone via Bluetooth. Upon success, the lock will automatically disengage, beginning the user's trip. The user, assumedly standing on the right-hand side of the bike as is common for right-handed individuals, will lift the kickstand from the retainer side with their foot, which will lock in place automatically upon becoming parallel with the ground. The power is therefore cut to the onboard electronics via the magnetic switch, and the user is then free to take their ride. Upon the ride's completion, the user will dismount the bike (again often to the right side), and press the button on the retainer with their foot, which will cause the kickstand to drop to the ground behind the rear wheel. The user can then roll the bike backwards, which will cause the bike to rise onto the kickstand with the rear wheel off the ground. With the kickstand now fully engaged, power returns to the onboard microcontroller, which locks the bike and prompts the user with end-of-ride options, such as keeping the bike on hold for an amount of time, requesting that the bike be serviced, or simply ending the ride.

## SECTION IV: THE FUTURE OF THE PROJECT

The completion of the alpha prototype marks a major milestone in the development of this product, and will allow Social Computing to begin testing their program in the coming months. There are still, however, several details left unresolved and significant development necessary before the system is ready to deploy on a large scale. These details include miniaturization and aesthetic improvements, weatherproofing, security improvements, choosing a method of self-recharging, and increasing the manufacturability.

### 4.1: Weatherproofing

As it stands, the prototype is not properly weatherproofed. It is made with corrosion-resistant materials, with the majority being aluminum and stainless steel, but the electronics need to be protected. There are two major strategies being considered now for weatherproofing. The first involves protecting only the electronics with some sort of interior bag that would be sealed upon installation, and the second involves sealing the entire body of the lock against moisture and debris. The first strategy may prove difficult because wires will need to exit the bag, so moist air may enter it over time and cause damaging condensation close to the electronic components. The major advantage of the bag system is that it does not modify the current design and would allow for disassembly of the device without breaking the seal. If the body were to be sealed, it would either require the machining of grooves in order to seat O-rings or it would require the use of a silicone sealant or something similar. With the current design, it would only be necessary to seal the metal-plastic interfaces, of which there are four, rather than having to seal between the numerous layers. This solution adds additional work to assembly/disassembly, or requires post-machining, neither of which are desirable, but protect a greater portion of the device.

### 4.2: Security

The resultant security of this lock is the product of a trade-off between convenience of installation and the security of the lock. Due to Social Computing's desire to be independent of infrastructure to achieve locking, it will never be possible to hold the bicycle in one place, only to render it inoperable and cumbersome to transport. When the kickstand is locked in place, the rear wheel is held off the ground, and as such the bike is rendered inoperable. It is necessary for the use model for the users to be able to convert the bikes themselves into shared bikes by installing the lock, and so it must be achievable with standard tools and human strength, or it is necessary to provide special tools for assembly and installation. By that same logic, it would be possible for a potential vandal or thief to disassemble the device while it is on a bike and therefore bypass the security. So a balance must be struck so that theft is deterred, but users are still willing to install the units themselves.

The first area of importance is the connection between the two modules, lock and retainer, and the bicycle that is facilitated by the castellated connectors. As of now, they simply screw onto the axle, and once the foot of the kickstand is in place, connecting the bottom of the "U", it is impossible to unscrew the connectors from the axles due to interference between the kickstand and the frame. Assuming, however, that the foot was not there, it is indeed possible to unscrew the connectors rather easily due to the large leverage provided by the kickstand. In addition, if the entire unit can be rotated while it is installed, it may be possible to bring the rear wheel to the ground while the kickstand is locked and thus the bike could be ridden. In order to combat this, it is necessary to determine a way of locking the connectors to the axle such that they will not loosen. Using a thread adhesive such as Loctite is the obvious approach, yet would make bike repairs extremely inconvenient if it became necessary to remove the rear wheel. Modification of the rear axle is also not allowable due to the nature of the project, but the connector may be modified freely.

The second area of importance is the external bolt circle on the outboard caps of both modules. If removed, they allow the entire system to be disassembled, although it is necessary to remove another bolt circle to disengage the lock. Because users would have no need of tampering with the mechanism itself, it is possible that thread-locking adhesive and/or security head screws may prove useful for this purpose to act as a deterrent, as without the proper driver it is likely that the screw head will strip before the adhesive is defeated. A specialized screwdriver may be included with the kit, along with a bottle of adhesive to make this feasible.

### 4.3: Recharging

Two ideas have been suggested in regards to recharging, and one has been tested. The first solution is to use solar energy, which has been shown to be sufficiently powerful in direct sunlight to power the system entirely, and can be used to charge the battery simultaneously via a commercially available charging circuit. The solar cell used is available on Adafruit.com for $25 and is 4.4"x5.4", which could easily be attached to a bicycle, but would require a separate mount away from the wheels to receive optimal sunlight. This system has obvious drawbacks in inclement weather and during winter, and the limitations of the solar cell have not yet been tested rigorously. The other option is to use a magneto attached to the wheels, as many cyclists do in order to operate running lights. This again would require an additional mount and increases the moving part count, but is a tried and true solution for powering bicycle accessories.

### 4.4: Manufacturability and Scaling Up

As of now the majority of the fabrication is done on the waterjet, and although industrial institutions exist that manufacture runs of waterjet products the fact remains that it is a very expensive process at any scale. If this product were to be manufactured at a large scale, it is necessary to determine a way to create the many layers in a cost-efficient manner. The proposed solution as of now is to create the parts via aluminum extrusion in vast thicknesses, then to take slices off the ends in order to produce individual parts. Parts with floating holes and complex contours can be produced by modern methods of extrusion, taking 80/20 beams as an example. Although there is a high fixed cost in producing the extruder heads necessary to make such complex parts, the marginal cost per part is extremely low and production could be very rapid.

## SECTION V: CONCLUSION

With the development of this alpha prototype the Social Computing group is ready to advance their bicycle-sharing project to the next stage, where they can integrate mechanics, electronics, and software and begin testing at a systems level. Several key operational and architectural issues have been resolved, and while there remain several key elements to address, such as weatherproofing and tamper deterrence, a reliable and flexible framework has been established on which to experiment. While Social Computing itself will continue to develop the device in-house, this document along with additional resources that will be made available online will serve as an open-source blueprint for all those interested in adapting and/or implementing the design in accordance with their own vision in their own communities, which harkens back to the Social Computing group's central research goal of improving communities through the application of science and technology.

## REFERENCES


1. "You Are Here" project by Social Computing. Map of most efficient mode of transportation in Cambridge, MA: www.youarehere.cc/p/bestmode/cambridge

**APPENDIX**

Figure A-1: An exploded view of the complete lock module.

**Figure A-2: A larger exploded view of the retainer module.**

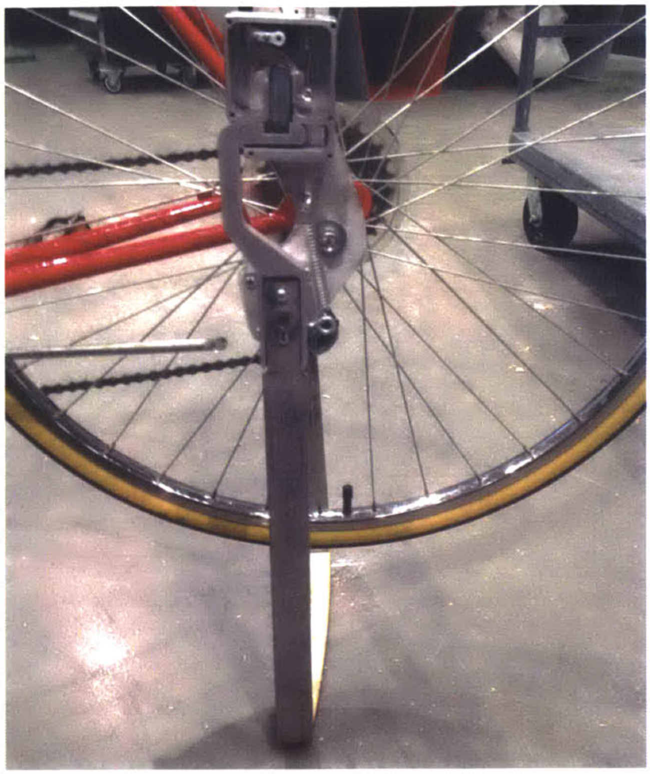

**Figure A-3: The first prototype of the project.**

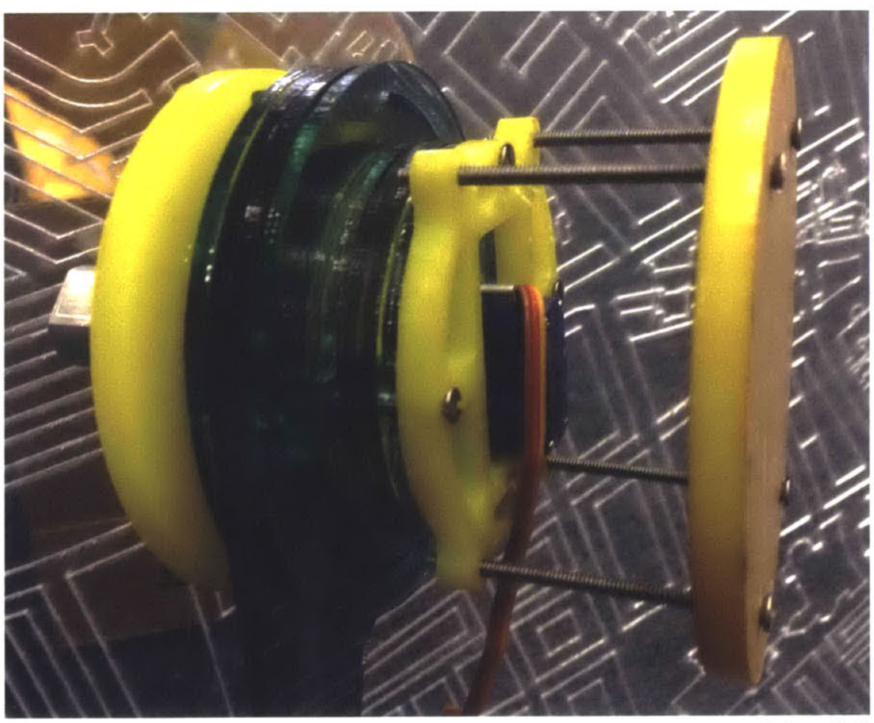

**Figure A-4: A functional acrylic mockup of the alpha prototype used for debugging.**

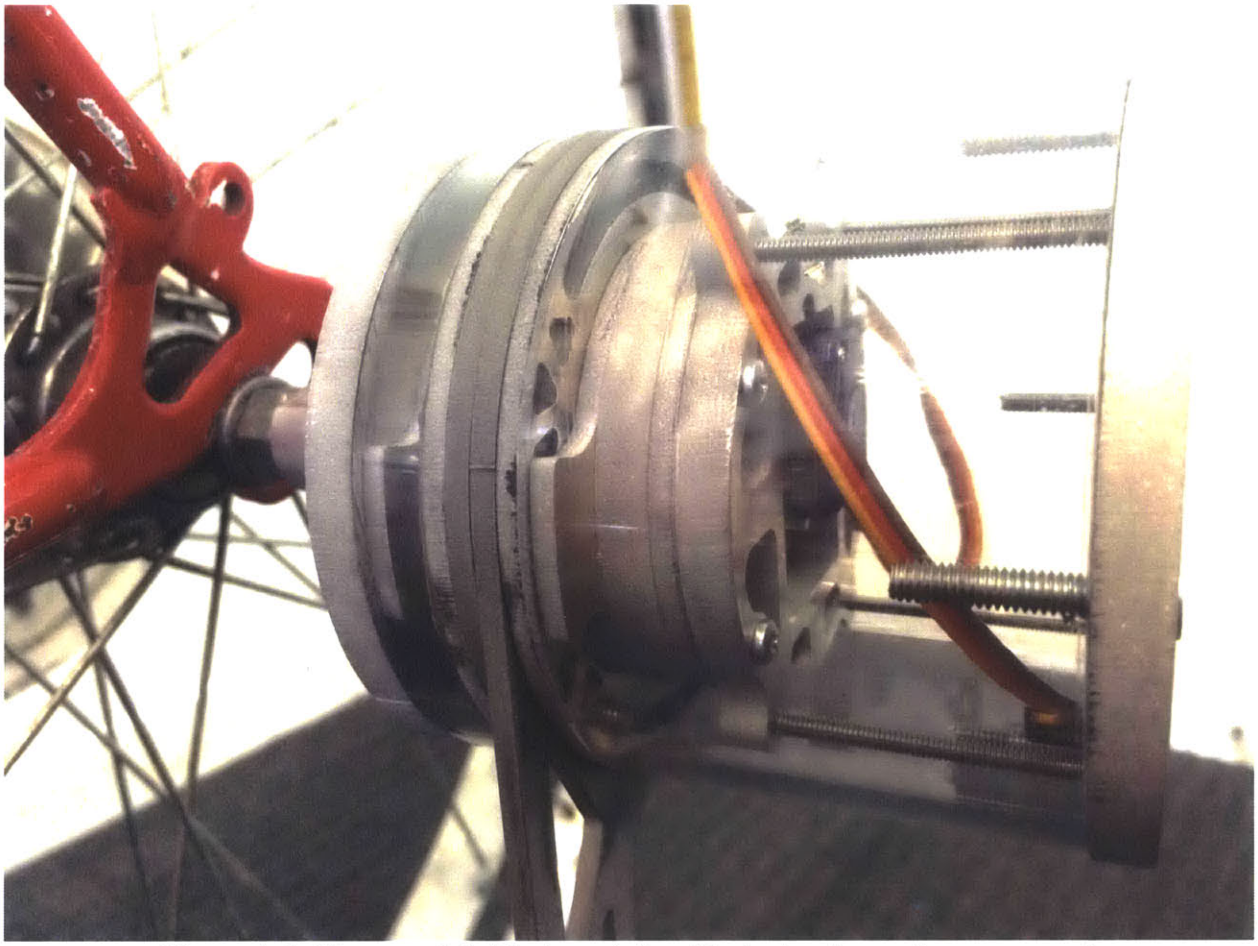

**Figure A-5: The completed lock module with electronics package removed.**