Low Cost Bicycle Share Security Solution for Universities

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Abstract

Many universities around the country, including Oakland University (OU), have instituted bicycle sharing programs in order to address the need for student body transportation. A past 'honor' based bike sharing program, which lacked security measures, proved too costly for the university due to theft and student negligence. Commercially available systems, such as that implemented by the city of Denver[1], carry a high, multi-million, dollar cost.

This article presents a low cost bike share program solution specifically for use on university campuses. The design comprises a dynamo powered microcontroller (MCU) wherein student access to each bicycle is coordinated through a single WiFi connected server. Each bicycle is accessed by operating a locking mechanism via a user interface. Additional theft deterrent features are included in the housing unit and intelligently operated by the MCU. The design presented in this article is a low cost alternative to commercially available systems.

Introduction

The popularity of municipal bicycle sharing systems has been increasing in the United States. The economic, health, environmental, and traffic decongestion benefits of bike share programs are becoming more attractive to municipalities with each passing year. However, many bicycle sharing programs on University campuses have been unsuccessful. The target customers of most commercial bike sharing products are municipalities whose yearly budgets and operational costs dwarf those of university campuses. Only large universities command the resources with which to implement municipal bike sharing solutions. Without the need for kiosks and/or bicycle racks, the security solution presented here allows universities to tailor their bike sharing investment according to their respective student body sizes.

Figure 1, below, presents a generic overview of the major bikeshare security system components. The bike share design presented here is tailored specifically for those university campuses that contain an existing WiFi infrastructure. The OU bikeshare security system is composed of relatively low cost components controlled by a microcontroller. The system is powered from a battery pack and dynamometer combination. All system components, aside from the server, are housed on the bicycle.

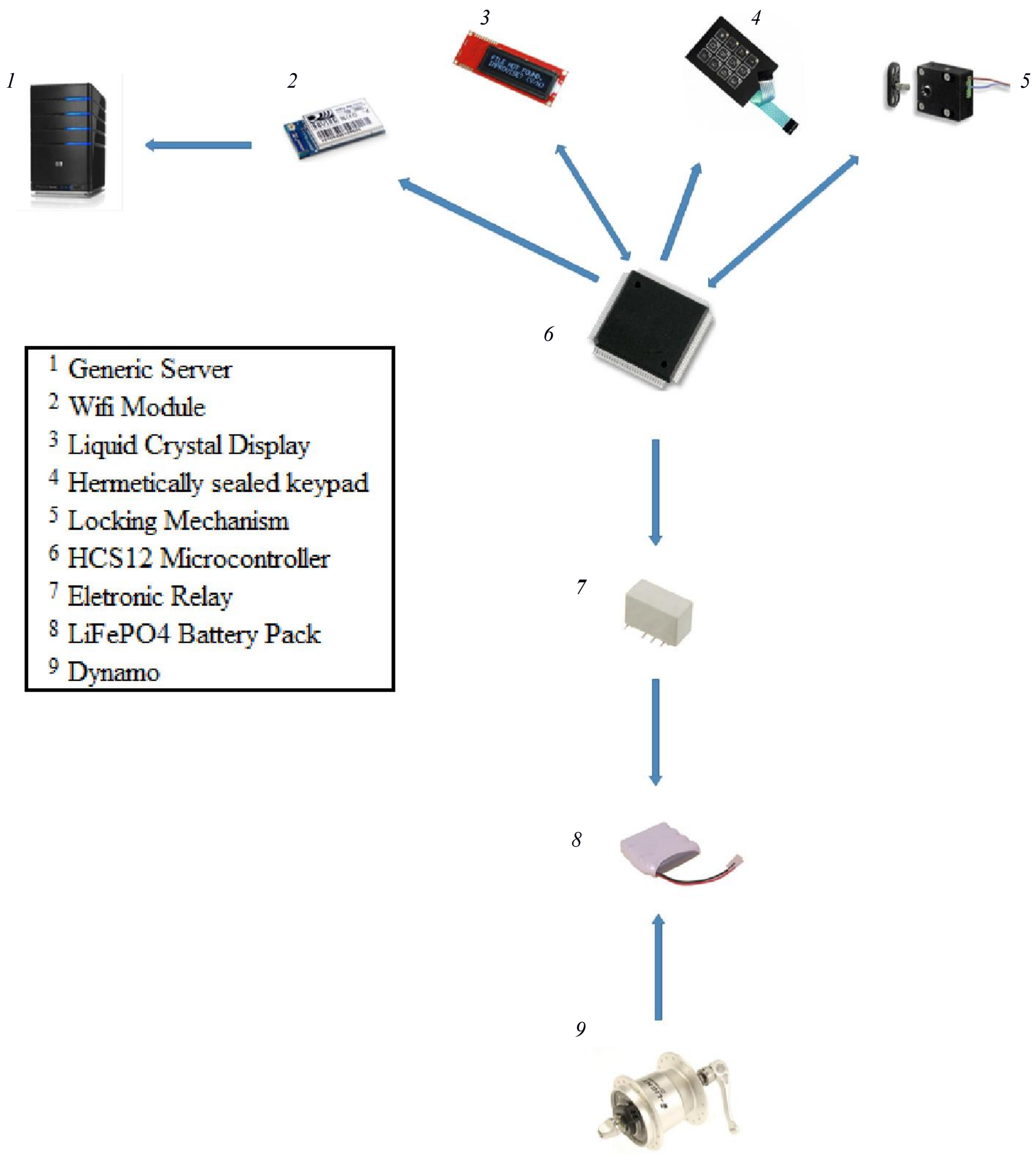

Figure 1 System Electronic Component Interface Scheme. With exception to both the server (1) and dynamo (9), the MCU (6) interfaces with and coordinates the actions taken by all system peripherals. The electronic locking mechanism (5), keypad (4), LCD module (3), Wifi module(2), and electronic relay (7) each interface with ports on the MCU. The Wifi module facilitates communication between the server and MCU. The electronic relay allows the MCU to disconnect power from the battery pack (8). The dynamo recharges the battery pack independent of MCU control.

System Operation

The bikeshare security system is composed of two components; bicycle-mounted hardware (BMH) and a coordinating server. Identical copies of the BMH shall be attached to all bicycles participating in the security program. Each mounted hardware unit will communicate, via the campus wide WiFi network, to the second component of the system; a bikeshare dedicated server. A generic overview of the bikeshare security system components is shown above in Figure 1.

Aside from the control electronics, the major components and their respective interfaces are described within the diagram.

Figure 2, below, provides a description of the system operation during normal conditions. The purpose of the BMH is to ensure that the bicycle is secured to an object (bicycle rack, small tree, light pole, etc) which prevents unauthorized users from accessing the bicycle. In its default state, the BMH control electronics are disconnected from battery power and the bicycle has been secured with the locking-mechanism. In order to access the bicycle, authorized users shall enter a personalized security code via the BMH keypad. After the security code has been entered, the BMH communicates the security code to the server via a WiFi transceiver. The server authenticates the transmitted security code and responds to the specific BMH with a permission or denial message. A permission message will allow the BMH to unlock the bicycle lock-chain. The locking mechanism, which holds or releases the lock-chain, is housed within the BMH. After the bicycle has been freed, the user is free to reinsert the lock-chain into the locking mechanism and use the bicycle as transportation. Once the user has arrived at his/her destination, the user simply re-enters their personal security code, removes the lock-chain from the BMH, secures the bicycle to a local object, and returns the lock-chain to the locking mechanism. The BMH then transmits a message to the server, notifying the server that the user has returned the bicycle to the default state. Throughout this process, status messages and commands are communicated to the user by the Liquid Crystal Display module (LCD) mounted on the BMH housing.

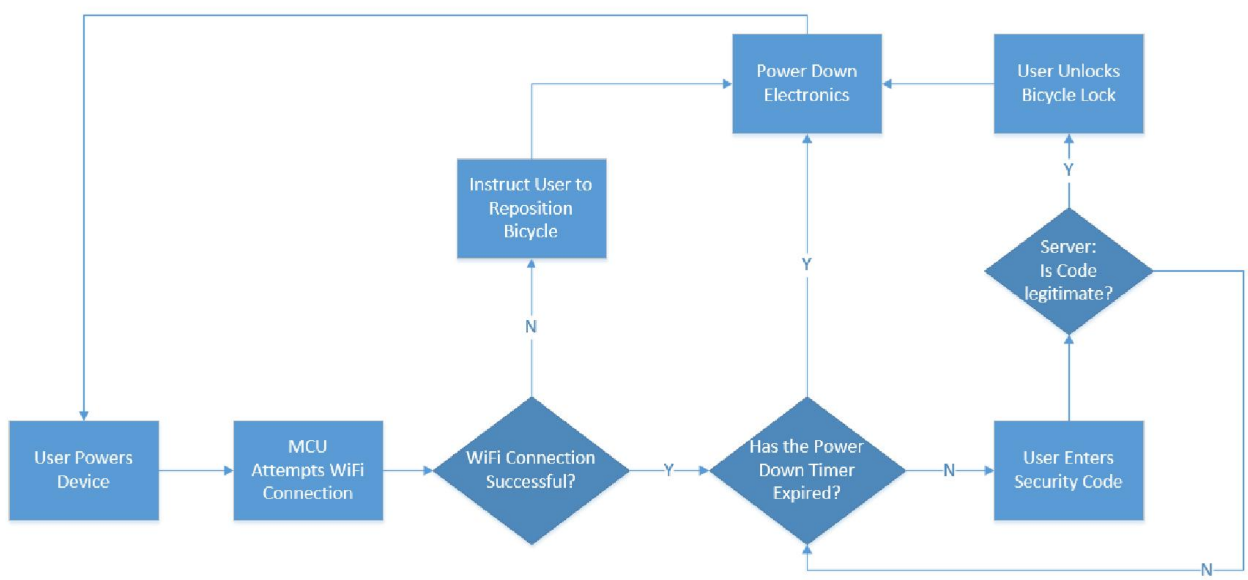

Figure 2. System Standard Operation. After the user powers the device, the MCU attempts to connect to the server via the Wifi. If the MCU fails to connect, then the user is instructed to reposition the bicycle and the MCU disconnects *the battery power. If the* Wifi connection attempt was successful, then a prompt is presented to the user requesting a security code. If the user enters a illegitimate security code (as verified by the server), then the prompt is again presented. The MCU will remove battery power from the system electronics after the timer expires, if a legitimate security code has not been entered. If the security code is legitimate, then the MCU unlocks the locking mechanism and powers down the system electronics after the lock-chain is removed.

While in the default state, the locking mechanism is electronically disconnected from the battery which results in no current draw for all electronics. Before a user can input his/her security code, the user must press a mounted button in order to provide power to the internal control electronics. This functionality is achieved via a double pole double throw electronic relay which establishes a connection between the control electronics and the Lithium Iron Phosphate ($LiFePO_4$) battery source. When the user presses the 'power button', the electronic relay is latched such that the system electronics are connected to the battery. The latch within the relay is reset only upon command from the MCU. The user is unable to disconnect power to the control electronics and, thus during normal operation, the MCU is able to perform all programmed tasks before removing power. With every keypad depress initiated by the user, an internal counter is reset within the MCU. If the internal counter reaches a count equivalent to 12 seconds, the MCU will disable power to the system via the electronic relay.

The campus WiFi network does not cover all points on the university campus. If a user gains access to a bicycle and transports the bicycle to an area in which the BMH cannot connect to the WiFi network, then the device will prevent the user from removing the lock-chain a second time. More specifically, the BMH will attempt to establish a connection to the server three times. If the third connection attempt fails, then the BMH will instruct the user to relocate the bicycle and remove power from the control electronics.

The system may also be powered from the default state by the vibration sensor contained within the BMH. The vibration sensor is present for security purposes. The vibration sensor is an anti-tampering device which will both enable power to the control electronics and notify the MCU that the housing has experienced excessive vibration. In this design, excessive vibration is a vibration which persists for a specified duration at or above a specified magnitude. If the MCU is powered from the default state due to excessive vibration, then the MCU will notify the bikeshare server that the vibration sensor has detected excessive vibration. An additional anti-tampering device, an internal photo-resistor, is monitored by the MCU. Depending on the value of the voltage drop across the photo-resistor, the MCU can determine if the interior of the case has been exposed to external light. If external light is present within the housing, it is assumed that the housing has been compromised and that the internal components are at risk of damage.

Power is provided to the control electronics via a $LiFePO_4$ battery. As the user pedals the bicycle, the dynamo hub mounted in the front wheel replenishes the charge of the battery. Once power to the control electronics is enabled, the MCU coordinates all functions and peripheral actions. The MCU is responsible for the order and timing in which power is both provided to and removed from the electronic components (including the MCU itself).

System Components

An HCS12 microcontroller controls and coordinates most of the major components in this system. For this design, all source code was written in the C programming language. The prototype bicycles produced for OU were created as a proof of concept. Therefore, the designers chose to utilize the ThunderBird12^{tm} DIP module produced by EVBPlus LLC (Bloomingdale, IL). The ThunderBird12^{tm} module requires 5V according to documentation. Power consumed by the module during operation was observed to be 0.17W. The microcontroller controls power to flow to the peripheral components via MOSFETs, acting as switches. The HCS12 only contains two onboard serial interface controllers and both are utilized in the design to communicate with the WiFi and LCD modules. In order to interface with the keypad, a device driver was written. The microcontroller's analog-to-digital (A/D) converter was called upon in order to read the photo-resistor output signal. The vibration sensor state, excessive vibration or lack thereof, is read in as a digital input.

The RN-131G Wireless LAN WiFly module, produced by Roving Networks, Inc (Los Gatos, CA), is used to facilitate a WiFi connection between the campus network and the BMH. The primary design considerations used for selection were power consumption and ease of use. With an expected consumption of 0.7 W, the RN-131G was determined to be satisfactory. Actual power consumption observed was 0.65W. The module is preloaded with software to simplify integration and minimize application development. In the simplest configuration, the hardware requires only four connections (PWR, TX, RX, and GND) to create a wireless data connection. In order to establish a connection, the MCU needs only to provide the WiFly with a network SSID, network password, and IP port number. Once a connection is established, all ASCII characters placed on the SCI channel are transmitted by the module to the connected port.

The three major components exposed to environmental conditions are the keypad, LCD, and locking-mechanism. The hermetically sealed keypad, which contains 12 isolated switches, is manufactured by APEM Components (Le Blanc-Mesnil, France) and is mounted on the outside of the BMH. Power is provided to each of the switches by the MCU. Therefore, the keypad power consumption is included in the power supplied to the ThunderBird12^{tm} module. Additionally, the switches exhibit very little bouncing upon transition, eliminating the need for either hardware or software based switch denouncing. The second major component exposed to the elements is the LCD. The LCD module contains a PIC 16F88 microcontroller, communicates over SCI, and is produced by Spark Fun Electronics (Boulder, CO). Relieving the programming burden on the designers, the on-board microcontroller takes the serial inputs and prints received characters directly to the screen. As a cheaper alternative to more robust screens, the Spark Fun LCD module is mounted behind a clear plastic to protect it from the elements. The locking-mechanism is produced by effeff Fritz Fuss GmbH & Co (Stuttgart, Germany) and can withstand up to 200lbs of force. The locking-mechanism requires 12V in order to actuate the lock into the unlock position, allowing the user to remove the lock-chain from the BMH. Additionally, lock-chain position feedback, secured by the locking-mechanism or no, is provided through the closure of a contact switch. The MCU provides power to the feedback switch allowing power to be removed from the locking-mechanism while allowing the MCU to monitor lock-chain status.

The dynamo used in the bikeshare system is the I-Light 730 model produced by SRAM International Corp (Chicago, IL). The dynamo provides 3W of power in the form of AC voltage. In order to charge the battery, the AC waveform produced by the dynamo was converted to a DC voltage. In order to accomplish the conversion a W10G-E4 full wave rectifier, produced by Vishay Semiconductor (Malvern, PA), was inserted. $LiFePO_4$ batteries can be recharged via a process known as float-charging[2]. In order recharge the battery, a voltage, higher than the 6.4V battery voltage, must be applied to the positive terminal of the battery. In order to limit the positive battery terminal voltage to 6.7V, a IN4736 zener diode was applied in parallel with both the battery and full-wave rectifier.

The electronics contained within the BMH include the vibration sensor, MOSFETs, and voltage regulators. Since the output pins of MCU cannot provide a current large enough to accommodate the components controlled, IRF510 MOSFETs were used as switch interfaces between the two. The system design requires three different voltages for powering the components. The WiFi module requires 3.3V, the locking-mechanism requires 5V, and the remaining devices require 5V. Two fixed voltage regulators, AP1117-5.0 and AP1117-3.3, were implemented to accommodate the 3.3V and 5V requirements. The step up from 6.4V to 12V is performed by CC6-0512SF-E DC-to-DC converter manufactured by TDK-Lambda Americas Inc (San Diego, CA). The electronic relay powers the 5V rail directly, while the MCU controls the 3.3V and 12V rails via respective MOSFETs. The vibration sensor circuit charges the capacitor as the vibration oscillates because the switch is connected directly to the positive battery terminal. If the vibration switch can fully charge the capacitor faster than the discharge rate, then MCU will power on and begin the initialization process.

Table 1 provides power consumption estimates of the major system components in order to determine the total system life per single battery charge. It is estimated that the system will be used 7 days a week for 12 hours a day twice every hour. The battery itself, when fully charged, is rated to have 19.2 Wh of work, as set by the manufacturer. The power calculations in Table 1 result from the assumption that the system is programmed to enter unlock/lock mode for 10 seconds and stay awake for 110 seconds. The system will therefore use 0.24 Wh of energy per day. Without recharging the system battery should last for up to 80 days. The dynamometer produces approximately 100 mA on average. It is assumed that the bicycle will be ridden for 10 minutes per hour, the dynamometer is expected to produce 6 Wh per day.

Table 1. Power Estimations

Part	Supply Current (mA)	Supply Voltage (V)	Power Subtotal (W)	Operation Time Per Day (h)	Energy per Day (Wh)
LCD and MOSFET	23	5	0.12	0.16	0.02
WIFI Transceiver	196	3.3	0.65	0.16	0.14
Photoresistor & Vibration Switch	0.1	5	0	-	-
Lock System	281	6.4	1.8	0.022	0.0396
MCU	33	5	0.17	0.16	0.04
				Battery Energy (Wh)	19.4
				System Life (days)	80.92

Cost Estimates

There are several approaches to bikeshare system design, the most popular of which is kiosk-based[3]. In this approach, automated bike stations or kiosks house the computer systems which secure and release the bikes to a bicycle rack connected to the kiosk. A kiosk based design requires the campus to have a plurality of racks positioned by the bikeshare administrators. In order to power the system, the kiosks will either be connected to the campus electrical grid or house their own battery systems. Electronics present on both the kiosk and bicycle work to establish a proper interface between the bike and kiosk, and track usage, location and bike status. Table 2 contains a cost estimate for a kiosk based bike sharing system estimate compiled for the city of Cinncinati[4]. At its most affordable, the kiosk based design was estimated to cost 1.6

million dollars for a 210 bicycle implementation.

Table 2. Cincinnati Bike Sharing Estimate[4]

Costs	Scenario 1 (21 stations/210 bikes)		Scenario 2 (35 stations/350 bikes)	
	Low	High	Low	High
Launch	$300,000	$350,000	$500,000	$550,000
Capital	$900,000	$1,000,000	$1,500,000	$1,750,000
Operating	$450,000	$600,000	$750,000	$1,000,000
Total	**$1,650,000**	**$1,950,000**	**$2,750,000**	**$3,300,000**

A more similar implementation to the design presented herein, SoBi: Social Bicycles is a kiosk-less bike sharing system. As opposed to the design described above, the electronics housed on SoBi bicycles include a GPS module. Additionally, the SoBi bicycles favor powering the system electronics with solar panels as opposed to the dynamo hub presented here. According to a feasibility study performed by the University of Illinois[5], the system costs are approximately $1,300 per bike.

Table 3. Cost Estimate of Bikeshare Security System

Part	Unit Price (USD)	Quantity	Extended Price (USD)
WiFi Module	32.35	200	6470
LCD Module	19.96	200	3992
Dynamo	71.71	200	14342
Locking-Mechanism	149	200	29800
Keypad	36.608	200	7321.6
Battery	38.66	200	7732
Electronic Relay	2.196	200	439.2
12V Regulator	15.25	200	3050
MCU	5.13	200	1026
		Rough Cost (USD)	74,172.80
		Per Bicycle (USD)	370.86

Using bulk unit prices of the components purchased for the prototype module, Table 3 shows an estimate of the bike sharing costs per bicycle. The bikeshare system design presented here was constructed mainly for use as both proof of concept and prototype testing. With the prototypes successfully built and test, the next phase of the project will focus on optimizing size, power consumption, reliability, and cost. It is predicted that the final production units will cost $100 dollars or less. The costs estimated in Table 3 do not include labor or the lower priced electronics, further testing and measurement will allow the designers to precisely tailor components for the device power needs. For example, perhaps lower cost and wattage can replace the current designed. Costing only additional development time, the cost of those components contained in modules may be lowered by offloading their device drivers to the MCU. Finally, a lower cost alternative to the most expensive item, the locking-mechanism, could be engineered. Even without said cost reductions, this system compares favorably against commercially available bicycle sharing systems.

Conclusion

The OU bikeshare system design presented above is a user driven kiosk-less bike sharing system. The system was designed consists mostly of off-the-shelf components and modules. According to cost estimates of the prototype, the OU bikeshare design price per bike is less than a third the cost of similar quoted prices for similar commercially available systems. Currently, the OU bikeshare design prototype is in the testing phase and an ergonomical housing is in the design phase. Should the OU administration choose to implement this system; it is the expectation of the designers that a more robust and lower cost design could be implemented for production.

Acknowledgements

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