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ELECTRONIC LOCK MECHANISM FOR BICYCLE

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Abstract: *Electronic locks have become more common in buildings and vehicles. A significant benefit of these locks is remote access control which allows easily to add access for new user or remove access from user's lost key. In this project our goal is to design and produce portable electronic lock for bicycle. This feature is expected to improve bicycle sharing that is increasingly common around the world. Lock's functionality is researched from battery life time perspective to discover how it would function in various temperatures.*

Keywords: *keyless lock, energy efficiency, portable lock, bicycle sharing*

1. INTRODUCTION

The rapid development and expansion of bicycle-sharing in all over the world in recent years shows that it is becoming an attractive and adaptable urban transportation concept [1]. Usually bicycle sharing is implemented so that user picks the bicycle from one docking station and returns it into the same or another station [2]. Installing a station takes time and is costly [3]. One way to make sharing more attractive in the future is to create a portable locking system and get rid of stationary docking stations. Wirelessly operated electronic locks provide easy remote access control. Ability to grant accesses is a key feature for bicycle sharing. One other key feature is the possibility to operate lock with mobile phone which already has the systems for locating and identifying users as well as method for payment [4].

In general creating bicycle sharing system with traditional means requires large investments to bicycles and docking stations [2]. Usage of portable locks would make it possible to create systems that are not tied to fixed place. This paper describes design of a mobile version of electronic lock that could be used for sharing bicycles. Furthermore it researches the problems there may lie on this kind of locks such as: lifetime of battery, user friendliness and effect of outdoor usage [5].

One of the challenges with portable electronic locks is to get energy last long enough without replacing batteries continuously. Locks that are developed by current startups have often energy harvesters such as solar panels to keep the battery alive [6]. At cold weather the lifetime of the lock may decrease dramatically. A battery manufacturers data sheet informs that the capacity of battery at –20 °C temperature may be 20-80 % of the capacity at +20 °C depending on battery type and usage. [7] Another study shows that some lithium-Ion batteries at -20 °C temperature may only have 10 % of the energy density compared to the battery at +20 °C [8]. Therefore, the battery lifetime is even more significant issue in countries with cold winters.

2. PROTOTYPE SYSTEM

2.1 Locking mechanism

The prototype lock was made in a shape of common U-lock. This shape was chosen because it is widely used in bicycle locks and it can be used in other applications as well. Dimensions of the lock's frame are a result from the size of the controlling circuit board. The inner part of lock was designed to be made from plastic and the outer shell to be made from steel. Steel is protecting the softer inside which is manufactured from lighter material.

Lock is protected by tubular shell made out of stainless steel. Cylindrical frame of lock located inside the shell consists of two parts that can be separated when removed from the shell. U-bar that is used to lock a bicycle is connected to the frame and locked with a locking plate that is sliding in a slot inside of the frame. Battery and control chip are located in the middle of frame. Both ends of shell are protected with steel plates to prevent opening of lock with a drill. One end has a button which opens the lock if it’s unlocked.

The mechanism was designed in a way that the lock's default status is locked and it is always possible to insert the u-bar without electric power. This feature is expected to save energy. Electric power is only used to turn the lock to open and closed position with as little movement as possible. The actual movement to free the u-bar is performed by the user. The driving logic opens the lock for few seconds and then automatically turn it closed. This feature was expected to prevent the lock from being left open. To prevent the lock from being opened by applying brutal force on the button, the mechanical structure was designed so that the locking action will not prevent the button from being pressed. Instead, locking action connects and disconnects the button from the actual locking plate.

Locking mechanism (Fig. 1) itself consists of locking spindle (2) and actuator to operate the related opening mechanism. Movement to open the lock is applied via button (1) located at the end of frame. Motor is located inside of this button and it rotates locking spindle. When the locking spindle is in unlocked position, the movement of the button is conducted via locking spindle to locking plate (3) which opens the lock. In locked position, the locking spindle is

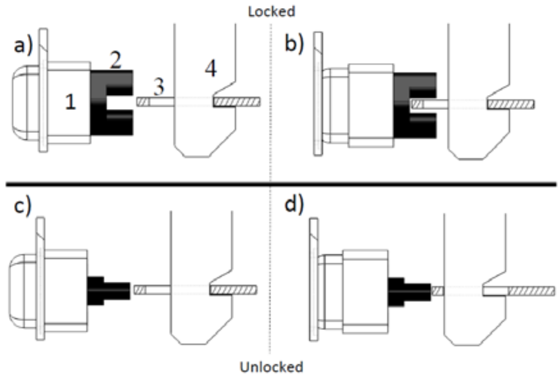

Fig. 1. Illustrations of the lock in different states. Figure a) show the lock in closed state at rest and in figure b) button (1) is pressed while lock is still in closed state. In figure c) lock is in open state when the button is not yet pressed and in figure d) button is pressed while lock is in open state.

sliding over the locking plate without touching it, thus the lock stays locked. Movement of the button and locking plate are monitored with switches. Pair of springs are used to return everything to home position when no force is applied.

While the lock is opened and the U-bar is removed the frame can be removed from inside of the protective shell for maintenance such as replacing the battery. Disassembly of the lock requires it to be unlocked.

While the end-user’s device is near enough to the lock, it’s possible to control the lock via Bluetooth (Fig 2). When the user chooses to unlock the lock, the lock system confirms from database whether or not the operation is permitted. This database can be located either locally in user's phone or on internet depending on how the system is administrated [[9]]. If the user has the right permits, the lock opens and led indicator is switched on.

2.2 Measurements

Bicycle locks are used in various weather conditions. Temperature can have great variation depending on the location and time. To figure out the effect of the temperature in locking electronics, energy consumption of the lock was measured at

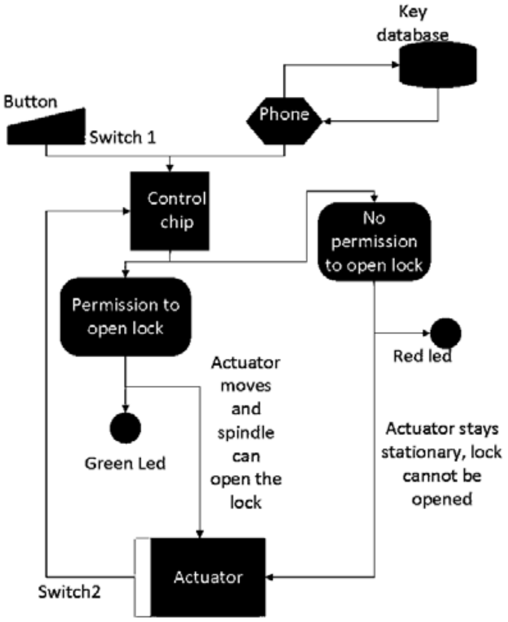

Fig. 2. Lock functionality chart

four different temperatures: +24 °C, +8 °C, +2 °C and -24 °C. Also characteristics of batteries in these conditions were studied.
At each temperature two measurements were made. First circuit board's standby energy consumption was measured for 15 minutes. During this period the energy consumption of the circuit board was settled. While board is in standby it scans for a Bluetooth device at specific time intervals. After this, energy usage of unlocking and locking cycles were measured. Locking electronics were placed in each measurement temperature 30 minutes before measurements. Temperature was measured during the entire measurement period with a digital thermometer. Energy consumption measurements were made with Monsoon Power Monitor.

3. RESULTS

The Figures 3, 4, 5 and 6 show the energy consumption of the controlling circuit board at standby state at different temperatures. In these measurements the lock scanned for Bluetooth device but was not controlled by any. The actuator was not used in these measurements.

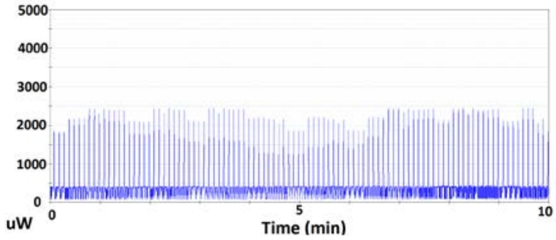

Fig. 3. Power usage of controlling circuit board at +24 °C temperature.

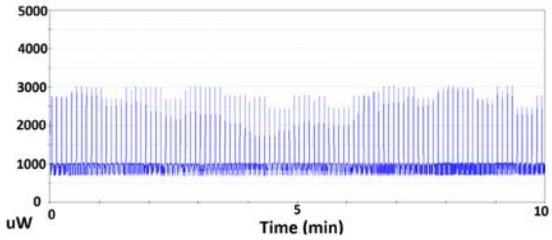

Fig. 4. Power usage of controlling circuit board at +8 °C temperature.

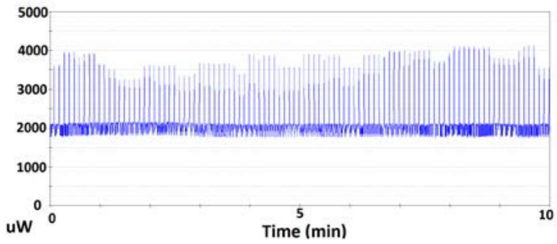

Fig. 5. Power usage of controlling circuit board at +2 °C temperature.

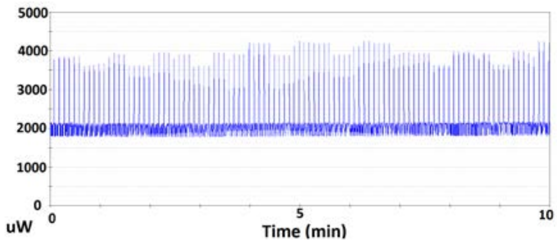

Fig. 6. Power usage of controlling circuit board at -24 °C temperature.

Circuit board uses 4,5 volts. Table 1 shows the measured average current in standby state at different temperatures. Average power consumption is calculated with equation P=UI. Average power is also easily seen in Figures 3, 4, 5 and 6. Table 1 also shows the measured consumed energy when the lock is opened in these temperatures.

Temperature	Avg. current	Actuator consumption
+24 °C	0,10 mA	107 uAh
+8 °C	0,23 mA	108 uAh
+2 °C	0,47 mA	110 uAh
-24 °C	0,48 mA	112 uAh

Table 1. Average current draw of control circuit board at standby state and energy consumption of actuator at different temperatures.

4. DISCUSSION

By the end of the measurements, several results were found.

- Cold temperatures has no significant effect for energy consumption of the opening and locking mechanism.
- Cold temperatures has great effect for energy consumption while the lock is in standby mode. Energy consumption can be multiple times higher compared to warm temperatures.
- Energy consumption in standby mode will raise as temperature falls, but the energy consumption has its maximum limit. When temperatures drops under 2 °C, the energy consumption has little growth.
- Battery life time at room temperature (24 °C) is 3,6 years.
- Battery life time at cold temperature (below 2 °C) is 260 days.

As it was seen from the previous results, temperature has a large effect against the life time of the batteries. In the countries where temperature drops to under 2 °C, batteries have to be replaced more often. By storing bicycles inside while they are not used during cold seasons, the effect of cold air can be reduced. When the bicycles are not under the influence of cold season, the life time of batteries can be over 3 years with configuration we did use. This is acceptable service interval for bike sharing and private use. Bike renting is also possible with cold seasons but in these circumstances the batteries has to be changed more often since the life time of the batteries are under 9 months.

Temp.	Lifetime (4 uses/ day)	Lifetime (6 uses/ day)	Lifetime (8 uses/ day)
+24 °C	2,99 y	2,76 y	2,56 y
+8 °C	1,34 y	1,30 y	1,25 y
+2 °C	0,70 y	0,68 y	0,67 y
-24 °C	0,68 y	0,67 y	0,66 y

Table 2. Battery life time estimations when lock is opened 4, 6 and 8 times per day with 3000 mAh battery at different temperatures.

Table 2 represents estimation of lock's lifetime in years with 3000 mAh battery and different utilization rates. In estimation circuit board's daily energy usage and actuator's usage times are taken into account. Board's daily energy usage is calculated from results of measurements. During the measurements average energy usage of one actuator cycle was also revealed. The effect of battery temperature is not taken into account in the table.
Keeping control chip of the lock turned on has largest affect to battery life in long term. Locking and unlocking the lock have only minor affect for battery life. Thus, the best results for increased battery life would be acquired by keeping the power off while not used. This way the user should turn the lock on before usage and wait till it wakes up.

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7. REFERENCES

1. Midgley, P. Bicycle-sharing schemes: enhancing sustainable mobility in urban areas. United Nations, Department of Economic and Social Affairs (2011): 1-12.
2. LTA Academy Singapore, Journeys - Sharing Urban Transport Solutions, http://www.lta.gov.sg/ltaacademy/doc/LTA%20JOURNEYS_IS02.pdf#page=23, Accessed on 15.02.2016
3. http://scholarcommons.usf.edu/cgi/viewcontent.cgi?article=1196&context=jpt Accessed on 15.02.2016
4. Antonis Ramfos, Stamatis Karnouskos, András Vilmos, Balázs Csik, Petra Hoepner, Nikolaos VenetakisSEMOPS: Paying with Mobile Personal DevicesBuilding the E-Service Society. Volume 146 of the series IFIP International Federation for Information Processing pp 247-261
5. Flueckiger, M. Optimal design and sensorless position control of a piezoelectric motor integrated into a mechatronic cylinder lock. Published in: Energy Conversion Congress and Exposition (ECCE), 2010 IEEE Date of Conference: 12-16 Sept. 2010 Page(s): 3428 - 3433 E-ISBN: 978-1-4244-5287-3 Print ISBN: 978-1-4244-5286-6 Publisher: IEEE
6. Skylock's web page, http://www.skylock.cc/Accessed on 17.03.2016
7. Energizer's comparison of different battery types in various temperatures, http://data.energizer.com/PDFs/temperat.pdf Accessed on 17.03.2016
8. Gaolong Zhu, Kechun Wen, Weiqiang Lv, Xingzhi Zhou, Yachun Liang, Fei Yang, Zhilin Chen, Minda Zou, Jinchao Li, Yuqian Zhang, Weidong He. Material insights into low-temperature performances of lithium-ion batteries, Publish date: 22.9.2015
9. Pascal, U. A secure cloud of electronic keys for NFC locks securely controlled by NFC smartphones. Published in: Consumer Communications and Networking Conference (CCNC), 2014 IEEE 11th. Date of Conference: 10-13 Jan. 2014. Page(s): 1120 - 1121. Print ISBN: 978-1-4799-2356-4. INSPEC Accession Number: 14816449. Conference Location: Las Vegas, NV. Publisher: IEEE