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Faruk Yildiz, Sam Houston State University

Self Powered Wireless Camera System Design

Abstract

Energy harvesting is described as the conversion of ambient energy into usable electrical energy. When compared with energy stored in common storage elements, such as batteries, capacitors and the like, the environment represents a relatively infinite source of available energy. Conventional electrochemical batteries power most of the portable and wireless electronic devices that are energized with electric power. In the past few years, electrochemical batteries and energy storage devices have improved significantly. However, this progress has not been able to keep up with the development of microprocessors, memory storage, and sensors of electronic applications. Battery weight, lifespan and reliability often limit the abilities and the range of such applications of battery powered devices. These conventional devices were designed to be powered with batteries as required, but did not allow scavenging of ambient energy as a power source. In contrast, development in wireless technology and other electronic components are constantly reducing the power and energy needed by many applications. If energy requirements of electronic components decline reasonably, then ambient energy scavenging and conversion could become a viable source of power for many applications. Ambient energy sources can be then considered and used to replace batteries in some electronic applications, to minimize product maintenance and operating cost. The potential ability to satisfy overall power and energy requirements of an application using ambient energy can eliminate some constraints related to conventional power supplies. Also power scavenging may enable electronic devices to be completely self-sustained so that battery maintenance can eventually be eliminated. Furthermore, ambient energy scavenging could extend the performance and the lifetime of the MEMS (Micro electromechanical systems) and portable electronic devices. These possibilities show that it is necessary to investigate the effectiveness of ambient energy as a source of power.

This research studied the waste mechanical energy from hydraulic door closers and its conversion and storage into electrical energy. The converted and stored energy powers a wireless camera to surveillance around the door during the specified time period. Human presence around the door (to open/close the door) is required to activate the hydraulic door closer to charge the storage device. Based on ambient energy source, electrical energy conversion and storage circuit was designed and tested for low power camera system.

The hydraulic door closer as an ambient energy source and typical camera components were investigated according to their power generation and consumption to make analytical comparisons. The steps of investigation of hydraulic door closer, door opening/closing phases, selection of a viable storage device, and camera integration have been conducted by senior electronics major students. Each student spent approximately 8 hours in the Electronics lab in the _____ Building at _____ State University. Progress meetings were scheduled every Wednesday to discuss issues and problems that encountered during research with course instructor. Some of the students spent their own money to purchase parts to help the project. The devices in the Electronics lab used for this experimental research project. Also, students were provided easy access to the lab any time during the day.

I. Introduction

Ambient energy sources can be considered and used to replace batteries in some electronic applications, to minimize product maintenance and operating costs ^[1,2,3,4,5]. Also power scavenging may enable electronic devices to be completely self-sustaining so that battery maintenance can eventually be eliminated. These possibilities show that it is important to examine the effectiveness of ambient energy as a source of power ^[6,7,8,9,10]. Recently, researchers have performed several studies in alternative energy sources that could provide small amounts of energy to low-power electronic devices. ^[11,12,13,14,15] These studies were focused to investigate and obtain power from different mechanical, electromagnetic, hydraulic, and thermodynamic energy sources, such as rotation, vibration, light, sound, airflow, heat, waste mechanical energy and temperature variations. This research studied a mechanical ambient energy source - waste mechanical (rotational) energy - from a hydraulic door closer in order to power a wireless security camera around the door. A person has to open the door in order for the hydraulic door closer mechanism to function. The waste mechanical energy is converted to electrical energy using appropriate devices and provides energy to a low power wireless camera system. Based on the nature of this ambient energy source, an electrical energy harvesting and conversion circuit was designed and tested for a self-sufficient low power wireless security camera electronic application. The components of the energy harvesting, conversion, storage and wireless camera system were investigated and chosen very carefully by the students to scavenge maximum energy. The block diagram of the overall energy harvesting and powering system is shown in Figure 1.

II. Hydraulic Door Closer Mechanism

Figure 2: A hydraulic door closer

For the purpose of this experimental study, a hydraulic door closer was secured and tested from the Physical Plant. ^[16] The door closer was separately mounted on wooden structure to simulate the operation and closing system. For this study, the arms of the hydraulic door closers were moved manually by hand to represent an opening/closing phase of the door by human power. A door closer which is mounted on the wood structure for testing purposes is shown in Figure 2, that shows the mechanical energy source with circle. There are two phases of the door system operations: the first phase is the opening phase that is generally activated by human power; the second stage is the closing phase that is controlled by a spring and a hydraulic damping mechanism. In the first phase the arm of the door closer was moved up to 90 degrees with constant speed to represent the opening stage of the door (the reason of rotating the arm 90 degrees is to simulate the maximum angle that the door can be opened

Figure 1: Block diagram of overall energy harvesting model

in reality). The opening and closing angles of the door may differ between 0° and 90° degrees depending on human size and the mechanical speed adjustment of the door closer. Another consideration of the system was the closing phase of the door. Since door closing is controlled by an internal spring and hydraulic damping mechanism, the closing speed of the door was adjusted on the hydraulic door closer.

III. Gear Train

The role of the speed increase gear sets was to increase the speed of rotation which was produced by the hydraulic door closer to provide sufficient input speed to a DC generator. This step up in speed was necessary, because it was found that without the increase of speed, rotation speed from the hydraulic door closer is not sufficient for the electric generator to provide enough power for the energy harvesting system. The different gear boxes that were purchased for speed increase purpose actually were designed as speed reduction purposes to decrease high speeds to lower speeds with the different assembly techniques. By changing the positions of gears and shafts, speed reduction gear boxes were converted to speed increase gear boxes.^[17] So these gear boxes were modified to be powered with mechanical energy (human power) instead of electrical energy in order to increase the mechanical speed. The pictures of the unassembled gearbox components and the assembled gear boxes are shown in Figure 3, and 4 respectively. Each gear box had different interchangeable speed ratios and assembly techniques specified by the manufacturer's data sheets. The assembly of the gearbox components was built by choosing the highest speed ratios to provide sufficient input speed to the generator unit. These gear boxes then were mounted with metal joints to the hydraulic closers where waste mechanical energy was obtained during the opening/closing operations of the door closer.^[18] Gear ratios and the number of gear sets in gearboxes were determined by considering the average opening/closing angle, speed of the door and the nominal input required by the generator unit.

Figure 3: Gear box components

Figure 4: Assembled gear boxes

IV. Generator Unit

As a generator unit two different types of direct current (DC) electric motors were selected and tested because of their power generation efficiency for low power electronic applications. A photograph of the two motors and their basic specifications are shown in Figure 5. These motors units were connected to output shafts of gear boxes to gain enough speed to generate electricity. The input rotations and power generation of the generator units were important factors due to constraints and nature of input rotation from hydraulic door closer.^[19] Power, torque, and speed constraints were very important to consider because of its relationship and the need to measure the power loss between them. Moreover, depending on motor specifications, a voltage could not be induced until specific rpm (rotation per minute) took place because most electrical machines start inducing voltage after specific speed ratings are achieved. To run the generator fast and gain more voltage, a higher gear ratio is needed. When the generator starts charging a battery, the load increase slows down the generator speed in rpm. Therefore every effort to increase the speed is mandatory.^[20]

Figure 5: Generator units

V. Storage Unit

For the purpose of energy harvesting from the hydraulic door closer, only small range (1.2V and 3.6V) rechargeable batteries are used to store the energy for test purposes. According to the electronic application device specifications, battery current and voltage can be adjusted by serial and parallel connections. The rechargeable battery type selection for this research was very difficult because of the charging time, and source, and leakage rate constraints. After careful consideration, different types of rechargeable batteries were purchased from different manufacturers. A photograph of the rechargeable batteries is shown in Figure 6. The battery regulator in the energy harvesting circuit was designed and built to respond to the battery charge level and to keep optimum efficiency. In this experiment mostly Nickel-cadmium batteries were chosen for testing because they contain cadmium and have relatively low capacity when compared to other rechargeable batteries.

Figure 6: Rechargeable batteries

VI. Energy Harvesting Circuit Design

A power harvesting and conditioning circuit was built to implement energy conversion and battery charging system. This circuit which was designed to handle the low source power, regulated the voltage level from the generator unit to charge 1.2V and 3.6V rechargeable batteries for low power electronic applications. Before implementation of the experiment, necessary computer simulations were conducted with LTSPICE Switcher CAD III advanced circuit simulation tool.^[21] The noisy AC voltage output of the generator unit was rectified by a full-wave bridge rectifier circuit that included four Schottky diodes and capacitors connected to the cathode of the diodes to filter a rectified voltage output of the latter.^[22] A rectifier circuit was essential to convert noisy AC output voltage from the generator to DC voltage because almost all electronic components operate at DC voltages. The AC voltage signal from the generator unit was converted to DC voltage signal using full-wave bridge rectifier.^[23]

After full-wave rectification, where the alternating current (AC) was converted to direct current (DC), the voltage was increased by a DC-DC boost converter.^[24] Consideration of energy harvesting components resulted in a decision to integrate an LTC3429 integrated circuit regulator chip which only needed 0.8V threshold input voltage to start running its internal circuitry. The actual energy harvesting circuit design is shown in Figure 7. Since the generator unit in this experiment generated electricity up to $3V_{AC}$ the voltage was configured to vary from 0V - 3V in the simulation interface. The frequency required for the circuit trigger was defined as 500Hz. The SwitcherCAD III simulation tool provided an advanced simulation toolbox which allowed simulating each component's voltage and current levels on the circuit. In order to make the circuit act according to the input and output voltage and current characteristics, replacement values of the capacitor and resistor are needed. Since we used rechargeable batteries which needed $1.2V_{DC}$ and $3.6V_{DC}$ voltage input, the boost converter increased and then fixed the

Figure 7: Energy Harvesting Circuit with DC-DC boost converter

voltage level at $1.2V_{DC}$ and $3.6V_{DC}$. The following calculations were done to determine resistor values for the boost converter unit to supply necessary voltage to the batteries.

$$V_{OUT}=1.23V [1 + (R1/R2)] \quad (1)$$

where

1.23 =Manufacturer constant;

R1 and R2 =Resistor values for voltage divider;

In the first case to charge a $3.6V$ at $60mAh$ NICD battery, $R1=194k\Omega$, $R2=100k\Omega$; $1.23V [1+(194k/100k)]=3.61V$.

Because of the voltage drops and leakages on the energy harvesting circuit, V_{OUT} (battery charging voltage) was increased and adjusted as $3.8V$ to avoid low power supply to the battery. To increase voltage to $V_{OUT}=3.8V$; $R1=209k\Omega$, $R2=100k\Omega$; $1.23V [1+(209k/100k)]=3.8007V$. The output current for the battery charging then was $I_{OUT}=16mA$ at $R=220\Omega$ load.

So, $16mA$ current is needed for the standard charging of the $3.6V$ rechargeable battery in 10 hours. Critical circuit components such as input voltage, output voltage, and output current were implemented and simulation screen shot is shown in Figure 8.

V_{IN} : Input voltage before boost converter (after rectification)

I_{ROUT} : Output current for the load (battery charging current)

V_{OUT} : Voltage level after boost converter (battery charging voltage)

In Figure 8, three important parameters of the energy harvesting circuit were simulated at the same time to show consistency of voltage and current levels. It is observed that input voltage V_{IN} waves a little bit because of the non-constant output voltage from the generator unit (which is absolutely normal according to hydraulic door closer characteristics).

Figure 8: Simulation of critical parameters for battery charging

VII. Testing & Verification

Initially all batteries were discharged with different resistive loads connected to battery terminals. Resistor values were chosen very carefully and measured during the discharge process to avoid having fully discharged batteries. The discharging process of batteries on the breadboard is shown in Figure 9 with different resistors. At the mechanical part of the system, gearboxes and electric generators were

Figure 9: Battery discharging process

connected to the hydraulic door closer. The door closer was moved manually by hand a number of times, then the battery voltage levels were recorded in Table 3 for comparison. The range used for measuring the battery voltages was after thirty times opening/closing cycles. The overall door opening stage was conducted to represent 180 people opening the door. So, measurement of the batteries was recorded six times for each of thirty runs representing human power used to open the door. Each battery was charged using a 1:344 gearbox ratio including the generator unit. After rectification of the AC signal, the high ratio gearbox was more reliable to reach minimum voltage level for the battery charging process. Test results concluded that there is a possibility to harvest energy from hydraulic door closer. The photograph of the overall test system is displayed in Figure 10. The voltage level increased considerably when batteries were empty at the beginning. After a certain voltage level, the charge (capacity) level of the batteries was hardly increased. For example to charge a typical fully discharged rechargeable battery, 10-15hrs is needed to reach its highest capacity at standard charge level. If the ideal case of charging a typical battery is compared with our case, a lot of door openings would be needed to make the battery fully charged. In the following application a wireless security camera system around the door is expected to have sufficient energy to fully operate according to the calculations in the next section.

Figure 10: Overall energy harvesting test system

Gearset ratio Generator Battery	Battery Initial Voltage (V) Temp (T)		30 Runs for each measurement Total Runs= 30*6 = 180 runs													
			Volt (V _{DC}) Measuring Temp (T)													
			30 run		60 run		90 run		120 run		150 run		180 run		FINAL	
	V	T	V	T	V	T	V	T	V	T	V	T	V	T	V	T
Ratio 1:344 FA-130 (1.5V)	0.02	55.4	0.43	71	0.74	73	0.84	73	0.89	73	1.31	74			1.21	53
	0.19	57.2	0.84	69	0.96	75	0.99	75	1.06	75	1.16	75			1.03	62
	0.03	59	0.92	66	0.94	69	0.96	75	0.98	77	1.01	75			0.94	68
	0.02	57.2	0.21	69	0.35	73	0.47	73	0.64	73	0.81	73			0.91	64
	0.87	44.6	2.46	73	3.01	73	3.11	73	3.17	73	3.31	73	3.62	73	3.29	59
	0.52	48.2	2.65	62	2.87	69	2.99	73	3.12	73	3.23	73	3.56	73	3.30	60
	0.13	59	0.95	73	0.98	73	1.03	73	1.12	73	1.22	73			1.11	60

Table 3: Energy harvesting system battery charging test results

VIII. Self-Sufficient Wireless Security Camera Application

A hydraulic door closer as an ambient energy source was considered as a viable energy source to make a wireless security camera self powered. It was proven above that a hydraulic door closer was able to provide enough charge to a small battery (depending on a sufficient number of people opening the door). The brief analytical battery charge time and number of door openings relationship were conducted above for fully discharged batteries. However, in the case of a low power wireless security camera, the battery initially starts operating in full charge. If daily charges balance daily consumptions and the standard leakages of the low power wireless security camera system, then it would be said that the hydraulic door closer source is viable for this

application. For this reason overall current consumption and current gained relationship estimations were conducted considering (I_1) as current consumption and (I_2) as current gained during a day/24hrs below.

$$I_1 (\text{LOSS}/24\text{HRS}) = (I_{\text{BATTERY_LEAKAGE}}) + (I_{\text{HARVEST_LEAKAGE}}) + (I_{\text{SWITCH_MOSFET}}) + [(I_{\text{WORKING}}) * (T) * (P_{\# \text{ OF RUNS}})] \quad (2)$$

Where,

$I_1 (\text{LOSS}/24\text{HRS})$:	Overall current loss per 24 hours;
$I_{\text{BATTERY_LEAKAGE}}$:	Leakages from the battery (hour*24 hrs);
$I_{\text{HARVEST_LEAKAGE}}$:	Discharge rate from the overall circuit components;
$I_{\text{SWITCH_MOSFET}}$:	Minimum standby current consumed by the MOSFET;
I_{WORKING} :	Current consumption of the wireless security camera for per run;
T:	Time takes for per run of the system/second; and
$P_{\# \text{ OF RUNS}}$:	Total number of runs of the system in 24 hours.

The equation above helps to calculate the overall current consumption including the total leakages. Also, the equation below helps to calculate the total gained current from hydraulic door closer source:

$$I_2 (\text{GAIN}/24\text{HRS}) = EG * NP \quad (3)$$

Where,

$I_2 (\text{GAIN}/24\text{HRS})$:	Total current recovered and stored from human power through hydraulic door closer per 24 hours;
IG:	Current gathered for per person who opened the door (current per charge); and
NP:	Number of the people opened the door in 24 hours.

For this application the current gained from a hydraulic door closer (I_2) should be bigger than or equal to the overall current loss (I_1) in 24 hours ($I_1 \leq I_2$). Otherwise the wireless camera system will be operating inconsistently because of the lack of enough current to run the camera circuitry. Another important point is to find out how much energy is recovered and stored from a person. An estimation equation of the stored energy for per person can be given as:

$$W = E (\text{Joule}) * P (\text{per person}) * T (\text{hrs}) * \text{Time (one day/hrs)} \quad (4)$$

Where,

W:	Overall energy stored;	Joule (J) = unit of energy	(5)
P:	Number of people a day;	$1\text{J} = 1\text{N.m} = 1\text{kg.m}^2/\text{s}^2 = 1\text{V.C} = 1\text{W.s}$	
E:	Energy recovered from one person;	Watt (W) = unit for power	(6)
T:	Time taken to store energy; and	$1\text{W} = 1\text{J/s} = \text{V.C/s} = \text{V.A}$	
Time:	Time span for one day.		

In order to calculate the total energy stored in a day (24hrs), it was considered that 1mJ energy could be recovered per person according to the equations 5 and 6. In this case the total energy stored in a battery can be calculated for 50 people as,

1mJ (person) * 50 people (per day) * One day (24 hours) * 24 hours, so
 1mJ * 50 people = 50mJ can be stored per day.

For the purpose of estimation, the components of a wireless security camera were chosen and studied. The specifications of the wireless security camera components necessary to calculate the overall system energy gain and consumptions are given further in this section. Also the self-powered wireless security camera system is explained and detailed with block diagrams. The photograph of the low power wireless security camera is shown in Figure 11^[25]. The C328 JPEG compression module performs as a video camera or a JPEG compressed still camera. Users can send a snapshot command from the host in order to capture a full resolution single-frame still picture (OV76xx sensor). The picture is then compressed by the JPEG engine (OV528) and transferred to the host computer. The microcontroller platform allowed us to propose the system in two different ways. The first way is to propose a system without transceivers just to store security camera surveillance information in the additional flash disk on the door. In this way, nothing is transmitted to the host computer which is more energy efficient but may have security concerns keeping the data around the door. This idea may eliminate the transceiver unit to reduce energy consumption because, a lot of power is consumed by the wireless communication when transmitting and receiving data. A second way is to just transmit the data (captured pictures) using a wireless communication standard such as ZigBee (802.15.4) to the remote host computer where the data are evaluated and stored. In the first approach the energy needed for the overall system is less than the second way and should be paid more attention since our power source is not constant and is limited with the small scale battery. However, for both ways the energy harvesting system would be enough if there is enough human presence. Also depending on how often the camera takes and transmits the pictures. The block diagrams of the devices for the door and the computer for the overall self powered wireless security camera system are given in Figure 12, 13 respectively. The circuit (receiver) at the host computer can get energy from the computer ports without any other external power supplies. The only part of the system which needs to be powered is the circuitry of the camera at the door. After intensive market research, energy and cost efficient components to estimate energy consumption for a wireless security camera system were chosen listed below in Table 4. All the components in the block diagrams are numbered and matched with the components in the table to ease the comparison and understanding the specifications.

Figure 11: Low power camera

The estimate energy leakages in 24 hours are calculated according to the specifications in Table 4. There are certain components in the system which are always at stand by either to sense the presence around the door or because of the part functionality. These components drain some quiescent currents while they are on standby including MOSFET, energy harvesting circuit, to keep the system up and running.

Figure 12: Wireless security camera system at the door site

Figure 13: Wireless security camera receiver at the remote host computer port

Table 4

Specifications of the parts for self-powered wireless security camera system

#	Part	Name	Voltage In/Out (V)	Supply & Operating Currents	Quiescent (Stand-by) Current & Leakages	Time	Total leakages & Stand-by currents
1	Gearbox Generator	Tamiya Micromo motors	N/A 1.5V	~0.20A	N/A	N/A	N/A
2	Energy Harvesting Circuit	Linear Technology IC & Electronic components	1.2V	~12mA	~18 μ A*	24hrs	~432 μ A
3	Battery	Typical NICD	1.2V	~110mAh	~12 μ A	24hrs	~288 μ A
4	Sensing Unit MOSFET	N-P Channels 585-ALD1115SAL	0.7/-0.7	~3/-1.3mA	~0.4nA	24hrs	~4.8nA
5	Voltage Regulator	Linear Technology	Varies (V _{OUT})	~Varies	~Varies	24hrs	N/A
6	Micro-Controller	PIC16F677-I/P	2V-5.5V	~11 μ A	~50nA	24hrs	OFF
7	Flash/EEPROM	Integrated memory in Microcontroller	N/A	N/A	N/A	N/A	OFF
8	CPU	Integrated in Microcontroller	N/A	N/A	N/A	N/A	OFF
9	Camera Module	C328-7640 (S)	3.3V	~60mA	~100 μ A	24hrs	OFF
10	Radio Transmitter	MRF24J40-I/ML	0.3V-3.6V	~22mA	~2 μ A	24hrs	OFF

* Leakage into output of energy harvesting circuit from battery

Before calculation of overall operating current for all components, the total leakages and quiescent current were calculated according to the equation, 2.

$$\begin{aligned} I_{1 \text{ (LOSS/24HRS)}} &= (I_{\text{BATTERY_LEAKAGE}}) + (I_{\text{HARVEST_LEAKAGE}}) + (I_{\text{SWITCH_LEAKAGE}}) \\ &= [(288\mu\text{A}) + (432\mu\text{A}) + (4.8\text{nA})] \\ &= 720.48\mu\text{A/24hrs} \end{aligned}$$

720.48 μA was estimated standard leakage from the system at stand-by mode in 24 hours. The total leakages and quiescent currents were added to the operating currents in 24 hours in order to calculate overall current consumption. The steps below indicate the order when a security camera is taking and sending a picture to the remote host computer.

Subject walks through the door
 Activates energy harvesting circuit and MOSFET switches
 Charger charges battery and closes wake-up switch (Solid State MOSFET)
 Microcontroller powers up – closes the hold switch
 Microcontroller takes a photo with a camera module
 Transmits the photo to remote host computer
 Microcontroller releases hold and powers down

The typical system event as explained above takes 3 seconds to send a photo (the time increases if more photos are transmitted to the base station). The advantages of this system is that security camera system does not work during the day time and can be programmed only to wake-up and activate the system during the specific time periods in the night time. This makes the system more energy efficient and viable to operate at low power rates. The overall operating system estimation is given below assuming that the system was activated during the night time.

$$I_{\text{WORKING}} = [(I_{\text{Microcontroller}}) + (I_{\text{Camera}}) + (I_{\text{RF Transmitter}}) + (I_{\text{MOSFET}} * 2) * (I_{\text{Photo}})] \quad (7)$$

Where

I_{WORKING} = Overall operating current for one object;
 $I_{\text{Microcontroller}}$ = Current consumption of microcontroller unit;
 I_{Camera} = Current consumption of camera module;
 $I_{\text{RF Transmitter}}$ = Current consumption of transmitter;
 I_{MOSFET} = Current consumptions for two switches (MOSFETs); and
 P_{Photo} = Number of photos for one object send to the computer database.

The calculation of energy consumption of the security camera system to transmit a photo for one object is;

$$\begin{aligned} I_{\text{WORKING}} &= [(11\mu\text{A}) + (60\text{mA}) + (22\text{mA}) + (4.3\text{mA} * 2) * (1)] \\ &= 90.11\text{mA} \end{aligned}$$

current is needed to send a photo.

The overall leakages and quiescent current for the system components during the system operation were calculated using I_1 equation 2. Since $I_{WORKING}$ was calculated above separately and added to the overall current consumption in 24 hours following,

$$I_1 (LOSS/24HRS) = [(288\mu A) + (432\mu A) + (4.8nA)] + [(90.11mA) * (1) * (3)]$$

= 273mA current is consumed to transmit a photo in 24 hours.

The calculated value for I_1 is converted to the power value in order to make a comparison between the power gain and the power loss.

$$P_1 (LOSS/24HRS) = 0.2731A * 3.6V$$

= 0.983W

As calculated above the total power drained from the storage unit estimated as 0.983W in 24 hours. The total energy gained from the hydraulic door closer depends on the number of people who open the door in 24 hrs. Since the door opening/closing phases take two seconds, the number of people opening the door is multiplied by two seconds.

$$P_2 (GAIN/24HRS) = EG * NP$$

= $[(3.6V * 0.016A) * (200 * 2)]$

= 23.04W

P_1 and P_2 were calculated and converted to the energy value in order to make comparison ratio if the energy gain is bigger than energy loss to balance the system power.

$$E_{GAIN} = \frac{E_{INPUT}}{E_{OUTPUT}} \quad (8)$$

Where

E_{GAIN}	= Overall energy gain/loss ratio
E_{OUTPUT}	= Energy consumption by the wireless security camera system
E_{INPUT}	= Energy gained from the human powered hydraulic door closer

$$EG = \frac{23}{0.983} \cong 23$$

As estimated above the energy gain from the hydraulic door closer mechanism is 23 times bigger than overall energy consumption of the wireless security camera system. The estimation comparison has been done running the system in the full operating range. Since the energy gained is 23 times bigger than the camera system, the latter can be run 23 times with the harvested energy. The energy gain/loss graph is shown in Figure 14 compares the power values for various number of images.

Figure 14: Energy gain/loss for the wireless security camera system

As indicated in Figure 14, the gained power would be sufficient to power a wireless security camera system. The energy harvesting circuit and generator unit including the gear box can be improved to increase the amount of energy scavenged from the hydraulic door closer. Also the energy loss can be decreased by replacing the circuitry of the self-powered wireless camera system. Moreover, if the number of people increases then the battery charging time to supply more power to the electronic device would be decreased.

IX. Conclusion

The design of an energy harvesting system from a hydraulic door closer was very challenging due to non-constant energy flow. As an analytical estimation, an electronic security camera application was theoretically designed to compare the gained and used energy. The generated power in 24 hours was able to power the security camera system in specific time frames. Depends on the number of people operates hydraulic door closer, the produced energy can be increased leading more energy in the storage device. The energy harvesting system from the hydraulic door closer were assigned to the students as a project to improve the system and information package files would be prepared for the patent application. After the patent application, taking the viability of the system into consideration the developed energy harvesting system would be shared with a hydraulic door closer manufacturer for further investigations. The mechanical design of the energy harvesting system will be redeveloped and placed inside of the hydraulic door closer with the gear train by decreasing the size of the components by the students as a later phase of the project. Also the camera module would be placed closer to hydraulic door closer to avoid voltage drops across the wires. Moreover, this experimental study also will be a part of new alternative energy course to teach students how to discover ambient energy sources starting Spring 2009. Also, faculty of Technology programs can use this research as a part of their courses in various areas such as electro mechanics, electronics etc. This unique experimental study can also transfer technology to the classroom in the form of energy conversion techniques for enhancement of related undergraduate curriculum as a new development. In addition, especially graduated students would be encouraged to study for further improvements.

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