Low Power Self Sufficient Wireless Camera System

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Abstract

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. Power scavenging may enable electronic devices to be completely self-sustained so that battery maintenance can eventually be eliminated. Ambient energy scavenging could extend the performance and the lifetime of the 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 for surveillance around the door during the specified time period. Human presence (to open or close the door) is required to activate the hydraulic door closer to charge the storage device. Based on an ambient energy source, an electrical energy- harvesting circuit was designed and tested for a 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 between energy generation and consumption. The steps of investigation of the hydraulic door closer, door opening/closing phases, selection of a viable storage device, and camera integration were conducted to create a low- power, self sufficient, and energy-efficient wireless camera system.

Introduction

Ambient energy sources can be considered for use in the replacement of batteries in some electronic applications to minimize product maintenance and operating costs [1-5]. In addition, 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 [6-10]. Recently, researchers performed several studies on alternative energy sources that could provide small amounts of energy to low-power electronic devices [11-15]. These studies were focused on investigating and obtaining 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 camera monitoring 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 camera application. The components of the energy harvesting, conversion, storage, and wireless camera system were investigated and chosen by students to scavenge maximum energy. The block diagram of the overall energy-harvesting and powering system is shown in Figure 1.

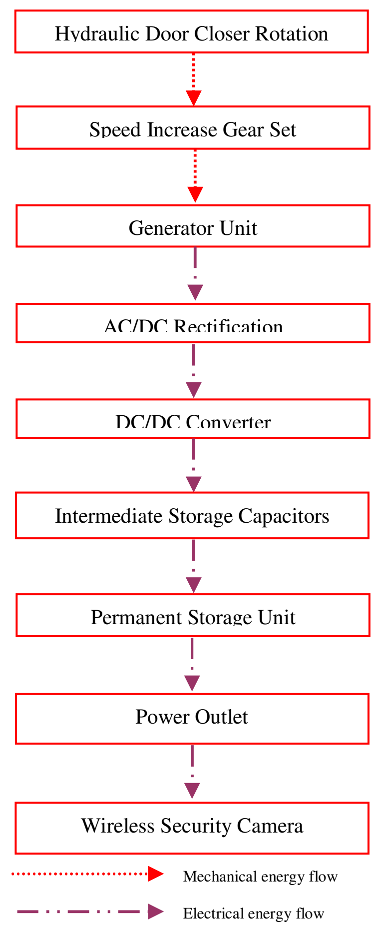

Figure 1. Block diagram of overall energy harvesting model

Hydraulic Door Closer Mechanism

For the purpose of this experimental study, a hydraulic door closer was secured and tested from the Physical Plant at the University [16]. The hydraulic door closer was separately mounted on a wooden structure to simulate the operation of the door opening and closing system. 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 mounted on the wooden structure for testing purposes (Figure 2) shows the mechanical energy source with a circle. There are two phases of the door system operations: the first phase is the opening phase, generally activated by human power; the second stage is the closing phase, controlled by a spring and a hydraulic damping mechanism.

Figure 2. Hydraulic door closer

In the first phase, the arm of the door closer was moved up to 90° to represent the opening stage of the door (the reason for rotating the arm 90° degrees is to simulate the maximum angle that the door can be opened in reality). The opening and closing angles of the door may vary between 0° and 90°, depending on the person operating the door 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.

Gear Train

The role of the speed-increase gear set was to increase the speed of rotation, which was produced by the hydraulic door closer to provide sufficient input speed to a direct-current (DC) generator. This step-up in speed was necessary because it was found that without an increase in speed, the rotational speed from the hydraulic door closer was 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 purposes had been originally designed for speed reduction and varied based on the different assembly techniques. By changing the positions of gears and shafts, speed-reduction gear boxes were converted to speed-increase gear boxes [17]. 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 Figures 3(a) and 3(b), respectively.

Figure 3a. Gear box components Figure 3b. Assembled gear boxes

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 accomplished by choosing the highest speed ratios to provide sufficient input speed to the generator unit. The reason for using a gearbox with high gear ratios is because of intermittent and slow rotational mechanical energy from the hydraulic door closer. In order to supply sufficient mechanical rotation to the generator unit for viable power generation, higher ratio gearboxes were necessary. These gear boxes 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.

Generator Unit

As a generator unit, two types of 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 4.

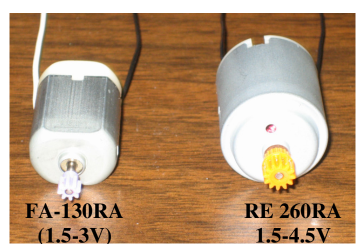

Figure 4. Generator units

These motor 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 the nature of input rotation from the hydraulic door closer [19]. Power, torque, and speed constraints were very important to consider because of their relationship and the need to measure the power loss between them. Depending on motor specifications, a voltage could not be induced until a specific speed (RPM) was achieved because most electrical machines start inducing voltage at specific speed ratings. In order to run the generator faster and gain more voltage, a higher gear ratio was needed. When the generator starts charging a battery, the load increase slows down the generator speed (RPM). Therefore, every effort was made to increase the speed [20].

Storage Unit

For the purpose of energy harvesting from the hydraulic door closer, only small-range (1.2V and 3.6V) rechargeable batteries were 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 a challenge because of the charging time, 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 5.

Figure 5. Rechargeable batteries

The battery regulator in the energy-harvesting circuit was designed and built to respond to the battery charge level and to maintain optimum efficiency. In this experiment, nickel-cadmium (NiCd) batteries were chosen for testing because they have relatively low capacity when compared to other rechargeable batteries such as lead acid, nickel metal hydride (NiMH), lithium ion (Li-ion), and lithium ion polymer (Li-ion polymer).

Energy Harvesting Circuit Design

A power harvesting and conditioning circuit was built to implement energy conversion and the battery charging system. This circuit, which was designed to handle a low source power, regulated the voltage level from the generator unit to charge the 1.2V and 3.6V rechargeable batteries for low-power electronic applications. Before implementation of the experiment, computer simulations were conducted with LTSPICE Switcher CAD III advanced circuit simulation software [21]. The alternating-current (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 the rectified voltage output of the latter [22, 23].

After full-wave rectification, where the AC was converted to 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 had a 0.8V threshold input voltage to start running its internal circuitry. The actual energy-harvesting circuit design is shown in Figure 6.

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 500Hz. The SwitcherCAD III simulation tool provided an advanced simulation toolbox, which allowed simulating each component's voltage and current levels in the circuit. In order to make the circuit perform according to the input and output voltage and current characteristics specified in the simulation model, replacement values of the capacitor and resistor were needed. Since rechargeable batteries were used, which needed $1.2V_{DC}$ and $3.6V_{DC}$ input voltage, the boost converter increased intermittent voltage from ~0.8V and then fixed the voltage level at $1.2V_{DC}$ and $3.6V_{DC}$.

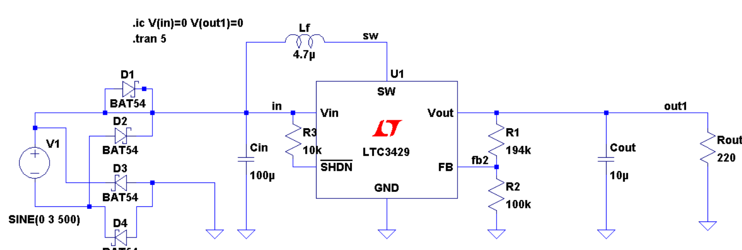

Figure 6. Energy-harvesting circuit with DC-DC boost converter

The following calculations were performed to determine resistor values for the boost converter unit to supply necessary voltage to the batteries.

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

Where,

1.23 = Manufacturer constant; and
R1 and R2 = Resistor values for the voltage divider.

In the first case, to charge a 3.6V NiCd battery at 60mAh, R1 needed to equal 194kohm with R2 equal to 100kohm, such that

$$V_{OUT} = 1.23V\ [1+(194k/100k)] = 3.61V$$

Because of the voltage drops and leakage current on the energy-harvesting circuit, V_{OUT} (battery charging voltage) was increased and adjusted to 3.8V in order to maintain voltage to the battery.

In order to increase this output voltage to 3.8V, the following changes were made:

$$V_{OUT} = 3.8V\ R1 = 209k\Omega,\ R2 = 100k\Omega$$
$$1.23V\ [1+(209k/100k)] = 3.8007V$$

The output current for the battery charging circuit then was I_{OUT}=16mA at R=220ohm load.

Therefore, 16mA of current was needed for the standard charging of the 3.6V rechargeable battery in 10 hours. Critical circuit values such as input voltage, output voltage, and output current were implemented and a simulation screen shot is shown in Figure 7.

In Figure 7, three important parameters of the energy-harvesting circuit were simulated at the same time to show consistency of voltage and current levels. It can be seen that input voltage, V_{IN}, fluctuates slightly due to the non-constant output voltage from the generator unit, which is consistent with the characteristics of the hydraulic door closer.

V_{IN} = Input voltage before boost converter (after rectification);
I_{ROUT} = Output current for the load (battery charging current); and
V_{OUT} = Voltage level after boost converter (battery charging voltage).

Testing & Verification

Initially, all batteries were discharged with different resistive loads connected to their battery terminals. Resistor values were chosen based on battery capacity during the discharge process to avoid discharging the batteries to levels from which they could not recover. The discharging process of the batteries on the breadboard is shown in Figure 8 with different resistors.

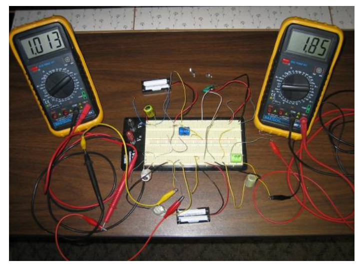

Figure 8. Battery discharging process

At the mechanical part of the system, gearboxes and electric generators were connected to the hydraulic door closer (Figure 9).

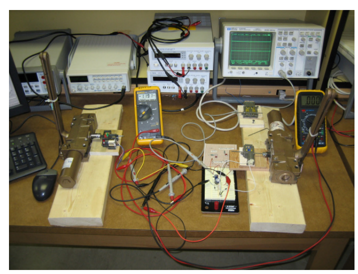

Figure 9. Overall energy-harvesting test system

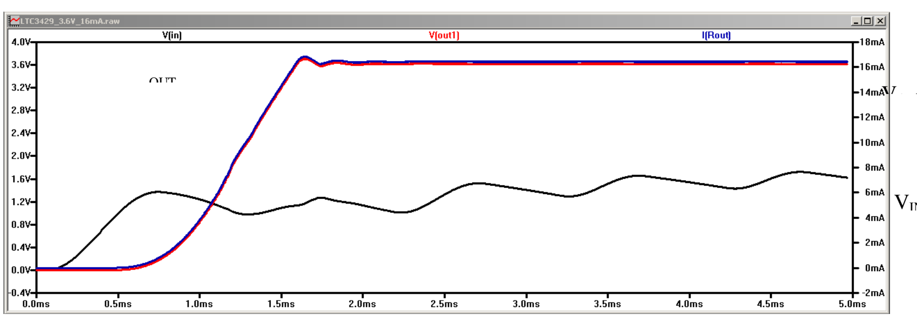

Figure 7. Simulation of critical parameters for battery charging

The door closer was moved manually a number of times, then the battery voltage levels were recorded (Table 1). A cycle of thirty opening/closings was used for measuring the battery voltages. The overall door-opening stage was conducted to represent 180 people opening the door. 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 found to be more reliable for reaching the minimum voltage level for the battery charging process. Test results concluded that it is possible to harvest energy from a hydraulic door closer. The voltage level increased considerably when batteries were discharged at the beginning. After a certain voltage level, the charge (capacity) on the batteries only showed a slight increase. For example, to charge a completely discharged rechargeable battery, 10-15hrs [25] is needed to reach its highest capacity at a nominal charging rate. Comparing an off-the-shelf charger with our energy-harvesting system, a considerable number (500-5000) of door openings would be needed to fully charge the battery.

In the following application, a wireless camera system monitoring the door is expected to have sufficient energy to fully operate according to the calculations in the next section.

Self-Sufficient Wireless Camera Application

A hydraulic door closer as an ambient energy source was considered as a viable energy source for a wireless camera system. It was proven above that a hydraulic door closer is capable of providing enough charge to a small battery (depending on a sufficient number of people opening the door). The relationship between the brief battery charge time and number of door openings was analyzed for completely discharged batteries.

In the case of a low-power wireless camera system, the battery initially starts operating at full charge. The analysis in the previous section was done on completely discharged batteries. If daily charges balance daily consumptions and the standard leakage current of the low-power wireless camera system, then the hydraulic door closer source should be viable for this application. For this reason, estimates were made on the relationship between overall current consumption and current gain, where I_1 was current consumption and I_2 was current gain during a 24-hour period.

$$I_{1\,(LOSS/24HRS)} = (I_{BATTERY\_LEAKAGE}) + (I_{HARVEST\_LEAKAGE}) + (I_{SWITCH\_MOSFET}) + [(I_{WORKING}) * (T) * (P_{\#\,OF\,RUNS})] \quad (2)$$

Where,

$I_{1\,(LOSS/24HRS)}$ = Overall current loss per 24 hours;
$I_{BATTERY\_LEAKAGE}$ = Leakage current from the battery (hr*24 hrs);
$I_{HARVEST\_LEAKAGE}$ = Discharge rate from the circuit components;
I_{SWITCH_MOSFET} = Minimum standby current consumed by the MOSFET;
$I_{WORKING}$ = Current consumption of the wireless camera per run;
T = Time required for each run of the system per second; and
$P_{\#\,OF\,RUNS}$ = Total number of runs of the system in 24 hours.

The equation above helps to calculate the overall current consumption including leakage current. The following equation allows us to calculate the total current gained from the hydraulic door closer source:

$$I_{2\,(GAIN/24HRS)} = EG * NP \quad (3)$$

Table 1. Energy harvesting-system battery charging test results.

Gear-set ratio Generator Battery	Initial battery voltage (V) temp (T)		Thirty runs across six measurements Volt (V_{DC}) Measuring Temp (T)														
			30 run		60 run		90 run		120 run		150 run		180 run		**Final Voltage***	
	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	X	X	**1.21**	**53**
	0.19	57.2	0.84	69	0.96	75	0.99	75	1.06	75	1.16	75	X	X	**1.03**	**62**
	0.03	59	0.92	66	0.94	69	0.96	75	0.98	77	1.01	75	X	X	**0.94**	**68**
	0.02	57.2	0.21	69	0.35	73	0.47	73	0.64	73	0.81	73	X	X	**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	X	X	**1.11**	**60**

* Final battery voltage level reached.

Where,

$I_{2\,(GAIN/24HRS)}$ = Total current recovered and stored from human power through the hydraulic door closer per 24 hours;
IG = Current gathered per person who opened the door (current per charge);
NP = Number of the people who opened the door in 24 hours.

For this application, the current gained from a hydraulic door closer (I_2) should be greater than or equal to the overall current loss (I_1) in 24 hours ($I_1 \leq I_2$). Otherwise, the wireless camera system's operation will be inconsistent, due to the lack of sufficient current (~60mA) to run the camera circuitry. Another important consideration is how much energy is recovered and stored per person. The following equation can be used to estimate the stored energy per person:

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

Where,
W = Overall energy stored;
P = Number of people per 24 hour;
E = Energy recovered from one person;
T = Time taken to store energy; and
Time = Time span for one day.

In order to calculate the total energy stored in a day (24 hours), it was first calculated that 40J of energy could be recovered per person (average weight 80-kg pushing at 1.0m/s) according to SI units for energy (J), power (W), and kinetic energy of pushing (moving) an object using equations 5, 6, 7, and 8, respectively. A 1-watt system consumes 1 joule of energy each second. In circuit design, the watt-hour (Wh) is generally more useful as a unit of energy than the joule (watt-second) since our devices generally run for hours, not seconds [26].

Joule (J) = unit of energy (5)
$$1J = 1N{\cdot}m = 1kg{\cdot}m^2/s^2 = 1V{\cdot}C = 1W{\cdot}s$$
Watt (W) = unit for power (6)
$$1W = 1J/s = V{\cdot}C/s = V{\cdot}A$$
$$1J = 1W{\cdot}s = 1.16 \times 10^{-5}\ W{\cdot}h \quad (7)$$
$$1W{\cdot}h = 3600J$$
$$U = \frac{1}{2}mv^2 \quad (8)$$

Where,
U = Kinetic energy of a moving object;
m = Mass; and
v = Velocity.

$U = (1/2)(80kg)(1m/s)^2 = 40J = 11mWh$

In this case, the total energy stored in a battery can be calculated for 50 people as

$$W = 40J\ (\text{person}) * 50\ \text{people (per day)} * \text{One day (24 hours)} * 24\ \text{hours}$$

So, 40J * 50 people = 2000J, which can be stored per day.

For the purpose of calculating power, the specifications of the wireless camera system components were determined and tested. Consumption rates are described in this section. The photograph of the low-power wireless camera is shown in Figure 10 [27]. The C328 JPEG compression module functions 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 utilize the system in two ways. The first was to utilize a system without transceivers in order to store camera surveillance information on 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 related to movement around the door. This idea may eliminate the transceiver unit to reduce energy consumption when transmitting and receiving data.

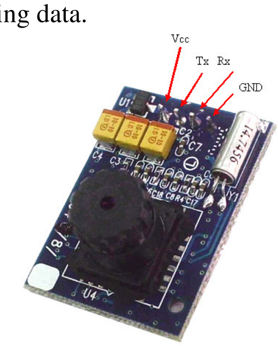

Figure 10. Low-power wireless camera

A ZigBee (802.15.4) wireless communication standard was used to transmit the data (captured pictures) to the remote host computer, where the data are evaluated and stored. In the first approach (using a flash disk around the door to eliminate a transceiver), the energy needed for the overall system was less than the second approach (using a wireless communication standard) and should be considered since our power source was not constant and was limited by use of the small-scale battery. However, for both approaches, the energy-harvesting system would be sufficient if there were enough human presence as mentioned in previous sections (500-5000 door openings). The viability of this energy-harvesting system is dependent on how often the camera takes and transmits the pictures, which changes energy consumption each time the camera transmits. The block diagrams of the devices for the door and the computer for the complete self-powered wireless camera system are shown in Figures 11 and 12, respectively. The circuit (receiver) at the host computer can receive 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 extensive research, energy-friendly components to estimate energy consumption for a wireless camera system were identified and are listed in Table 2. All of the components in the block diagrams are numbered and matched with the components in Table 2 for ease in comparing and understanding the specifications.

The estimated energy leakage in 24 hours was calculated according to the specifications in Table 2. There are certain components in the system, which are always on standby, either to sense the presence around the door or because of the part's functionality. These components experience quiescent drain currents while they are on standby, including the MOSFET and energy- harvesting circuit, to keep the system up and running.

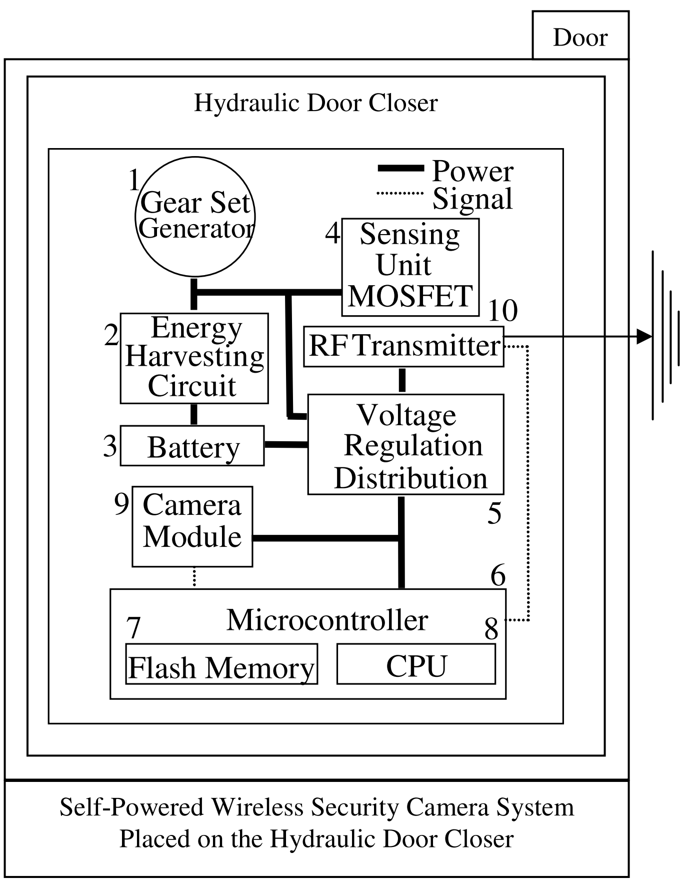

Figure 11. Wireless camera system at the door site

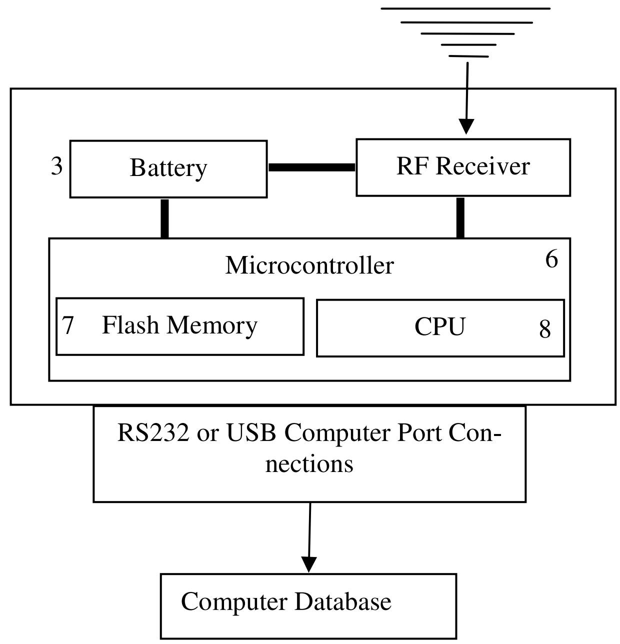

Figure 12. Wireless camera receiver at the remote host computer port

Before calculating the overall operating current for all components, the total leakage and quiescent currents were calculated according to equation 9.

$$
\begin{aligned}
I_{1\,(LOSS/24HRS)} &= (I_{BATTERY\_LEAKAGE}) + (I_{HARVEST\_LEAKAGE}) \\
&\quad + (I_{SWITCH\_LEAKAGE}) \qquad (9) \\
&= [(288\mu A) + (432\mu A) + (4.8nA)] \\
&= 720.48\mu A/24hrs
\end{aligned}
$$

A value of 720.48µA was estimated to be the standard leakage current from the system in the standby mode over a 24-hour period. The total leakage 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 of operation when a camera is taking and sending a picture to the remote host computer.

1. Subject walks through the door.
2. Subject activates the energy-harvesting circuit and MOSFET switches.
3. Charging system charges battery and closes wake-up switch (solid-state MOSFET).
4. Microcontroller powers up and closes the hold switch.
5. Microcontroller takes a photo with a camera module.
6. System transmits the photo to the remote host computer.
7. Microcontroller releases hold and powers down.

Table 2. Specifications of the parts for the self-powered wireless camera system

#	Part	Name	Voltage In/Out (V)	Supply & Operating Currents	Quiescent (Standby) & Leakage Currents	Charging and Operation Times	Total Quiescent & Leakage Currents
1	Gearbox Generator	Tamiya (Manufacturer) Micromo motors (Manufacturer)	N/A 1.5V	~0.20A	N/A	N/A	N/A
2	Energy Harvesting Circuit	Linear Technology IC & Electronic components	1.2V	~12mA	~18µA*	24hrs	~432µA
3	Battery	Typical NICD	1.2V	~110mAh	~12µA	24hrs	~288µA
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	~11µA	~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	~100µA	24hrs	OFF
10	Radio Transmitter	MRF24J40-I/ML	0.3V-3.6V	~22mA	~2µA	24hrs	OFF

* Leakage into output of energy harvesting circuit from battery.

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

$$I_{WORKING} = [(I_{Microcontroller}) + (I_{Camera}) + (I_{RF\ Transmitter}) + (I_{MOSFET}*2) * (I_{Photo})] \quad (10)$$

Where,

$I_{WORKING}$ = Overall operating current for one object;

$I_{Microcontroller}$ = Current consumption of microcontroller;

I_{Camera} = Current consumption of camera module;

$I_{RF\ Transmitter}$ = Current consumption of transmitter;

I_{MOSFET} = Current consumption for two switches (MOSFETs); and

P_{Photo} = Number of photos for one object sent to the computer database.

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

$I_{WORKING}$ = [(11µA) + (60mA) + (22mA) + (4.3mA*2) * (1)]
= 90.11mAh
(current needed to send a photo)

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

$$I_{1\,(LOSS/24HRS)} = [(288\mu A) + (432\mu A) + (4.8nA)] + [(90.11mA) * (1) * (3)]$$
$$= 273mA \text{ (current consumed in order to transmit a photo in 24 hours)}$$

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 is 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 hours. 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 a comparison ratio if energy gain is greater than energy loss in order to balance the system power.

$$E_{GAIN} = \frac{E_{INPUT}}{E_{OUTPUT}} \quad (11)$$

Where,

E_{GAIN} = Overall energy gain/loss ratio

E_{OUTPUT} = Energy consumption by the wireless 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 greater than the overall energy consumption of the wireless camera system. The estimation comparison was performed running the system across its full operating range. Since the energy gain is 23 times greater than the camera system, the latter can be run 23 times with the harvested energy. The energy gain/loss graph shown in Figure 13 compares the power values for various numbers of images.

As indicated in Figure 13, the power gained would be sufficient to power a wireless camera system. The energy-harvesting circuit and generator unit, including the gear box, can be improved by increasing the gear ratio and motor power output to increase the amount of energy scavenged from the hydraulic door closer. The energy loss can be decreased by replacing the circuit components with the more energy-friendly parts of the self-powered wireless camera system. Moreover, if the number of door openings increases, the battery charging time would be decreased. More door openings would keep the battery charged to supply sufficient power to the electronic devices without any intermittent power failures.

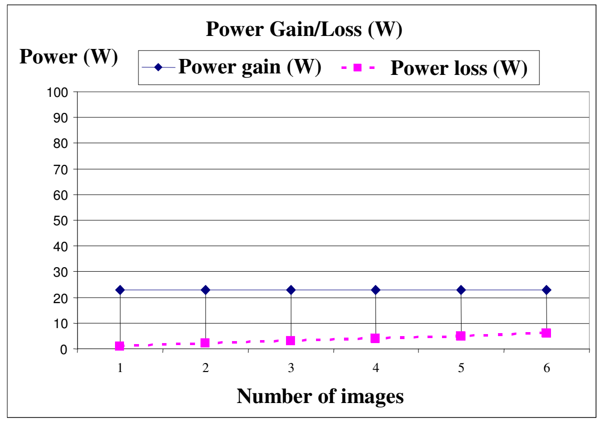

Figure 13. Energy gain/loss for the wireless camera system

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 camera application was designed to compare the energy gained and lost. The power generated in 24 hours was able to run the camera system within specific time frames. Depending on the number of door opening/closings, the power produced can be increased, resulting in more energy in the storage device. Taking the viability of the system into consideration, this 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 the hydraulic door closer by decreasing the size of the components during a subsequent phase of the project. The camera module could also be placed closer to the hydraulic door closer to avoid voltage drops across the wires.

This experimental study will be a part of a new alternative energy course starting in the spring of 2010, and is designed to teach students how to discover ambient energy sources. Faculty of technology programs can use this research as a part of their courses in various content areas such as electromechanical, 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 curricula.

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