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DESIGN AND EXPERIMENTATION OF A SOLAR-POWERED SENSOR NETWORK

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ABSTRACT

Battery capacity is a big issue for wireless sensor networks, therefore the ability to harvest energy from the environment is particularly interesting. Using solar power for outdoor applications appears to be the best option. In addition, it is difficult to correctly measure the solar panel because of how much energy the sun provides. This study presents a model that predicts how much solar power can be harvested and how much battery charge can be stored. This report also includes the first six months of our long-term validation experiments.

Keywords*: iSense sensor nodes; rechargeable battery; solar energy harvesting; wireless visual sensor network.*

1. Introduction

Traditional wireless sensor networks rely on primary batteries for power, which reduces their lifespan and raises the cost of ownership due to battery replacement. Design procedures and applications are complicated further by the low duty cycle necessitated by the constrained power source. A variety of power sources have so been proposed, including systems that capture energy from the environment on a continual basis. Wireless sensor networks can be powered by air movement, pressure change, vibrations, human power, and solar energy, to name a few examples (Roundy et al., 2004)s part of the FleGSens project(Rothenpieler et al., 2009) a prototype sensor network consisting of 200 iSense sensor nodes (Buschmann & Pfisterer, 2007)looked into solar-powered sensor nodes as a means of keeping tabs on critical areas. The aim with FleGSens is ensured that all warnings are real and authenticated, and research has resulted in a realistic design guide for solar-powered devices that incorporates our findings.

1.1Expected power estimation

Unfortunately, solar panel manufacturers only provide information on the amount of energy their panels can produce in controlled laboratory lighting circumstances, making it difficult to make an informed decision about the type of solar panel to use for a sensor node. Standard test conditions (STC) include a 100mW/cm2 illumination intensity. However, the amount of solar energy that reaches the panel over the course of a year is rarely given (Voigt et al., 2003).

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It's critical to know how much solar electricity can be harvested in a year using data on how much sunlight reaches the ground on a monthly basis.

Month	Daily solar radiation [mWh/cm^2]	Days in month	Monthly solar radiation [mWh/cm^2]
Jan	85	31	2635
Feb	155	28	4340
Mar	255	31	7905
Apr	360	30	10800
May	440	31	13640
Jun	490	30	14700
Jul	440	31	13640
Aug	430	31	13330
Sep	330	30	9900
Oct	205	31	6355
Nov	105	30	3150
Dec	50	31	1550
Σ		365	101945

Fig. 1 Solar radiation in Hamburg on a monthly basis, (R(M)).

Figure 1 depicts the corresponding data in monthly mW h/cm2 for Hamburg, Germany. Using a surface slanted 450 degrees south of north, a yearly average radiation dose of 1.120 kW h/m^2 was determined (Powernext, 2004)a = cos(α) A rechargeable battery is a common method since it can hold a lot of energy. However, when it comes to charging, popular battery technologies have temperature constraints that limit the amount of energy they can deliver (Nahapetian et al., 2009). It is not possible to charge lithium-ion batteries at temperatures below 00C or above 450C. Since solar power cannot be stored when it is too cold, it will occasionally be useful in winter. Temperatures in the enclosure can reach deadly levels even in the summer, so this is also true. Figure 2 illustrates the numbers used in this model, despite the fact that the factor's influence has not been properly explored.

Month	Temperature corridor exceedance loss
Jan	25%
Feb	10%
Mar	0%
Apr	0%
May	10%
Jun	25%
Jul	25%
Aug	10%
Sep	0%
Oct	0%
Nov	0%
Dec	10%

Fig. 2 Expected energy loss due to temperature exceedance (L(M)

2. Methodology

As a result of the above-mentioned impact factors (see figures 1–3), a devised model to anticipate the amount of energy that can be gathered with a solar panel and to estimate the development of a battery's charge over time under the condition of a certain sensor node's power dissipation.

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Description	Symbol	Value	Unit
Battery capacity	C	21120	mWh
Panel size	A	170	cm^2
Panel Efficiency	e_{panel}	0.07	
Electrical loss	e_{el}	0.7	
Angular loss	a	0.7	
Duty cycle	d	0.179	
Sleeping node power dissipation	P_{sleep}	0.165	mW
Maximum node power dissipation	$P_{running}$	148.5	mW
Average node power dissipation	P_{node}	26.72	mW
Starting month	t_{start}	6	

Fig. 3. Constant factors with sample values

"E_{solar} (M) in a given month's harvest of solar energy $E_{solar}(M) = (1 - L(M))$ eel $e_{panel}AaR(M)$ can be used to predict M ∈ {1,..., 12}A panel made out of $e_{els}AaR(M)$
the drop in temperature throughout the course of a particular month M, the efficiency of a solar panel and its particular size, the loss caused by a radiation angle, and the total solar radiation during M all come together to form M. All of these aspects have been considered."

"While sensor nodes are running, their power consumption is believed to be Prunning. When they are sleeping, their power consumption is Psleep. As a result, Pnode has an average power dissipation if the node is functioning at a duty cycle d∈ [0.0; 1.0], which means it is awake 100 d % of the time and asleep the rest.

$$"P_{node}= d\ P_{running}+ (1 - d)\ P_{sleep}"$$

To get an idea of how much energy the node uses in a given month, we can use the following formula:

$$"E_{diss}(M) = P_{node}\ 24\ DiM(M)"$$

All input parameters have been entered and the quantity of energy stored in the battery may be computed for the number of days in the month. Using the initial charge of the battery, E, it is possible to determine E(t) (0).

$$"E(t) = \min\{C, E(t - 1) + E_{solar}(M(t)) - E_{diss}(M(t))\}$$
$$M(t) = ((t - 2 + t_{start}) \bmod 12) + 1"$$

The number of months tstart∈ {1, ..., 12} it has been running is equal to the t ∈ N number of months since it started. The utility function M : N ⇒ {1, ...12} is used to convert the month index based on the original month."

The image on the right depicts the battery energy model. As a starting point, Figures 1 through 3 provide the data. By losing more energy than it received from the solar cell, Figure 4(a) demonstrates that node depleted the battery. During the winter months, the duty cycle has been reduced to 25%, which is the maximum that can be maintained. Negative numbers are shown in column three of Figure 4a because the sensor node ran out of batteries in that month if it had been raised any higher.(Moser et al., 2007)

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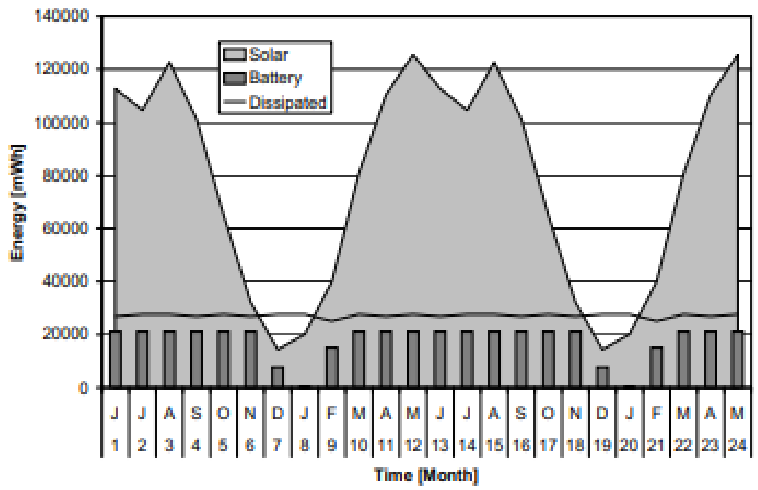
t	$((t-2+t_{start}) \bmod 12)+1$	E(t) [mWh]	E_{solar} [mWh]	$E_{dissipate}$ [mWh]
0		21120		
1	6	21120	104958	24683
2	7	21120	97390	25506
3	8	21120	114211	25506
4	9	21120	94248	24683
5	10	21120	60500	25506
6	11	21120	29988	24683
7	12	8895	13280	25506
8	1	2203	18814	25506
9	2	16350	37185	23038
10	3	21120	75256	25506
11	4	21120	102816	24683
12	5	21120	116868	25506
13	6	21120	104958	24683
14	7	21120	97390	25506
15	8	21120	114211	25506
16	9	21120	94248	24683
17	10	21120	60500	25506
18	11	21120	29988	24683
19	12	8895	13280	25506
20	1	2203	18814	25506
21	2	16350	37185	23038
22	3	21120	75256	25506
23	4	21120	102816	24683
24	5	21120	116868	25506

(a) Table representation



(b) Graph representation

Fig. 4 Batteries' power use throughout the course of a year

Figure 4 depicts the table data in a more visible form (b). While the monthly power dissipation is mostly constant, the collected power changes greatly over time due to the varied number of days in each month. Batteries run down because they don't generate as much electricity as they consume. This is due to a decrease in harvesting power during the winter months. The charge graph never exceeds the battery capacity of 21120mWh.

3. Experimental results

We started testing the model experimentally in December 2008 to make sure it was accurate. iSense sensor nodes had solar cells affixed to them(Buschmann & Pfisterer, 2007)hat had three distinct types of solar cells.There were three types of solar cells in this headgear. Figure 5 shows the power management module, battery, and solar panel that were installed on each node. It is the job of the

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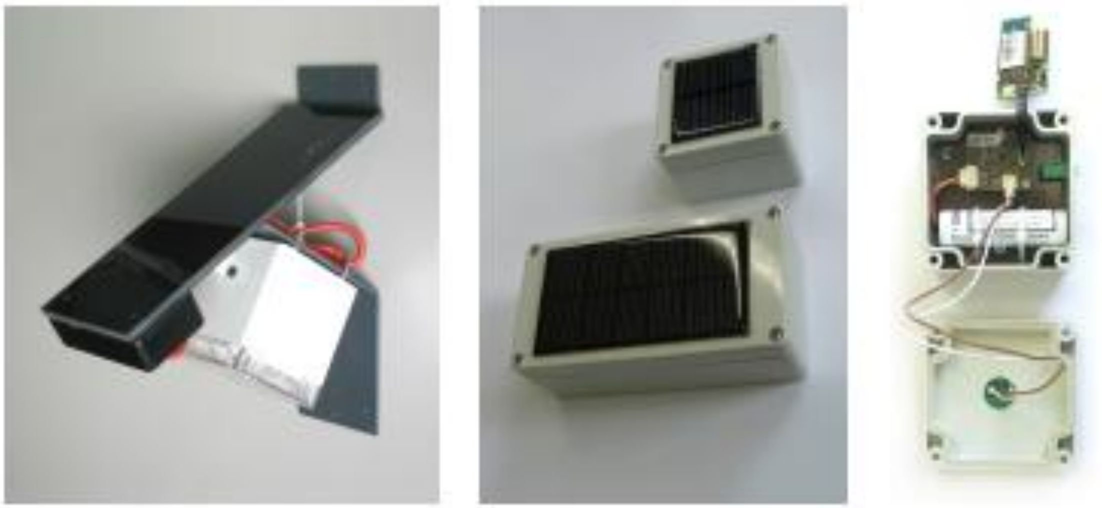
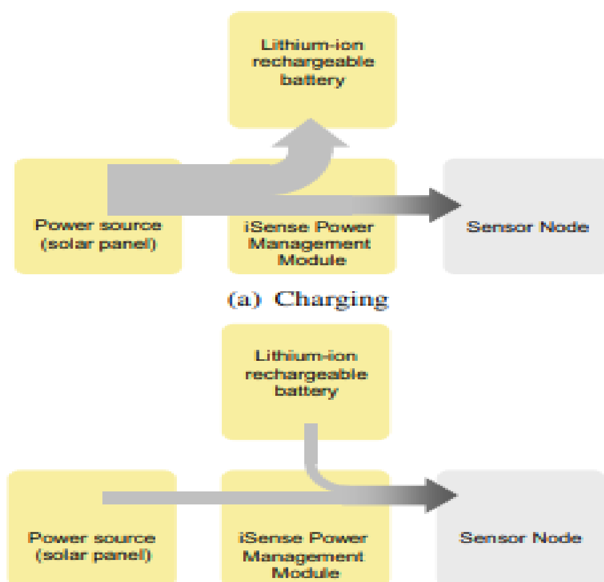
power management module to intelligently distribute the energy generated by the solar panels. If the solar panel delivers more power than the sensor node requires, the lithium ion battery is charged (a). Solar power can be supplied to the node while drawing from the battery to reduce battery drain (see Figure 6(c)).



(a) Large (b) Medium, Small (c) Inside view

Fig. 5 Panel types and node setup



(a) Charging

(b) Reducing discharge

Fig. 6 Energy Flows

A charge controller is also included for charging the battery. When the battery is charged or discharging, the current flowing into and out of the battery is measured by a battery monitor, which also records the readings. This data offers exact information on the battery's stored energy.

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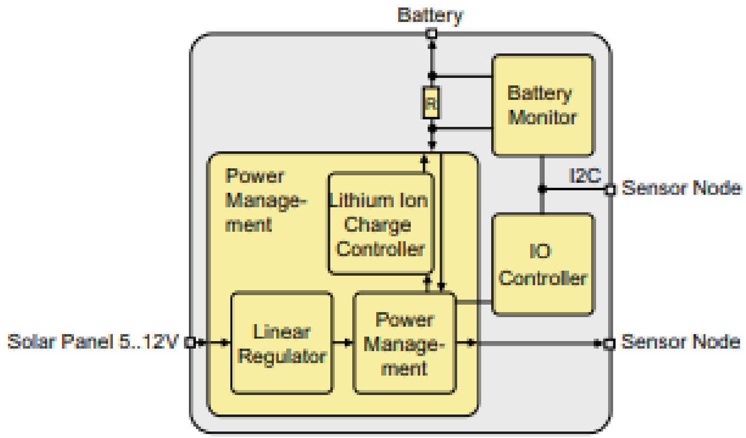

Fig. 7 Power Management Concept

Figure 8 provides a summary of some of the solar panel and model settings utilised in the next sections.

	Large Panel	Medium Panel	Small Panel
Panel efficiency	0.09	0.12	0.11
Panel size	170	81.25	37.05
Open circuit voltage at MPP	6	9	5
Short circuit current at MPP	250	109	81
Electrical efficiency	0.8	0.4	0.63
Radiation angle efficiency	0.8	0.7	0.7

Fig. 8. Technical cell data and model settings

Fig. 9 shows the anticipated and actual energy captured by each of the three distinct types of solar panels Figure 9: The model's predicted values are shown in white, while the actual energy obtained is shown in black. Predicted and measured values are strikingly similar throughout the first two months of our experiment, The battery was always full, so only a small percentage of the sun's energy could be harnessed. For the first time, we were able to prove that at least one of our sensor nodes had an empty battery at all times in May. "Harvested max" displays how much energy was harvested by that percentage in May. Interpolating the data from February to April allowed us to estimate the maximum amount of energy that may have been obtained. Figs. 9(b) and 9 show the amount of power generated by the smaller solar panels (c).

Small and medium-sized panel nodes are clearly separated from larger panel nodes in these trials. In spite of the model's projection of a decline in captured energy in June, the large panel consistently rose from January to June. Figure 5 shows how the sensor node housing is positioned under the solar panel (a). Sunshade: The solar panel functions as a sunshade when it's hot outside, preventing overheating in the house This implies that the battery can be recharged even in the middle of the day. L(M) loss values should be lowered or possibly cancelled out for nodes with large panels throughout the months of May through August, based on the results of this study. Even more importantly, this highlights the importance of a sturdy housing for the sensor node in addition to well-designed electronics and the right panel.

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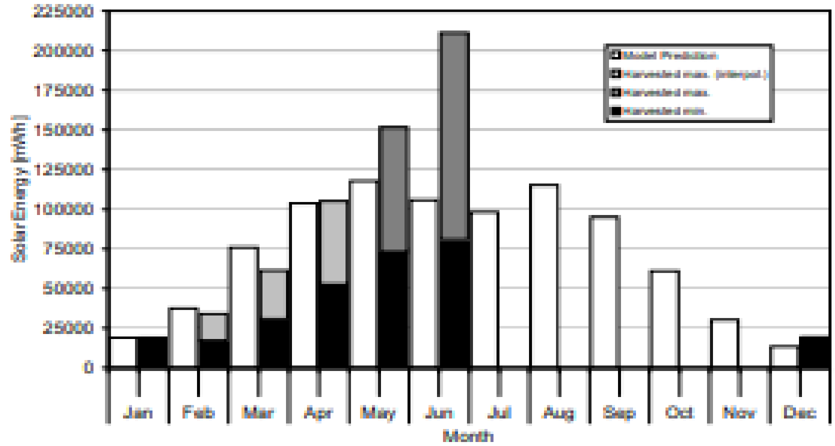
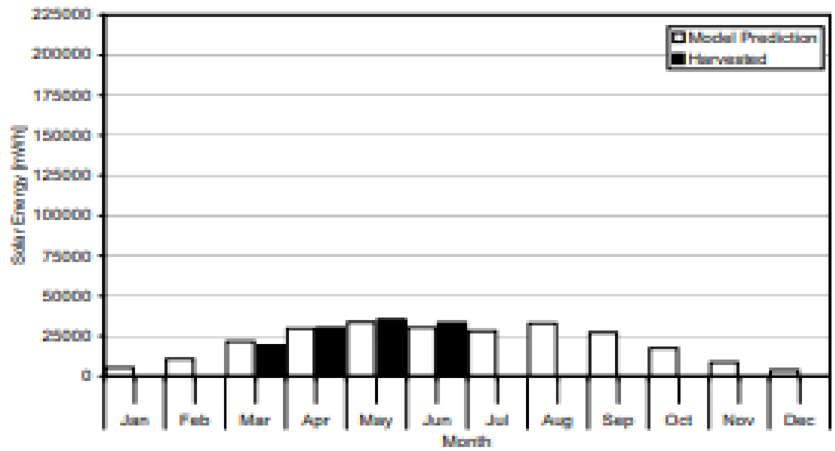
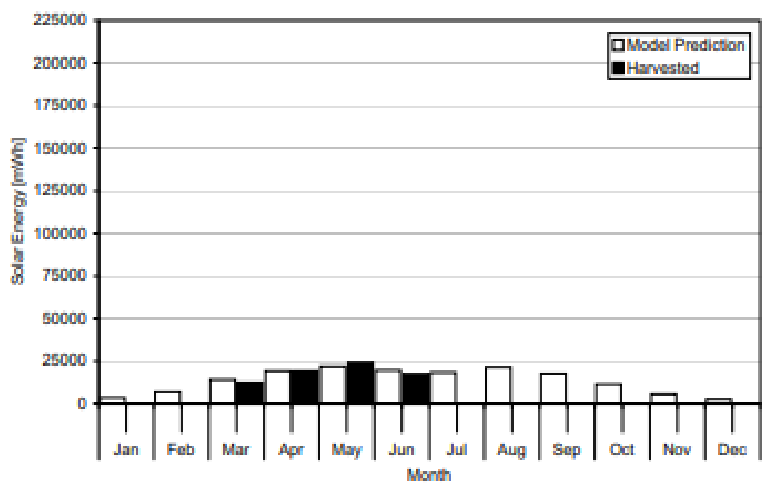


(a) Large Panel



(b) Medium Panel



4. Conclusion

Many factors affect the amount of solar energy that can be captured and must be taken into consideration while making design selections. Using this model, we were able to forecast both the amount of captured energy as well as the amount of battery charge that would be generated. The outcomes of our long-term studies with different solar panels are also proven to back up our model. Even if the model's projections about the amount of energy that can be harvested in the real world are rather accurate, more research is needed. According to the first set of findings, the expected values for temperature exceedance loss aren't accurate across the board. In any case, the experiments will yield more information that will help to improve our current model. Different shadings for the housings of nodes will also be tested. Based on the models described here, we propose to construct a duty cycle control system.

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