

DESIGN OF SELF POWERED EMBEDDED WIRELESS SMART CAMERA USING MULTIMODAL VIDEO ANALYSIS

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Abstract

Surveillance is a key aspect in security scenario in existing world. The existing systems consist of continuous monitoring and recording of the scenario or area under surveillance. This causes considerable amount of power expense and unnecessary data recording. To counteract these two problems we propose here a system which has an energy harvester and intelligent power saving technique. The proposed system consists of an PIR and a proximity sensor placed in the line of sight of the camera. When any kind of anomaly is detected in the foreground of the camera, the camera is powered on by the energy harvester unit to turn on the camera. Once the foreground is cleared of the anomaly the energy harvester unit stops the power to the camera and shut down the camera. This helps in significant improvement in power saving and longer battery life in wireless sensor network. The image process techniques use the background subtraction to detect the geometry of anomaly. The proposed method also has renewable energy production system with a solar panel and a energy management unit for charging and discharging unit. The total system will have codes written in MATLAB for the blob analysis of image acquired. The frames will be analyzed by MATLAB for same. The proposed system offers significant improvement in power saving in image acquisition.

Keywords: surveillance, infrared sensor, anomaly, wireless sensor network, energy harvester, power saving technique

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1. INTRODUCTION

The focus of surveillance missions is to acquire and verify information about enemy capabilities and positions of hostile targets. Such missions often involve a high element of risk for human personnel and require a high degree of stealthiness. Hence, the ability to deploy unmanned surveillance missions, by using wireless sensor networks, is of great practical importance for the military. Because of the energy constraints of sensor devices, such systems necessitate energy aware design to ensure the longevity of surveillance emissions. Solutions proposed recently for this type of system show promising result. However, the simplified assumptions they make about the system in the simulator often do not hold well in practice and energy consumption is narrowly accounted for within a single protocol. One of the key advantages of wireless

Sensor networks (WSN) is their ability to bridge the gap between the physical and logical worlds, by gathering certain useful information from the physical world and communicating that Information to more powerful logical devices. If the ability of the WSN is suitably harnessed, it is envisioned that WSNs can reduce or eliminate the need for human involvement in information gathering in certain civilian and military applications. In the near future, sensor

devices will be produced in large quantities at a very low cost and densely deployed to improve robustness and reliability. They can be miniaturized into a cubic millimeter package in order to be stealthy in a hostile environment. Cost and size considerations imply that the resources available to individual nodes are severely limited that limited processor band width hand memory are temporary constraints in sensor networks.

They will disappear with fast developing fabrication techniques. The energy constraints on the other hand are more fundamental. According to R.A. Powers battery capacity only doubles in 35 years. Energy constraints are unlikely to be solved in the near future with the slow progress in battery capacity and energy scavenging. Moreover, the untended nature of sensor nodes and the hazardous sensing environment preclude manual battery replacement. For these reasons, energy awareness becomes the key research challenge for sensor network protocol design.

2. RELATED WORK

A video sensor node in a wide area sensor network is a node capable of performing on-board video processing, and communicating the information over a self-organizing and fault-tolerant wireless network. Commercial CCTV and PC-based surveillance systems are not suitable for wireless sensor net-

work surveillance application, and are orthogonal to our approach. In fact, the CCTV are not processing the data on line and are wired for power consumption, while PC-based and commercial cameras rely on high power consumption, which is not suitable for the WSN. For this reason, this section does not re-view these kinds of solutions.

Recently, several platforms and commercial cameras with similar goals have been developed within a sensor.

We can classify these approaches in three categories:

- Lowcost nodes with wired interface (e.g., commercial USB/LAN camera, or the node designed by Corely[12];
- Wireless nodes with significant power consumption
- Application-specific single ultra-low power single chip solution

Being wired, the nodes in the first category obviously do not satisfy the basic requirement of being wireless, thus usually these cameras send the data to a remote host to be processed, although novel commercial cameras have the possibility to do it on-board they still send the results by means of a wire. Instead, nodes in the second category consume roughly more power than a typical first generation wireless sensor node and for this reason they are not suitable for wireless sensor network which should work for several months. Finally, single-chip solutions have extremely low-power consumption, but they are neither programmable nor configurable in field. One important common point among current video wireless nodes belonging to the first and second category is that the digital signal processing sub-system is the main power bottleneck. This is due to the fact that the high data rate of CMOS image sensor imposes the selection of fast processors and memories with high power consumption. Hence, the main open challenge in this area is to synergistically develop algorithms and architectures for energy-efficient image processing without giving up the flexibility of in-field configuration.

The academic literature provides more similar approaches in terms of low-power cameras and wireless sensor application. In sensor nodes equipped with PIR, acoustic and magnetic sensors have been deployed in order to achieve adjustable sensitivity, stealthiness and effectiveness in a distributed military surveillance applications. To balance privacy and security in surveillance applications, networks of infrared sensors (IR) and cameras are employed also in. Cameras are used in public areas while networks of IR detectors [14] are deployed in private areas. The system processes the data from IR sensors in order to detect an event of interest in the private area to identify the author by correlation with the images grabbed in the public area. Energy conservation through limiting the sensing to a small part of the network was also considered in. In, the activation pattern is swept across the network. Both schemes assume a simple topology and do not handle sensing holes due to the sleeping time of the sensors.

In fact in this previous work the sleeping time is fixed and the sensor could sleep also when it is need have data acquisition. In, the activation pattern follows a user-defined path through the sensor network as a sentry. In, a sleep/wakeup strategy in solar-powered wireless sensor is presented. Our work incorporates many similar ideas to the ones mentioned above however in contrast to the other works we present a combination of video sensor with other low-cost and low-level sensors, which are used mainly for triggering the camera at the right time and not to promote a reduction of the system energy requirements. In fact the PIR sensor can be used as an ultra low power wake-up trigger to reduce the power consumption when the video processing is not needed. Moreover, data from PIR sensors can be used from the application to understand when the best moment for starting an image acquisition occurs. This will bring both a reduction of false positives and a reduction of the number of frame being processed, thus also a reduction of power consumption. Finally, we equipped the node with a solar panel to recharge the batteries and achieve perpetual work.

3. SYSTEM ARCHITECTURE

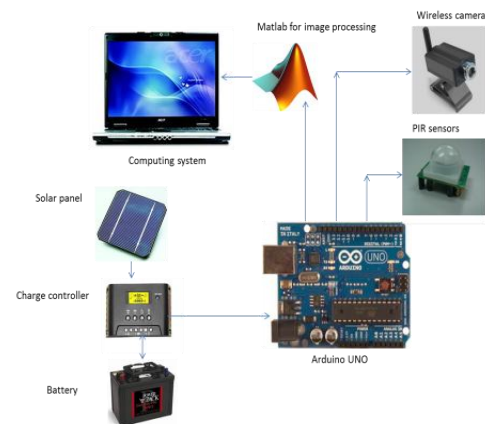


Fig 1 Camera sensor with PIR sensor, processing unit ATMEGA 328 microcontroller with SRAM

Fig. 1 shows the smart camera structure. A smart camera is a camera that can do on-board processing instead of transmitting all video data to a central controller. The choice of a smart camera is motivated by the notably reduced power consumption required by processing on-board compared to a solution relying on transmitting raw data through a wireless interface. The wireless smart camera consists of a camera sensor, an embedded processor (Atmega328 from STM), a CMOS video sensor (VS6624 from STM), a pyroelectric infrared sensor used as trigger and a wireless communication module, being supported through a suitable interface which can host either a ZigBee or Bluetooth compliant transceiver. The whole system is designed to achieve low power consumption. Each device provides a power saving mode to reduce consumption when not in use. The smart camera is connected to a host (central PC) to send alarms or relevant

image content; moreover it can receive wireless messages from the host so as to modify its settings was very easy to implement .the transformation is made by using Zigbee or other latest technology.

3.1. Processing Core

Choosing the suitable target hardware for a smart camera processor is an important issue. Due to the very large amount of data involved in image processing and computer vision tasks and the aforementioned constraints on power consumption, we have chosen The high-performance Atmel 8-bitAVRRISC-based micro controller combines 32 KB ISP flash memory with read-while-write capabilities, 1 KB EEPROM, 2 KB SRAM, 23 general purpose I/O lines, 32 general purpose working registers, three flexible timer/counters with compare modes, internal and external interrupts, serial programmable [21]USART, a byte-oriented 2-wire serial interface, SPI serial port, 6-channel 10-bit A/D converter (8-channels in TQFP and QFN/MLF packages), programmable watchdog timer with internal oscillator, and five software selectable power saving modes. The device operates between 1.8-5.5 volts. By executing powerful instructions in a single clock cycle, the device achieves throughputs approaching 1 MIPS per MHz, balancing power consumption.

3.2. CMOS Image Sensor

To achieve low power consumption we chose the VS6624 CMOS imager from STMicroelectronics as the video device. The image sensor provides full SXGA (1280 1024) resolution at 15 frames per second, or VGA (640 480) resolution at 30 frames per second. A very important feature is the power consumption, which is just 120 mW when active (2.8 V and 12 MHz frequency), while it goes down to 23 mW when it switches to standby. The CMOS camera can be programmed and controlled via internal registers using I C serial interface. It supports several output formats, however most video processing algorithms use grayscale image, thus we adopt 8-bit grayscale images with YCbCr 4:0:0 formats. Although it supports SXGA resolution, due to limited size of the internal SRAM only little parts of the images can be processed, typically 160 120 pixels, but the node can use external RAM extending the memory capability. This resolution is enough to perform our image processing algorithm, and to save time and energy for storing and processing data.

3.3. Pyroelectric Infrared Sensor

Pyroelectric devices, such as the PIR sensor, have +ve elements made of a crystalline material that generates an electric charge when exposed to infrared radiation. The changes in the amount of infrared striking the element change the voltages generated, which are measured by an on-board amplifier. The device contains a special filter called a Fresnel

lens, which focuses the infrared signals onto the element. As the ambient infrared signals change rapidly, the on-board amplifier trips the output to indicate motion.[17]



Fig 2 A SN PIR Infrared sensor (Passive Infrared Sensor)

Table -1: Recommended operating condition

Parameter	Symbol	Rating	Unit
Operating Power supply	Vcc	+4.5V - 5.5 V	V
Operating Temperature	T	-15 degCelcius	°C

3.4. Wireless Transceiver

Analog wireless is the transmission of audio and video signals using radio frequencies. Typically, analog wireless has a transmission range of around 300 feet (91 meters) in open space; walls, doors, and furniture will reduce this range. Analog wireless is found in three frequencies: 900 MHz, 2.4 GHz, and 5.8 GHz. Currently, the majority of wireless security cameras operate on the 2.4 GHz frequency.

Most household routers, cordless phones, video game controllers, and microwaves operate on the 2.4 GHz frequency and may cause interference with your wireless security camera. 900 MHz is known as Wi-Fi Friendly because it will not interfere with the Internet signal of your wireless network. The advantage of transceiver is multiple receivers per camera: the signal from one camera can be picked up by any receiver; you can have multiple receivers in various locations to create your wireless surveillance network.

3.5. Energy Harvesting Unit

Solar power is the conversion of sunlight into electricity, either directly using photo voltaics (PV), or indirectly using concentrated solar power (CSP). Concentrated solar power systems use lenses or mirrors and tracking systems to focus a large area of sunlight into a small beam. Photo voltaics

convert light into electric current using the photoelectric effect. Photo voltaics were initially, and still are, used to power small and medium-sized applications, from the calculator powered by a single solar cell to off-grid homes powered by a photovoltaic array. They are an important and relatively inexpensive source of electrical energy where grid power is inconvenient, unreasonably expensive to connect, or simply unavailable.

A charge controller, charge regulator or battery regulator limits the rate at which electric current is added to or drawn from electric batteries. It prevents overcharging and may prevent against overvoltage, which can reduce battery performance or lifespan, and may pose a safety risk. It may also prevent completely draining ("deep discharging") a battery, or perform controlled discharges, depending on the battery technology, to protect battery life. The terms "charge controller" or "charge regulator" may refer to either a stand-alone device, or to control circuitry integrated within a battery pack, battery-powered device, or battery recharger. Charge controllers are sold to consumers as separate devices, often in conjunction with solar or wind power generators, for uses such as RV, boat, and off-the-grid home battery storage systems. In solar applications, charge controllers may also be called solar regulators. Some charge controllers/solar regulators have additional features, such as a low voltage disconnects, a separate circuit which powers down the load when the batteries become overly discharged.

Lithium-ion batteries are common in consumer electronics. They are one of the most popular types of rechargeable battery for portable electronics, with one of the best energy densities, no memory effect and only a slow loss of charge when not in use. Beyond consumer electronics, LIBs are also growing in popularity for military, electric vehicle and aerospace applications. Handheld electronics mostly use LIBs based on lithium cobalt oxide (LiCoO₂), which offers high energy density, but presents safety risks, especially when damaged.

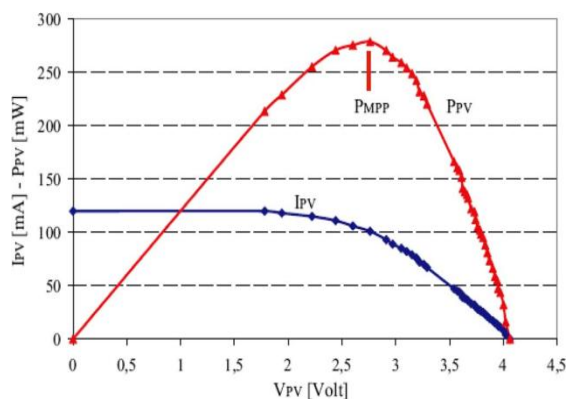


Fig 3 Characteristic of the photovoltaic module

Table -2: Characteristics of solar cell

Feature	Parameter	Value
Nominal open circuit voltage VOC	V	4.6
Nominal voltage @ maximum power point VMPP	V	3.3
Nominal short circuit current ICC	mA	160
Nominal current @ maximum power point IMPP	mA	150
Lead Length	mm	750
Power Rating	mW	500
Size-Length	mm	114
Size-Width	mm	66.8

4. VIDEO ANALYSIS ALGORITHM

In the field of computer vision, blob detection refers to mathematical methods that are aimed at detecting regions in a digital image that differ in properties, such as brightness or color, compared to areas surrounding those regions. There are two main classes of blob detectors: (i) differential methods are based on derivatives of the function with respect to position, and (ii) methods based on local extreme are based on finding the local maxima and minima of the function. Another common use of blob descriptors is as main primitives for texture analysis and texture recognition.[23]

The contours of an object in an image are determined by calculating the gradient magnitude of each pixel in the image. The stronger the intensity transition, the greater the magnitude will be. The gradient magnitude is calculated at each pixel position from the image's first derivatives. It is defined as:

$$\text{Gradient magnitude} = \sqrt{I_x^2 + I_y^2}$$

Where: I_x and I_y = the X and Y derivative values, respectively

They define the components of the gradient vector as:

$$\text{Gradient vector} = \begin{bmatrix} I_x \\ I_y \end{bmatrix}$$

An edge element (edge) is located at the maximum value of the gradient magnitude over adjacent pixels in the direction defined by the gradient vector. The gradient direction is the direction of the steepest ascent at an edge in the image while the gradient magnitude is the steepness of that ascent.[6][7]. The gradient direction also is perpendicular to the object contour. Well-defined contours are extracted from strong and sharp intensity transitions. A strong contrast between the objects and their background improves the edge detector's robustness and location accuracy.

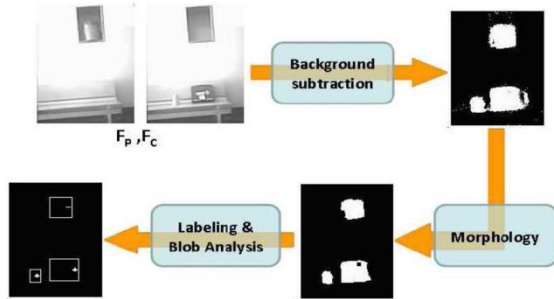


Fig 4 Flow diagram of the proposed video analysis algorithm

5. EXPERIMENTAL RESULT

5.1. Video Analysis Evaluation

Experiment concerns an indoor setup aimed at monitoring a sector of a hallway in a building. The camera was placed a few meters away from the wall and switched on. In order to achieve the best performance, the camera has to be firmly attached to the wall or placed over a vibration-free surface [24]. In fact, although the camera is mounted on a mobile device, the image processing algorithm assumes the presence of a static camera. Meanwhile several real abandoned/removed object instances were generated. The processed images were sent directly to a host PC via Bluetooth. We have analyzed three continuous footages where, each time the camera was switched on by the PIR sensor, the current frame was processed by the proposed algorithm. We have collected a total of 64 frames, with each frame containing at times even multiple abandoned/removed objects, for a total of 78 abandoned/removed objects. Also, a subset of frames does not contain any case of object removal/abandon. As for the background subtraction algorithm, out of 78 ROIs, 77 ROIs have been correctly detected by the algorithm, yielding only one false negative and four false positives, for a correct segmentation rate of 98.7%. These 77 ROIs, fed to the classification stage, were then correctly classified in 73 cases as abandoned/removed object, yielding to a correct classification rate of 94.8%.

Fig.5 reports some qualitative examples of correct segmentation and classification yielded by the proposed algorithm on the dataset of Experiment 1. In the figure, seven examples are reported (indicated by letters a–f), where for each example the two frames and the final output of the algorithm are shown. As for the output, each detected ROI is indicated by a white bounding box, while the classification result is encoded as a symbol shown inside each detected bounding box: the “ ” symbol stands for abandoned object (as if it is added to the scene) while the “ ” symbol stands for removed object (as if it is subtracted from the scene). As it can be seen from the figure, the proposed algorithm is able to achieve correct segmentation and classification also in presence of very small, partially transparent objects (cases e and f) and with multiple ROIs (cases a–f).

In Experiment 2, we present a qualitative evaluation of the proposed algorithm in an outdoor environment under sunny conditions, which concerns specifically the case of monitoring a wall from undesired events such as graffiti, stealing or unauthorized poststicking. In this case the distance from the wall was around 5 m in the case (a–c) Figs.6 m in (d) our system has been tested against events such as graffiti (case a), wall affixtures (case b), object removal [case c and Fig. 10(d)]. Finally a situation where only illumination changes occur in the scene is shown in Fig. 9(d) In this test the camera was left at 1000 in morning and the video processing were performed 2 h later with different light. As it can be seen, our algorithm is capable of robustly handling all the aforementioned cases, yielding correct classification also when the object ROI is particularly small (e.g., case c of both figures and d Fig. 10, and with each single writings appearing in the graffiti situation concerning case a) and despite the nonoptimal illumination conditions.

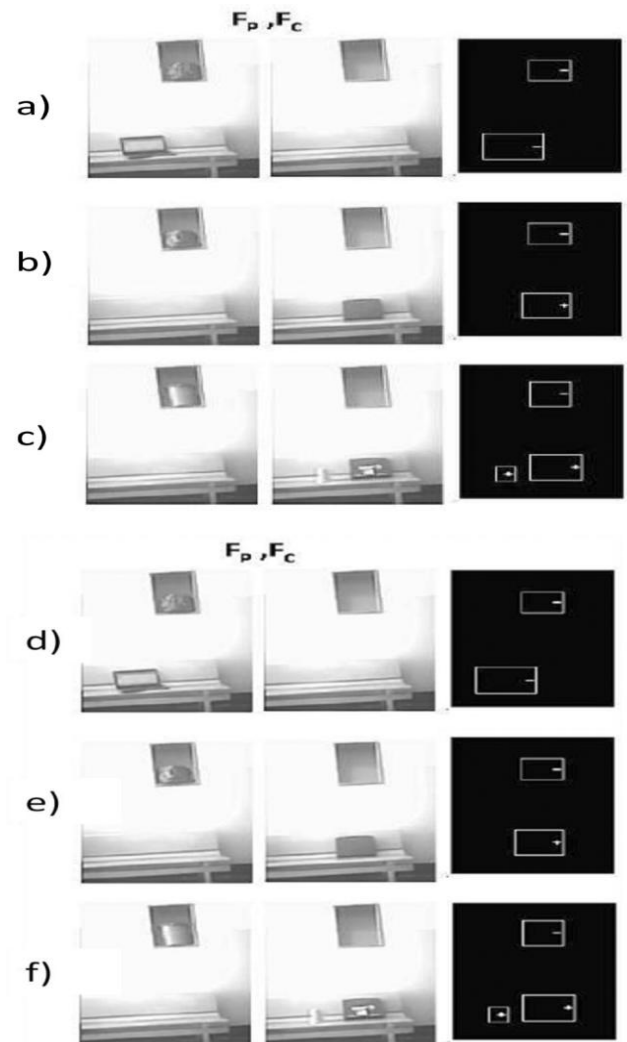


Fig 5 segmentation and classification examples yielded by the proposed algorithm

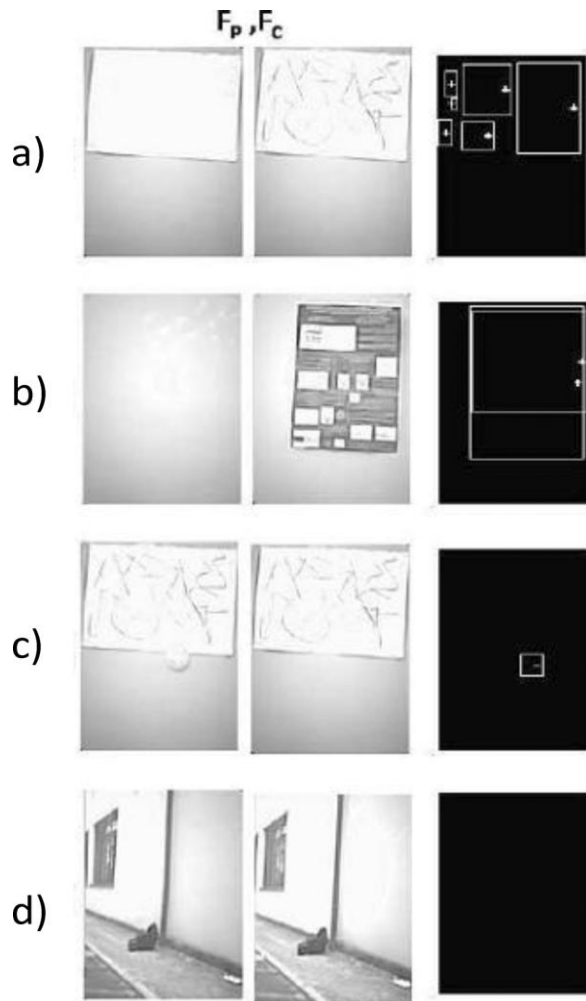


Fig 6 Performance of the proposed video analysis algorithm in different out- door circumstances: (a), object abandon (b), object removal (c), illumination change (d).

5.2. Power Consumption Analysis

Table IV shows the power consumption of our prototype. The table shows how the power consumption of the whole system in sleep mode is more than 10 times less than that in normal mode. We estimated that the average time to elaborate one abandoned/ removed object event is about 3 s from the moment when the detection starts. Moreover, the amount of time required for blob analysis depends on the number and size of the detected ROIs. Hence, it will be zero if the system does not detect any blob and about 100 ms for three ROIs sized 16 pixels. To evaluate the benefits provided by our approach in terms of improvement of battery life we consider the same system without PIR sensor. More specifically, we compare the two approaches assuming different amounts of random events (i.e., 50, 100, 300 events per hour) and by estimating the lifetime of the three scenarios using a full 2000 mAh battery. In the first simulation the PIR sensor is disconnected and the system does not know when to switch

off/on the camera or when to turn into sleep mode, so it will work continuously and the power consumption will be independent from the number of events. Then, in our approach, and as previously mentioned, the PIR sensor detects events and wakes up the microcontroller which waits until the FOV is empty to start the video analysis. When the video analysis is over the microcontroller turns the camera off to reduce power consumption.

Table -3: Power consumption of the video sensor node

Component	Power [mW]
ARM9 (RUN mode)	450
ARM9 (IDLE mode)	49.5
ARM9 (SLEEP mode)	15
Video sensor (ON mode)	165
Video sensor (IDLE mode)	23
TX/RX (ACTIVE mode)	98
TX/RX (IDLE mode)	10
PIR sensor	1.5
VIDEO NODE	
Active with video sensor	626.5
Active, without video sensor	484.5
Alarms Transmission	572.5
Sleep, only PIR is Active	51

Using the solar panel to harvest the energy, we can obtain an additional improvement of battery life, achieving perpetual working in an application scenario with 50 events per hour. A simulation verifying the performance of the proposed system is depicted in Fig. 7, where the energy harnessed from the solar cell powers the sensor node and recharges the battery with the exceeding events. In our simulations we assume a rate of 50 events per hour representing people walking within the field of view of the video node. Furthermore we measured the energy intake from the energy harvester and the solar light intensity during five days (Fig.8). All the information was stored in files used as input to our simulations. Finally the energy level of the battery at the beginning of the simulation is half its full capacity (2000 mAh, expressed in Joules). This simulation shows how the system can work perpetually with a small PV panel. The node without the energy harvester stops working after approximately 40 h, as it can be seen from Fig. 7. Instead, the node with the harvester can recharge its battery during the day, the energy accumulated in the battery being sufficient to keep the node on during the night.

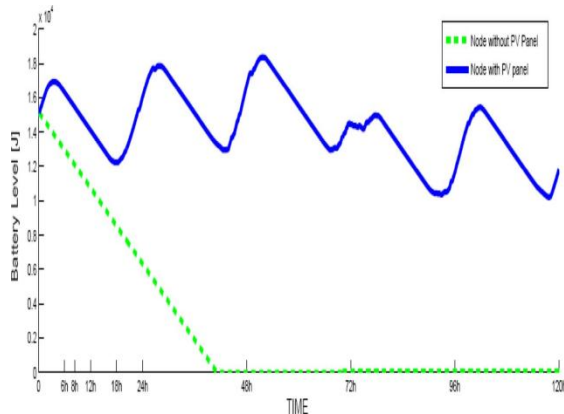


Fig 7 Simulation of our system with and without PV harvester (50 events/h)

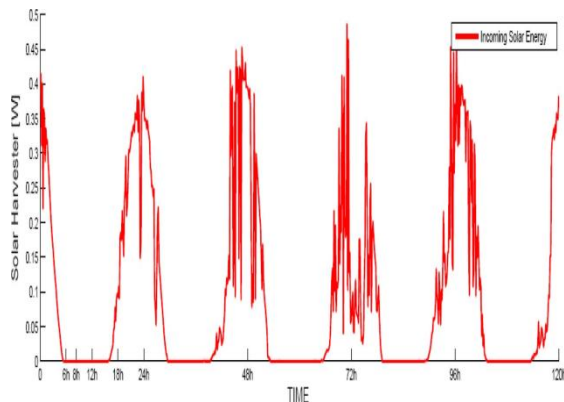


Fig 8 energy harvested during five consecutive days from our PV panel

6. COCLUSIONS

Proposed method utilizes the efficient energy harvesting methodology for increasing the charged battery life. The Codes written in the Arduino board helps in significant controlled discharge of battery during the surveillance and efficient charging from environment. The use of MATLAB subsequently gives a better environment for image processing and blob analysis. The present algorithm can be enhanced by smart optimization techniques. In this work, a self-powered wireless smart camera for run time video processing has been presented. The proposed approach have shown that combing advanced hardware/software solutions makes possible high accuracy and perpetual work in video processing on wireless sensor network where smart cameras find the most critical constrain in the power consumption.

In fact, energy harvesters provide energy to replenish the batteries, while the combined use of different sensors with heterogeneous features allows for a remarkable reduction of the overall power consumption. We designed the camera for real time video processing algorithm and an ad-hoc

abandoned/re- moved object using PIR features. Data were presented to evaluate the performance of our approach in term of energy consumption, video processing application and accuracy. The experimental results showed the versatility of the application in indoor and outdoor scenario and the simulation showed the perpetual work was achieved in simulation outdoor scenario. Future work will include a complete campaign of new experiments in order to analyze better the issue of background changes and more challenging condition (i.e., direct sun light, shadows). Moreover they will be directed towards improving the hardware of the smart camera node, video processing algorithm, and distributed intelligence.

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