Toward Battery-free Smart Cameras

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ABSTRACT

Conventional wireless camera systems and the computations running on them for machine vision applications are demanding power-wise. The battery life of wearable camera systems (such as Google Glass) is under an hour when operating with full capacity. Similarly, due to power requirements, surveillance cameras need to be plugged in, which decreases their reliability because cutting the wire would totally disable the camera. In addition, it limits their deployment to places that have access to power wires. My recent work (WISPCam) enabled battery-free image capture by harvesting energy from Radio Frequency signals, but there is a long wait time between receiving consecutive images due to the large power consumption of the camera. The proposed work would extend from my current projects to explore reasons causing cameras to consume significant amount of power and presents ways to eliminate them. In addition, this proposal presents some novel techniques to reduce wearable camera systems' power consumption by exploring low-power hardware architectures and algorithms.

1. INTRODUCTION

In my recent works [2] [4] [1] I have focused on WISPCam, the world's first programmable battery-free RF powered camera, that transmits pictures wirelessly over a backscatter link (an ultra low power communication technique). Figure 1 shows the WISPCam prototype. We extended this work and enabled it to harvest energy from Wi-Fi signals as well [5]. I also worked on how to use WISPCam in more computationally demanding scenarios such as face detection and recognition [1]. One aspect of my research aims to make **surveillance video cameras** totally battery-free by 1) studying the power hungry parts of a wireless video camera, and 2) finding ways to decouple the power hungry components from the camera front and bring them into the basestation with which the camera is communicating by leveraging a passive communication technique called backscatter.

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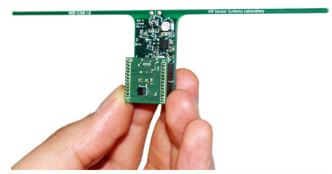

Figure 1: Latest prototype of WISPCam, a battery-free wireless camera

These cameras will be powered from ambient radio waves, so they will not need a battery or running wires.

I also have been working on implementing a novel ultra low power wearable vision system called Glimpse [3]. In this project we consider the problem of continuous computer vision based analysis of video streams from mobile cameras over extended periods. Given high computational demands, general visual processing must currently be offloaded to the cloud. To reduce mobile battery and bandwidth consumption, recent proposals offload only ”interesting” video frames, discarding the rest. However, determining what to discard is itself typically a power-hungry computer vision calculation, often well beyond what most mobile devices can afford on a continuous basis. In this project we present a re-design of the conventional mobile video processing pipeline to support such ”early discard” flexibly, efficiently and accurately.

In the following I will go through two main directions I am pursuing for the rest of my PhD, one of them targets wearable cameras and the other focuses on surveillance cameras. These directions will better understand what makes wireless camera systems power hungry devices and how to, practically, make them ultra low power.

2. ULTRA LOW POWER WEARABLE CAMERAS

During two internships at Microsoft Research, my collaborators and I designed and built a wearable ultra-low-power camera architecture called Glimpse, which is a programmable, early discard, camera architecture for continuous mobile vision. One application is to combine our system with a high resolution wearable vision system to reduce its power consumption by turning it off whenever nothing ”interesting” is happening in the field of view. The designed and implemented prototype of the Glimpse System is shown in Figure 2.

Glimpse detects situations where there is a human body close to the wearer, a conversation is happening between the wearer and a person, or the wearer is interacting with

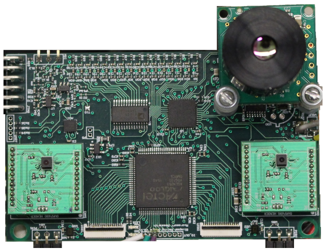

Figure 2: Glimpse Prototype that measures 3×2 inches

an object. This is done by extracting low-level features from the environment. We use passive infrared sensors to detect motion, thermal camera to detect human body boundaries, and stereo pair RGB cameras to measure the depth of an object using a novel low-power approximated algorithm implemented on an FPGA. Based on these inputs, a user can implement a module within our framework to predict whether something interesting is happening.

3. BATTERY-FREE SURVEILLANCE CAMERAS

Earlier in my PhD, my collaborators and I developed the worldâĂŹs first battery free camera, called “WISPCam”, which is powered and read by radio signals. Because cameras are power hungry sensors (burning about 100mW when capturing at 30 frames per second) and the power budget of wirelessly powered devices is very limited (about 100uW), one way to make battery-free image capture feasible is to heavily duty-cycle the camera, thus decrease its frame rate significantly. This is a requirement that made WISPCam possible.

How to enable a true video streaming wireless camera? To answer this question we should first identify what are the power consuming components of a wireless camera system and try to eliminate or redesign them. Wireless camera systems burn a significant amount of power because of the following power hungry components:

- Traditional image sensors are power hungry because they integrate analog to digital converters, digital image processor, high-speed digital IO interface, and a photo detector array on a single integrated circuit.

- Conventional cameras are inherently data-rich sensors. Today’s wireless communication is far from being capable of carrying the raw video stream generated by the cameras. Thus a power hungry video compression module (CODEC) is an integral part of every video camera to reduce generated data by few orders of magnitude.

- Communicating the video data is a power hungry step too, the wireless communication module burns the most power in a wireless camera system.

My current PhD work addresses designing and implementing an ultra low power wireless camera architecture that can stream video to a base-station while consumes sub-milliwatts of power. This camera leverages analog backscatter, a passive communication technique, to off-load raw analog data from the individual pixels directly to the base station, skipping all of the intermediary blocks that listed above. This results in reducing the power consumption by about three orders of magnitude compared to existing solutions.

Another focus of my work, toward battery-free security cameras, will be on removing video compression overhead from the wireless camera systems as well. The most power hungry component of traditional wireless video cameras is communication which will be eliminated leveraging analog backscatter. Then, the second most power hungry part of a wireless video camera is compression. This module also can be eliminated by using the base-station to predict which pixels are most likely to change in the next frame, then the base-station requests the camera to only transmit these possibly changing pixels. We call this compression technique **Interactive Compressed sensing**. This technique tries to bring the compression overhead to the base-station.

4. APPLICABILITY TO MOBISYS COMMUNITY

In the rest of my PhD I will focus on enabling the battery-free video cameras that stream compressed video over RF signals. If fully carried out, the work proposed herein will enable true ubiquitous dense camera networks that can be cheaply distributed everywhere. Some of the applications of such cameras are in the following.

Imagine a city that has traffic control cameras everywhere instead of only important junctions and routes. Some applications such as “Google Map” can benefit from this massive visual information to recommend the best possible navigation routes to the users and consequently help reduce traffic jams. They can also help accelerate the emergence of autonomous driving cars by serving as countless external eyes which provide the cars with visual feedback from hidden viewpoints and enable them to make predictions regarding possible accidents far ahead of time. Also, in cases like micro-drones that power consumption is a very important factor, these cameras can be the primary navigation and obstacle avoidance arms for the drone by having negligible power overhead.

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