Wireless Body Sensor Enhanced Tracking for Extended In-Home Care

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ABSTRACT
In this paper, we present a medical embedded tracking system that harnesses local, efficient sensor data to trigger and enhance the accuracy and efficiency of tracking applications, specifically targeted to medical and nursing applications. The project involves enhancing the highly parallelizable vision applications with low-level sensor data that are continuously being gathered by various lightweight devices. We leverage the system's hierarchical structure to trigger cameras equipped with reconfigurable devices to carry out various types of machine vision for medical sensing and monitoring. The system is composed of various heterogeneous embedded devices, with various computation capabilities and power costs, and hence the system is arranged in a hierarchical fashion in order to take advantage of the low cost devices to wirelessly trigger the operation and the actuation of the more capable but higher cost vision systems. The experimentation provide substantive data to confirm that the coordination of the two types of sensors can have a large potential to decrease cycles of execution on the FPGA, and hence allow for power savings or the addition of tailoring of the vision applications.

Keywords
Medical Embedded Sensing Systems, Machine Vision, Extended In-Home Care.

1. INTRODUCTION
The increase of wellness healthcare programs and patient management emphasizes the reality that patient information can be readily and continually made available for monitoring of patient health. The current proliferation of broadband wireless services, along with more powerful and convenient handheld devices, is helping introduce real-time monitoring and guidance for a wide array of patients. Low-cost sensors and wireless systems can now create a constantly vigilant and pervasive monitoring capability at home and in conventional point-of-care environments (*e.g.,* primary care physician offices, outpatient clinics, rehabilitation centers). A variety of devices and sensors exist, which can be unobtrusively incorporated into patient life and which can then wirelessly transmit data to caregivers and healthcare professionals.

In our system, we target the development of a wireless medical embedded sensing infrastructure for the purpose of extending in-home care for the elderly. The continuation of normal living patterns for the elderly can have a large impact on the quality of their lives and the financial burden of their care, as the transition to a nursing home facility is often a one-way process.

The purpose of this system is not to target any specific medical condition, but instead to develop a useful infrastructure that can be used for various conditions. The system we present harnesses local, efficient sensor data to trigger and enhance the accuracy and efficiency of tracking applications. There exists a range of medical conditions that can be robustly addressed with this type of system.

Specifically, we have considered Alzheimer's disease early onset detection and disorientation monitoring. Alzheimer's disease onset detection is often a difficult task since the disease is one where patients have good days and bad days, and with only the occasional visit to the physician there can be a long delay between disease onset and proper diagnosis. Additionally, the data that patients provide is qualitative and possibly even inaccurate. Our system aims to aid in this diagnosis dilemma, by capturing information about patient disorientation. Additionally after the diagnosis phase, patient disorientation can be monitored and caregivers can be alerted to these instances.

Additionally, we have considered the use of gait monitoring in the elderly to study the cause of falls as well as prevent their occurrence [20][18]. Simple falls can have a huge impact on the lives of the elderly, since they often result in serious and life-threatening health condition and hospitalization. Gate monitoring can be used to determine the common causes of falls in the elderly, and even work to prevent them from happening if immediate aid is available. Additionally, it can be used to alert caregivers, which can allow patients to receive faster care and more specific diagnosis. Researchers at Virginia Tech have looked into the determination of the possible causes of falls in the elderly [8]. In contrast with our system which is intended for continual and nondisruptive use with a limited number of sensors with a small form factor placed on or near the body, their system is quite large and cumbersome and is not intended for everyday use.

Our system is composed of med nodes, which are small constrained wireless sensing devices and video sensors equipped with FPGAs. The med nodes, which are in this case equipped with accelerometers and placed on the knee of the patient, send low level data measurements to the video sensor systems, which triggers them to adapt the operation of their tracking application. The overall system carries our tracking and data inference based on its sensor data. The combination of the different types of sensors allows for enhanced sensing, error prevention, and increased computation efficiency.

In the remainder of this paper, we present the related work and the broad implications of research in this area. We also present in detail the system infrastructure and components, with a special focus on the vision application that has been developed for the FPGA for this system. Finally we present the experimental results that show the benefits of fusing two different types of sensor data in a hierarchical fashion.

2. RELATED WORK

There have been two related projects that have explored a specific aspect of the problem that we have addressed. The GALORE Project developed a network of cameras that collaborate and reconfigure their FPGAs to meet the real-time needs of the vision applications, but with the adaptability offered by loading different computationally intensive applications onto the FPGA [10][11][15]. The coordination of services and computational reconfiguration were explored in a tiered system of motes and cameras [13][14][16].

Additionally, work has been done on habitat monitoring that has employed a tiered structure for its processing [17][19].

The Assisted Cognition Project [21] specifically explored the aiding of Alzheimer's patients, using AI systems to support and enhance the independence and quality of life of patients. The goal of the Assisted Cognition project was to develop a novel computer system that would enhance the quality of life of people suffering from Alzheimer's disease and similar cognitive disorders. Assisted Cognition systems use ubiquitous computing and artificial intelligence technology to replace some of the memory and problem-solving abilities that have been lost by an Alzheimer's patient. Two concrete examples of the Assisted Cognition systems are an Activity Compass that helps reduce spatial disorientation both inside and outside the home, and an Adaptive Prompter that helps patients carry out multi-step everyday tasks.

Additionally, there has been work done in the area of power minimization for lightweight embedded systems. [6] examined the power usage of lightweight mobile systems during various modes, data transmission, data collection, and hibernation. Power aware computation on the lightweight systems was achieved by selecting modes of operation that were most efficient for a task. Several power management techniques for lightweight embedded systems are discussed in [2], but they are only explored on a theoretical level.

Similarly, dynamic power optimality has been achieved in sensor networks through the use of rotating cluster heads [4]. These systems minimize power utilization using a distributed approach to maximize the entire lifetime of the system [4][3]. Our work specifically reduces power consumption on a lightweight embedded system through using context sensitive information to improve the algorithm for a lightweight medical application.

Additionally, other systems have also explored using context to reduce power consumption in passive or groggy wakeup schemes that use state-based sensing to achieve better power utilization [5][1][7]. Our work differs in that it specifically looks at minimizing power utilization by improving the accuracy of the vision algorithm.

3. BROAD IMPLICATIONS

The larger vision of our system is to personalize care for the elderly through early detection and diagnosis of conditions and the extension of in-home care. A key requirement, however, is the pervasive yet unobtrusive incorporation of medical care into their everyday life. There is a growing, aging population as shown in Figure 1, taken from the United Nations world population prospects. There is an urgent need to address the medical conditions of this growing segment of the population. Systems that address the quality of life issues in addition to the strictly medical issues will have a much larger potential to impact lives. Additionally, there is large potential for cost savings, since these embedded sensing devices will be more cost efficient than constant healthcare professional or family member monitoring.

A key challenge involves the fusing of the data from heterogeneous embedded sensing devices from both body area networks and environmental networks, and when the data is both physiological and psychological in nature.

The increased and standardized availability of this data can have a profound impact on patient care. Key predictors can be used to monitor patient status, and in turn allow for the extension of in-home care of patients, thus increasing their quality of life and decreasing the financial burden of their care.

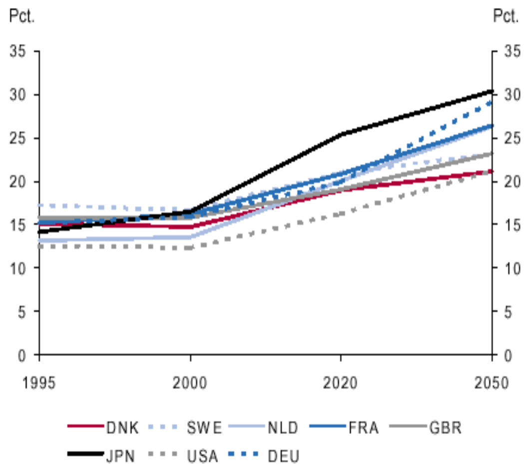

Figure 1. Growing Aging Population [Source: United Nations, World Population Prospects]

However, aside from the challenge of making the sensor devices feasible and usable, continuous monitoring of various parameters introduces key problems with data management. Due to system constraints, the large amounts of data cannot be transmitted to a physician or even a base station. Instead local and adaptable data filtering and clustering have the potential to handle the large amount of data captured, stored, and transmitted. Techniques can analyze the data to infer key health measures and also can adaptively probe or discard the medical data. Another challenge that is specific to multiple sensor type monitoring is the need to determine the correlations and the dominances between the various medical parameters. However, with the data management techniques we propose, this sort of analysis can be done by the system, specifically for each patient, and can even be made adaptable over time to match the changing condition of the patient.

4. SYSTEM INFRASTRUCTURE

4.1 Overall System Functionality

Generally, our medical embedded tracking system harnesses local, efficient sensor data to trigger and enhance the accuracy and efficiency of a machine vision tracking applications. Med nodes, which are equipped with constrained computational devices and sensors, here specifically accelerometers, wirelessly transfer the sensor data to the mote that is connected to the FPGA. The data is then passed to the FPGA through a UART port. The FPGA uses the sensor readings to determine variance of the acceleration and hence determine the sensing range in the frame. We developed a color detection based vision sensing and tracking application. Based on the variance of the accelerometer readings, the application adjusts the window size for which the image processing algorithms are run.

The application tracks a person through a space, while matching the tracking range to the level of mobility of the person. If there is low mobility, which is most often the case, then the algorithm on the FPGA works more efficiently doing processing on only a part of the frame. When there is high mobility, the algorithm is forced to increase the range of pixels on which the processing is performed, resulting in a decreased level of efficiency.

The advantage of this approach is that it allows for the elimination of unnecessary computation and even memory usage, thus allowing for other processing or even the shutting down of system components.

The system is used to demonstrate the effectiveness of the data fusion of physiological and psychological data. In this case, the physiological data comes from the med node's accelerometer, and the psychological data comes from the vision sensor, which is able to determine disorientation and other similar psychological states. Additionally, the system provides evidence for the effectiveness of a hierarchical structure that can be broadly applied in similar heterogeneous embedded sensing systems.

The project involved the development of the VHDL code for the tracking application. Additionally, we coordinated the wireless communication between the Berkeley Mica2 dote motes in the med nodes with the FPGA connected to the vision sensor. Finally, the system required the extraction and the wireless communication of the accelerometer values from the med node devices. In the future, we intend to enhance the system by doing more node level data processing to decrease the burden of communicating the data wirelessly.

In the remainder of this section we will present all the systems components and their interaction with other components.

4.2 Med Node

"Med nodes" are stand-alone components equipped with processing units and batteries. They support various types of sensors for obtaining physiological readings from the human body. They can be adapted to suite a range of applications and can be adapted to perform multiple types of operations. Furthermore, they support a variety of analog and digital sensors.

The med node architecture consists of an accelerometer sensor, sensor adaptation board, Crossbow Mica2Dot processing element developed by UC Berkeley, and a power supply (coin cell battery). Figure 1 illustrates the med node we used in our system.

Figure 2. Med Node Package

We connected an ultra compact three-axis linear accelerometer to the med nodes. The LIS3L02AL is a low-power 3-axis linear capacitive accelerometer that includes a sensing element and an IC interface that is able to take the information from the sensing element and to provide an analog signal.

The analog output is then fed to ADC channels on Mica2Dot (analog to digital converter) and read by the Atmega128 processor on the Mica2Dot board.

The LIS3L02AL recommended frequency range spans from DC up to 2.0 KHz, which in our application is much larger than our value. The sensor board is responsible for power supply decoupling and noise reduction. We omitted the final stage buffers in our system since the input resistance of the ADC channels on the Mica2Dot is high enough to lower the loading effect.

The period which we sample the acceleration values is set to 50ms which yields an approximately 20Hz sampling frequency. The sampling frequency can be changed adaptively by reconfiguring the device wirelessly.

4.3 Reconfigurable Component: FPGA

In addition to med nodes, our system is composed of video sensors equipped with FPGAs, on which we developed our tracking application. We implemented the algorithm on a Xilinx Virtex-II pro FPGA board, which includes two IBM PowerPC microprocessors. The PowerPC architecture is a 64-bit architecture with a 32-bit subset and a 32-bit data interface with the on-chip memory (OCM) [9].

FPGAs or field programmable gated array has been used as an alternative for digital components in a variety of systems. The FPGA architecture consists of programmable logic, reconfigurable interconnects and input/output devices. The programmable logic components can be configured to have the functionality of basic logic components, such as ANDs and ORs, as well as more complex combinational functions. FPGAs also have memory elements such as flip flops and memory blocks.

The FPGAs enable parallelism to achieve high performance with moderate power consumption. Image processing algorithms are inherently parallelizable, since similar processing must be done on various individual or groups of pixels. Therefore, hardware implementation for these algorithms enables a significant increase in system operation speed which facilitates the real-time application needs. Also, since FPGAs are reconfigurable architectures, these algorithms can be updated/modified through reconfiguring of FPGAs without redeployment of the system. In our proposed system we have used VHDL as the high level description language.

4.4 Video Sensor and Vision Applications

The final component of our system is the video sensor and the image processing that is done on the captured images. We use 260X zoom color cameras manufactured by Kocom. This camera has a 26x optical and 10x digital zoom. It is currently in use for a variety of applications including for surveillance purposes. It has S-video output that we use to connect the camera to the FPGA board.

The image processing application is based on a color tracking procedure. To detect only moving objects, frame subtraction is performed. Since there is not enough space to store past frames entirely, we store only the down sampled version, which is 1/64 of the original frame. Then, for every sixtieth frame saved, each pixel of the current frame is subtracted from the corresponding pixel of the saved frame.

Once background subtraction has been completed, all pixels' RGB values are compared to the small range of values that are used to identify the person being tracked. In this application we equipped each person with a green marker that was used to identify them in space under most lighting conditions.

The accelerometer data is used to enhance the window size where the RGB comparison is carried out. Based on the mobility information received, the algorithm varies the window size for which the RGB comparison is carried out. There is some account made for error in acceleration measurement, by adding an extra buffer region to the window size. Additionally processing is done to account for the mapping of three-dimensional movement to the two dimensional frame representation.

The window is centered on the person, or rather the green marker, that is being tracked. If there are multiple regions of the frame to which the processing maps, then the more prominent region is used for analysis. This can result in some error, but it can quickly be corrected during the subsequent frame processing.

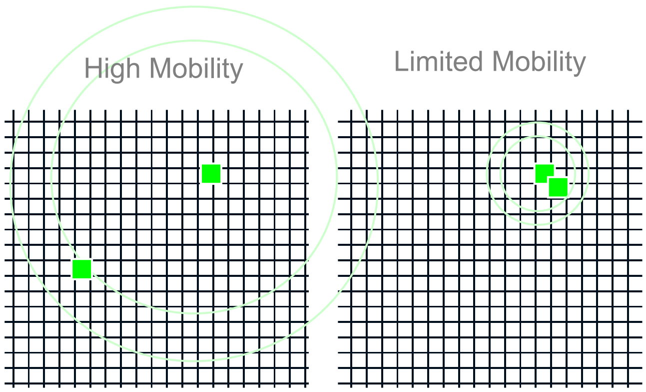

Figure 3. Summary of the adaptation of the tracking algorithm based on accelerometer data, where the green points highlight the position of the person over time in the frame

5. EXPERIMENTAL RESULTS

To verify that med node data successfully aided the operation of the tracking application, we measured the computation cycle execution savings for various different window sizes, as dictated by the patient's mobility level. The first graph in Figure 4 shows that by decreasing the processing pixel area, the cycles of execution are also decrease in a linear fashion.

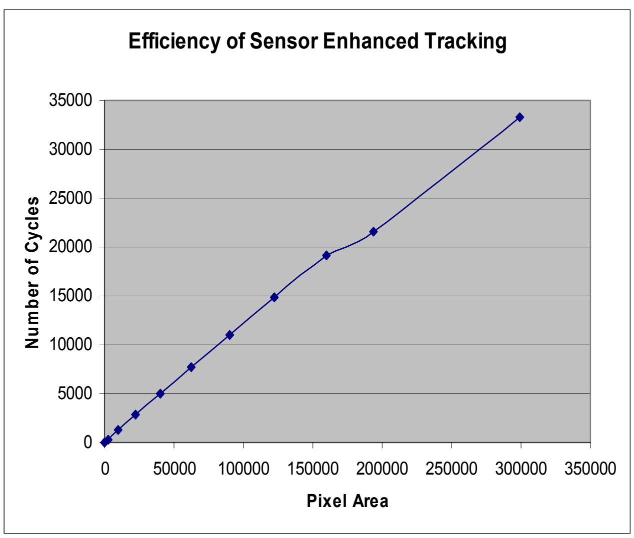

Figure 4. Computation cycles savings as the pixel area of the processing is decreased

The second graph in Figure 5 shows a quadratic decrease in the number of computation cycles as a function of the mobility of the patient, presented as the diameter of patient's movement in the frame. In the case of low mobility, such as with limited movement in place, there is 2,887 cycles/frame of computation. With high mobility, such as a brisk walk across frame, there is 14,791 cycles/frame of computation. Without any sort of mobility information, 33,319 cycles/frame of computation must be carried out for each frame. As expected from the first graph which has a linear relationship with area, this graph shows a quadratic decrease as a function of diameter.

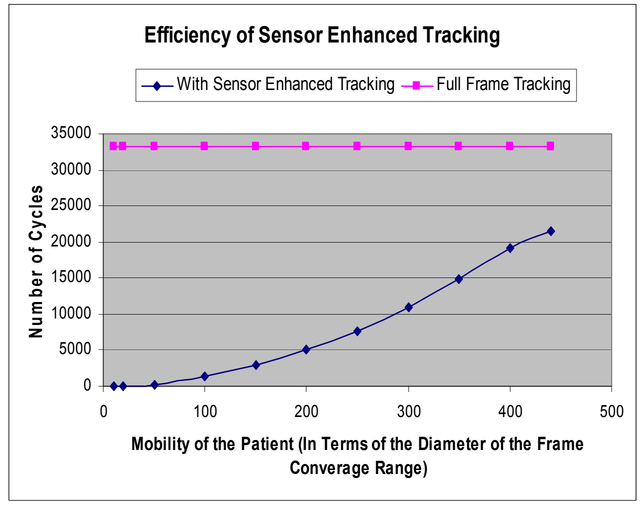

Figure 5. Computation cycles savings as a function of patient mobility

The results demonstrate that incorporation of the med node data provides a large degree of computation efficiency, which can be mapped to power savings or even the increased system functionality, during low mobility periods.

Additionally, the mobility information allows for error minimization in the tracking application, verification of inferences using redundant data, and finally in the future the compression and filtering of the large amount of data that is the result of continuous sensing.

6. CONCLUSION

In this paper, we presented a medical embedded tracking system that harnesses local, efficient sensor data to trigger and enhance the accuracy and efficiency of a patient tracking applications. We discussed the broad implications of developing such systems for extending in-home care for the elderly, by developing pervasive yet unobtrusive heterogeneous sensor data. The project involved the triggering by med nodes placed on the body of cameras equipped with reconfigurable devices to carry out various types of machine vision for medical sensing and monitoring. The experimentation demonstrated a quadratic decrease in computation cycles if med node sensing data was incorporated into the tracking application.

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