An In-Situ Disaster Prevention Framework with Sustainable Electronics and Cyber-Physical Systems

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Abstract—Landslides cause huge losses of life and property. Warning communities of the incoming hazards gives people enough time to remediate, safeguard things and abandon a site if needed. Emergency Response (ER) frameworks can be modeled as a Cyber-Physical System (CPS) with sensors and actuators for environmental monitoring. This article focuses on the instrumentation level of Visual Sensor and Actuator Networks (VSANs) using sustainable electronics and re-engineering to ease the complications brought in by the present economic crisis and scarce availability of financial resources. This approach examines ways that salvaged electronic components can assist distant to reach and economically deficient locations. The complexity of these systems and their necessity for self-sufficiency within the perspective of a developing country while keeping them maintainable and available to nontechnical workers poses challenges.

Keywords—landslide detection, motion estimation, emergency response, salvaged electronics, cyber-physical system, sensors, humanitarian engineering, green design.

I. INTRODUCTION

Landslide recognition and monitoring can be done two-fold: (i) via Remote Sensing (RS), and (ii) by in-situ measurements. The second category allows for more intensive reuse of electronic components, which leads to sustainable practices.

Nowadays, regions subject to landslides should consider not only social approaches to resilience, but also opportunities created through science and technology. A Cyber-Physical System (CPS) can improve greatly natural disaster resilience because its architecture along with its Sensor and Actuators Networks (SANs) can reduce the impact of an event [1, 4, 9].

Communication Networks regulate remote communication and information sharing among devices. Resource scheduling in shared SANs is challenging and plays a vital role in CPS operation. Actuation coordination is essential to schedule actuators for a particular action or to manage control actions properly. Decision Making requires a control unit to monitor and manage the overall CPS via communication among sensors and actuators.

This paper focuses on the development of an ER-CPS with in-situ sensors for landslide monitoring using salvaged
electronic components and re-engineering because this paradigm is very convenient to model the prevention, remediation, and adaptation to risks in underprivileged regions. At the instrumentation level, in-situ Visual Sensor and Actuator Networks (VSANs) can ease the problems brought in by the current economic crisis and scarce availability of financial resources.

This article is organized as follows. Section II explains a possible setup for an ER-CPS. Section III explains the concept of Optical Flow (OF). The use of OF Sensors (OFSs) made with sustainable electronics for landslide monitoring is described in Section IV. VSANs are described in Section V. Finally, Section VI brings in a discussion and conclusions.

II. EMERGENCY RESPONSE SYSTEMS AS CPSs

Emergency Response (ER) refers to handling the threats to public safety, health, and welfare and protecting the nature, properties, and valuable infrastructures. CPS can provide fast ER via a large number of sensor nodes in the areas subject to natural or man-made disasters. Nonetheless, this rapid response entails the nodes to collectively evaluate the situation and rapidly inform the central authority even in the frequently-changing environments. So robustness, efficient resource utilization, adaptiveness, and timeliness come into play in this ER [9, 10].

ER and disaster management have always drawn attention because of their societal implications. Emergency management in the future should adopt emerging ICTs and social media. Strong cooperation amongst emergency management professionals, local/national authorities, and the community are compulsory. The efficient use of forewarning, response, and recovery mechanisms is required in the future emergency management systems [4]. Unmanned aerial or ground vehicles can be deployed to provide efficient search and rescue efforts. New technologies having physical awareness can be integrated into the infrastructures to manage ER and disaster recovery in the future.

III. OPTICAL FLOW SENSOR AS DISPLACEMENT DETECTOR

Optical Flow (OF) methods date from the 1980s [5, 6] and many different implementations have been proposed since (e.g., [12, 13, 14, 15, 16]). They rely on radiometric differences between consecutive frames from a scene assuming constant intensity changes or corrected factors such as the imaging system and scene illumination. Let us consider the intensity at an image frame \( k \) at a pixel location \((x, y)\):

\[
I_k(x,y) = I_{k-1}(x-dx, y-dy),
\]

where \( d = (dx, dy) \) is the Disparity Vector (DV) or Motion Vector (MV) in the image space describing the transformation mapping \( I_k \) onto \( I_{k-1} \). For small offsets \( d \), this relationship obtained from a Taylor series expansion holds

\[
I_k(x,y) - I_{k-1}(x,y) \approx -d_x(x,y) \frac{\partial I_{k-1}(x,y)}{\partial x} - d_y(x,y) \frac{\partial I_{k-1}(x,y)}{\partial y},
\]

and it shows that the deformation between two frames is encrypted in the brightness differences. This expression yields an ill-posed problem, since only the parallel component to the image brightness gradient \( \partial I_{k-1}(x,y)/\partial x, \partial I_{k-1}(x,y)/\partial y \) of the MV can be found. With the help of a local window, the problem can be regularized, assuming that the disparity field is constant over a certain area (smoothness constraint) or using a global regularization methodology. Ideally, the performance should only be limited by the radiometric noise. The OF technique is effective to measure strain from photogrammetry, but it fails when the images have different view angles, the surface roughness at the pixel scale is large (e.g., with high-resolution imagery of important areas) or when the displacement field is locally discontinuous. OF is very sensitive to intensity variations not due to scene deformations. OF methods can model higher-order deformations, particularly, to measure locally affine distortions and to account for minor contrast variations [2, 3, 7, 8, 12].
IV. LANDSLIDE MONITORING

Landslides can completely wipe away houses and structures within seconds and inflict a tragic toll on communities. The motivation for early warning technology is to find a way to mitigate losses and save lives. Several types of pre-failure strains like elastic, plastic and viscous volumetric and shear tensions arise as initial indications of imminent landslides (Fig. 6 and Fig. 7). While the magnitudes of pre-failure strains are influenced by the rock or soil involved, they are measurable. Sensors can help to detect small changes in soil slopes that lead to the onset of landslides.

Although Digital Image Correlation (DIC) and photogrammetry from ground-based optical sensors are usually sensitive to meteorological conditions, they provide higher temporal and spatial resolution than space- and airborne systems, and therefore a better possible integration with other physical parameters measured in-situ. For qualitative monitoring of displacement patterns, a single monoscopic camera can be used. To reduce the need of an external DEM, stereo-camera arrangements are often used in experimental mechanics are currently being installed operationally on several landslides [2, 14, 17, 20].

An OF Sensor (OFS) from a computer optical mouse is suitable for displacement assessment because it is stable (please, refer to Fig. 4 and Fig. 5). This OFS uses a light source, typically an LED, and a light detector, such as an array of photodiodes, to detect movement relative to a surface [9, 11, 21, 22].

Salvaged optical sensors from computer mice can be part of an inexpensive tool to monitor particular environmental conditions such as landslides. The Real-Time Communication (RTC) functionality allows for date and time stamping of each data point to look for correlations or relationships within data. The increasing availability of sensors, actuators, and processing platforms make it easier to interface and share work to easily and quickly create functional solutions.

With proper selection, electronic components can be securely reused in low-cost applications, where tolerances are not particularly severe. Despite the low price of electronics parts, in developing countries, they are not easily found outside big cities. Hence, such recycling can reduce the impact on landfills and reduce the burden of remanufacturing the materials from electronic equipment. Accessibility through lower cost means an awareness boost of the environment care and perhaps better management of surroundings and resources.

V. VISUAL SENSOR NODES

Salvaged components can be used to build VSANs, where each node can have several types of in-situ sensors [1, 4, 9]. A simple one would use optical circuitry from optical mice to detect motion via optical flow and landmarks. Processing capabilities can also reuse microprocessors and microcontrollers. Some re-engineering could be done to adapt the communication interfaces such as ZigBee and Bluetooth. Energy harvesting technologies coupled with low-power low-cost visual nodes with sensing, information processing, and communication capabilities can acquire images, process them, and send mined information to each other and to some base station for additional analysis. Regrettably, the massive amount of data obtained from several similar VSANs and processed by the control units of other parts of the ER-CPS pose constraints on the decision making strategies. There are several challenges involved in the design and implementation of VSANs [10].
The number of sensors installed in studying several types of phenomena may be in the order of hundreds or thousands.

A typical VSAN controller (refer to Fig. 8) has an 8/16-bit microcontroller, some memory, and it processes and exchanges collected data during short active periods of time. A VSAN has long periods when it listens to the channel (idle periods) and it tries to keep its energy consumption appropriately small, so that it can work for a sufficiently long time. It is appropriate to preserve the same low-power characteristics in the design of VSANs, even though in this case more energy will be desired for information capture, processing and communication.

The actuator parts of the VSAN can be sound and visual alarms, servo-mechanisms that can interact with the physical environment, Unmanned Aerial Vehicles (UAVs), water drainage systems, pan/tilt cameras, robotic arms, etc.

VI. CONCLUSION

This paper focuses primarily on for the development of an ER-CPS with sensors and actuators for environmental monitoring applications. The prevention, remediation, and the adaptation to the risks of natural disasters in underprivileged cities and regions are considered. It addresses the instrumentation level of sensor networks using sustainable electronics and re-engineering to ease the problems brought in by the current economic crisis and limited availability of financial resources. This approach discusses how salvaged electronic components can be reused and help distant to reach and economically deficient locations. It is noteworthy to point out that sending such components to landfills is very dangerous. Reprocessing electronics components to extract and reuse materials can be difficult, especially in developing countries.

Ideally, in-situ and RS methods should be used together. Given the great variety of landslide methods and site features, it is difficult to evaluate the advantages and limitations of different combinations of RS technologies and their integration with in-situ and process-based models.

REFERENCES


