Human Activity Monitoring in an Intensive Care Unit Using 3D Perception Techniques

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Background: If you talk to most staff at a hospital's Intensive Care Unit (ICU) you will get the same story. Process is inefficient, everyone is very busy, and there is a lack of written direction. For every patient there are many hundreds of tasks that need to be completed by a team of up to fifteen staff members. These include actions like giving patients medication, emptying chest tubes, and documenting vital signs on a regular basis. Over the past few weeks I have been working with a team starting to help overcome some of these problems and recently traveled to the Johns Hopkins Medical Institute (JHMI) Pediatric ICU to talk with doctors and nurses about current hospital operations. It is apparent that vision-based activity monitoring may help determine tasks being performed and provide insight into making the ICU a safer and more efficient workplace.

Hypothesis: Activity analysis using 3D perception techniques can be used to monitor patient-staff interactions in a hospital's ICU with sufficient accuracy for physical deployment. This analysis can furthermore be used to keep a real-time record of daily activities and prevent problems like patient fall. Current processes are considered inefficient so a long-term overview of task execution can be used to create a more optimal staff workflow.

Research: Activity monitoring in video has been prevalent in computer vision over the past twenty years and is becoming an even greater area of interest. The recent advent of inexpensive 3D imaging systems like the Xbox Kinect brings a new dimension of data without relying on complex 2D camera meshes. While there has been a significant amount of activity recognition work based on video sequences, discussed below, new techniques will need to be developed to incorporate extra structure for the 3D paradigm. Using 3D data eliminates traditional video problems such as determining depth cues and makes segmentation less difficult, which will provide greater robustness to our algorithms. The goal is to determine a high level understanding of patient and staff interactions, thus having extra data and inherent structure will make this more feasible.

Current state of the art activity recognition algorithms vary depending on the level of task granularity and the types of interactions taking place. For individual actions, techniques using sequential methods like Hidden Markov Models (HMMs) and more advanced Linear Dynamic Systems have provided strong results [1]. Spatio-temporal techniques such as in [2] work well when analysing video with a large set of potential actions. Higher-level sets of actions have seen success using methods such as context free grammars and hierarchical graphical models, which encode each sub-action into a more broad "process" [3]. For further review of state of the art methods see [3]. Our problem features many small tasks that do not necessarily need to be grouped into a complex hierarchy, thus at the beginning focus will be attended towards sequential methods. My practical experience with these models includes implementing and evaluating a Hidden Markov Model for optical character recognition. Additionally, my development of hierarchical graphical models for object recognition may also be beneficial.

Similar work has been done in a mock operating room (OR) at the Technical University of Munich (TUM), in the "Aware Home" at Georgia Tech, and in the Quality of Life Center "Kitchen" at Carnegie Mellon. Recognition in an ICU is different than these in part because of the types of interactions involved. We have three main action types: patient, patient-staff, and staff-device. Tasks can happen in a variety of physical locations and sometimes rely on subtle differences in appearance. Actions in the OR, in contrary, happen in close proximately to each other and are defined more by acute hand motions. Work in the Aware Home features a similar workspace but relies on 2D video for unsupervised learning. The Quality of Life Center uses a suite of sensors including an Inertial Measurement Unit to recognize human action with greater accuracy.

There are two key applications that activity monitoring has in an ICU. The first is to prevent problems from occurring in real-time. There are certain actions that should not happen over the course of a stay such as the patient leaving their bed. According to doctors in the JHMI ICU, there are many cases where a patient will try to get up and accidentally slip and fall. This can be prevented if a nurse is alerted whenever a patient tries to leave. The second application is analogous to a black-box flight recorder. An activity log can be created and accessed retrospectively in order to analyze procedure efficiency and look at specific cases where procedure went wrong. This can be used to prevent future problems and recognize where processes can be changed.

Having a high-quality dataset for training and testing is very important for model generation and validation, thus our system incorporates multiple phases. In late 2011, data will be collected at the Johns Hopkins Medicine Simulation Center where the same situation, such as chest tube placement, can be monitored multiple times. The procedures carried out in simulation are representative of the real ICU and, because of the repetition, are ideal for cross-validation. Later in the study we will record data inside the ICU at the medical campus to get more varied and realistic data.

While ideally we would like to use more information than just a 3D sensor, like vital signs, currently it is not feasible. As part of the High Tech ICU project we are developing a system to do this. Thus, in the future we will seek to incorporate vision and other medical devices into this recognition system. It should also be noted that we will leverage Point Cloud Library (PCL), a new set of tools for working with 3D data, which is maintained by Willow Garage. We intend to use and extend the capabilities of PCL for our research on activity recognition to help the 3D perception community. My current experience is in implementation of a 3D feature detector for my Parallel Programming class which will be contributed to PCL and may be used for our project.

Research Support: For this work to have a notable effect there needs to be close interaction with individuals at the medical campus and other organizations. I have already been in contact with Dr. Jim Fackler who is a research faculty member and a doctor at the pediatric ICU. I am working with a group from the Applied Physics Lab and Systems Institute who are creating a High Tech ICU and am extending their scope by adding a vision component for task analysis. At Johns Hopkins there are a number of faculty members who are capable of mentoring this project including Dr. Russ Taylor, Dr. Greg Hager, Dr. Rene Vidal and others who are working on activity recognition with time-series data and general computer integrated medicine. Additionally, I have access to the ICU at the medical campus and test beds at the simulation center. My experiences working on 2D and 3D computer vision problems in the past have given me the abilities to continue in this direction.

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