Monitoring Practitioner’s Skills in Pure-Tone Audiometry

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ABSTRACT

So far, there exists no standard, to evaluate a practitioner’s skills in pure-tone audiometry. To narrow the gap, this article presents an artificial patient (AP) emulating various types of hearing impairment. In contrast to other solutions, the AP autonomously listens to real pure-tones in soft real-time, while taking into account elements from psycho-acoustics. The emulated patient profiles are reproducible. New profiles can be easily added. The AP is able to recover from error. In this contribution, the authors develop software requirements specifications and derive a modular system architecture. To analyze the performance, the article proposes a stochastic extension to existing synchronous data flow graphs, taking into account the unbounded nature of the tasks’ worst case response time. Maximization and summation over the graph reveals the joint distribution of the response time with first and second central moments corresponding to, respectively, the expected response time and the jitter of the task. The theoretical results have finally been validated by measurements on the target.

KEYWORDS
Artificial Patient, Data Flow Graph, Medical Robot, Real Time

INTRODUCTION

Background

Medical malpractice is a rising concern to all healthcare providers. “Otolaryngologists have not been immune to the acceleration of the malpractice crisis” (Hong, Yheulon, Wirtz, & Sniezek, 2014). Medical errors not only contribute to wrongful death and injury of people, but they add more expenses to an already inflated healthcare cost structure. For the USA alone, it has been estimated that a minority (7%) of all malpractice lawsuits reach trial, with only 18% resulting in a plaintiff verdict, topping USD 100 million in just a 6-year period from 2000-2005 (Hong, Yheulon, Wirtz, & Sniezek, 2014). The situation in the European Union is similar. The two top legal allegations against the defendants are failure to supervise and inadequate training. Focusing on the latter in pure-tone audiometry, the question arises as to what kind of standard is applicable to evaluate the skills of a practitioner? Currently, there is no such available. Quality of medical services depends on knowledge and skills.

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Related Work

To develop clinical reasoning skills in pure-tone audiometry while avoiding the costs implied by long test sessions with real patients, several patient simulators were developed over the past years (Round, Conradi, & Poulton, 2009). Among them are Otis - The virtual patient (Innoforce Est., 2013), AudsimFlex (Nova Southeastern University, 2015), and Audiology Clinic (Parrot Software, 2009). To comply with the test procedure in New Zealand, Heitz developed in (Heitz, 2013) the Clinical Audiology Simulator (CAS) complying with the test batteries by the New Zealand Audiology Society. All these patient simulators never make mistakes, as they only simulate hearing thresholds in noise-free environments without considering the patient behavior. To close this gap, an autonomous artificial patient (AP) mimicking the patient’s hearing thresholds and psychoacoustics in real-time and real-environments is sought.

There exists a large number of integrated development environments. To design applications that require test, measurement, and control with rapid access to hardware, Laboratory Virtual Instrumentation Engineering Workbench (LabVIEW™) is ideally suited (Vose & Williams, 1986). LabVIEW™ is based on a graphical dataflow environment developed by National Instruments and comes shipped with a real-time module, to create life-critical applications such as that of a full-flight simulator (Keenan, 2008). In such cases, the programs run on stand-alone embedded hardware targets such as Ardence Phar Lap ETS, Wind River Systems VxWorks, or NI Linux Real-Time Operating System (RTOS). When reliability of software is soft-critical such as user experience in e-health applications (Raval, Sakinala, Jadhav, & Karia, 2017), LabVIEW™ code may be executed on a General-Purpose Operating System (GPOS) in soft real-time, bypassing the constraints of the RTOS module. That implies incorporation of optimized C-code as Dynamic Link Library (DLL) within the VI, de-allocating memory for temporary variables inside the DLLs, and fixed-point arithmetic operations for the code (Peddigari, Kehtarnavaz, & Loizou, 2007). The performance of the code could be notably improved with parallel computing. However, a small number of specialized developers has only considered this option, so far.

Data flow models and their corresponding analysis methods can be used to derive a periodic schedule at compile time, guaranteeing hard real-time threads meet their deadline (Lee & Messerschmitt, 1987). To schedule a streaming task across multiple processors sharing memory without contention, the original Synchronous Data Flow (SDF) graph is transformed into a Directed Acyclic Graph (DAG) that not only exploits functional parallelism but also data parallelism (Pino & Lee, 1995). When executed in soft real-time, the task still has the same schedule but different response time, mainly because the worst case response time is unbounded as the scheduler meets deadlines only in a stochastic way. Current design practice for minimizing the system latency is to i) either annotate each actor in the SDF graph with the worst case response time obtained by simulations and then, use the properties of the graph, to obtain the worst case response time of the entire task (Bekooij, et al., 2005); or to ii) assign a stochastic response time to the entire task (Maxim, 2013) without exploring the properties of the underlying graphical model. In both cases, the predicted task latency is sub-optimal.

Contribution

In (Kocian, Cattani, Chessa, & Grolman, 2018), the authors proposed a multiple-input multiple-output (MIMO) auditory hearing model containing elements from psychoacoustics, developed a hardware realization, and verified its functionality. This paper presents the software architecture of the AP and evaluates its performance theoretically as well as by measurements. In contrast to other solutions, the proposed is based on a theoretical framework supporting physical as well as psycho-acoustic parameters. Moreover, our AP is able to handle not only ipsilateral but also contralateral air and bone conduction testing. The modular software architecture is built on adaptability, autonomy, consistency, extensibility, reactivity and robustness, hosting general-purpose tasks such as operator interfaces and databases but also time-critical tasks such as audio streaming and actuation. The code
Using a Public Key Registry for Improved Trust and Scalability in National E-Health Systems
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