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Improved Microcontroller-Based Electronic Respiratory Training

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Abstract—**Respiratory training is a critical component of many rehabilitation plans, including those of stroke patients. Many current respiratory training techniques lack efficient methods for quantifying progress and updating testing parameters. A previously-developed microcontroller-based device, designed in conjunction with clinicians at the Institute for Rehabilitation Science and Engineering at Madonna Rehabilitation Hospital, has demonstrated promising results. Here, a prototype of a revised device that is network connected and remoatly sends trial information is presented.\ The proposed device demonstrates enhanced functionality, while being smaller and using less power than the original prototype.**

I. Introduction

SOME neurological conditions can affect respiratory drive and therefore cause speech impairment. Alveolar air pressure varies during speech – increasing sharply at the start of an utterance and then staying constant for the duration of that utterance – and can be used as an indicator of respiratory drive [1]. Intraoral air pressure during the production of voiceless plosives can in turn be used to assess respiratory support for speech.

There have been several attempts to use Intraoral air pressure to improve respiratory therapy, including biofeedback “blow-bottle” approaches [2], [3]. While these approaches are effective, they lack the ability to collect performance data or individualize the trial specifications including trial duration and upper/lower pressure thresholds. And while there are systems that do not have those downsides[4], they usually are not portable, and thus patients cannot practice at home. With the proliferation of network attached devices, including remote data logging functionality to such a system so that it can remotely upload trial results to a central server is both desired and necessary.

Here, a portable network connected respiratory training device is presented that is easy for patients to use at home but has the ability to collect trial data and set trial specifications remotely. In this paper we will present our prototype, developed on a 32-bit microcontroller with a graphical liquid crystal display used for feedback.

A. Previous Work

The Aerowin RT [4] is a full featured aerodynamic test suite. Using a National Instruments 16-bit I/O card hooked up to a desktop computer’s PCI slot, it collects data on air pressures, flow, airway resistance (including nasal cavity, velopharyngeal, and laryngeal airway resistance), and audio levels. It collects these measurements as the user is speaking over a several minute session. The system is designed to be used in a laboratory setting to diagnose speech disorders and allows the clinician to design test protocols.

A portable device called the Madonna Expiratory Respiratory Trainer (MERT) has been presented before [5]. MERT was designed to be a take-home system that users could operate with out the supervision of a clinician, but that still recorder trial data for later analysis. That system is housed in a 20 × 15 × 7.6 cm box that is powered by two AAA batteries. The system uses a PIC18F 8-bit microcontroller that operated at 20MHz and has 32KB of on-board flash memory. This portable system can hold up to 40 trials before needing to upload the trial data to a computer via a serial port. The trial data can be opened in a LabVIEW program that provides a graphical view of the data for each trial. The software also allows the device to be programmed with individualized therapeutic regimens, including pressure thresholds and trial durations. While this system was an improvement over other attempts it had some core problems. It was not wirelessly network connected and instead needs to connect to a computer over RS-232. And while it is more portable then the Aerowin RT, it is still has a large form factor and is power inefficient.

The device has a pressure sensor, a power switch, two push buttons, a monochromatic, character based, liquid crystal display, and 12 LEDs. One of the push buttons is used to start a trial. The user breathes into a rubber hose connected to the pressure sensor. The color-coded LEDs provides feedback on his or her expiratory pressure compared to the target pressure. This system can be seen in Figure 1.

B. .NET Micro Framework

Traditional embedded applications are written in low-level ANSI C. While this can allow for more efficient applications, it has longer development times when compared to higher level languages. Microsoft’s open source .NET Micro Framework (NETMF) aims to expedite the development process of embedded platforms by leveraging existing .NET ecosystem technologies [6]. It uses a version of Microsoft’s Common Language Runtime (CLR) that only needs 256 KB of flash and 64 KB of RAM while still having many of the CLR libraries used in the full version of .NET Framework. It has become

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Figure 1. Existing MERT device with its monochromatic LCD, two button interface, and large form factor.

popular for investigating or developing low-power wireless systems [7]. NETMF has also proven useful in developing mobile medical systems for monitoring ECG signals [8], even under real-time constraints [9].

Another issue with embedded platforms is prototyping hardware. While many processors are available on manufacturer-supplied development kits, these kits rarely provide the sorts of hardware peripherals needed to fully implement a prototype of the embedded system, and instead are designed moreso as a marketing tool to advertise the functionality of the device; not to actually provide a useful platform for prototyping.Therefore, much time is spent designing and debugging these hardware platforms – platforms that, by and large, are modular and reuse blocks of functions. .NET Gadgeteer is an interoperability standard of hardware and software to make prototyping with NETMF easier [10]. The Gadgeteer standard defines “sockets” that allow peripherals to interface with the system processor on a Gadgeteer main board. Microsoft has built an add-on for NETMF and Gadgeteer into Visual Studio, which gives the whole ecosystem a familiar and easy-to-use integrated development environment. Gadgeteer and NETMF can dramatically speed up development of networked attached embedded systems, particular for the Internet of Things [11].

II. IMPLEMENTATION

For many of the reasons stated previously, we chose to develop the system using NETMF on a Gadgeteer board. The FEZ Hydra from GHI was selected as the mainboard for its ability to support a liquid crystal display. There are currently several other Gadgeteer mainboards on the market, but the FEZ Hydra was also chosen because it is the fastest and is completely open source. The FEZ Hydra has an ARM9 processor running at 208 MHz, with 16 MB SDRAM and 4 MB flash memory. The GHI T35 Display Module – a full color, 320x240 pixel, 8.9 cm liquid crystal display– was used to provide a graphical interface to the user.. The same Honeywell 164PC01D37 differential pressure sensor used in the previous MERT device was used for sensing expiratory pressure. The hardware for the prototype can be seen in Figure 2. This hardware system cost slightly more than $200.

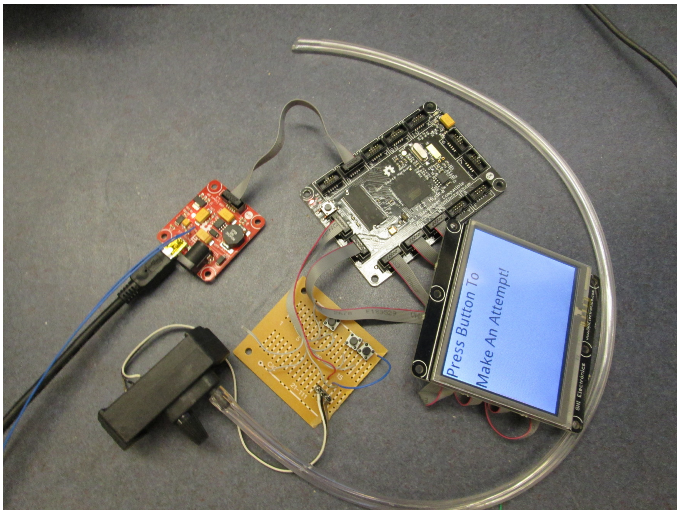

Figure 2. Prototype hardware consisting of (clockwise from top left) USB power supply, FEZ Hydra main board, T35 LCD, Costume built UI board, and the Honeywell 164PC01D37. The WiFi module is not shown.

A. *User Interface Overview*

The device behavior and graphical user interface were modeled after the previous MERT device which was designed with input from a speech language pathologist and individuals with motor speech disorders [5]. The proposed device is designed to be simple to operate: a trial begins with the push of the start button; a countdown screen appears, preparing the user for the trial; once the trial begins, two bar graphs appear – one indicating the goal pressure and one indicating current pressure on the pressure sensor. The user tries to match the two bar graphs by blowing into the rubber hose attached to the pressure sensor. During the trial, another countdown timer informs the user of how much of the trial is left. Once the trial ends, the cumulative deviations from the goal is shown. The device is ready to start another trial, initiated again by the user pressing the button. The bar graph feedback system is shown in Figure 3.

B. *Networking and Server Infrastructure*

Wireless connectivity is provided by a GainSpan GS1011MIPS. The GS1011MIPS is a WiFi Module that supports data rates up to 11 Mbps and is compliant with 802.11 b/g/n wireless networks. The device is designed to remotely upload trial results to a database for analysis.

III. METHODS

To test the portability and effectiveness of our new system, several characteristics were compared, including volume, memory, and power consumption. The volume was computed from measurements of the parameter of each device and the power consumption was measured as a trial was running. The ease of prototyping new features was also compared.

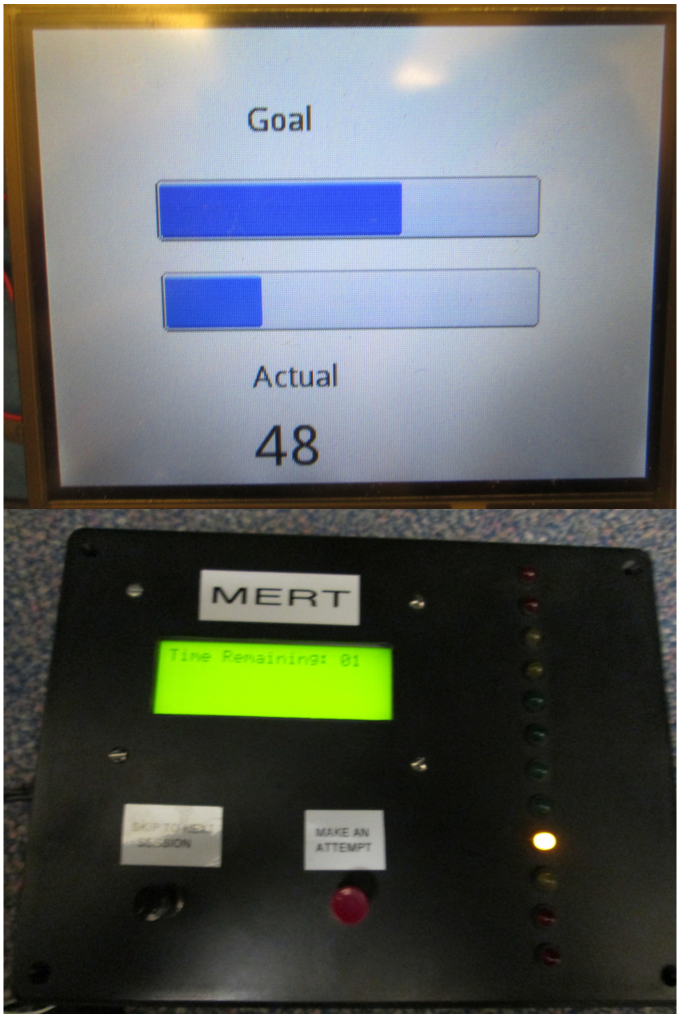

Figure 3. Above: Bar graphs representing goal pressure and current pressure give the user feedback on trial progress. Below: The user interface of the old system consisting of a series of LED indicating pressure level in relation to the goal pressure.e

IV. RESULTS

The new systems outperforms the previous MERT device in several quantifiable ways. The MERT device used nearly three watts of power and could only store 40 trials at a time. The new system uses only 1.25 watts and has 4 MB of FLASH memory, nearly eight times that of the MERT device. The MERT device takes up 2280 cubic centimeter, while the new system takes up no more then 500 cubic centimeters. The size comparison can be seen in Figure 5. The decrease in size and power consumption coupled with the increase in memory over the MERT device make this system considerably more portable.

Qualitatively, the new system outperforms the previous MERT device in that is much easier to add new features and its potential for future development. The MERT device, conversely, would be rather difficult to add new functionality to, since its firmware is written in C and is running on an 8-bit micro controller. The comparison between the two devices is summarized in Table I.

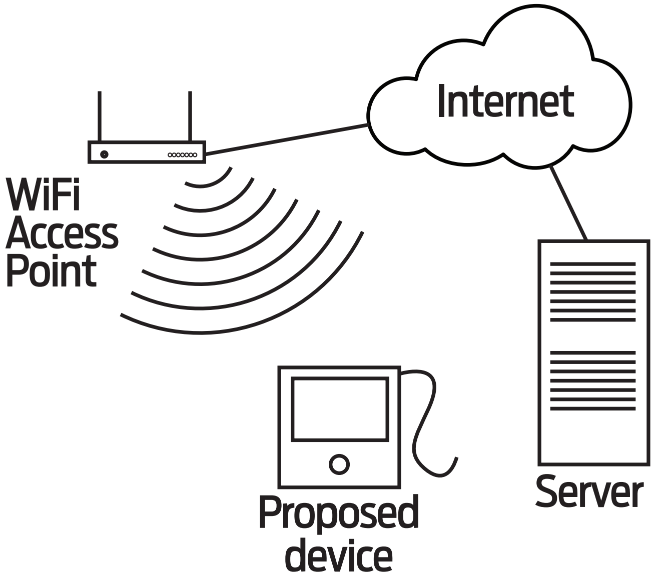

Figure 4. The proposed device uses WiFi to connect to a central sever to transmit trial information and receive trial parameters.

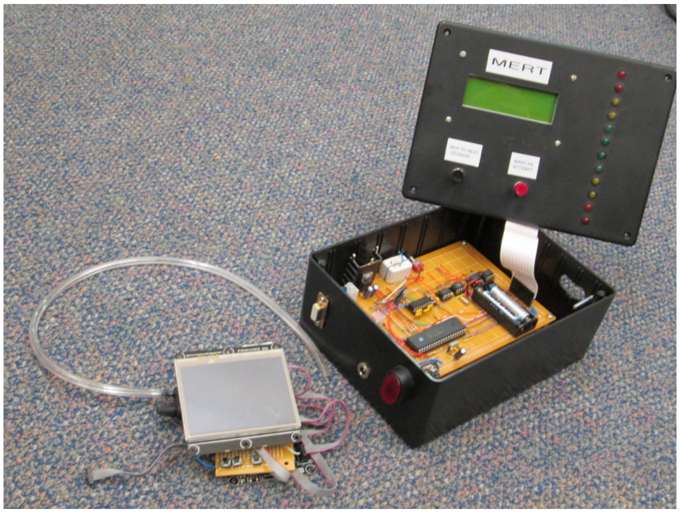

Figure 5. Visual size comparison between MERT device and prototype device.

V. CONCLUSION

These results show that the new system succeeds at being portable and flexible. It compared favorably against the previous MERT device in both terms of portability and performance. While it is not designed to replace a diagnostic device such as the Aerowin RT, these results show it has the promise of supplementing this those device by enabling

Attribute	MERT device	Our device
Power (W)	2.93	1.25
Memory (KB)	256	4096
Volume (cubic cm)	2280	418

Table I
PHYSICAL ATTRIBUTE COMPARISON BETWEEN MERT DEVICE AND OUR DEVICE

patients to receive respiratory therapy sessions away from a clinical environment. It also has shown the ability to allow clinicians the ability to individualize care.

A. Future Work

Future work will including adding further wireless functionality, such as adding ability to remotely change trial parameters. Work will also include improving the interface that clinicians use to aces the database, allowing for various forms of trial analysis.

The current prototype has no enclosure and has rudimentary input hardware. Designing hardware for users who potentially have poor motor skills is a difficult challenge that requires the consideration of many facets of human factors and ergonomics. The system presented in this paper was designed to be portable, but to ensure usability the enclosure and user interface will need to undergo an iterative design process with feedback from potentially users and caregivers.

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