Utilizing Paper Microfluidics in the Design of Wearable Biosensors

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Abstract

Modern biosensing technology has applications in many fields including, agriculture, mining, health, and fitness. However, the products currently available do not utilize the full potential of the technology. There are not many marketable designs that are affordable, user friendly, and capable of delivering accurate, onsite readings.

The purpose of our work was to successfully fabricate a wearable biosensor that measures the levels of lactate present in human sweat. The primary variables were the width of the lateral assay channels, the volume of the pump's well, and the arrangement of the paper pumps. The optimal result would be a design that transfers a target flow rate of sweat through the lateral flow assays to each well over a consistent period of time. A paper microfluidic approach will be implemented in the design allowing for an affordable and possibly disposable product.

Introduction

Paper microfluidics is an emerging field with a wide range of applications particularly in the development of point-of-care testing. Due to the limitations associated with time, expenses, and travel in many regions of the world, reliable PoC testing via microfluidics presents an opportunity to revolutionize healthcare models in these parts of the world. Paper microfluidics lateral flow assays can be coupled with electrochemical, optical, colorimetric and fluorescent detection processes through nanoparticle enhancements (1) which enable them to be used to sense a host of different analytes. Our work this summer focused on applying these techniques in the design of a colorimetric lateral flow assay for a lactate biosensor.

Why Lactate detection?

The presence of lactate in sweat correlates with muscle exertion (2). There may be a relationship between sweat lactate levels and blood lactate levels(3).

Darcy's law was used in determining the capillary flow in the different microfluidic channel designs throughout the experiment. Two hypotheses were formulated when determining the flow rate of the different microfluidic channels.

1. If the channel width is increased, then the flow rate will increase.
2. If the volume of the well is increased, then the fill time will increase.
3. By manipulating the width and volume of a system of pumps can be designed where each has approximately the same fill time.

Procedure

1. Channels were designed in Solidworks.
2. Both sides of the cut paper channel were covered with adhesive.
3. Design was printed using the Silhouette paper cutter.
4. Adhesive layer was removed from the entry point.
5. Dyed water was dropped on the entry point and timed.

6a. Time was marked at two different points in the channel to determine flow rate

6b. Time was marked when the solution reached the end of the channel.

7. Time was stopped and recorded when it completely filled the well.
8. The process was repeated for a network of pumps.

Data / Observations

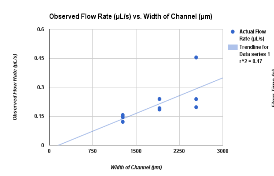

Figure 1: Flow rate vs. channel width.

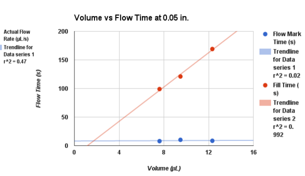

Figure 2: Flow time at channel width 0.05 in.

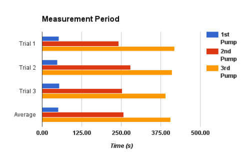

Figure 3: Measurement period.

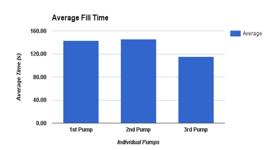

Figure 4: Average fill time.

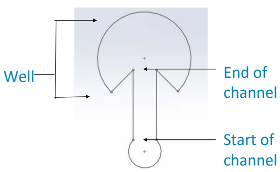

Figure 5: Microfluidic pump.

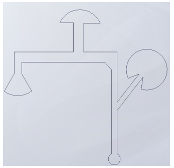

Figure 6: Final microfluidic network design.

Conclusion

Each design had either the shape, size, or configuration of its paper pumps varied so as to determine the effect of each variable on the flow rate of sample solution through the paper pump. There was a clear correlation between the width of the channel and the observed flow rate as seen in Figure 1. The initial hypothesis was supported in that the flow rate increased with the channel width. When keeping the channel width constant it was also observed that there was no change in the flow rate. As a result the time necessary to reach from one end of the channel to the other only increase if the volume of the well increased as seen in Figure 2.

Finally the well volume and channel widths of pumps in a system were manipulated until a combination where each pump had a similar fill time was discovered. The average fill time for each pump in the final design can be found in Figure 4.

Future Directions

1. Coat lateral flow assay with colorimetric indicator
2. Extend pump fill times
3. Increase the consistency of each pumps fill time
4. Analysis of other biochemicals
5. Multiplexing (analysis of multiple biochemicals at simultaneously)
6. Incorporation of multi- layered channels
7. Utilize other detection processes (electrochemical, optical, fluorescent etc.)

Works Cited

- 1.Ge, X., Asiri A.M., Du, Dan., Wang, S., Lin, Y., (2014). Nanomaterial-enhanced paper-based biosensors. Trends in Analytical Chemistry, 58, 31-39. http://dx.doi.org/10.1016/j.trac.2014.03.008
- 2.Falk, B., Bar-Or, O., MacDougall, J. D., McGillis, L., Calvert, R., & Meyer, F. (1991). Sweat lactate in exercising children and adolescents of varying physical maturity. *Journal of Applied Physiology*, *71*(5), 1735-1740.
- 3.Sakharov, D. A., Shkurnikov, M. U., Vagin, M. Y., Yashina, E. I., Karyakin, A. A., & Tonevitsky, A. G. (2010). Relationship between lactate concentrations in active muscle sweat and whole blood.

Acknowledgements

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Dynamic Periphery Display: Enhancing Pilot Decision Making in Simulated Flight

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Mentors: Christina Bloebaum, PhD, Elliott Tibor, Christopher White

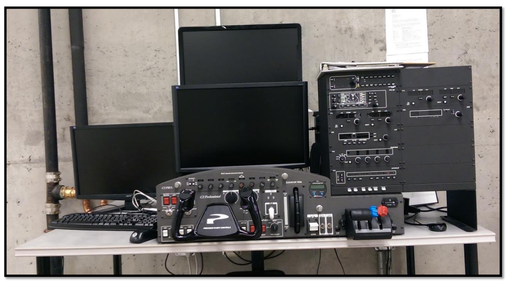
Funded by NSF Grant CNS-1156841

Motivation

High Cognitive Load for Training in Flight Simulators

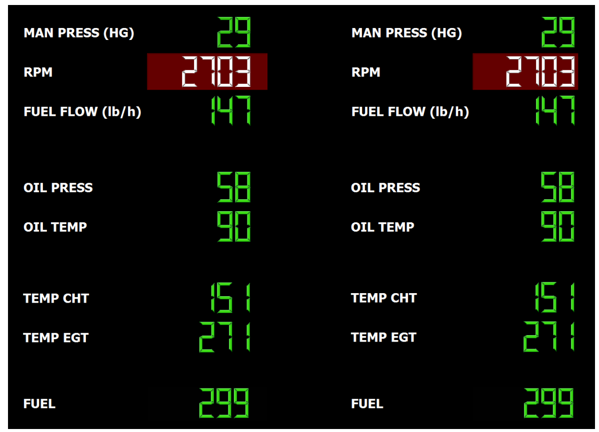
- Heavy stream of aircraft data
- Inconsistent instrument layouts across different aircrafts
- Ineffective analog gauge design
- Complex tabletop simulator controls

FAA-Certified Table-Top Flight Simulator



Simulated Cockpit of Beechcraft B58

Dynamic Engine Gauge Interface



Development

Goal

Create a dynamic interface to enhance flight trainee's decision making during flight simulation

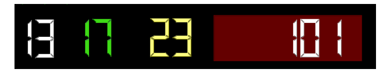
Design Framework for Enhancing Decision Making

- Gestalt Grouping
- Proximity Compatibility Principles
- Component Arrangement Guidelines
- Situation Awareness Design Heuristics

Application Features

- Digital readings for accurate state access
- Account for failure of system components
- Color emergence for status reporting
- User-centered and task-sensitive layout
- 8 fundamental engine gauges for B58 aircraft

Peripheral Warning Cues



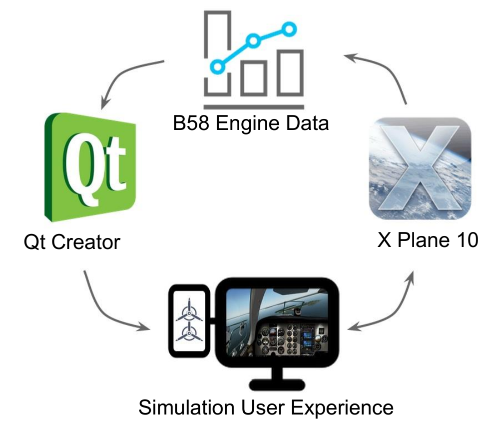
White = idle

Green = healthy engine state

Yellow = cautionary

Flashing Red = dangerous engine state, take action

Data Transfer Process



Future Work

Research

- Perform user experimentation in Aerospace classroom
- Evaluate system with computational models

Expansion

- Commercialize for classroom environments, if found effective
- Adapt for physical aircrafts to improve pilot Situation Awareness
- Incorporate heads-up flight instruments

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Limitations of Microsoft Kinects for Controlling Virtual Environments

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Introduction

Commodity tracking devices are starting to be used to accommodate demands outside the entertainment industry. The benefits of using such devices within Virtual Environments (VEs) could outweigh their limitations, and surpass the benefits of more expensive devices if enough research is conducted [1]. Latency, a common limitation, can cause simulator sickness, nausea, etc., [2, 3]. Previous researchers focused on the latency of HMDs [2, 3], but this study focuses on body-based devices. This research determines the limitations and advantages of using body-based, commodity tracking devices for controlling VEs by studying latency of the Microsoft Kinect.

Results

Test #	Wood (ms)
1	108
2	80
3	98
4	96
5	102
Avg.	96.8

Table 1. Results of latency for one condition using the Kinect v1

Test #	Steel (ms)	Wood (ms)
1	132	136
2	122	116
3	128	112
4	126	118
5	126	114
Avg.	126.8	117.2

Table 2. Results of latency for two conditions using the Kinect v2

The above values represent the latency for the Kinect v1 and Kinect v2. This latency value includes the latency from the computer. The Kinect v2 had a higher latency value which may have been caused by the processing power needed to handle the greater amount of data emitted by the Kinect v2.

Methods

Latency

High speed camera captures frame number from Kinect

Kinect frame number is compared to the high speed camera frame number

Figure 1. Experimental setup

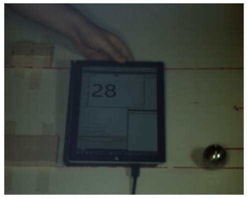

Figure 2. Frame from high speed camera recording

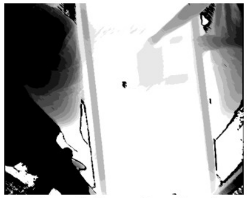

Figure 3. Frame from Kinect camera recording *(photo is enhanced for clarity)*.

Demo Application

Incorporates object manipulation: scaling/moving objects in a VE

Conclusion

The results from this study show that latency is worth researching for the Kinect v1 and Kinect v2. Meehan, et. al [3] suggest that latency above 120 ms is problematic for users. While other tolerance values exist, this highlights the importance of latency in commodity virtual reality systems. Based on this study, the Kinect v1 is below this threshold value, while the Kinect v2 is above it. However, future studies should examine the latency of other interaction modules, such as skeletal tracking.

Future Work:

- Accuracy of Microsoft Kinects
- Crosstalk of networked Kinects
- Effects of latency/accuracy on users for demo app

Acknowledgements

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References

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[3] M. Meehan, S. Razzaque, M. C. Whitton and F. P. Brooks, "Effect of latency on presence in stressful virtual environments," Proceedings of IEEE Virtual Reality 2003, pp. 141-148, 2003.

NSF

Iowa State University
Virtual Reality Applications Center

Designing a Rhino® Plug-in for Isogeometric Analysis

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Alexis Moreno, *Iowa State University*
Mariama Wilson, *City College of New York*
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Ming-Chen Hsu Ph.D

Overview

Engineers and analysts do not have the required tools to communicate:

- There are currently no options for FEA in CAD.
- The CAD-to-FEA integration introduces error.

One solution that has been shown to significantly reduce error is the use of isogeometric analysis (IGA) on designs.

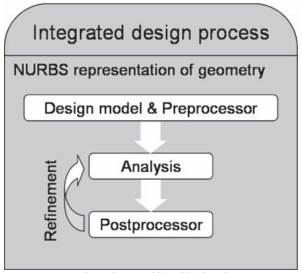

Fig 1. Design process of CAD and CAE integration

Schmidt, R., J. Kiendl, K. U. Bletzinger, and R. Wüchner. "Realization of an Integrated Structural Design Process: Analysis-suitable Geometric Modelling and Isogeometric Analysis." *Computing and Visualization in Science* 13.7 (2011): 2. 14 Jan. 2011. Web.

Motivation

Isogeometric analysis is used for a more precise analysis of objects:

IGA relies on the use of NURBS which are accurate representations of curves.

Develop a Rhino® plug-in that will perform IGA on a CAD program.

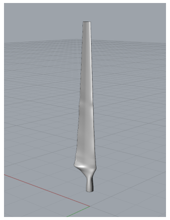

Fig 2. Rhino® model of S809 wind turbine

Materials & Methods

C# is the main programming language of the isogeometric analysis plug-in:

- Can be compiled on a wide range of computer platforms.

Rhino® is a 3D modeling software for producing curves and surfaces:

- Only CAD software that supports user developed plug-ins.

Grasshopper™ is a visual programming language plug-in:

- Allows members to engage in the development process in a non-trivial manner to produce faster prototyping.

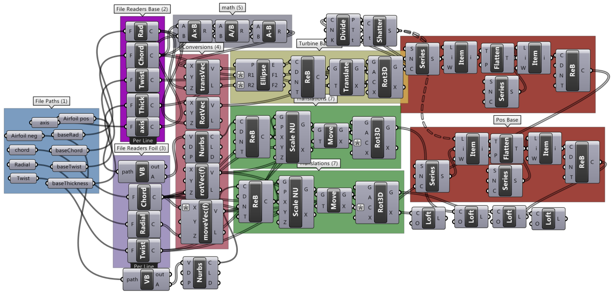

Fig 3. Grasshopper loop function for S809 wind turbine.

Results

A successful script was created to design a wind turbine blade using Grasshopper™. The S809 airfoil was used for a design because this airfoil incorporates all important functions within the program such as moving, scaling, and rotating. After programing the interface needed to be designed. The interface gives users the flexibility to have multiple cross sections of their desired object.

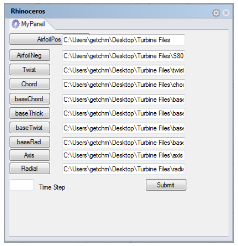

Fig 4. Sample plug-in interface

Future Work

After creating the first version of the plug-in, many steps have to be taken to guarantee maximum user experience of the interface:

- GUI development (design layout and interface changes)
- Drag-and-drop functionality
- Greater range of analysis options
- User testing (Fitts' Law analysis)
- T-spline analysis support
- Brower-based IGA

Iowa State University

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