Thesis Portfolio

Voice Restoration Device Using Machine Learning of Acoustic and Visual Output During Electrolarynx Use

(Technical Paper)

The Digital Age and the Insufficiency of HIPAA in Protecting Virtual Data

(STS Paper)

An Undergraduate Thesis

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Sociotechnical Synthesis

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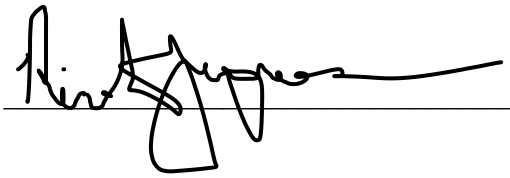
Signature:  Date: 4 May 2022

Introduction

Research guides the knowledge that society has, especially medicine and healthcare. Healthcare is an ever-evolving field of continuous collaboration and innovation. This innovation and progress primarily stem from the increase in data needed to understand new phenomena. With this increase in data, there has been so much computational innovation, coupled with exponential increases in computing power and processing capabilities. This innovation has allowed for innovative applications of biomedical research for direct healthcare applications. Each year, approximately 3,000 people undergo total laryngectomy for laryngeal cancer, a major source of speech dysfunction (Kohlberg et al., 2016). After the procedure, patients are unable to phonate, requiring alternate methods of communication such as the electrolarynx. The electrolarynx, first introduced in the late 1920s, relies on a single frequency vibration transmitted via an external device to the oral and pharyngeal mucosa, which results in monotonic robotic voices and limitations in tonal languages. (Rameau, 2020). The technical portion of this thesis focuses on applying computational methodologies, specifically machine learning, to improve the usability of the electrolarynx to ensure proper quality of life for patients. The trained Deep Neural Net (DNN) that will be implemented will be able to interpret visual and auditory data- from laryngectomees using electrolarynxes- to produce computer-generated, intelligible speech. With this innovation, laryngectomees will be able to communicate easier with less hassle, reducing the limitations that come with an inability to speak. However, it is important to be cognizant of the drawbacks that the digital age brings, such as an increase in data breaches and more prevalent privacy issues. The STS research of this thesis discusses the need for preserving privacy and security when using patient data for biomedical research through the analysis of the The Health Insurance Portability and Accountability Act (HIPAA) bylaws, last updated in 2013. Since then, the predominance of technology in every sector of the world, especially healthcare, has increased exponentially. This invisible network of data has expanded the possibilities for collaboration and advancement, while revealing more pathways for breaches and unlawful access. As we recognize the positives in which technological advancement helps us innovate, it is important to understand that with

every new idea and innovation, there will be new risks and problems that must be addressed and mitigated to prevent distrust and abuse (Patil & Chakrabarti, 2021).

Topic Synthesis

The technical portion of this thesis resulted in the development of two separate algorithms. Ultimately, the goal was to individually process each portion of the patients' videos-audio and video- separately using different DNNs and then combine the two algorithms into one cohesive algorithm that would be able to process audio and video together. However, because of the structure of the data and the complexity of the original goal, this project has resulted in a separate video and audio pipeline. The video processing portion used software known as DeepLabCut, which accurately tracked the movement of the lips of the patients in the given data (Nath et al., 2019). For the audio portion of the technical project, there were multiple pathways taken due to the complexity of noisy audio labeling with machine learning; sadly, no tangible results were obtained. In the end, it was concluded that the methodology for data collection would have to change to provide a more consistent and simple dataset that could be used for the initial development of a model.

The STS research I conducted in this thesis analyzed the history of HIPAA and the foundation it provided in defining the methodology for protecting patient data to determine how effective it was currently since its last major update was in 2013. Through various case studies, it was clear to see significant gaps in the regulation's definition, which inevitably resulted in numerous privacy breaches, exposing millions of American lives. With a thorough analysis of how privacy-protecting was described, the idea of including the concept of differential privacy, a PPDM, into the bylaws of the HIPAA privacy law was proposed (Clifton & Tassa, 2013). This new legislature, which discusses this state-of-the-art security algorithm, will supplement the syntactic model encryption design already included within the law. The combined use of these algorithms will help provide for a more robust infrastructure for patient privacy protection and will also help with the protection of data held by non-covered entities. HIPAA has revolutionized how healthcare is provided and research is conducted. It is vital that it continues to adapt to

the ever changing digital age to continue to provide concrete standards for privacy protection while also encouraging the advancement of the healthcare industry.

Conclusion

These projects clearly demonstrate the chain effects of innovation and risk. With every new idea comes ways to abuse the idea. It is important to recognize how integral computational resources are becoming in every aspect of healthcare and research and how great of a risk this complete digitization poses to millions of individuals. For the technical part, it was interesting to see such potential for improvement in patients' quality of life with the simple application of machine learning and code. Being able to allow a return to normalcy with a combination of tools provided by already existing data is just one of many ways that healthcare can be improved for individuals. For the STS portion, it was eye-opening to note that the leading federal regulation guiding all healthcare practices was falling behind in an exponentially advancing world. Recognizing the duality that advancement brings is the only way that technological innovation can continue to improve patients' lives without opening up individuals to other vulnerabilities that could compromise their privacy and data.

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References

Clifton, C., & Tassa, T. (2013). On syntactic anonymity and differential privacy. *2013 IEEE 29th International Conference on Data Engineering Workshops (ICDEW)*, 88–93. https://doi.org/10.1109/ICDEW.2013.6547433

Kohlberg, G. D., Gal, Y. (Kobi), & Lalwani, A. K. (2016). Development of a Low-Cost, Noninvasive, Portable Visual Speech Recognition Program. *Annals of Otology, Rhinology & Laryngology*, *125*(9), 752–757. https://doi.org/10.1177/0003489416650689

Nath, T., Mathis, A., Chen, A. C., Patel, A., Bethge, M., & Mathis, M. W. (2019). Using DeepLabCut for 3D markerless pose estimation across species and behaviors. *Nature Protocols*, *14*(7), 2152–2176. https://doi.org/10.1038/s41596-019-0176-0

Patil, A. P., & Chakrabarti, N. (2021). A review into the evolution of HIPAA in response to evolving technological environments. *Journal of Cybersecurity and Information Management*, *Volume 4*(Issue 2 : Special Issue-RIDAPPH), 5–15. https://doi.org/10.54216/JCIM.040201

Rameau, A. (2020). Pilot study for a novel and personalized voice restoration device for patients with laryngectomy. *Head & Neck*, *42*(5), 839–845. https://doi.org/10.1002/hed.26057