‘Origami’ Horn Antenna for Contactless Vital Signs Monitoring

The Geographic Constraints of Technological Innovation

A Thesis Prospectus
In STS 4500
Presented to
The Faculty of the
School of Engineering and Applied Science
University of Virginia
In Partial Fulfillment of the Requirements for the Degree
Bachelor of Science in Biomedical Engineering

By
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November 1st, 2022

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On my honor as a University student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments.

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Monitoring a patient's vital signs, such as heartrate and respiration rate, is a critical component in determining the type of care required for the patient, as well as the care that is able to be provided given their condition. Existing methods of monitoring vital signs require contact or close proximity with the patient, but there are some situations in which contact with an individual could put the care provider at risk. These situations include instances where the patient has a communicable disease or is in a hazardous environment. Additionally, the patient's condition might not allow for the attachment of monitoring devices, such as if the patient has damaged or destroyed tissue where the monitoring devices would need to make contact. A method of contactless vital signs monitoring would prove useful in these situations as it would unconditionally provide necessary information to care providers while simultaneously maintaining their safety. There are existing methods for contactless monitoring but they are limited in their performance by requiring a clear image of the patient, which could be obstructed by environmental factors or rendered useless if the patient is severely deformed by injuries (Molinaro, 2022).

Experimentation has been done with radiometric measurement of vital signs, but current devices are expensive and have limited application. Horn antennae are a promising tool for the development of radiometric measurement systems, as their frustum shape allows for the specific transmission and reception of radio waves used to detect the subtle signals produced by the heart and lungs. However, current horn antennae on the market are costly to produce and not feasible for the applications for which they have potential. Thus, the incentive to develop a cost efficient, contactless vital signs monitoring system derives from the limitations and high cost of current devices. Existing imaging solutions require specific conditions be met, and their algorithms used to analyze images are frequently unreliable and thus not widely implemented. A reliable, easily operated radiometric system could cater to a variety of potential users including those in the military, medical staff, and law enforcement personnel, offering safe and accurate monitoring of an individual's vital signs.

Over the past century, certain geographic regions have dominated the fields of technological innovation and research. The regions include parts of North America, Western Europe, and Eastern Asia. The top three producers of scientific publications per capita are the US, the UK, and China (NCSES, 2018). Additionally, some of the largest and most innovative companies in the world, such as Apple, Google, Tesla, Pfizer, and Novartis, are based in these same countries (Forbes, 2022). A contemporary example of constrained innovation and talent concentration is shown in Figure 1.

Figure 1- Top 25 cities ranked by talent concentration, clustered by relative geography (Figler, 2022).

It would not be irrational to point to the wealth and education quality of these regions as explanations for the high rates of innovation and research, but studies show that these factors don't necessarily lead to innovation (Paunov et al., 2016). Egypt, Brazil, and India are developed countries with high levels of education and high GDPs, yet see nowhere near the number of innovative companies or scientific research as those in Europe, North America, and East Asia. The aim of this research is to determine the causes of these geographic constrains, and suggest solutions to broaden the boundaries of technological innovation and development. This would offer improved autonomy of developing countries that are currently reliant as consumers on the regions more operational in technological innovation, while also improving general welfare of their citizens. The schedule for the completion of these projects is shown in the following Gantt chart in Figure 2.

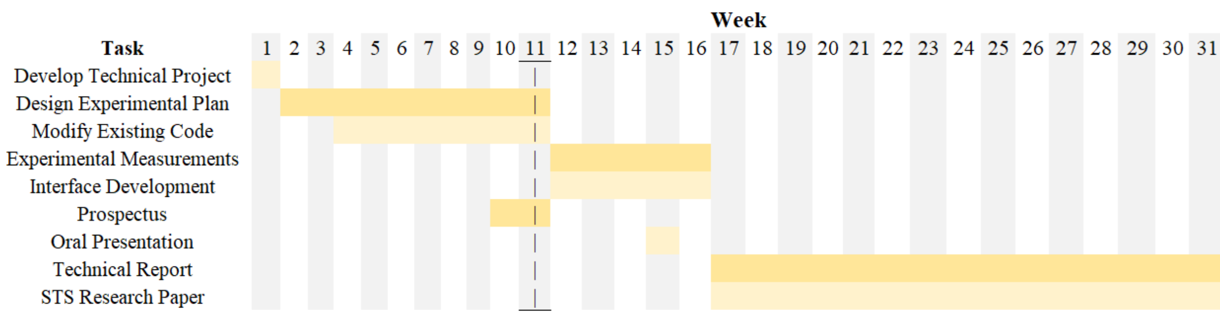

Figure 2- Gantt chart of ideal schedule for the completion of the technical and STS projects. (Figler, 2022)

HORN ANTENNAE FOR CONTACTLESS VITAL SIGNS MONITORING

High frequency radio waves (~60 GHz) offer a promising technique for the detection of a patient's vital signs (Teniente et al., 2011). This method would allow unconditional monitoring, improving the care provided to the patient and reducing risk for the care giver. To transmit and receive these beams effectively, a horn antenna is optimal due to its shape being a frustum, which is essentially a pyramid with a flat face parallel to the base rather than converging to a point at the top as shown in Figure 3. This allows for the generation of a confined beam with a

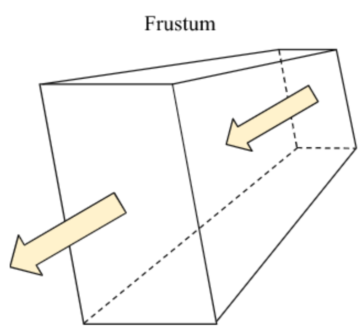

Figure 3 - Frustum shape and general direction of radio waves emitted when used as an antenna (Figler 2022).

specified focal depth for the detection of the subtle signals produced by the heart and lungs at a specific distance (Lee, 2020). Currently, the production of horn antennae is a lengthy and costly process of machining aluminum and plating it with copper, and they typically sell for around $2,000-2,500 (Khazaal et al., 2018). Furthermore, the geometry of available antennae does not vary greatly and thus reduce their versatility.

A variety of potential users would benefit from the generation of inexpensive antennae that fit their specific needs. In hospitals, a short focal depth of just a few meters, a room's width, would be valuable to medical staff for the monitoring of patients with communicable diseases. This detection method could operate through thin barriers, such as polymer or glass, and would enable the staff to monitor the patient while reducing potential exposure to infectious diseases. Conversely, a large focal depth could prove useful to emergency responders or military personnel. If the target is unresponsive in a hazardous environment, a fire or chemical leak for example, where approaching them could put the caregiver at risk, they could be safely monitored from a distance. This method could also be used to detect signs of life within wreckage or debris where the targets may not even be visible, such as in the case of a building collapse during an earthquake. If horn antennae were more inexpensive and available in a wide variety of different geometries providing different utility, there would be more of an incentive for potential users to implement them.

The objective of this work is to develop an inexpensive, parametrizable horn antenna that can be generated based on user defined beam patterns and focal depths. This will be done by modifying an existing program, developed by Kevin Owen, that allows for the input of antenna geometry, and this geometry is then exported by the program to a software called KiCAD that generates a 2D template of the 3D model with all the relevant layers. The primary material to be used is an inexpensive PCB material that can be easily 3D printed and folded into the final 3D form, hence the ‘origami’ title. Additionally, the software will generate a copper layer that will be added during manufacturing. Soldering will be used to complete the construction of the folded 2D template, yielding a 3D copper coated PCB antenna. The template models would be sent to PCBWay for manufacturing, and the unfolded template would be constructable via soldering the castellations on the PCB, forming the final usable 3D model.

One goal to be achieved is to edit the program so that rather than inputting geometry, the desired focal depth and beam parameters can be inputted and the geometry produced by the program. Existing formulae will be used to implement this modification (Bevelacqua, 2008). Another goal will be to experimentally determine the efficacy of various antennae at detecting vital signs at certain focal depths. Given a specific focal depth, the distance from the focal depth at which the signal to noise ratio still allows the vital sign signals to be distinguished will be determined. Furthermore, this effective range will be measured at increasing focal depths to determine the relationship between distance and signal to noise ratio. The resources available to achieve these goals are those at the disposal of Kevin Owen, the co-founder and chief architect of Rivanna Medical. He has already developed and provided the program required for the desired goals. Additionally, he has the device that actually generates the high frequency signals used to detect vital signs, as well as the means to produce antennae for the experimental measurements. Owen will provide funding as he is actively seeking to develop and market this concept in the private sector.

The anticipated outcomes of this project are to fully parametrize the existing program and develop a user-friendly interface. This will enable users to simply input desired focal depths that will satisfy their specific needs, and the program will automatically generate and output the appropriate geometry for manufacturing an assembly. The main constraint to be operated within is the cost of manufacturing and the cost to users. The project itself solves the existing issue of lack of versatility, but it is equally as important to achieve significant cost reduction through use of inexpensive materials. In addition to Owen's desire to produce a market ready product, if time permits a scholarly article will be written about the relationship between focal depth and effective range of beam patterns produced by horn antenna, as it pertains to the detection of target's vital signs.

THE GEOGRAPHIC CONSTRAINTS OF TECHNOLOGICAL INNOVATION

Geographic constraints of technological innovation and research have formed a cycle in which specific regions of the world, such as North America, Europe, and East Asia, lead these fields and thus attract more talent globally to enhance them, at which point the process repeats itself, which is demonstrated in Figure 4. This further constrains the geography of innovation and research and allows those regions to wield a certain power over other parts of the world. These regions produce a wide array of technologies used worldwide that create a producer-consumer dependency on a very large scale, as entire economies can be dependent on the activity of these innovative regions. This power is influenced by the economics, politics, and culture of the regions that

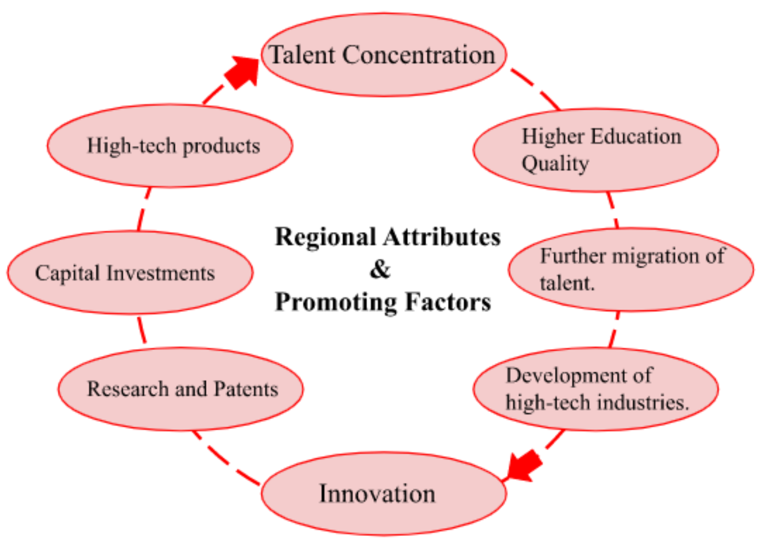

Figure 4 - Regional attributes and their promoting factors that result in a cycle of increased innovation and talent concentration (Adapted by Figler, 2022 from JLL, 2022).

dominate innovation and research, which indirectly gives people in various social groups that may have limited power locally a large sphere of influence globally.

There is a phenomenon known as the “brain drain” that refers to the migration of talent, which most frequently refers to high level industrial skills, from less developed countries to more developed countries (Dodani, 2005). Research into this phenomenon tends to focus solely on education and wealth of these regions as the primary promoting factors, but this is insufficient in explaining it in its entirety. Studies have shown that wealth and education levels alone do not result in fostering innovation and research (Celeste, 2014). There are countries with, based on global standards, high GDPs, education levels, and HDIs (human development index) that still suffer from an emigration of talent. There is a need for more research to be done into other social aspects of the regions experiencing emigration of talent as well as the social aspects of the common destination countries. These social aspects could include culture, industrial agglomeration, industry dependencies, existing local laws, and the economic drivers, not necessarily strength, of various regions.

The objective of the research work will be to explain the “brain drain” as it relates to the geographic constraining of innovation and research beyond existing explanations based on superior education and economies of destination regions. The approach taken will be through the lens of the Social Construction of Technology (SCOT) theory (Bijker et al, 1984). This theory will be used to explain the relationships between groups of businesses and academic institutions that are responsible for research and innovation. These relationships include their dependencies on each other, factors contributing to agglomeration, and factors that contribute to their formation (Ellison, 2010). Additionally, other social factors including law and culture in regions of emigration will be analyzed to determine if these can act as driving forces in directing talent towards specific regions. Throughout the research, various social groups will be defined and categorized depending on where they stand in the process of talent migration in order to create a general web of trends that explain the focal point of the research. A major constraint to be worked within will be to not solely focus on the migration of talent from undeveloped regions to developed regions, as this can adequately be explained by existing research. The anticipated outcome of this research is to determine causes beyond economic and educational factors that drive the emigration of talent to specific regions of the world, and demonstrate those driving forces through SCOT.

The results of this research should be able to offer information to relevant groups in these emigration centers in order to address the issue of "brain draining". This will hopefully shed light on opportunities to promote the retention of talent so that innovation and research can be harbored outside of existing geographic constraints. The benefits of regions retaining talent will make them partners in the global production of new technology and novel research, while also giving them some amount of autonomy as they could potentially become less dependent on other regions for development. These developments could take form in infrastructure, healthcare, defense, food production, and many other fields that contribute to the general welfare of these region's inhabitants.

ULTIMATE GOALS OF THE TECHNICAL AND STS PROJECTS

The STS research topic and technical topics are not related to each other at all, but a particular interest is shown in both separately. The technical project focuses on a particular technological interest as it applies to human health, and the STS research topic stems from an interest in human geography, specifically how it relates to the diffusion of technology and technological systems. The ultimate goal of the technical project is to yield a market ready, user-friendly product that allows for the automated, inexpensive design and production of horn antennae for a wide variety of applications utilized by medical staff, military, and law enforcement personnel. This will be distributed and marketed by Kevin Owen and Rivanna Medical. The aspirations of the STS research are to explain reasons for the migration of talent to specific, concentrated regions of the world and suggest solutions that will allow other parts of the world to become partners in the global development of new technology and research. This will not only benefit the regions hindered by the migration of talent, but also the global community as it accelerates efforts to advance technological innovation and research.

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