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AN AUTONOMOUS APPROACH TO FACILITATE GLOBAL REMOTE HEALTHCARE SERVICES

Ahmed M.S. Chowdhury
Research Assistant
Mechanical and Civil Engineering
Florida Institute of Technology

Lakshmi Narasimhon A.V.
Research Assistant
Mechanical and Civil Engineering
Florida Institute of Technology

Advisor: Chiradeep Sen
Assistant Professor
Florida Institute of Technology
Melbourne, Florida-32901

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1 Statement of Purpose

This document provides an outline to illustrate the medical needs in 2035 for a global design and manufacturing (D&M) company in the healthcare industry called Aegle Systems. The advice laid out in this document is based on research on medical trends and current medical technology. In order for Aegle systems to achieve a competitive edge, we believe that the investors will need to address the unique set of challenges that the healthcare industry will face in the next 15 years and prepare by partnering with educational and research institutions.

2 Overview of Society in 2035

Society will make significant leaps – mainly for the betterment of mankind – by the year 2035. With the advancement of artificial intelligence (AI), machine learning (ML), deep learning (DL) and automations – human workforce will be very different. People will resort to more creative avenues of work whereas autonomous systems would have completely erased most repetitive jobs. The transportation industry will take the brunt in employment as self-driving cars will become more prevalent. The educational sector will also change significantly and where the delivery of information will occur over the internet aided with Virtual Reality (VR) and Augmented Reality (AR). These technologies will be crucial in training the youth of 2035 for jobs in fire control, surgery, aviation, and automotive technicians by minimizing the risks associated with on-site injuries.

Additionally, cities will have to expand significantly to support a growing working populations in countries located in continental Africa, and in countries like in Japan, rural areas will see more development as the growing population of the older generations will likely want to have a quieter lifestyle. Across the globe, populations will migrate to seek better work and educational opportunities which will lead to certain parts of the world have diminished workforces. Advances in automation may become a necessity to meet basic human needs in such geographic areas. The next section illustrates a hypothetical scenario on how remote healthcare will play a role in improving quality of life of an elderly couple.

Overview of Healthcare through the perspective of an elderly couple

Warren belongs to the generation group known as baby boomers, and by the year 2035 he will be in his mid-80s. Due to advances made in healthcare, a higher proportion of the human population will have longer life expectancy – albeit not free from complications. He lives in a non-metropolitan area of the state where housing is more affordable but is further away from public services such as hospitals. Due to his economic standing he is not able to purchase a self-driving car and is reliant on public transport. He lives with his aging partner, Charlie, who has been diagnosed with atherosclerosis while he himself has a compromised immune system due to his anemia. Charlie has already had a heart attack when an autonomous ER unit pulled into their yard and a couple of medical personnel carried Charlie into the facility. Inside the unit pre-programmed AI augmented robots injected IV fluids and took blood samples for instant testing. Meanwhile, bionic scans of Charlie's retina allowed access to his medical history and an oxygen mask assisted him in breathing. Abnormalities in his blood pressure and cardiac rhythms and high concentrations of LDL cholesterol indicated the need for further examination of his arteries. Machine learning (ML) assisted X-Ray scanners detected a blockage in his arteries and signalled for an autonomous cardiologist to be deployed by the hospital. The cardio unit was equipped with sensors, high resolution cameras, robotic arms, medical and surgical equipment’s such as anaesthesia machines and advanced DaVinci surgical systems. After being anesthetized, cameras around him projected a virtual simulation of him onto a cardiologists remote-operation system which they used to manoeuvre the end effectors of the surgical system to precisely perform a cardiac catherization. After the procedure, nanofluids were injected into his bloodstream so that his blood flow patterns could be used to instantaneously update a simulation of his heart in his medical profile. Charlie and Warren both rely on multiple at-home diagnosis systems that monitor their health and update their medical profiles. The physiology of their simulations is updated regularly as they take at-home blood and urine tests, while ECG sensor equipped head and wrist bands instantaneously updates their blood pressure and stress-levels. Well trained pattern recognition algorithms are used to detect abnormalities in patient physiology to anticipate complications and prepare for deployment of an ER unit to their geographic location. Pharmaceutical companies use their simulations to test on and supply the right dosage of prescribed drugs to their doorstep. The couple regularly consult an AI at-home physician on their health and when necessary holds virtual meetings with human doctors. Healthcare, like many other services, has become a door delivery system that has significantly raised their quality of living.

3 Establishment of Need

Currently, over 5 million people globally do not have access to surgical care, over 143 surgical procedures are required in low to middle income countries to prevent losses of life or avoid disability, and over 83 countries fall below the threshold of having 23 medical professionals per 10,000 people. The population over 65 years is expected to double by 2030 and a third of the physician population is expected to retire within the next decade [1]. Additionally, growing number of chronic patients who will need healthcare physician burnout is increasing and a shortage of physicians is projected – especially in low income areas (depicted in figure 1) [2]. In order for the global population to achieve quality healthcare, it has to become more accessible and available across the globe. To tackle the issue of physician shortages, we propose to mobilize hospitals via remote healthcare systems that could be controlled from a central hub. Since medical and surgical specialists are not evenly distributed across the globe, their services would reach the under privileged via remote healthcare systems.

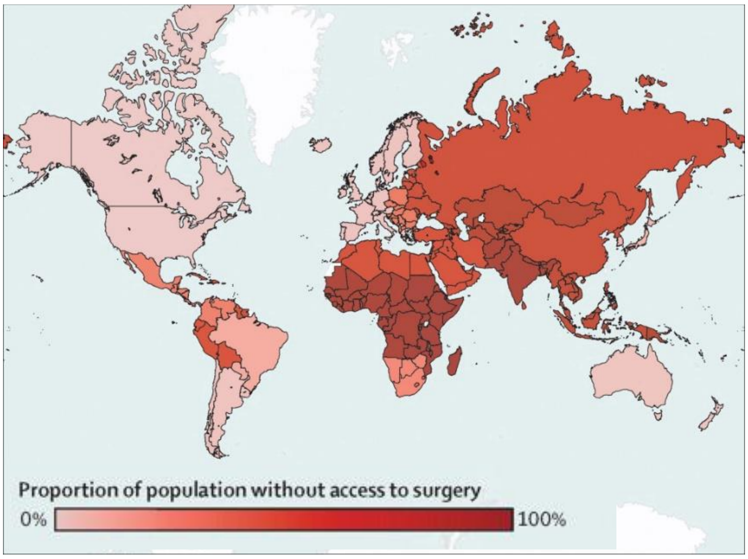

Figure 1 Proportion of the population without access to safe and affordable surgery [2]

Additionally, remote healthcare facilities will be paramount in treating patients who are required to be quarantined to reduce risks to front line healthcare professionals. In unanticipated social circumstances, such as a viral outbreak or nuclear accidents, where there is a significant threat of viral infections or radiation poisoning. Lastly, military services and global healthcare organizations such as WHO and Red Cross will need access to immediate deployment of quality healthcare for disaster relief in situations of natural disasters or warfare.

4 State of the Art in Remote Healthcare in 2020

Remote healthcare today is limited to homecare devices in the form of telemedicine to deliver health services over large distances for patients with chronic illnesses over smartphones and other wireless communications devices. Remote healthcare is widely used in monitoring patient's health post-surgery using ECG sensor systems [3,4]. Figure 2 shows the general architecture of remote healthcare systems currently in place. Body sensors range from physiological sensors used to monitor vitals such as body temperature, blood pressure, and electrocardiographs (ECG) to biokinetic sensors that can monitor body movements.

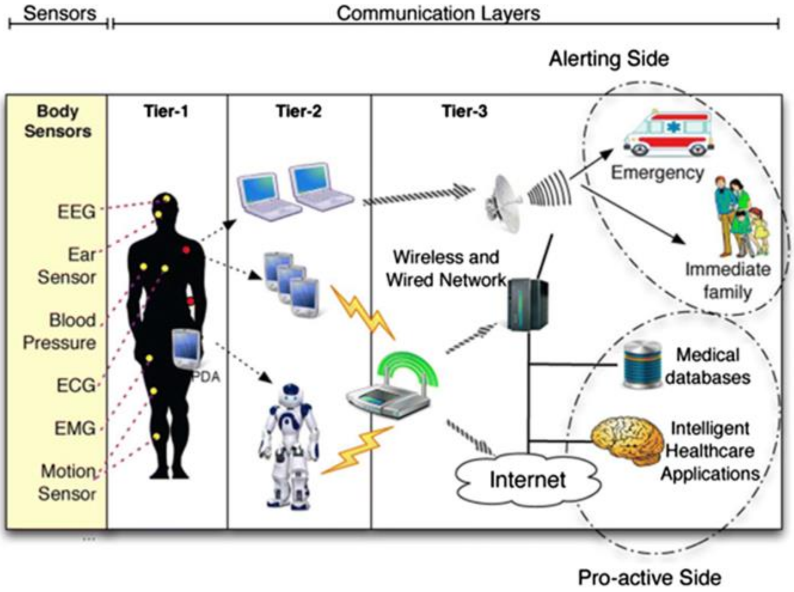

Figure 2 Three tiered architecture of telemedical service [4]

Currently the scope of remote healthcare is limited to more affluent societies where wireless communications are more prevalent. Current technology does not service patients who live in remote areas where there is a definitive need for such healthcare. Lastly, medical examinations, surgical procedures and most professional diagnosis are still performed at a healthcare centre. Aegle systems hopes to expand the scope of remote healthcare services beyond rehabilitation and facilitate services that would otherwise be performed at a hospital.

5 Anticipated Mode of Operation of Aegle Systems in 2035

Aegle Systems will operate as a design and manufacturing firm that provides healthcare services in three unique, but symbiotic areas as shown in figure 3. Each branch of the organization will have different design processes as dictated by their distinct stakeholders and various societal demands. While the economies governing each division may vary significantly, a common thread uniting the medical systems will be remote accessibility and minimized human interactions, achieved via intelligent robotics, VR technology, and Artificial Intelligence. The R&D services offered by each branch is elaborated in detail in the following subsections.

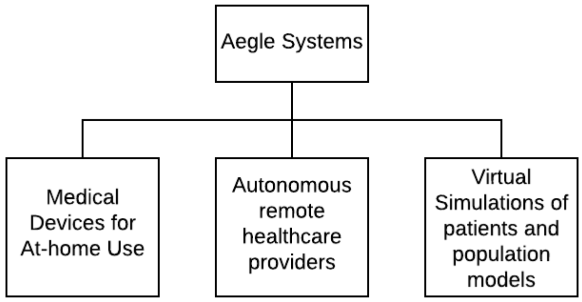

Figure 3 Three primary focus divisions of Aegle Systems

5.1 Medical Devices for At-home Use

Wearable health-tech is already a prominent emerging field in biotech, yet significant leaps have to be made for at-home care to offer a medical diagnosis. Aegle systems will design medical devices ranging from blood pressure and stress monitors to blood testing systems for at home use by patients to monitor their health. All at-home devices will upload the user's vitals onto their virtual simulations. AI algorithms running on the virtual simulations will be trained using the wide network of diverse users by medical professionals to identify anomalies and predict complications in their physiology. Additionally, this sector of the company will also produce AI-augmented virtual doctors that can offer therapeutic and diagnostic services by inquiring users of symptoms, assess risk factors, and alert the user's physicians after a weighty diagnosis. The company will have to work in tandem with hospitals to train their machine learning algorithms to offer high fidelity diagnosis.

5.2 Autonomous Remote Healthcare Providers

In the present, hospitals are sizable buildings that act as a hub for a diverse set of services ranging from Intensive care to plastic surgery. With autonomous remote healthcare providers (ARHP) hospitals will be able to operate at multiple locations based on public needs from a single hub. ARHPs would be self-driving units stationed at a central location. They will be equipped with robotic arms, sensors, cameras, medical equipment, and projection screens. Cameras will be used in projecting a 3D simulation of the patient into the physician's office and robotic arms will mimic the hand movements of the doctor to perform any given task. The patients will be able to interact with the doctor by means of a projection screen that offers virtual communications. Advances in tele-robotics, machine learning (ML) and VR technology will enable specialist physicians to perform tasks ranging from offering diagnosis to conducting surgeries without physically interacting with the patient. The global distribution of ARHPs will be used in training neural networks for various medical procedures. As the dataset for procedures grow, the network will become better equipped at predicting the sequence of actions that will be performed by the system and build a collective surgical consciousness and can alert physicians if an unusual step is made, thereby limiting medical errors.

AHRPs could be divided into three categories based on their expected missions: remote doctors, remote surgeries, and remote vaccinations. Human assistance may be required for key tasks such as transferring patients to and from surgical and examination tables, but skilled labour such as that offered by a surgeon or an anaesthesiologist will be delivered remotely. It is anticipated that ARHPs will be expensive and custom-built units that will be commissioned based on stakeholder needs. We prognosticate that (1) hospitals will use ARHPs to widen their area of coverage by having multiple units that will be serviced by experts from a single hub based on public needs; (2) philanthropic organizations such as the Red Cross and Doctors Without Borders will commission ARHPs to offer vaccinations, disaster relief, and blood donation services in remote locales; (3) military will use ARHPs to offer relief in war zones to wounded soldiers and civilians. Lastly, ARHPs will be a necessity in countries such as Japan where a significant portion of the population are projected to be elderly individuals and is forecasted to have a shortage of physicians.

5.3 Virtual Simulations of Patients and Population Models

Using patient data from home-care medical devices and ARHPs Aegle Systems will build virtual simulations of a patient's physiology. The simulations will mimic the patient's biology by synchronising the data available from the aforementioned devices and create a digital rendition of a patient's biological systems (nervous, cardiovascular, lymphatic, etc.). The digital models of patients will serve the patients in two distinct ways:

1. Efficient pattern recognition ML algorithms will run on the digital network of virtual patients to detect abnormal patterns and identify risks to alert patients on their health. Preventative care and precautionary actions based on pre-emptive notice will reduce exacerbation of patient health.
2. The digital simulations will be used by pharmaceutical companies to prescribe personalized drugs based on the severity of the ailment. Drugs could be tested on the simulation to determine dosage and side-effects before being assigned to a patient. Tailored drug prescriptions will be especially vital in combating antibiotic resistance by bacteria.

The cloud of virtual patients will also be pertinent in medical research and student education. High fidelity models could be built from the data available on diverse sects of human population that could be classified based on region, race, gender, etc. to conduct human subject studies. Additionally, physiological trends could be studied by researchers to predict illnesses and observations on population models could be used to predict the onset of viral outbreaks. Finally, in education, students could examine symptoms and conduct surgeries on augmented reality (AR) projections of virtual patients. AR technology will be used to project the effect of student's actions based on causal principles obtained from ML algorithms for any given medical procedure.

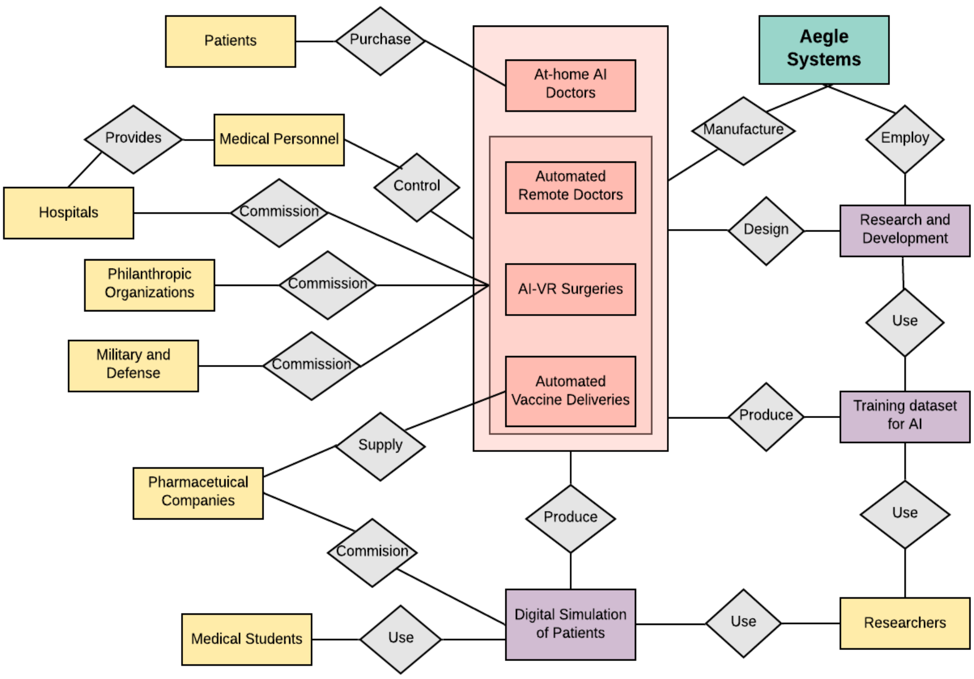

Figure 4 Entity Relationship diagram exploring stakeholder-company interactions

To summarize, Aegle Systems will be the crux of the changing healthcare culture that affects multiple sects of the society. Through intelligent automations and virtual patients, the company aspires to tackle several issues that are currently inundating global health and will continue to prevail if advancements are not made. The interactions between Aegle Systems and its various stakeholders is shown using an entity relationship diagram in figure4. Stakeholders are shown in yellow entity boxes, red entity boxes are used to depict manufactured systems and purple entity boxes are used to represent virtual information. The cultural shift around healthcare will have to be supported through ingression into multiple facets of society which Aegle Systems hopes to achieve through partnerships with various educational, pharmaceutical, military, medical and research institutions.

6 Recommended Partnerships for Aegle Systems to Engage In

The company partnerships will be two-fold: university and industry partnerships. The university partnerships provide the company an opportunity to perform research experiments on the systems and processes developed. The research will be testing the usability, performance efficiency, and areas of improvement of the systems. Thus, allowing the company to stay up to date with the evolving technology. Industry partnerships provide the company an ability to introduce the AI incorporated medical assistants in the medical field and offer a platform to test the technology on. These partnerships are suggested due to their contributions in scientific research pertinent to meeting Aegle Systems' vision.

Research partnerships	**Industry partnerships**
Dept. of Computer Science, Johns Hopkins University, Baltimore, US	Sheikh Zayed Institute for Pediatric Surgical Innovation, Children's National Health System, Washington DC, US
Computer Science and AI Laboratory, MIT, Massachusetts, US	Massachusetts General Hospital, Department of Surgery, Massachusetts, US
Department of Complex Systems Science, Nagoya University, Nagoya, Japan	Occipital VR, Toronto, Canada
Istanbul Medeniyet University, School of Medicine, Department of Surgery, Istanbul, Turkey	CompBioMed, European Union
University of Medicine and Pharmacy "Gr. T. Popa", Iasi, Romania	

7 Recommended Areas of Scientific and Engineering Research for Aegle Systems

Aegle System's prominence in the healthcare industry of 2035 is riding on the back of several technological and scientific leaps that the research community would have made by then. The following subsections elaborate primary areas of research interest that must be actualized for the company to achieve its goals.

7.1 Autonomous positioning of surgical equipment:

Significant progress has already been made in robotics to allow precise and controlled positioning of surgical equipment to assist in surgeries. For instance, visual servoing using laser spots have been used in teleoperating laparoscopic surgery systems to guide surgical equipment to surgeon's field of view [5]. Image guided robotic systems such as NeuroMate and ROSA have been implemented for drilling, electrode insertion, and orienting neuroendoscopy during neurosurgery [6]. Robotic catherization devices such as Sensei X and Magellan – that are controlled by an expert using a joystick – have been used to in electrophysiology applications such as cardiac mapping and endovascular aneurysm repair [7]. Moving forward, research in developing holistic and intelligent visual servoing systems that are capable of identifying organs in diverse sets of human populations is going to be pertinent. In order for autonomous devices to be applied in non-sedative medical procedures such as physical examinations and vaccinations, robotic systems will have to be extremely sensitive to human movements and body orientations. Programming of autonomous devices will have to work in tandem with data received from high resolution image recognition programs and motion sensors. The scope of robotics will have to expand beyond surgeries to accommodate tasks ranging from taking a patient's temperature to delivering IV fluids.

7.2 Telerobotic surgeries:

Telerobotic surgical systems comprise of a master control unit that offers up to 7DOF control to the surgeon and an operative robotic unit performs precise surgical tasks. Surgeons can control the robotic surgical unit using various interfaces such as regular keyboards, leap motion controller (mimics hand gestures), Omega 7 haptic devices (offers haptic feedback for tactile precision), gaming joysticks and Kinect (tracks surgeon's body movements). The robotic surgical unit controls the mechanical arms equipped with end effectors for grabbing surgical tools and cameras [8]. Research in telerobotic surgery has been going on since the 1970's and in 2001 the first telerobotic surgery – a 45-minute-long cholecystectomy – took place in New York, United states on a patient located in Strasbourg, France. For telerobotic surgery to be effective and common place, technological leaps in data transmission speeds – especially in rural areas – and communication latency must be overcome [9]. Additionally, surgeon's control units need to improve to provide tactile feedback to support sensitive minimally invasive surgeries such as those performed on soft tissues. Finally, delays in visual feedback in telerobotic surgery will be important issue to tackle for improving surgical accuracy and dexterity .

7.3 Artificial Intelligence in diagnostics and prognostics:

AI applications in healthcare is starting to take leverage across various disciplines. For example, Deepmind Health has been mining over a million eye scans with related medical records to aid in diagnosis, Medical Sieve is building a cognitive assistant that is capable of analysing medical records and detecting medical issues, Atomwise uses supercomputers to find new therapies in pharmaceuticals and deep learning algorithms have demonstrated to aid in diagnosis of cardiological, dermatological and oncological conditions [10]. Moving forward, integration of decision-making algorithms with AI is going to be pertinent for AI to be used in diagnosis. The integration of deep learning algorithms to teach diagnostic tools empathy and communications is going to be important to provide a human touch.

7.4 Machine Learning in building a surgical consciousness:

ML based suggestions in surgery is not yet available for use in operation theatres despite its popularity in academic literature. Current research uses ML to predict hypoxaemia during surgery [11], to predict postsurgical seizures from pre-operative diagnostic tests , to predict mortality after cardiac surgery [12], to facilitate the production of surgical outcomes in aesthetic plastic surgery [13], etc. While the academic community has realized the lofty potential of ML in niche fields, efforts in integrating multiple predictive technologies is not yet actuated. A recent paper in applications of AI in surgery proposes the idea of a collective surgical consciousness (Figure 5) that draws conclusions from a population of clinical data to aid in surgical decision making for individual cases [14]. Going forward, research in integrating multiple ML and deep learning algorithms into a single collective consciousness needs to be actualized to predict surgical outcomes, minimize surgical malpractice and aid in patient recovery.

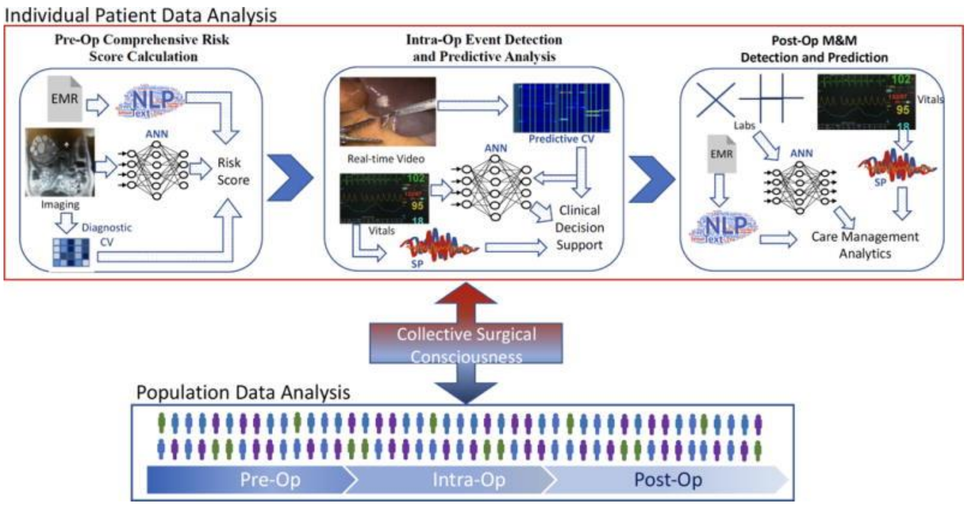

Figure 5 Interactions between the collective surgical consciousness and patient database [14]

7.5 Pharmaceutical testing in virtual simulations:

Animal testing, along with in vitro and in vivo drug testing are prevalently used in pharmaceutical drug testing and in pre-clinical trials. However, testing new drugs and dosages using traditional means for personalized use is cost prohibitive and the inaccuracies that arise from these testing methods will prove them to be sub-optimal for the future of drug safety . Human engineered heart tissue-based drug testing may prove to be more accurate – yet not suitable for personalised drug development [15]. More recently, studies in in-silico drug testing (individualised computer simulations) have shown that simulation-based drug testing are more accurate than animal testing [16]. Compbiomed, a European commission on developing computational tools for biomedical applications is currently working on a virtual model of the entire human body for use in drug delivery testing (amongst others). Moving forward, research on streamlining the simulation development/augmenting process to reflect individuals is going to be vital in the development and testing of personalized drugs.

7.6 Augmented and Virtual Reality in surgeries:

Applications of AR in surgery is currently confined to superimposition of tactile, audio, or visual senses – for example AccuVein projects vasculature maps onto patient skin to assist in neurosurgery. VR technology has been widely used in training applications for surgery due to high-risk real-life threats [17]. Future directions for research in this area include advancements in AR technology to construct 3D models from radiographs and CT scans for superimposition in surgeries, overcoming latency in superimposition of the nervous system, and ergonomic issues regarding the wearability of AR devices in a surgical setting.

7.7 High fidelity modelling of human physiology:

Modelling of human physiology has been an active field since late 1960s. Computational models exist at organ and cellular levels and can simulate organ systems such as respiratory, cardiovascular, nervous, etc. Multiple centres across the globe are focusing on developing integrative models of human physiology: IUPS Physiome Project supports computational modelling of cell functions and its interactions with organs, SimBios project supports modelling of RNA folding, computational fluid dynamic flow analysis of blood flow, etc., and SAPHIR Project supports modelling of body fluid regulation [18]. HumMod is a more integrated modelling platform capable of supporting multiple biological systems and allow simulations of interactions between multiple systems [19]. Research on integrated, multi-level, scalable computations models will be necessary going forward to better suit the mission of the company.

8 Anticipated Challenges for Aegle Systems

8.1 Transition from traditional to autonomous medical systems

One of the main challenges expected to be faced by the company is the transition from conventional medical services to an environment that incorporates the use of complex technical systems loaded with multiple machine learning algorithms. This transition, while tested out in small steps, may be a slow process due to the nature of human-subject experimentation. For example, surgeon operated laparoscopic surgery was the state of the art for several years until DaVinci surgical systems became a proficient method to accomplish surgeries. The next level of transition from these robotic surgical units to autonomous surgical units would be quite challenging due to the involvement of the 'surprise factor' and the need for instantaneous decisions that often arises in situations such as surgeries. It would be a giant leap for AI programs to be able to tackle such decisions.

Another complex stage involved in transition would be the transfer of data set from traditional health charts to formats that are digitally accessible. This would require the patient's authorization to digitize their health record into a dataset that can be communicated remotely. While it is expected to face some reluctance in its early stages, it is expected that it could become a practice over the course of time as seen with technologies such as internet banking. Consecutively, if the person wishes the retain their traditional course of health care program, then the transition to getting them enrolled for a remote service should be simple enough to be incorporated, if they would ever desire one.

8.2 Retaining humane aspects of the health care service

While having the ability to seek medical help anytime and anywhere is of high value, the core part of the medical services, both prognosis and diagnosis, is the human-touch involved. Human doctors are taught to follow ethics while practising their profession. This promotes a sense of compassion between the doctor and the patient. It is possible for some patients to be reluctant to the remote service as they could experience it to be less compassionate. To tackle this problem, the devices are to be designed and developed around the needs of the patient. As the need of the patient changes, there should be a change in the course of the service, as needed.

8.3 Cost

A technology-based innovation such as AI incorporated health care is estimated to incur high investment costs during research, development, and administration. This issue is mainly tackled by having heavy partnership-centric model. In addition, to the partners listed in Section 6 the company will also attempt to partner with the government. The government agencies could experience a reduction in cost to operate and provide emergency services such as ambulances, first responders, etc., the funds that are saved in such avenues could alternatively be invested in better autonomous health care systems provided by our company. It is also estimated that by establishing the devices and services on a global scale the cost can be reduced.

8.4 Implementation (Establishment of the infrastructure)

A global multi-level operation is estimated to face feasibility related issues during its implementation stage. These issues arise mainly due to the lack of pre-requisites, such as internet, availability of high-tech devices for usage, and even electricity in some rural areas. The company plans on tackling this issue by dividing the area of interest into multiple zones, namely green, yellow and red. The green zones will be areas were the implementation will be tested out in its early stages followed by yellow zones and then red. Some of the considerations needed to be taken into account for this classification include the number of people frequently in need of immediate health assistance, technological advancement available at disposal, population density, spending capacity, and average age group of the population.

Additionally, implementation of a remotely operable device includes the issues related to repair, maintenance and upgrade. The devices would have to be frequently inspected to be in accordance with the standards in which they are expected to operate. This level of operational needs incurs high maintenance cost. The company should also have a plan to roll out the software and hardware upgrades to the on-duty machines periodically. Having a smooth transition is crucial for a time sensitive service such as health care.

Finally, the operators of the machine (including the repair technicians, IT technicians, and assemblers) should have to be certified and licensed to use the machine. This ensures proper usage of the machinery and their adherence to the company's code. This licensure will have to be reviewed and renewed periodically.

8.5 Ethical Concerns

When administering remote treatment, it is possible for the AI loaded machines to experience a dilemma that would need an override. For example, patients with terminal illness may have a DNR (Do Not Resuscitate order) based on their wish. In such a scenario, the programming of the machine would have to be altered to deal with the situation with a modified response. At the same time having an ability to override the linear programming of the machine exposes it to other possible vulnerabilities which raises ethical concerns.

It is possible to experience a depletion in the privacy between the doctor and patient, especially when the data collected is used to drive the AI algorithm. Although the data collection could be remunerated with better and "smarter" health care system, the idea of one's health status being a digital data could extend beyond the comfort level of patients and even some doctors.

8.6 Cybersecurity and Patient Data Hijacking Threats

In a digital age, it is important to have data security. This need intensifies especially in an environment where life altering decisions are made remotely. The data set collected from the patient is to be securely stored in a server that gets backed up frequently. The history of the patient including the doctor's notes and prescriptions must be stored securely. They must be revealed only on a need-to-know basis. This restricted access could be extended to the patient's emergency contact if approved by the patient.

While precautions are taken for securing the data once they are loaded onto the system, necessary measure may also be needed to ensure if the legitimacy of the current person using the machine. Additional steps may be needed to check the identity of the user (both on doctor end and patient end) before a session begins.

9 Conclusions

It has been proven that there is ample need for a better health care system that can be implemented at-home. A significant growth in population who would need such services is estimated. Consecutively, Aegle Systems a company which administers remote medical assistance using machines that incorporate machine learning algorithms is developed. Existing technology which lays the foundation for the company is elaborately presented. The partnerships that allow the company to excel through several layered contributions are discussed. The challenges faced by the company from a logistical, ethical and financial perspective are discussed. The company aims to be a core contributor to the medical revolution that is expected to happen in the next decade.

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