

## Worcester Polytechnic Institute Digital WPI

---

Interactive Qualifying Projects (All Years)

Interactive Qualifying Projects

---

March 2016

# Research Roadmap for Robotics for Advance Response to Epidemics

Andrew Ngo Huynh  
*Worcester Polytechnic Institute*

Kevin Anthony Valente-Comas  
*Worcester Polytechnic Institute*

Follow this and additional works at: <https://digitalcommons.wpi.edu/iqp-all>

---

### Repository Citation

Huynh, A. N., & Valente-Comas, K. A. (2016). *Research Roadmap for Robotics for Advance Response to Epidemics*. Retrieved from <https://digitalcommons.wpi.edu/iqp-all/2910>

This Unrestricted is brought to you for free and open access by the Interactive Qualifying Projects at Digital WPI. It has been accepted for inclusion in Interactive Qualifying Projects (All Years) by an authorized administrator of Digital WPI. For more information, please contact [digitalwpi@wpi.edu](mailto:digitalwpi@wpi.edu).

# **Research Roadmap for Robotics for Advanced Response to Epidemics**

An Interactive Qualifying Project Report

Submitted to the Faculty

of the

Worcester Polytechnic Institute

Degree of Bachelor of Science

by

Kevin A. Valente-Comas

Robotics Engineering

Trung-Nghia N. Huynh

Robotics Engineering

Date: February 29, 2016

Professor Michael A. Gennert

Director of Robotics Engineering

## Abstract

This project's main goal is to create a roadmap on possible use of robots in future epidemics. In order to understand the current capabilities of robots within the medical field articles, videos, and any information posted on the company's website was used as reference. Our objective is to determine: if using a robot during an epidemic is currently a viable option, potential improvements to these robots to improve their performance, what benefits and/or drawback to using robots, and whether or not the robot would be accepted.

## Executive Summary

Robotics is a multidisciplinary field including Medical Robotics, Logistics Robotics, Industrial Robotics, etc. Epidemics are a widespread occurrence of an infectious disease in a community at a particular time. The main goal of this project is to analyze the current Robotics technology and evaluate whether the technology is ready to assist in the fight against epidemics and write down the result in a roadmap.

Since the place these robots will be working at is a hospital the Medical Robotics field was the obvious field to focus on. After careful consideration the areas where robots could make an impact are Logistics, Bio Lab, and Patient Care. In addition to the roadmap this project will also employ the Technology Readiness Level (TRL) and the Technology Acceptance Level (TAL).

The roadmap was written with the intentions of making it into a standalone document which means the reader is not forced to read the roadmap along with this report. Each task was made into a section in the roadmap and every section has a Domain Overview, Current Capabilities, Future Possibilities, and Challenges. Domain Overview sub-section contains a brief description of the field and some of the benefits of using the robot(s). Current Capabilities sub-section contains the tasks the robot(s) can carry out, their efficiency, and the robot's components. The Future Capabilities sub-section contains a few suggestions on how to improve the robot. Challenges sub-section states defects currently hindering the robot.

The TRL was used to determine the state-of-the-art for the robots within each task. Not all robots within a certain task possessed the same TRL level so they were further divided into the specific tasks each robot could accomplish. These specific tasks are as follows transportation of goods, disinfection, telepresence, checking vitals, assistive nursing and companions. BioLab was the only one to not be divided further as there is only one type of robot which has the same TRL level across the many models designed by different companies. All of the robots that

were researched and included for this project were at least TRL level 6, which means there is at least a working prototype for each robot.

The TAL is a scale devised for this project. Its intended use is to determine how accepting society is towards a certain technology (for our intended purposes that technology is Robotics). The scale also takes into account how the society would react to the technology. Unlike the TRL level, no further division was needed apart from the first three tasks. Based on the result of the research it was concluded that today's society willingly accept these robots.

In conclusion while robots were incapable of participating in the recent Ebola case they can provide assistance in the next outbreak. These robots can provide direct assistance in a doctors and/or nurses daily routine as well as takeover some of the more cumbersome tasks.

## Authorship Page

Introduction	Kevin A. Valente-Comas & Trung-Nghia N. Huynh
Background	Kevin A. Valente-Comas & Trung-Nghia N. Huynh
Methodology	Kevin A. Valente-Comas & Trung-Nghia N. Huynh
Result	Kevin A. Valente-Comas & Trung-Nghia N. Huynh
Conclusion	Kevin A. Valente-Comas & Trung-Nghia N. Huynh

## Table of Contents

1.0	Introduction.....	1
1.1	Robots, Robotics, and Medical Robotics.....	1
1.2	Epidemics.....	1
1.3	Terminology.....	2
	Robots.....	2
	Robotics.....	3
	Roadmap.....	3
	TRL.....	3
	TAL.....	3
1.4	The Project.....	3
2.1	The Problem.....	4
2.2	The Solution.....	6
	Logistics.....	6
	Bio Lab.....	7
	Patient Care.....	7
3.0	Methodology.....	8
3.1	Technology Method.....	8
	TRL.....	9
	Roadmap.....	9
3.2	Social Method.....	10
	TAL.....	10
4.0	Results.....	12
4.1	Logistics.....	12
4.2	BioLab.....	14
4.3	Patient Care.....	16
5.0	Conclusion.....	17
6.0	Bibliography.....	19
	Company's Website.....	21
	TRL.....	22
	Bio Lab.....	22
	Logistics.....	22
	Patient Care.....	22

TAL .....	23
Logistics .....	26
Patient Care .....	26
Bio Lab .....	27
Roadmap.....	27
Introduction.....	27
Logistics .....	28
<i>Domain Overview</i> .....	28
<i>Current Capabilities</i> .....	30
<i>Future Opportunity</i> .....	32
<i>Challenges</i> .....	33
Bio Lab .....	34
<i>Domain Overview</i> .....	34
<i>Current Capabilities</i> .....	34
<i>Future Opportunity</i> .....	36
<i>Challenges</i> .....	36
Patient Care .....	37
<i>Domain Overview</i> .....	37
<i>Current Capabilities</i> .....	37
Telepresence .....	37
Checking Vitals.....	38
Assistive Nursing .....	39
Companion.....	39
<i>Future Opportunity</i> .....	39
Telepresence .....	39
Checking Vitals.....	40
Assistive Nursing .....	41
Companion.....	41
<i>Challenge</i> .....	41
Telepresence .....	41
Checking Vitals.....	41
Assistive Nursing .....	42



Conclusion .....	42
Bibliography .....	43

# 1.0 Introduction

## 1.1 Robots, Robotics, and Medical Robotics

Some of the earlier recorded robots date as far back as Third Century B.C., originally these robots were called automaton<sup>(1)</sup> (a mechanical device capable of movement made to resemble a human)<sup>(2)</sup>. However, it wasn't until 1961 when the first robot by today's standards was invented. That robot was an industrial robot by the name Unimate whose task simply involved welding die casting on auto bodies<sup>(3)</sup>.

The first medical robot was an assistive surgical robot, PUMA 560, used in a delicate neurosurgical biopsy, a non-laparoscopic surgery, in 1985<sup>(4)</sup>. In 1998 a microprocessor along with hydraulic and pneumatic controls was implanted into a prosthetic knee, which provided the user with a more natural walking ability<sup>(5)</sup>. Robots then appeared in rehabilitation, pharmacy, telepresence, and logistics.

## 1.2 Epidemics

Epidemics, they are a widespread occurrence of an infectious disease in a community at a particular time. In times of epidemics, it is crucial to manage resources in order to save those who are infected and prevent as many deaths as possible. If not treated in a careful and swift manner, the epidemic could become a pandemic, which is a more widespread form of epidemic, and events like the Black Death, which killed approximately more than 20 million people, i.e., about one-third of the European continent's population at that time<sup>(6)</sup>, are more likely to happen. However, thanks to modern technology, epidemics nowadays cause much less deaths. Take the Ebola outbreak in West Africa, for example, though it has caused a total of 11,302 reported deaths<sup>(7)</sup>, the number of casualties are decreasing due to the fast growth of new technology.

In order to improve healthcare in times of epidemics, it is important to single out any and all hindrances during these events. One such hindrance is that, from time to time, human limitations such as personnel getting infected due to the constant exposure to the pathogens, slows down the process of containment and curing. When a suspected pathogen is declared an epidemic, thousands could have already been infected. The area, where the pathogen is detected, gets isolated immediately. Any hospitals within this area may be forced to receive more patients than their possible capacities. Due to the constant stress and exposure they face after the epidemic broke out, the staff could easily contract the infection, resulting in the hospitals being understaffed. In the recent Ebola outbreak, a report confirms a total of 881 cases of medical staff contracting the pathogen within Guinea, Sierra Leone, and Liberia and 512 out of those cases died<sup>(8)</sup>. Having robots, be it fully or semi-autonomous machines, that can accomplish certain tasks on their own or assist nurses and doctors can greatly reduce the threat of infection among the staff by reducing their dangerous and risky tasks.

### 1.3 Terminology

Some terms used that are relevant to this project are non-conventional terms. As such these terms will be explained within this section.

#### Robots

The word robot was originally introduced by K. Čapek in his play Rossum's Universal Robots (R.U.R.), its original meaning was forced labor (robota)<sup>(9)</sup>. Today the word robot has less of a concrete definition, but most define it as a machine that can be programmed. In this report a robot will be referred to as a programmable machine that is capable of detecting its environment and responds accordingly.

## Robotics

The branch of technology that deals with the design, construction, operation, and application of robots. The term was originally used by Asimov in a short story composed in the 1940s<sup>(10)</sup>.

## Roadmap

A technology roadmap is a type of research paper wherein the contents include current capabilities, possible improvement, and any shortcomings of a specified technology, in our case Medical or HealthCare Robotics.

## TRL

Technology Readiness Level (TRL) is used to determine a technology's development stage. It is based on a scale from 1-9. For the full range please refer to the NASA website<sup>(11)</sup>.

## TAL

Technology Acceptance Level (TAL) is used in this report to assess how readily a technology is accepted or rejected. This scale was constructed for the purposes of this report since other existing scales do not account for all of the required aspects pertaining to the social acceptance of a technology. For the full range refer to the TAL in the Appendix.

## 1.4 The Project

The goal of this IQP is to analyze the process in which epidemics are handled and responded, to determine where robots could be employed to increase the efficiency in containing and treating the infected patients. The focal question is which tasks will the robots be the most useful and efficient in in order to allocate the resources and robots accordingly so that the damage caused could be reduced in an

efficient fashion. As suggested in the name, this project employed a roadmap as a medium to display the results of the research.

The roadmap was constructed as a stand alone document and as such will have its own Introduction and Conclusion. It is recommended to read the roadmap along with the report, however, the reader can opt not to read the report along with the roadmap as neither is needed to understand the contents of the other. The primary focus of the roadmap is the technological aspects, i.e. what is the current state of these robots, what are possible improvements, and what are their limitations. The report took into account the social norms and cultural background of distinct regions; the resources available to the facilities that will be employing these robots; and whether or not they have the means and resources of maintaining these robots.

The project was conducted with the assumptions that curing the disease and keeping the patients alive do not require surgery nor physical therapies. The report and the research roadmap is intended to be used in Fully Developed and Developing Countries.

## 2.0 Background

### 2.1 The Problem

In the US several hospitals use or have purchased robots with the intention of assisting the staff or relieving some of their workload. Most of the hospitals use surgery robots such as the Da-Vinci. However, only a few hospitals use the robots considered for this project. This number is even less worldwide. To place things into perspective, a company that sells one of the robots used as reference for this project has sold at least one unit to 300 hospitals<sup>(c)</sup>. If all the robots were sold in the US that means only a total of 5.33% of registered hospitals in the US purchased this robot

(total number of registered hospitals in the US: 5,627)<sup>(12)</sup>. The total number of hospital worldwide registred or otherwise is unknown. However, according to Maps of World the total number of hospitals within the top ten countries which contain the most hospitals is 155,237 (China 69105, India 15067, Vietnam 12500, Nigeria 11588, Russia 11200, Japan 9413, Egypt 7411, South Korea 6446, Brazil 6410, US 6097). If the robots were sold to any of these countries that means approximately 0.19% of these hospitals purchased this robot<sup>(13)</sup>. It is safe to assume that most hospitals do not use any type of robot.

Since very few hospitals employ robots, cost and being able to incorporate these robots into their procedures becomes a key factor. Many hospitals can afford these robots, but not all of them and if the hospital waits until an epidemic hits before they buy any robot then it will be even harder for the hospital to gather enough resources to purchase the robot(s). It is also important to note that these hospital are constantly busy with or without an epidemic so incorporating a robot(s) into their daily procedures may prove a challenge. The robots used will need to be easy and ready to use without any extensive training. Even if training is required, it should remain a short, precise, and clear session.

Most of these robots have not been used to fight against an epidemic. So it is unknown whether or not these robots could even be used during an epidemic. Only one has fought against an epidemic while another one came close. The first one was used to disinfect a room where one of the few Ebola patient in the US resided in. This means the robot was used to fight against the pathogen, but not in the area where the epidemic was taking place. Despite being the only robot to have been used to fight of the pathogen causing an epidemic it is still unknown whether the robot would display the same results in the actual epidemic site.

The use of the other robot was covered by betaboston.com. There were two articles they released about robots being employed in an Ebola ward, or so they wrote since the robots never had a chance on the field. The co-founder of Vecna

Technologies, Deborah Theobald, went to Monrovia to test her company's software and VGo Communications telepresence robot. Unfortunately, she could not use the robot due to social issues. This was mostly due to the concerns many doctors and nurses had that the robot would receive a negative response from the patients in the hospital<sup>(14)(15)</sup>. The incident showed that another country's perspective of robots may or may not agree with the perspective of our own society. This incident also reminds those who plan on sending robots over to help to study the cultures and backgrounds of the regions in interest.

## 2.2 The Solution

The companies and their products used as reference will first need to go through a check list. First, the robot has to be classified as a Healthcare or Medical Robot. Second, the robot has to be state-of-the-art. The robot is required to represent the most advanced in its field since it will be used to fight a deadly pathogen. Third, the robot needs to be cost efficient and be efficient in their task. The robots don't necessarily need to be working alongside the staff, they can take over less urgent tasks to allow the staff to dedicate their time and efforts on more pressing matters. Fourth, the robot will need to have a simple UI (User Interface). Its use should be intuitive or at least simple enough that any personnel can use it without the need of a professional to run it. In the end the robots chosen were designed for the following tasks Logistics, Bio Lab, and Patient Care.

### Logistics

Within Logistics two types of robots were chosen, disinfecting robots and robots used for transportation. Currently two types of disinfecting robots are available. One of them uses UV-light, the other uses hydrogen peroxide vapor. The transportation robot comes in one of two form a slender one that is used to drag carts, the other one comes with built in cabinets. Unlike the disinfecting robot, both versions of the transportation robot can be bought from the same company. For the

UV-light method the robot used as reference was Xenex Germ-Zapping Robot<sup>(c)</sup>. When researching the vapor method no data (make or company) was provided all information was kept generalized. Therefore, all information about the hydrogen peroxide disinfecting robot will be presented as general information. The transportation robots used as reference are Aethon's TUG and Vecna's QC Bot and QC Pot<sup>(a)(b)</sup>.

## Bio Lab

These robots are used in Bio Labs (as the name suggests), which is short for Biological Experiment Laboratory. They assist researchers and doctors in analyzing an organism and finding a cure (they are capable of accomplishing more tasks, however, for this project's intended goals these two are the most important tasks). These robots are usually called liquid handling robots because their main task is pipetting (measuring or transporting liquid through a pipette). The companies used as reference were Andrew Alliance, Beckman Coulter, Hamilton, and Opetrons (for this field more than one robot was used for reference from each company, this is why no robots were specified)<sup>(d)(f)(g)(h)</sup>. There are also two cloud-based Bio Lab startups, Transcriptic and Emerald Therapeutics<sup>(j)(i)</sup>. While they do not sell robots, they do provide an automated system that can accomplish certain experiments at a reasonable price. Thus these two companies will be considered as an alternative.

## Patient Care

All robots whose task requires physical contact with a patient will be included within this field. This was the most diverse group since many would fit the description. Included in this field are telepresence, nursing, and companion robots as well as robots that can check a patient's vitals (the word check is used because the robot 'checks' or samples the patient vitals every so often it does not continuously monitor the patient's vitals). This is the only field where some of the robots are still in their development stage. For telepresence the robot used as reference was VGo Communication's VGo (at the time this report was written Vecna



purchased VGo, but the company still retained its name)<sup>(p)</sup>. For nursing the robot used as reference was Riken's RoBear<sup>(m)</sup>. VascuLogic and Veebot were used as reference for the robots capable of checking vitals (the company and robot are named after each other)<sup>(n)(0)</sup>. The robots used as reference for companion robots were Aldebaran's Pepper and Buddy<sup>(k)(i)</sup>.

For a fully detailed description about each field and the robots used as reference please refer to the roadmap.

### 3.0 Methodology

As stated previously, this IQP will be focusing on making a research roadmap. Precisely put, the roadmap will examine possible tasks that current or future robots can perform and focus on those that prove to be the most useful. With that considered: Logistics, Bio Lab, and Patient Care become the ideal jobs for the robots to perform usefully and efficiently. All robots considered have simple UIs (User Interface) and are simple to integrate.

This section will explain how the conducted research contributed to the results. The research included: reading article, surveys, research papers, watching videos demonstrating a robots performance, and searching information of the robot within the company's website. The subjects researched were the robot's performances, their uses, and social interactions between humans and robots.

#### 3.1 Technology Method

This subsection will discuss what methods were used in the development of the roadmap. The methods used in placing each technology into its appropriate TRL will also be discussed.

## TRL

It is important to note that the TRL takes into account in which phase the technology is at. It does not take into account whether it is suited or ready to be employed during an epidemic. Logistics, BioLab, and Patient Care each have their own TRL level. Patient Care was further divided into subsections since it has the most diversity of robots that are also at different TRL levels.

All the robots used as reference had at least a working prototype, therefore none of the fields have a TRL lower than 6. If the robot was a prototype then depending on the results of various tests and its performances either a 6 or 7 was given. 6 meant that a prototype was just developed. The results range from incapable to suboptimal and/or the robot still required a substantial amount of time before it could be used for real world applications. 7 meant the robot was a more developed prototype with results ranging from suboptimal to optimal and/or required only slight tuning before it becomes readily available (anywhere between 1 month to 3 years before it is available to the market). Most of the technologies were 9 as they are readily available, were proven to work as efficiently in the real world as it did in a controlled environment. One of them was 8; while the technology is readily available because of some unforeseen factors it is not working at optimal levels.

## Roadmap

Within the roadmap each task (Logistics, BioLab, Patient Care) was used as a section. Each section contained the following subsections: Domain Overview, Current Capabilities, Future Opportunity, and Challenges.

The results and compilation of our research was written down in the roadmap within the Domain Overview and Current Capabilities sections. Domain Overview contains a brief description of the field and some of the benefits of using the robot(s). Current Capabilities contains the tasks the robot(s) can carry out, their

efficiency, and the robot's components. These sections were constructed with the intention of investigating whether or not these robots currently have the capabilities to fight in the next epidemic.

These robots definitely aren't perfect thus there is room for improvement. All such improvements were written in the Future Opportunities section. These improvements were chosen after careful consideration and critical thinking. The intention of these improvements is to increase the robot's efficiency, its autonomy (such as having the robot complete a task without the need of an intermediary), and its usefulness. Additional improvements, aside from the ones mentioned in the roadmap, can be done to better the technology. The reader is, therefore, encouraged to think critically and find more opportunities on how to improve the robot(s).

The last section is the Challenges sections. The Challenges section contains defects currently impeding the robots efficiency. Only the more demanding defects were included, minor challenges that require little to no resources were excluded. Again this section was written after careful consideration, therefore, many defects may not be included within this section.

## 3.2 Social Method

This subsection includes methods used to the TAL level for each field. This section will also explain how and why the TAL was constructed.

### TAL

There are several models used to determine acceptance of a technology. These models, however, assume the society has already accepted the technology or will accept the technology and are slowly starting to purchase said technology. In other words these models focus more on the whys and hows a technology is accepted. However, this project also need to take into account the what if a society or its people do not accept said technology. This is especially true for robots since

not all robots are socially accepted. Many robots have been discontinued because their demographic were uninterested despite the technology being proven to work. Not to mention, just because the society of one country accepts it doesn't mean the society of another country will accept it. An important part of this project thus becomes to find whether or not these robots are or will be accepted by society. The solution adopted was the construction of the TAL. Despite its intended use being on whether certain robots would be accepted or not the TAL was kept general so it can be used for other technologies.

For the purposes of this project the TAL has to be able to depict both negative and positive social attitudes and how would the society respond. This was carried out by first deciding on the two extremes and how the residents would react in those extremes. The negative extreme is when the society or its residents take on active aggression against the technology, such as public protests, vandalism, or laws that prohibit the use and marketing of the technology. The positive extreme is when almost everyone living in the society uses the technology. In between stages were then chosen depicting either milder opposition or a society less inclined in the use of the technology. The scale starts at a neutral position assuming the society has never heard of the technology. Depending on various circumstances the society's attitude could change to either positive or negative. For the details of each level please refer to the Appendix.

Once the TAL was finalized, each field was given an appropriate level. Each field also received a different TAL depending on the region. The US, Europe, and Japan were chosen as they are the only regions where sufficient research in human-robot social interactions were conducted. The sources used to obtain the results of human-robot interaction were articles and surveys.

While research was being conducted, several trails of thought or trends associated with the social interaction of people and robots were observed. One of those trend seemed to be people fearing the 'overlord' or 'homicidal' robots which,

according to some, have been instilled into people's minds due to Hollywood. Many of the articles used as research included the words scary, creepy, job stealers, homicidal, and overlords to describe robots. Another trend observed was that many believed that Japan's 'love' and/or 'obsession' with robots is partially due to their Shinto beliefs. However, no concrete evidence exists that these trends are true<sup>(16)(17)</sup>.

## 4.0 Results

The results section will include recommendations as well as the results gathered from the research. The results will include both the technological and socio-economic results. The technological results will be a short description for the full details on these robots capabilities please refer to the roadmap. For the social results all Developing Countries were given 0 as most of them have just started to introduce robots in their industries. Fully Developed Countries, however, varied depending on the robot and region.

Important note: theoretically most of these robots are fully equipped to be used in the fight against epidemics. Realistically, however, there is no concrete evidence proving or disproving these robots will function as efficiently during an epidemic.

### 4.1 Logistics

Hospitals are being hard pressed to decrease their expenditure and decrease the number of patient that acquire hospital borne infections. Hospitals that have employed the use of Logistics Robots experience just that. One such hospital claimed that in the transportation robot's lifetime (10 years) the costs that the robot would incur were nearly five times less than on human personnel to produce roughly the same results. The hospital employed a total of 81 robots were employed the total cost is \$8.1M (\$100k each) not including repairs and maintenance, which incur an annual cost of about \$300k, in its lifetime the robot would incur a total cost of about

\$11.1M. The minimal number of human personnel they would need is 120 with a salary of about \$45k per year. The same amount of years the robot would be in service, the cost incurred by employing human personnel instead would be a minimal of about \$54M<sup>(18)</sup>. Hospitals that employ this robot not only cut down costs by a substantial amount, but also gives the hospital staff more time to focus on the patient.

The transportation robot can deliver 1,000 meals per day or haul 1,000lb of linen per day. These robots can transport medicine, live samples, and equipment safely only opening for staff members. These robots can navigate the entire hospital with prerecorded maps. Through multiple onboard sensors these robots can avoid collisions and drive around the object, if the robot senses too many obstructions it will stop until the obstructions are moved. If the hospital has multiple floors these robots can send simple elevator commands through wi-fi.

The disinfecting robots are to be used to enhance the cleaning process, cleaning staff are still required to do a quick sweep beforehand. The robots also need to be rolled into the room and be activated by the staff. They also have on board sensors that alert the robot when someone enters the rooms causing the robot to forcefully shut down. One of the robots that use UV-light uses a germicidal light across a spectrum of 200 nm to 320 nm. This robot has been proven to reduce hospital's detected infections such as MRSA by 74% and more than 80% for C.diff. The robot that uses the hydrogen peroxide method comes in pairs. One releases the vapor covering all exposed surfaces with a thin layer of about 2-6 microns in thickness. The other breaks down the vapor into water and oxygen. The hydrogen peroxide method was proven to reduce the likelihood of patient getting infected with drug-resistant pathogens by 64%. The percentage of a patient contracting enterococci, a bacterium resistant to antibiotics such as vancomycin, was reduced by 80% because of the hydrogen peroxide disinfecting robot.

Hospitals that decide to purchase the disinfecting robot have to choose between the two distinct disinfecting methods. Which is better? Within a technological standpoint neither is superior since one offers speed (UV-light) and the other clean efficiency (hydrogen peroxide) and no research has been conducted comparing the two. However, taking into account that in an epidemic the hospital might be over capacity and at any time there could be an influx of patients the UV-light method is better. While more expensive this method only takes 5 minutes. The other method would take 3 hours to disinfect a single room, meaning by the time the UV-light method disinfects a room the hydrogen peroxide method would have disinfected 36 rooms (not taking into account the time for transportation).

One of the most common ways of getting infected is by coming into contact with an infected surface. Both robots can reduce the odds of hospital staff contracting the infection by reducing the time the personnel comes into contact with the infected object and by having the robot kill/neutralize the infection before any personnel or patient coming into contact with the object (one of the disinfecting robots UV-light doesn't always kill the infection, sometimes it leaves it ineffective hence the use of the word neutralize). This could be an important factor in preventing the pathogen from spreading within the hospital.

As many marketing personnel know, just because something works doesn't necessarily mean it will sell. Whether a product will sell or not depends on the will of the buyer. Based on the research results this technology would sell fairly well. Many would agree the benefits they provide are worthwhile. Logistic Robots received a fairly positive response from both patients and doctors.

## 4.2 BioLab

BioLabs robots allow for full or partial automation of an experiment effectively cutting down errors and time spent on the experiment. These robots come in two different forms. The first one is a simple version only capable of

pipetting. The second is a complex system of robots capable of accomplishing multiple procedures.

The simple version is small enough that even the biggest can be placed on top of a table. The smaller ones are light enough that they can be easily transported by hand. Some are capable of setting their workplace and can store the results. The workplace of this robot has a predefined setup. However, a startup company is currently making an open-source robot that can have its workplace altered without the need of altering the code.

The complex version is capable of automating almost any experiment. The entire robot is controlled through a single computer, despite being multiple robots working simultaneously. This version can perform pipetting, use centrifuges, incubators, storage devices, and heaters/shakers. The robot is also capable of storing the samples and barcoding them to allow for easy and quick retrieval. The robot can even assist in reading the results by creating a unified data set.

These robots price range varies greatly, the cheapest costing \$1,095 and the most expensive of the simple version costing nearly \$100,000. For the complex version no price ranges are known as the companies only give price ranges when requesting a quote. The BioLab startups charge per protocol as well as per sample. The cost per protocol can be \$2,000 or \$3,000. The cost per sample varies depending on the number of samples (the more samples the less the cost per sample).

The BioLab robots are tricky when it comes to its acceptance. No surveys nor social experiments were conducted for these types of robots. Although based on the feedback provided by researchers and doctors that use this technology, they have a very positive view of this technology.



### 4.3 Patient Care

The Patient Care Robots provide a number of benefits. Allows experts in certain fields or diseases to provide their knowledge to the hospital regardless of his/her physical location. Assist nurses during their daily routine. Monitor patients and alert staff if their condition worsens.

The telepresence robot can be used to connect experts to hospitals without the expert being physically present. This could become an important factor in proceeding epidemics. During the Ebola case approximately 881 medical personnel were infected and 512 of them died even killing of some experts<sup>(8)</sup>. There might be only a few experts of the pathogen that is causing an epidemic and losing just one of them would cause a substantial impact. Having them use the telepresence robot can prevent these experts from contracting the pathogen while allowing them to share their expertise. The robot can also download the results obtained from any medical equipment.

Robots whose task is to check the patient's vitals can help doctors identify whether or not the patient contains the pathogen. A venipuncture robot can draw the blood of a patient with high precision (83%-100%)<sup>(19)(20)</sup>. One of them is portable and the other is slightly more autonomous. Both robots are still in their early prototype phase though. Despite being no longer available there was a robot that could check blood pressure, sugar levels, and body temperature. This means that the technology is viable and could potentially be used.

A few robots are classified as Assistive Nursing, however, only one was considered for this project which is the robot that can move a patient (other assistive nursing robots are used to assist disabled patients). Currently there are only two robots under development that can move around a patient. One of them is called RoBear the other Cody. Both are still under development and the creator of RoBear stated that the robot may not be available for another 10 years. The robot is intended to move a patient from the bed to a wheelchair.

Companion robots could be used to constantly monitor patients. In a hospital a doctor or nurse can only stay a certain amount of time with a patient. During an epidemic that time may decrease due to the large amount of patients. Another reason doctors and nurses may have less time to interact with each patient is to decrease their chances of contracting the pathogen. If the robot becomes infected a simple disinfection will fix the problem as most disinfection methods don't damage electronics. These robots could also be a social companion to the isolated patients or provide some form of communication to allow the patient to contact his family.

Similar to Logistics Robots, the Patient Care Robots receive a fairly positive response from both patients and doctors. However, the robots within this field are intended to have heavy interactions with the patient. More than the previous two this field requires the designer to come up with a design that would not pose as intimidating to the patients. The robot should also be able to communicate in the country's native tongue. Surveys have uncovered that robots are more readily accepted if they can speak in the native tongue. These robots are also fairly inexpensive. Not including the three that are still in their prototype phase, the telepresence and companion robots cost no more than \$2,000.

## 5.0 Conclusion

This project has focused on the current medical robotics that are available as well as those still in researches. The research methodology involves looking up the information of the medical robots that could be categorized in bio-lab, patient care, or logistics. Each of these robots is then ranked according to the Technology Readiness Level and a newly constructed Technology Acceptance Level. The process was done to produce general numbers for entrepreneurs, investors, or anyone interested in developing these types of robots.

The major findings of the research are that the number of robots available for logistics, bio-lab, and patient care is high. However, to satisfy the high and harsh demands to deal with epidemics like Ebola, the current technology is still lacking. For that reason, suggestions and pointers were made for each of the sections so that the robotics technology could be advanced further to meet the requirements.

This project was a great opportunity for the research team. We explored much about the field of medical robotics, the social impacts brought by robotics, and the connections between humans and robots. The team also gained experience in searching details and information in research journals and also in creating a ranking system.

Today's robots are capable of assisting in the fight of tomorrow's epidemics. Many of these robots provide a definite advantage over more conventional methods, such as allowing doctors and nurses to spend more time with the patients while the robots do all of the time consuming work behind the scenes.

## 6.0 Bibliography

- (1)Robotics. (n.d.). Retrieved February 11, 2016 from Wikipedia  
<https://en.wikipedia.org/wiki/Robotics>
- (2)Automaton. (n.d.). In Dictionary.com. Retrieved from  
<http://dictionary.reference.com/browse/automata>
- (3)Unimate. The Robot Hall of Fame. Retrieved from  
<http://www.robothalloffame.org/inductees/03inductees/unimate.html>
- (4)Samadi, B. (n.d.). History of Robotic Surgery. Robotic Ontology. Retrieved from  
<http://www.roboticoncology.com/history/>
- (5)Sanchez, M. (2012). THE HISTORY OF MEDICAL ROBOTS! Neurochangers.  
Retrieved from  
<http://neurochangers.com/2012/08/09/the-history-of-medical-robots/>
- (6) Benedictow, O. J. (2005). The Black Death: The Greatest Catastrophe Ever. History Today, 55. Retrieved from  
<http://www.historytoday.com/ole-j-benedictow/black-death-greatest-catastrophe-ever>
- (7)The Economist. (2015). Ebola in graphics: The toll of a tragedy. Retrieved from  
<http://www.economist.com/blogs/graphicdetail/2015/08/ebola-graphics>
- (8)THE DATA TEAM. (2015, August 27). The Toll of a Tragedy. Retrieved from  
<http://www.economist.com/blogs/graphicdetail/2015/08/ebola-graphics>
- (9)Robot. (n.d.). In Oxford Dictionaries. Retrieved from  
[http://www.oxforddictionaries.com/us/definition/american\\_english/robot](http://www.oxforddictionaries.com/us/definition/american_english/robot)
- (10)Robotics. WhatIs. Retrieved from  
<http://whatis.techtarget.com/definition/robotics>
- (11) Retrieved from  
[https://www.nasa.gov/directorates/heo/scan/engineering/technology/txt\\_accordi on1.html](https://www.nasa.gov/directorates/heo/scan/engineering/technology/txt_accordi on1.html)
- (12)Taken from the Americans Health Association’s website. Retrieved February 28, 2016  
<http://www.aha.org/research/rc/stat-studies/fast-facts.shtml>

(13)Taken from World of Maps. Retrieved February 28, 2016

<http://www.mapsofworld.com/world-top-ten/world-top-ten-countries-by-hospitals-map.html>

(14)Subbaraman, N. (2015). This is what happens when you bring a robot to an Ebola ward. Betaboston. Retrieved from

<http://www.betaboston.com/news/2015/06/03/this-is-what-happens-when-you-bring-a-robot-to-an-ebola-ward/>

(15)Subbaraman, N. (2014). Vecna tests Ebola technology in Monrovia. Betaboston. Retrieved from

<http://www.betaboston.com/news/2014/12/10/vecna-tests-ebola-technology-in-monrovia/>

(16)Traveler. (2013, May 14). Debunked: Japan's "Special Relationship with Robots". (Web log comment). Retrieved from

[http://www.homejapan.com/robot\\_myth](http://www.homejapan.com/robot_myth)

(17)Dyloco, P. (2010). Robots: The future of Japan? Maybe not. Japan Today.

Retrieved from

<http://www.japantoday.com/category/features/view/robots-the-future-of-japan-maybe-not>

(18)Morse, S. (2015). More hospitals investing in robots to cut costs in the long run. HealthCare Finance. Retrieved from

<http://www.healthcarefinancenews.com/news/more-hospitals-investing-robots-cut-costs-long-run>

(19)Perry, T. S. (2013). Making a robot that can draw blood faster and more safely than a human can. IEEE Spectrum. Retrieved from

<http://spectrum.ieee.org/robotics/medical-robots/profile-veebot>

(20)N.A. (2014). Medical Imaging: Robot performs IV procedures autonomously.

Vision Systems. Retrieved from

<http://www.vision-systems.com/articles/print/volume-19/issue-9/departments/technology-trends/medical-imaging-robot-performs-iv-procedures-autonomously.html>

Veracka, Elizabeth Warner, Alexander Louis Segala, and Erin Kathleen Dolan (2011).Directions for Wind Industry in Massachusetts. Unpublished Interactive Qualifying Project. Worcester Polytechnic Institute.

Yaralia Castillo, Bryan Ferguson, Joshua Rodden, Roman D Walsh (2006).

Emergency Packaged Water Distribution System. Unpublished Interactive Qualifying Project. Worcester Polytechnic Institute.

Adam Carmichael, Denise Gleason, Ryan Christopher Lehrmitt, Christopher Roy Luppino (2007). *The City of Westminster Livability Index*. Unpublished Interactive Qualifying Project. Worcester Polytechnic Institute.

Andrew Canniff, Jin Kyung Kim, Cing Lun Thang (2012). *Factors Affecting the Transition from Prescriptive to Performance-Fire Codes in Korea, Poland and Brazil*. Unpublished Interactive Qualifying Project. Worcester Polytechnic Institute.

Mahir Ugurtan Derman, Jason Correia. (2015). *Treasure Valley Scout Reservation Solar Energy Sustainability Study*. Unpublished Interactive Qualifying Project. Worcester Polytechnic Institute.

### Company's Website

(a) Aethon, Logistics: <http://www.aethon.com>

(b) Vecna, Logistics: <http://www.vecna.com>

(c) Xenex, Logistics:

[http://www.xenex.com/?gclid=CjwKEAiAi4a2BRCu\\_eXo3O\\_k3hUSJABmN9N1Vubv\\_o9OeSISStjk2YRPR1Eo1PbabbsKsCA1HxVWIHpRoC6hju\\_wcB](http://www.xenex.com/?gclid=CjwKEAiAi4a2BRCu_eXo3O_k3hUSJABmN9N1Vubv_o9OeSISStjk2YRPR1Eo1PbabbsKsCA1HxVWIHpRoC6hju_wcB)

(d) Andrew Alliance, BioLab: <http://www.andrewalliance.com>

(f) Beckman Coulter, BioLab:

<https://www.beckmancoulter.com/wsrportal/wsr/research-and-discovery/products-and-services/research-automation/index.htm>

(g) Hamilton, BioLab: <http://www.hamiltoncompany.com/products/automated-liquid-handling>

(h) Opentrons, BioLab: <http://opentrons.com>

(i) Emerald Therapeutics, cloud-based BioLab: <http://emeraldcloudlab.com>

(j) Transcriptic, cloud-based BioLab: <https://www.transcriptic.com>

(k) Aldebaran, Patient Care: <https://www.aldebaran.com/en/cool-robots/pepper>

(l) Buddy, Patient Care: <http://adoptbuddy.com/en/>

(m) Riken, Patient Care: [http://www.riken.jp/en/pr/press/2015/20150223\\_2/](http://www.riken.jp/en/pr/press/2015/20150223_2/)

(n) VascoLogic, Patient Care: <http://vasculogic.co>

(o) Veebot, Patient Care: <http://www.veebot.com>

(p)VGo Communications, Patient Care: <http://www.vgocom.com>

## TRL

### Bio Lab

Following the TRL scale 8. The reason this technology isn't at 9 is due to a consistency issue as you are not guaranteed of getting the same results from an experiment unless your using the exact same robot. The robots we used as reference were from the following companies: Hamilton, Versa, Hudson Robotics, Inc.

### Logistics

Following the TRL scale 9. Only robots whose intended market is hospitals were included. Most logistics robots are used to transport; items transported vary from food, medication, sterile equipment, linens, and medical waste. While others disinfect a room through either UV light or hydrogen peroxide vapor. Both have been proven to increase efficiency and reduce overall hospital cost. The robots we used as reference were from the following companies: Aethon, Vecna. Xenex, Bioquell.

### Patient Care

Patient Care, or how it is most commonly called Nursing, will be divided further depending on the robot's task as some robots are more developed than others depending on their intended use. For telepresence its TRL is 9. The robot is available on the market and it accomplishes its intended use, have doctors who are far away be able to assess patient and give advice. The robots we used as reference were from the following companies: VGo, InTouch Health, Suitable Technologies.

Robots capable of checking vitals have two TRL levels; one is TRL 9, the other is TRL 6. A Japanese company constructed a robot capable of checking a patient's blood pressure, body temperature, and blood sugar levels. However, due to lack of

sales the robot was discontinued. Despite no longer being in sale the technology did work thus its TRL is 9. The other TRL level belongs to robots capable of venipuncture. The venipuncture robots are all American owned and are yet in their initial testing with research at a slight halt due to lack of funding. The robots have been proven to work in a controlled environment, but much work is still required before the robot is available on the market. The robots we used as reference were from the following companies: VeeBot, VascuLogic.

The Research Institution Riken is currently working on a robot that assists nurses in moving patients. The TRL is 6 as the robot is currently in its testing phase and its developer has expressed that a substantial amount of time was still required before the robot displayed good enough results before it would become available to the market. The most recent version of this robot is called RoBear.

The TRL level of robots that are able to be friends and companions to patients is 9. The robots in market are all imported from Japan since robots in this category from other countries are still in R&D phase. The Japanese companies that sell these robots are Buddy and Alderbaran.

## TAL

TAL (Technology Acceptance Level) – A scale that measures the level of acceptance of a society towards a specific technology based on the combination of attitudes, intentions, behaviours, and knowledge. Attitude is determined by an individual's positive or negative feelings, or opinions, towards the technology. Intention is determined by the perceived usefulness and ease of use of the technology. The behaviour is determined by the individual's interactions with the technology and the environments and the circumstances under which they interact with it. Finally, knowledge is determined by the amount of information as well as awareness, regardless of the truth, the customers have of the technology. Attitude and intention directly affect level of acceptance, i.e., one's positive or negative opinions towards the technology and the degree of one's willingness of using it



based on his perception of the technology's usefulness and ease of use. The attitude and intention are driven by a person's behavior, which, in turn, is determined by his knowledge of the technology. For our purposes it will be used to measure how accepting several societies are to robots providing assistance in logistics, patient care, and Bio-Lab.

1. Society doesn't understand what the technology is - in this stage the society has just been introduced to the new technology; a few are interested, but many pay the technology no heed.
  - Most of the people's attitude is neutral and intention zero.
2. Society has little knowledge on the technology - the majority of the society has gained a bit of information of the technology, but they don't know whether the technology is beneficial or detrimental.
  - The lack of interactions kept the people's attitude neutral but their intention slowly increasing due to the early phase of the new technology, i.e., people are curious about new things.
3. Society has some knowledge of the technology and are afraid of it - at this point there may have been misinformation and misunderstanding due to newly discovered defects. This is a critical state as the society may take active aggression attempting any method to remove said technology.
  - People's attitude drops to negative and their intention decreases because of the confusion between the new technology's defects and utilities.
4. Society finds the defects outweigh the benefits - a large majority shows an understanding of the technology, the technology may have a too many defects or the society may see that the defects are worse than the benefits and they don't want the technology to be integrated.
  - As people's knowledge of the technology is deepened, they can generalize the big picture and judge that the technology cannot, or yet, be accepted,

thus further negatively decreasing their attitude and almost zeroing intention.

5. Society unwillingly accepts it - It could be caused by the government forcing the people to use it, it could be that the people realize they need the technology to improve their lives though many don't like it, or the company publicly promises to fix and improve their technology.
  - With some drive or incentive from an outside source, the people's negative attitude is eased and intention is back to increasing bit by bit.
6. Society starts tolerating the defects - The society has gotten used to the technology. Many still see the defects often times just to confirm that the technology isn't perfect, but some choose to ignore it.
  - People find ways to get around the technology's defects, increasing their attitude bit by bit and intention linearly increases.
7. Society starts evaluating the benefits - maybe the technology improve and has less defects or maybe the society is starting to realize that the benefits outweigh the defects.
  - From their increasing interactions with the technology, people's attitude linearly increases and intention still linearly increases.
8. Society ignores most of the defects and focus on the benefits - some are still skeptical and a few avoid it when possible, but most use the technology without reserve.
  - Due to people's deep knowledge of and high interactions with the technology, they choose to ignore the technology's defects and focus on the benefits it brings, thus further increasing their attitude linearly and intention exponentially.
9. Society completely accepts the technology - Whether it's intended use is in the workforce or as an item of leisure almost everyone uses it, a few may not use it

because they don't see a reason why they should or it might be too expensive for them.

- People have completely accepted the new technology. Their intention has reached a safe stage but their attitude can still be negatively affected.

\*Note: at any time the scale can increase or decrease by more than one for various reasons, such as a new technology is slowly replacing the old one and many are starting to prefer the new one, paranoia, misinformation, among others

Several models were viewed for reference such as Technology Acceptance Model (TAM), Technology Adoption Curve, and Technology Readiness Level (TRL). Technology Adoption Curve assume that society has already accepted the technology and it is up to the individual to find out whether it is beneficial to them or worth their time and what they represent is how the consumption of the object is divided amongst certain demographics. TAM assumes the individual will eventually buy the product, though it was somewhat useful since it modeled how people would eventually come around buying the products. Our model used the TRL, hence where the name came from, as reference in building this model.

### Logistics

- USA - TAL 7
- Europe - TAL 6
- Japan - TAL 8

### Patient Care

- USA - TAL 7
- Europe - TAL 6
- Japan - TAL 8

While dealing with two distinct problems, reducing job load (logistics) and improving patient - doctor or nurse interaction, they are treated as a single field

(healthcare). Thus the opinion on both is very similar. In the US many see the robots as an improvement to the healthcare system, while others simply see them as job takers. In Europe based on a survey conducted more than half support Healthcare Robots while 28% want it to be banned. Japan seems to have the highest approval of robots in healthcare. There are many factors contributing to this, one of them being Japan's rapidly aging population. Developing countries such as China are just starting to have robots appear in the industrial market so their TAL for both Logistics and Patient Care is 0.

## Bio Lab

No articles were found about how people felt about robots working in this field. This is most likely due to lack of knowledge this technology exists. However, for those who do know that this technology exists, which is usually the scientists/doctors that use them, their opinion is very positive.

General - TAL 0

Those who use this technology - TAL 9

## Roadmap

### Introduction

Robotics is one of the emerging technologies that have the potentials to improve the society's daily life and the ability to leave strong impacts as it is finding its way into everyone's home. For that reason, countless robots have been made and used for a wide range of areas, namely, manufacturing, healthcare, agriculture, commercial, logistics, transportations, and military. In the beginning, robots were made only to assist in simple repetitive tasks. Over the span of a few decades, robotics technology has evolved so that it can now cover more complicated and sophisticated jobs either through semi-automation and remote controls or full autonomy.

Currently, there are many robots working in the medical field such as surgical robots, logistics robots, rehabilitation robots, nursing robots, and so on. But with large-scale outbreaks and epidemics, especially Ebola and MERS, unexpectedly and suddenly bursting out and sweeping through wherever they go, leaving nothing behind, fears and worries are sure to rise. Questions and concerns were voiced whether the up-and-coming capabilities of the healthcare robotics could help lessen or control the damage done by the epidemics at critical locations. Since the healthcare robots are originally designed to be employed in hospitals and clinics, they give no guarantees on the same benefits they bring about to the affected areas as they do in hospitals. In fact, the researches on the effects of robotics on epidemics number less than one's fingers.

Before we begin with the actual roadmap we must consider, why should robots participate in an epidemic? Robots provide a wide array of benefits such as increase in efficiency and turnaround time, but more importantly they limit the exposure the doctors and nurses experience with the pathogen. In addition, these robots are meant to reduce staff workloads and allow for doctors and nurses more time to provide better care for their patients. The purpose of this research roadmap is to suggest guidelines on how robots can provide assistance during an epidemic.

## Logistics

### *Domain Overview*

Logistics domain includes the overall management and coordination of the supply of the goods and materials. Robotics have evolved to a stage where such tasks can be achieved automatically and timely without human intervention. However, this roadmap only presents the logistics robots with consideration of only the medical fields.

The sub-processes of logistics involve transporting materials; and disinfecting areas.

Transportation systems of the robots include the ability to sense and percept the environment to an extent and the ability to navigate and coordinate in a certain area. Guiding and communication systems need to be configured to work with transporting robots and to uphold the safety in the areas where the robots are employed.

Disinfection systems of the robots wipe out the bacterias, viruses, and pathogens using either ultraviolet light or hydrogen peroxide. The former way, though fast, only yields a humble disinfection rate while the latter one can guarantee the job in exchange for its high dangers.

It is unarguable that making the moving and delivering process of goods and materials autonomous will bring about a wide variety of new opportunities. Logistics represents about 22 to 25 percent of a hospital's average costs and could go up to 50 to 70 percent depending on the number of special situations. On average, 30 percent of their total time, nurses find their hands full with handling the logistics, namely, documents, drugs, supplies, and medications. Considerable interest is aimed towards logistics robots as the benefits they bring are worth the investments. One of the prominent benefits of the robots is that nurses can reduce the time of each logistics task by around 50 to 60 percent<sup>(1)</sup>. Nurses can now pay more attention to patient care with the time and efforts they claim during their shifts. The cost efficiency will not pose a problem, either as the amount the hospitals have to spend of the robots in at least 10 years are five times less than what the hospitals have to spend on human personnel to produce roughly the same efforts<sup>(2)</sup>.

Another research goal was to find whether or not the disinfecting robot improved room maintenance within the hospital, more specifically the one that uses the hydrogen peroxide method. The research concluded that using the robot reduced the number of patients who got infected with common drug-resistant organisms by 64%. For one particular bacterium, enterococci (VRE), the percentage of a patient contracting it was reduced by 80%<sup>(3)</sup>.

### *Current Capabilities*

Please note the following information and data was gathered from the more well-known robots of their respective industries. For the transportation robot TUG made by Aethon was used as reference. For the disinfecting robot Xenex Germ-Zapping Robot made by Xenex was used as reference for the UV light method. For the hydrogen peroxide method, the information was kept general.

The robots used for the transportation of goods and waste within a hospital usually comes in two forms. The first is more reminiscent of a pickup truck. This version is capable of hauling linens, food, and biohazards through a big cabinet that can be attached and detached. Hospitals that employ this robot usually buy multiples and have some specifically to haul linen and others to haul food. The robot is capable of hauling as much as 1,000 pounds of linen or it can deliver up to 1,000 meals a day.<sup>(4)</sup> The second version has built-in cabinets. This version is typically used to haul medicine, live samples, and sterile equipment. It is also more secure as the robot will not open unless the proper receiver, aka a doctor or nurse, opens the cabinet.

Most of these robots use a digitally pre-generated map to navigate throughout the hospital. The robot also has onboard sensors to avoid collision with patients and staff members alike. The sensors are infrared and ultrasonic laser sensors. The robots possess a simple User Interface (UI) as the staff member only has to load up the robot and choose a destination. The robot can be easily tracked so the staff constantly know the condition of any delivery and its current location. While the robot can't climb stairs it isn't stuck on a single floor. These robots are capable of accessing simple elevator commands such as calling an elevator and choosing a floor through wi-fi.

There is a common misconception about the transportation robot. The misconception is only new state-of-the-art hospitals can use these types of robots or the hospital would require a renovation. That might have been true for the earlier

stages of this robot and a few of the current robots. However, most of the current robots require a big enough hallway, which most hospitals already have, and stable wi-fi.

The other type of logistics robot, the disinfection robot, are helping hospital disinfect rooms. These robots can kill bugs, viruses, bacteria, and fungi. These robots need to be rolled into a room and before use, the staff is required to shut any doors and windows. After the robot is turned on and the room is vacated it starts to disinfect the room. The robot has onboard sensor in case a person walks into the room while its performing its task and it immediately shuts down. It is recommended for the staff member to clean the room beforehand as both robots are intended to enhance the cleaning process not replace it.

Currently there are only two distinct disinfection methods the robots use. The more well-known are those that use UV light as a disinfecting method. The other method uses hydrogen peroxide in vapor form and usually comes in pairs.

The UV light disinfection robot works with a Pulsed Xenon ultraviolet light, also known as UV-C (since the Xenex Germ-Zapping Robot was used as reference, other robots may use other bulbs). The UV-C releases a flash of Full Spectrum™ germicidal light across the entire disinfecting spectrum (from 200 nm to 320 nm) delivered in millisecond pulses. It is fast requiring a mere 5 minutes. The UV-C light is fairly safe as the light is incapable of penetrating the epidermis, but prolonged exposure can cause eye damage. The robot uses sensors such as heat sensors to detect any person that walks into the room which causes the robot to deactivate<sup>(4)</sup>.

Robots that use the hydrogen peroxide usually come in pairs. The larger one releases the vapor which covers all exposed surfaces with a very tinny layer about 2 - 6 microns in thickness. Since the hydrogen peroxide is in gas form it can reach and disinfect any nook and cranny in the room. The other smaller one breaks down the vapor into its water and oxygen components<sup>[3]</sup>. The robots that use this method are



cheaper than those that use the other method, costing as low as \$31,000 compared to \$76,000<sup>[5]</sup>.

Both robots could potentially be used to disinfect other robots as both methods don't damage electronics. However, of the two the hydrogen peroxide method is a surer way to ensure that the robot is fully disinfected. Both robots have been proven to kill hospital acquires infections including those that are drug resistant (most of the tests and research were done or funded by the companies that make the robot).

#### *Future Opportunity*

The transportation robot possesses good pathfinding algorithms for an average hospital setting. However, a hospital that is housing patients infected by the pathogen of an epidemic will more likely have cluttered hallways experiencing heavy traffic., but it could always be improved. That is why these robots should be programmed to re-plot a course (if an alternative is available) to its destination rather than being stumped until traffic clears.

The UV disinfection robot is fast and fairly safe to use. However, for this method to be more efficient the robot needs to be able of disinfecting every surface in the room. As an example for an improvement: the robot instead of being stationary could be made to move around the room. The UV light could be attached to an appendage which would have several degrees of freedom in order to wave the light over, around, and under any surface.

However, its cleaning efficiency is highly offset by the amount of time it needs to disinfect to room. Companies that employ the UV method are dominating the industry because of its speed. For the companies that use the vapor method to rival the sales of the other companies the robots cleaning speed needs to be reduced.

Another option to improve the disinfecting robot is to design a robot that could be controlled by the staff member that is in charge of cleaning the room. Those who clean a room after it has been vacated can easily get infected by a simple mistake such as scratching their eye while working. So ideally it is best if they do not come into contact with any potentially infectious surfaces and/or objects, but instead uses the robot. The robot could also be kept versatile being able to adopt any disinfection method the hospital might prefer.

### *Challenges*

The transporting robot can move around most obstructions in its path, but if it detects too many obstructions it gets stuck. The robot will not move until a few seconds after the obstruction(s) is(are) gone. Therefore, they are unable to traverse in cluttered hallways.

Each disinfecting method has its own flaws. The UV light robot can only disinfect exposed surfaces, any hidden surface such as closed cabinets and beneath the beds are not disinfected. Many pathogens like dark and damp places, areas which are normally hidden. These areas remain infectious as the robot will be incapable of disinfecting these areas and continue to be breeding grounds for pathogens.

The hydrogen peroxide robots take a long time to fully disinfect a room, around 1.5 - 3 hours. In an epidemic were rooms will be constantly getting emptied and filled this will become a big handicap on hospitals. Also hydrogen peroxide is capable of damaging the skin and the eyes. If inhaled, it can cause significant morbidity as well as asphyxiation since it is heavier than air. When in contact with organic matter, hydrogen peroxide may spontaneously combust.<sup>(6)</sup> In an unforeseen accident such as mechanical malfunctions the robot becomes a safety hazard and could potentially harm staff and patients.

## Bio Lab

### *Domain Overview*

BioLab is short for Biological Experiment Laboratory, a term for biological researches on small plants, small invertebrates, microorganisms, cells, and tissue cultures. These topics had been always done solely by human efforts and about to reach saturation of research breakthroughs. The assistance of computer technology has made the development of these researches success. The inventions of the robotics computing technologies and laboratory robots open even more opportunities for Bio Lab experiments that were previously impossible. However, with the current technology, only liquid handling robots and robotics laboratory system are taken in account for this roadmap.

The robots in this area are typically called liquid handling robots. Liquid handling robots are called as such because their main task is pipetting (measuring or transporting liquid through a pipette). These robots are employed for a wide variety of tasks: analyzing organisms and finding a cure (they are capable of accomplishing more tasks, however, for this project's intended goals these two are the most important tasks). It's not one of the most well-known areas of robotics. However, the area is fairly well developed with multiple companies having multiple models capable of performing a wide range of tasks.

### *Current Capabilities*

Currently in the market this robot is sold in two forms: a simple version or as a complex system of robots.

The only task simple versions of the liquid handling robot can accomplish is pipetting. The size ranges of this robot change depending on the number of microplates it can hold/store, number of pipets it holds, and number of pipets it can use simultaneously. The smaller ones need to have the workplace manually set in them before they can start working. The bigger ones are capable of setting up the workplace and some are capable of storing samples. Both require the user to set the

samples manually. Both are also capable of completing the following pipetting routines: serial dilutions, reagent additions, plate replications, tube to plate, PCR setup, and SPE.

There are some benefits to using this version than using the complex version. For starters it is smaller. Even the larger ones can still be supported by a table. The smaller ones are so lightweight and compact they can be placed almost anywhere.

More complex versions of the robot are not only capable of pipetting, but also contain the following devices: <sup>(7)</sup>centrifuges, microplate readers, heat sealers, heater/shakers, bar code readers, spectrophotometric devices, storage devices and incubators. Unlike the simpler version, all complex versions are capable of setting their workplace. However, the sample still needs to be set manually. With its many add-ons the robot is capable of effectively automating almost any experiment. The plate readers in the robot can be used to simplify the process of analysis by creating a unified data set<sup>[8]</sup>. It can even store samples and barcode them allowing easy tracking of each sample.

There is a cloud-based Bio Lab startup called Transcriptic that is currently available to the market<sup>(9)</sup>. The protocols currently available through this system are liquid handling, plate reading, PCR, Incubation, Plate Sealing, Plate De-sealing, Centrifugation, Gel Electrophoresis, Reagent Dispenser, Flow Cytometry, and Colony Picker<sup>(10)</sup>.

Another cloud-based Bio Lab startup that employs robots is Emerald Therapeutics. This startup offers a broader range of experiments than Transcriptic. A few of the experiments include Analytical Balance Readings, Apoptosis Assays, Autoclaving, Buffer Prep, Centrifugation, DNA/RNA Synthesis, Epifluorescence Microscopy. For the full list it is recommended to search their website<sup>(11)</sup>.

Both startups require the researcher to provide the samples for the experiment(s). Both also provide the results in an electronic format.

### *Future Opportunity*

Currently there is a start-up company (OpenTron) that is trying to Kickstart an open-source liquid handling robot; the robot is a simple version. Today's liquid handling robots all require to follow a certain preset when managing the workplace. This robot will allow the user to reconfigure the setup as well as use different types of pipettes without the need to reprogram.

A possible improvement is to make simple robotic versions of the add-ons. Small laboratories may not have enough room for the complex version of the liquid handling robot, but they may still want to reduce the time taken to complete an experiment. Even if the researcher is forced to manually move the sample from one robot to another having robots handle some of the more time consuming tasks will decrease the time needed to complete the experiment.

Transcriptic keeps adding more and more lab equipment and procedures. Their goal is to allow researchers access to the latest equipment and high quality results without the need to spend millions of dollars in investments. Emerald Therapeutics plans on adding more experiment by late 2016<sup>(11)</sup>.

### *Challenges*

The biggest problem in this area is the low reproducibility of results across various experiments and laboratories. In other words a very low percentage, <sup>(12)</sup>around 10%, of results were successfully reproduced by another laboratory. Even with robots this issue isn't fully resolved. The laboratories must be using the exact same robot if they want to have a higher probability of reproducing the results.

Robots within this domain are mostly used for pipetting. Pipetting may be a big time waster within an experiment, but ultimately it is just one of multiple processes required to complete the experiment. For the robot to accomplish additional tasks add-ons are required. This causes the workstation to expand on size

and an increase in the time needed for its setup. Not all laboratories have large amounts of space available limiting the amount of add-ons they can purchase.

Both Transcriptic and Emerald Therapeutics are situated in California. For researchers that are too distant careful transportation will incur substantial costs. Additionally, there is still a chance the samples could get damaged/destroyed, lost, or altered in some way.

## Patient Care

### *Domain Overview*

Robots within this category are normally called Nursing robots. While there are different types of robots that fall under this category, their tasks generally require them to directly provide some form of assistance to doctors and/or nurses during their daily routine, which usually involves the robot coming into physical contact with the patient. Telepresence, robots capable of checking vitals (due to the lack of a common name we will refer to them as such), assistive nursing robots, and companion robots are all robots that fall within this area. Many robots within this field are still under development and therefore are not available commercially on the day this roadmap was created.

### *Current Capabilities*

Since Patient Care currently has the most diverse types of robots this section will be further divided into sub-sections.

### *Telepresence*

Telepresence robots allow doctors to be present in hospitals despite working from home or from a distant place. These robots are equipped with a camera, speakers, microphones, and a screen which provide real-time feedback to both the doctor using the robot and any staff providing assistance. Some of the most recent versions of this robot is also capable of connecting to any medical equipment and downloading the results from any test conducted. To be able to use and control the telepresence robot the user first needs to download a specialized app developed by

the company, the app can be downloaded to iPads and computers. The robot also requires wi-fi to the network, some robots can be provided 4G LTE service. Some of the more modern versions of this robot can connect to medical equipment and download the results.

In today's hospital settings this robot allows experts in certain fields and diseases to provide their expertise. In areas such as surgery and treatment. This is done regardless of where the doctor is physically located at.

#### Checking Vitals

As their names suggest these robots are capable of checking a patient's vital signs without a doctor. Vital signs include body temperature, blood pressure, pulse, and breathing rate. The robots in this area are all prototypes and are thus still underdevelopment. The task these robots can accomplish is venipuncture. While it may not be able to check the patient's vitals, drawing blood is still a crucial step in identifying the pathogen that has infected the patient.

These robots use both ultrasound and infrared sensors to zero in on veins. Their precision varies from 83% - close to 100%<sup>(13)(14)</sup>. One of these is portable, while the other is stationary. Their degree of autonomy also differs: one being fully autonomous only requiring the doctor to start it up, the other is semi-autonomous requiring the doctor to select a vein before the robot starts drawing blood.

There was also a Japanese robot that could check the user's body temperature, blood pressure, and glucose level. The robot could diagnose eye diseases and question the user about their health (the word "user" was used rather than "patient" because the robot was not intended to be sold to health care facilities, but to the "users" themselves). The robot would then send the results via email to a doctor. However, the robot suffered low market sales and was thus discontinued.

### Assistive Nursing

These robots generally help nurses in their daily routine. Their main purpose is to allow the nurse to focus more on interacting with the patient as well as increase the number of patients the nurse can attend. Robots in this field are still underdevelopment due to the robot's inability to replicate human level dexterity.

One of the robots in this section assists nurses by carrying patients. One of these robots is RoBear, a robot created by the Japanese institute Riken. RoBear's original task is to assist the elderly, but it can be repurposed to assist nurses.

### Companion

These types of robots will include any robot that interacts directly with the patient without the need of a doctor and are capable of interacting with the patient. While hospitals or any health care facility may not be the environment these robots were designed for, many of their capabilities may be useful in a hospital.

Many companion robots in the market are capable of socializing, entertaining, and monitoring their users as well as reminding the user of any event. This robot could be repurposed into monitoring patients and alerting a doctor or nurse if the patient's condition worsens. The robot can act as an emotional pillar and quite possibly increase a patient's recovery time. A nurse within her daily routine could leave the patient's medicine for that day and the robot could remind the patient when to take the medicine. The next day the nurse following her routine again can then check up on the patient, make sure he/she took the medicine and leave that day's dose. This robot could also help deliver food to the patients.

### *Future Opportunity*

#### Telepresence

For telepresence many improvements need to happen before doctors are capable of being fully operational without being in the room with the patient. The ideal future of telepresence is to connect any expert unable to physically be in the



hospital or in extreme cases used to reduce risk of infection amongst staff members not as a full substitute for doctors and nurses.

One such improvement is adding sonar sensors to the robot as a substitute for procedures such as: auscultation (one of several methods doctors use to listen to the internal sound of the body), palpation (used during physical examination where the health care provider touches and feels a patient's body(15)), and percussion (a doctor to taps the patient's body and listen to the echo to identify the location and size of an organ). The robot would then create a 3D image based on the feedback.

Another improvement is attaching appendages to the robot. The appendages could be a set of human-like arms or it could be customizable attaching certain equipment to match the buyer's intended use. This will allow the doctor controlling the robot to not only provide guidance, but to actively take part in a patient's treatment.

#### Checking Vitals

An improvement that could be done before the venipuncture robot becomes available to the market is to make it more autonomous. Once the patient inserts their hand into the robot the robot should automatically activate and draw out the blood. The robot should then label the blood sample and replace the needle and vial. Ideally a single doctor should be capable enough to oversee multiple patients getting their blood drawn by multiple or a single robot(s).

There are many portable vital sign sensors available in the market. These sensors could be reconfigured to fit within a robot, such as a companion robot. The robot would store the patient's vitals in order to monitor the patient's health. If the patient vitals become unstable the robot could alert a nurse or doctor.

### Assistive Nursing

These robots undoubtedly need to have their dexterity improved further. The robot needs to be able to reproduce or come close to reproducing human-like dexterity to be able to provide assistance within a nurse's daily routine.

### Companion

In order to further assist doctors in monitoring a patient by fitting the robot with that can check a patient's vitals. There are many portable devices that can check its user's vital signs including some that can be connected to a smartphone to download the results. Since companion robots are open source an app could be easily made so that the robot would check the patient every so often and alert doctors when the patient's vitals unstable.

### Challenge

#### Telepresence

Doctors using telepresence robots are heavily limited. The robot is unable to traverse a hospital by itself because it can't open doors nor can it operate an elevator. The doctor is forced to travel with a staff member for optimal performance. The robot cannot operate equipment it merely downloads results.

#### Checking Vitals

The only robot capable of checking a patient's vital signs was discontinued in 2009 due to a lack of interest. However, the robot was intended as an answer to Japan's aging problem meaning the robot was intended to be marketed to the elderly populace not to healthcare facilities.

One of the reasons venipuncture robots are being made is to reduce the likelihood of needle stick injury, however, the robot is incapable of changing the needle. For the doctor this means they have to remove the used needle and replace it with a new one, which does not effectively drop needle stick injury rates.

## Assistive Nursing

These robots are the furthest from being readily available as their prototypes still aren't ready to be tested in a healthcare facility. The aforementioned RoBear is believed to become available to the market within 10 years<sup>(16)</sup>. Not to mention the only assistive nursing robots currently under development are robots that move patients out of bed and into a wheelchair or another bed.

## Conclusion

Medical Robotics is one of the most recent robotics fields; thus this field is still in its earlier stages of development. This means several robots within this field are currently unavailable to market and those that are available are usually very expensive. Despite these setbacks many companies have managed to produce affordable robots that provide decent service for their manufactured roles for a good profit.

The transporting robot can transport medication faster, safer, and with reduced chance of it getting lost than alternative methods. Some of the disinfecting robots have been used in the few cases in the US of the recent ebola outbreak and have been proven to work. Liquid Handling robots are capable of carrying out various experiments with precision better than the average doctor or researcher. Patient care robots offer a wide range of benefits such as monitoring patients without the need of a doctor being present and experts that are at a fair distance can provide their expertise in real time.

Many of the robots mentioned in this roadmap are already well suited to fight epidemics and a few can be easily repurposed to do so. There are several companies that make the same type of robot because of these hospitals have a wide variety to choose from. With time and newer models these robots will become more affordable, have improved efficiency, and be easier to produce.

## Bibliography

(1) Chan, C. (2011). Mobile Robots Improve Hospital Logistics. Humantech. Retrieved from <http://www.humantech.com/mobile-robots-improve-hospital-logistics/>

(2) Morse, S. (2015). More hospitals investing in robots to cut costs in the long run. HealthCare Finance. Retrieved from <http://www.healthcarefinancenews.com/news/more-hospitals-investing-robots-cut-costs-long-run>

(3) March, D. (2013). Hydrogen Peroxide Vapor Enhances Hospital Disinfection of Superbugs. John Hopkins Medicine. Retrieved from [http://www.hopkinsmedicine.org/news/media/releases/hydrogen\\_peroxide\\_vapor\\_enhances\\_hospital\\_disinfection\\_of\\_superbugs](http://www.hopkinsmedicine.org/news/media/releases/hydrogen_peroxide_vapor_enhances_hospital_disinfection_of_superbugs)

(4) Simon, M. (2015). This Incredible Hospital Robot Is Saving Lives. Also, I Hate It. Wired. Retrieved from <http://www.wired.com/2015/02/incredible-hospital-robot-saving-lives-also-hate/>

(5) Lee, J., Rice, S. (2015). The robot will clean up now: More hospitals buying automated systems to reduce infections. Modern Health. Retrieved from <http://www.modernhealthcare.com/article/20150110/MAGAZINE/301109980>

(4) Ebola Zapping Robot Prevents Disease | CNBC. Retrieved from <https://www.youtube.com/watch?v=nXdnxEp3dG8> na

(6) Medical Management Guidelines for Hydrogen Peroxide. (2014). Agency for Toxic Substances & Disease Registry. Retrieved from <http://www.atsdr.cdc.gov/MMG/MMG.asp?id=304&tid=84>

(7) Liquid Handling Robot. (n.d.). Retrieved December 11, 2015 from Wikipedia [https://en.wikipedia.org/wiki/Liquid\\_handling\\_robot](https://en.wikipedia.org/wiki/Liquid_handling_robot)

[<sup>8</sup>]Dr Stuart Warriner: Robotic Liquid Handling facility. Retrieved from <https://www.youtube.com/watch?v=67J1Na5PR5g>

(<sup>9</sup>)Buhr, S. (2015). Cloud-Based Bio Lab Startup Transcriptic Lands \$8.5 Million In Series A Funding To Help It Scale. TechCrunch. Retrieved from <http://techcrunch.com/2015/02/19/cloud-based-bio-lab-startup-transcriptic-lands-8-5-million-in-series-a-funding-to-help-it-scale/>

(<sup>10</sup>)Retrieved from <https://developers.transcriptic.com/docs/devices>

(<sup>11</sup>)Retrieved from <http://emeraldcloudlab.com/lab-experiments>

(<sup>12</sup>)Begley, S. (2012). In cancer science, many "discoveries" don't hold up. Reuters. Retrieved from <http://www.reuters.com/article/us-science-cancer-idUSBRE82R12P20120328>

(<sup>13</sup>)Perry, T. S. (2013). Making a robot that can draw blood faster and more safely than a human can. IEEE Spectrum. Retrieved from <http://spectrum.ieee.org/robotics/medical-robots/profile-veebot>

(<sup>14</sup>)N.A. (2014). Medical Imaging: Robot performs IV procedures autonomously. Vision Systems. Retrieved from <http://www.vision-systems.com/articles/print/volume-19/issue-9/departments/technology-trends/medical-imaging-robot-performs-iv-procedures-autonomously.html>

(<sup>15</sup>)A.D.A.M. Medical Encyclopedia. (1997). In MedlinePlus. Retrieved from <https://www.nlm.nih.gov/medlineplus/ency/article/002284.htm>

(<sup>16</sup>)Byford, S. (2015)This cuddly Japanese robot bear could be the future of elderly care. The Verge. Retrieved from <http://www.theverge.com/2015/4/28/8507049/robear-robot-bear-japan-elderly>