TOURBOT: A RESEARCH AND PRODUCT DESIGN STUDY APPLYING HUMAN ROBOT INTERACTION AND UNIVERSAL DESIGN PRINCIPLES TO THE DEVELOPMENT OF A TOUR GUIDE ROBOT

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TOURBOT: A RESEARCH AND PRODUCT DESIGN STUDY APPLYING HUMAN

ROBOT INTERACTION AND UNIVERSAL DESIGN PRINCIPLES TO

THE DEVELOPMENT OF A TOUR GUIDE ROBOT

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Date of Graduation

VITA

Robert Vern Terrell Jr., Son of Robert V. Terrell and Barbara A. Terrell, was born January 9, 1979 in Jupiter, Florida. He attended Jupiter Elementary School in Jupiter up to second grade, and continued elementary at Pleasant Grove Elementary School in Inverness, Florida. He also attended Inverness Middle School, and graduated from Citrus High School in 1998. He began his undergraduate studies at Auburn University in the Fall Quarter of 1998, receiving a Bachelor of Arts degree in Criminology December 16, 2005. He then received a Bachelor Science Degree in Environmental Design May 10, 2007. He was then accepted into the Auburn University Graduate Program and began work towards a Masters of Industrial Design in the summer of 2007.

THESIS ABSTRACT

TOURBOT: A RESEARCH AND PRODUCT DESIGN STUDY APPLYING HUMAN ROBOT INTERACTION AND UNIVERSAL DESIGN PRINCIPLES TO THE DEVELOPMENT OF A TOUR GUIDE ROBOT

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Robots have intrigued the imagination of society since their introduction in 1921 by Czechoslovakian writer Karel Capek in his play, Rossum's Universal Robots. Since that time, advances in the field of robotics have increased the opportunities for robots to interact with humans in various situations and environments. With that being said, it should be noted that less focus has been placed on the design of robots that can be used by people of all abilities and disabilities.

The purpose of this study is to combine the principles of Human Robot Interaction and Universal Design in an effort to formulate an approach that will assist in the development of human interaction robots, by specifically applying the approach to the design of a tour guide robot. The approach consists of five steps. The first step is developing a task chart that lists each task that the robot is to complete during its function. The second step is that the chart is applied to a task map that helps visualize the tasks in the intended sequence to make sure nothing was overlooked and to see the function as a whole. Once this is complete the third step is that the tasks can be applied to an interaction chart that divides the tasks into four sections. The sections will identify what hardware and software is needed to complete the tasks and meet the needs of the user. The fourth step combines the information obtained from the three previous steps into a universal flowchart. The purpose of the flowchart is to visualize all the information in the intended sequence that the robot is to perform during its function, and make adjustments to the tasks, hardware, and software as needed. The final phase of the approach is formulating a complete list of the robot's components that includes the hardware and software needed in order for each component to function. The completed list was then applied to the design of a tour guide robot.

Style manual or journal used:	APA Style
Computer software used:	Microsoft office 2007, PC
	Adobe Photo Shop CS3
	Adobe Illustrator CS3
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	SolidWorks 2008
	Maxwell Render

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Chapter 1 Introduction

Robots have intrigued the imagination of society since their introduction by Czechoslovakian writer Karel Capek in his play, Rossum's Universal Robots, in 1921. Since then robots have been featured in popular Sci-fi films, characters such as Sonny in (I Robot), C3PO and R2D2 in the (Star Wars saga), form an exciting and interesting direction for future robotics. Unlike the robots of today that autonomously perform tasks with minimal human interaction, the robots featured in these films are androids that serve as companions or partners, working side by side with humans to solve problems and perform tasks. Advances in the field of robotics have increased the possibilities for robots to interact with humans in many different situations. With the development of next generation robots like the Honda ASIMO humanoid robot and the Toyota partner robot, robots similar to the fictional characters mentioned above are becoming a reality. It was with the development of humanoid robots that the field of Human Robot Interaction (HRI) research was initiated. In the future more robots will be used to help people in many ways. They can perform many routine chores and duties, with greater efficiency, reliability, and long term coast effectiveness (compared to humans). However, there is an estimated 386 million of the world's working-age people that have some type of disability. The world's population of people 65 years of age plus is said to grow from eight-percent to seventeen percent by the year 2050 (U.S. Census Bureau, 2004), this part of the population has been little attention in terms of robot design. With this occurring it is clear that robots need to be designed to include the needs of these people.

The purpose of this study is to combine the principles of Human Robot Interaction and Universal Design in an effort to formulate a set of guidelines that will assist in the development of human interaction robots by specifically applying these guidelines to the design of a tour guide robot.

1.1 Need for Study

There have been many advances in the field of robotics. However, a great deal of work remains to be seen before successfully introducing autonomous robots into homes and work places. Robots can have many advantages over humans. For example robots can enter environments or territories that may be far too dangerous for humans. Unlike humans, robots can perform repetitive tasks with precision, strength and efficiency, without getting bored or fatigued. There are robots being developed to fill many positions currently being held by humans. Currently roboticists are working on systems for the elderly with hopes of extending the amount of time that seniors can live independently. They are also working on systems that can serve as classroom aids for teachers and also as caretakers for children, allowing the parents to have jobs and work full time if they choose to do so. The two examples mentioned above provide just a small glimpse into what the future can hold utilizing the growing and ever advancing field of robotics.

As of 2008 the world's robot population has reached 4.49 million, and that number is projected to almost double by 2010. (World Robotics, 2008)

Figure 1 is a table that represents the projected growth rate of the world's robot population by 2010

One specific opportunity presents itself in Japan. Anthropologist Jennifer Robertson is researching the effects of robots on Japanese society; she states "the industrial sector of Japan prefers robots over foreign laborers, because machines do not enhance racial tensions by evoking wartime memories as foreigners do". Another pressing issue faced by the Japanese is a decrease in birth rates coupled with an ageing population. It has been projected that forty percent of their population will be over age sixty five by the year 2055. "As Japan's population grows older and its labor force shrinks, researchers say new types of robots will play a major role as there simply won't be enough people to do these jobs” (Robotics.com, 2007).

Robot production is growing at an astonishing rate therefore roboticists should adapt the principles of universal design to their design process. Doing this will give robots the ability to serve a majority of the population. If robots are to be an integral part of tomorrow’s society, they should be able to adapt to users of all abilities and environments.

1.2 Objectives of Study

The objective of this thesis is to provide individuals in the field of robotics with an approach that combines the principles of human robot interaction and universal design for the purpose of developing human interaction robots. The approach will consist of two components. The first being human robot interaction and the second being the principals of universal design. When the two components are combined the end result or product is a robot that can be used by more than the majority of the population in a variety of situations or environments.

1.3 Assumptions

During the course of this thesis, there are some components assumed to be true. First, the principals of universal design can be applied to robotics and the current level of technology can facilitate the needs of individuals with disabilities. Second, there is a direct correlation between Universal Design and Human Robot Interaction. It is also assumed that the two disciplines can be combined and applied to the development of social robots. The third and final assumption is that incorporating universal design principles with robot design, the result will be a robot that is more accessible to people with all abilities.

1.4 Scope and Limits

This study focuses on the field of robotics. The design effort will be focused on the development of a tour guide robot, but with great opportunity for the approach to be applied to all robots that interact with people. The primary research will be directed toward universal design and human robot interaction with an attempt to combine the two sets of principles to use as a guide for the design phase. The endeavor of the tour guide robot will be coupled with the Auburn University Tourbot program. The limits of this study will include the time, funds, and resources required to build such a complex entity, and the robot already has a function (giving tours).

1.5 Procedure and Method

The development of a robot that is capable of operating intelligently with humans is a complex process that requires a vast understanding of psychological, technical, and contextual influences. It also requires determination and creative problem solving when considering all the abilities and disabilities of the users.

The procedure of this study will begin with a design brief and a list design goals. It will also include research in the areas of universal design and human robot interaction to devise a combined list of principles that will provide a foundation for the study. This will be followed by product comparison research with similar robots. The results of this research will then be used to formulate an approach which will consist of a task chart that identifies the main functions that robot is to perform. This chart will then be applied to a task map that shows the functions and the progression of the robot in its environment. This will be followed by an interaction chart that breaks down the tasks into four sections and identifies what hardware and software is needed to meet the needs of the user and complete each task. This list will then be incorporated in to a universal flowchart that highlights the secondary functions and interactions with the user to identify any additional components or functions the robot will require. From the flowchart a comprehensive list of hardware and software will be generated and applied to the design and prototyping phase of the study. The testing phase will include the construction of a full scale foam core mockup to test the height adjustability of the robot and the viewing height of the LCD with various users. The results of the test will then be reviewed and applied to the final design, and a quarter-scale model will be constructed for the final presentation.

1.6 Anticipated Outcome

The anticipated outcome of this study will consist of the completion of two main goals. The first goal will be the development of an approach for robot design that combines the principles of human robot interaction and universal design. The second goal is to apply the approach to the design a tour guide robot.

Chapter 2 History and Definitions

2.1Origins

Figure 2 1921 R.U.R poster

Although the notion of robots dates back to the Iliad 2500 years ago, the actual term Robot is derived from the Czechoslovakian word robota or robotnik meaning slave, compulsory servant, or forced work. It was introduced to the public by Czechoslovakian playwright Karel Capek in 1921 in his play R. U. R. which is an acronym for Rossum's Universal Robots. In the play, the character Rossum portrayed an Englishman that used biological methods to invent and mass-produce artificial people called robots. The robots' purpose was to serve humans.

Eventually the robots rebelled, wiping out humanity in the process, becoming the dominant race. (Clarke, December 1993)

Karel did not coin the word robot himself, naming his brother Josef Capek the actual originator. In an article in the Czech journal Lidove noviny in 1933, he explained that he had originally wanted to call the artificial people labori (a word derived from the Latin word labor, meaning work). After much deliberation he came to the conclusion that he did not like the word. He then sought advice from his brother Josef Capek who in turn suggested "robota" and so the word robot was introduced to the English language.

The term robotics which is known as a branch of engineering was coined by Isaac Asimov in his 1942 short story Runaround. Robotics refers to “a science or art involving both artificial intelligence (to reason) and mechanical engineering (to perform physical acts suggested by reason)” (Chandor, 1985).

2.2 Definition

The Robot Institute of America defines a ROBOT as: *"A reprogrammable, multifunctional manipulator designed to move material, parts, tools or specialized devices, through variable programmed motions for the performance of a variety of tasks."*

As the current definition states, robots exhibit three key elements:

- *Programmability* - implying computational or symbol- manipulative capabilities that a designer can combine as desired (a robot is a computer);

- *Mechanical capability* - enabling it to act according to its environment rather than merely function as a data processing or computational device (a robot is a machine)

- *Flexibility* - it can operate using a range of programs and can manipulate and transport materials in a variety of ways.

As defined by the IEEE Robotics and Automation Society, ROBOTICS involves designing and implementing intelligent machines which can do work too dirty, too dangerous, too precise or too tedious for humans.

2.3 Defining Characteristics

Tech Bytes is an article written by CBC news that included interviews of four professionals in the field of robotics. In the interview the professionals were asked "Your view: Hoy would you define a robot?" According to them a typical robot may have several or possibly even all of the following properties.

- It is artificially created.

- It can sense its environment, and manipulate or interact with things in it.

- It has some ability to make choices based on the environment, often using automatic control or a preprogrammed sequence.

- It is programmable.

- It moves with one or more axes of rotation.

- It makes coordinated movements.

- It moves without direct human intervention.

- It appears to have intent or agency.

2.4 Components

Today's robots are comprised of advanced sensory and servo motors that work together to perform a task. A robot can include any of the following components:

- effectors - "arms", "legs", "hands", "feet"

- sensors - parts that act like senses and can detect objects or things like heat and light and convert the object information into symbols that computers understand

- computer - the brain that contains instructions called algorithms to control the robot

- equipment - this includes tools and mechanical fixtures

- Characteristics that make robots different from regular machinery are that robots usually function by themselves, are sensitive to their environment, adapt to variations in the environment or to errors in prior performance, are task oriented and often have the ability to try different methods to accomplish a task.

2.5 Categories of Robots

There are three different ways to categorize robots. They can be categorized by their type of control, locomotion, or by their application by the user. This is illustrated through the following tables.

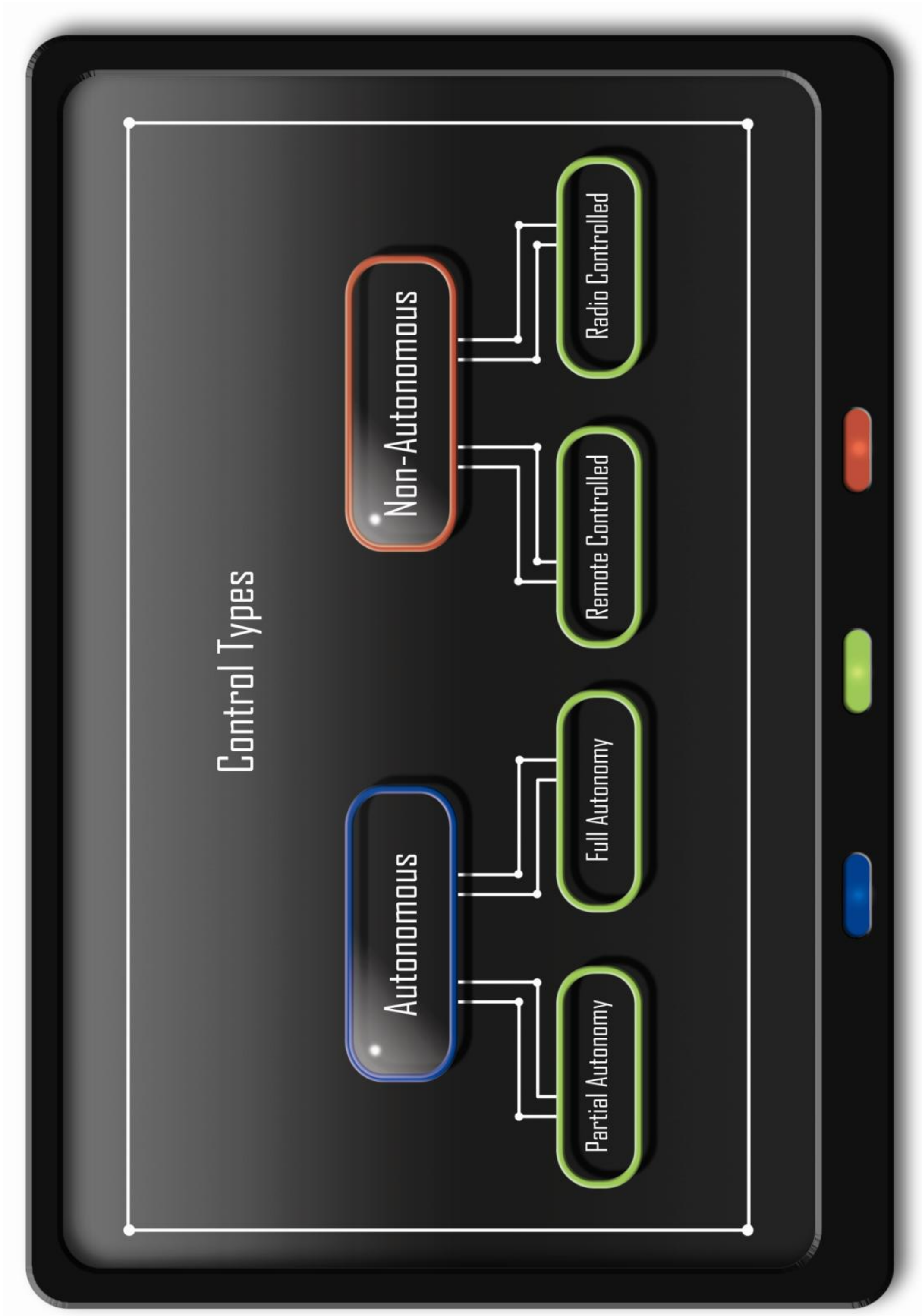


Figure 3 Robots categorized by type of control

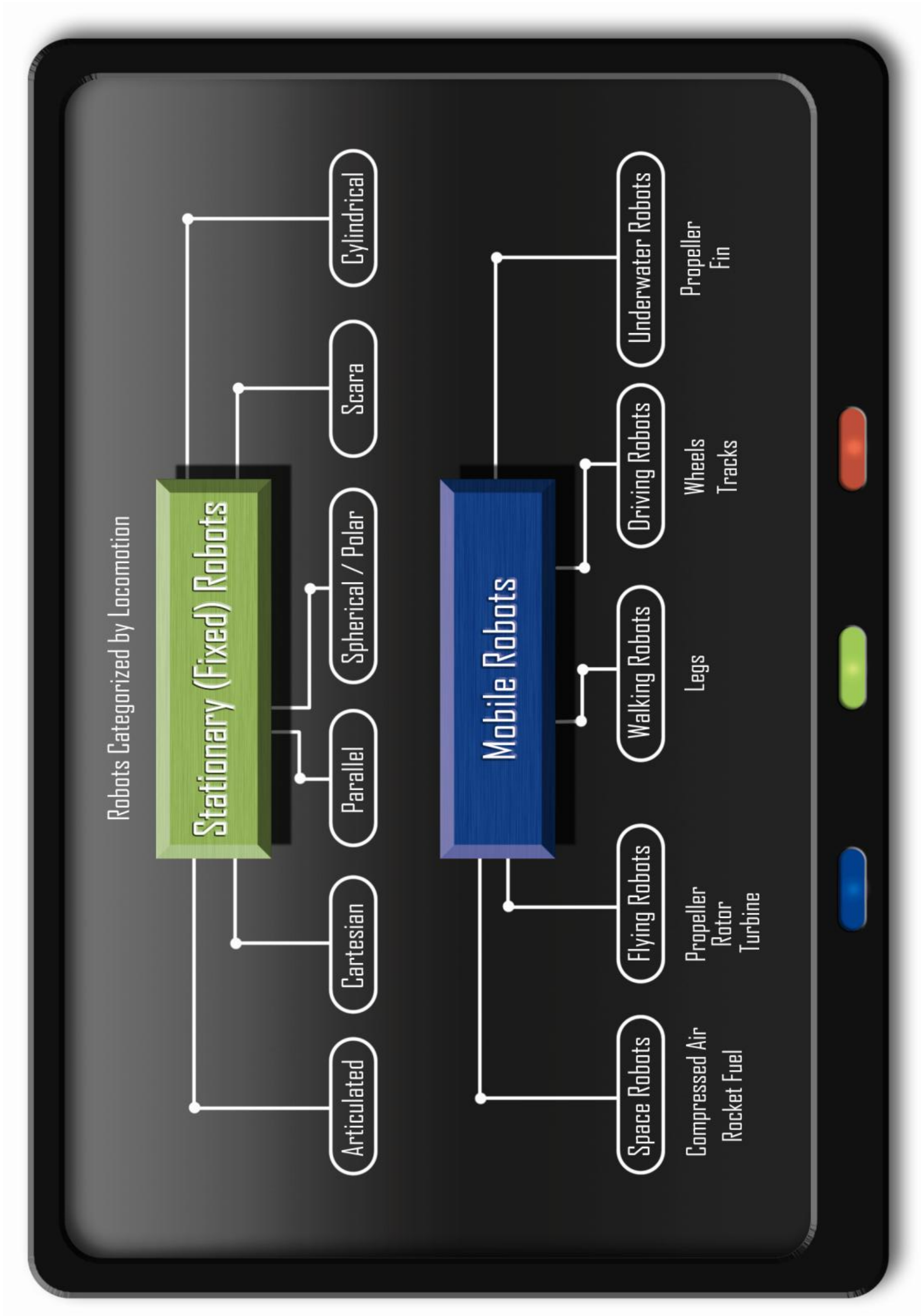


Figure 4 Robots categorized by locomotion

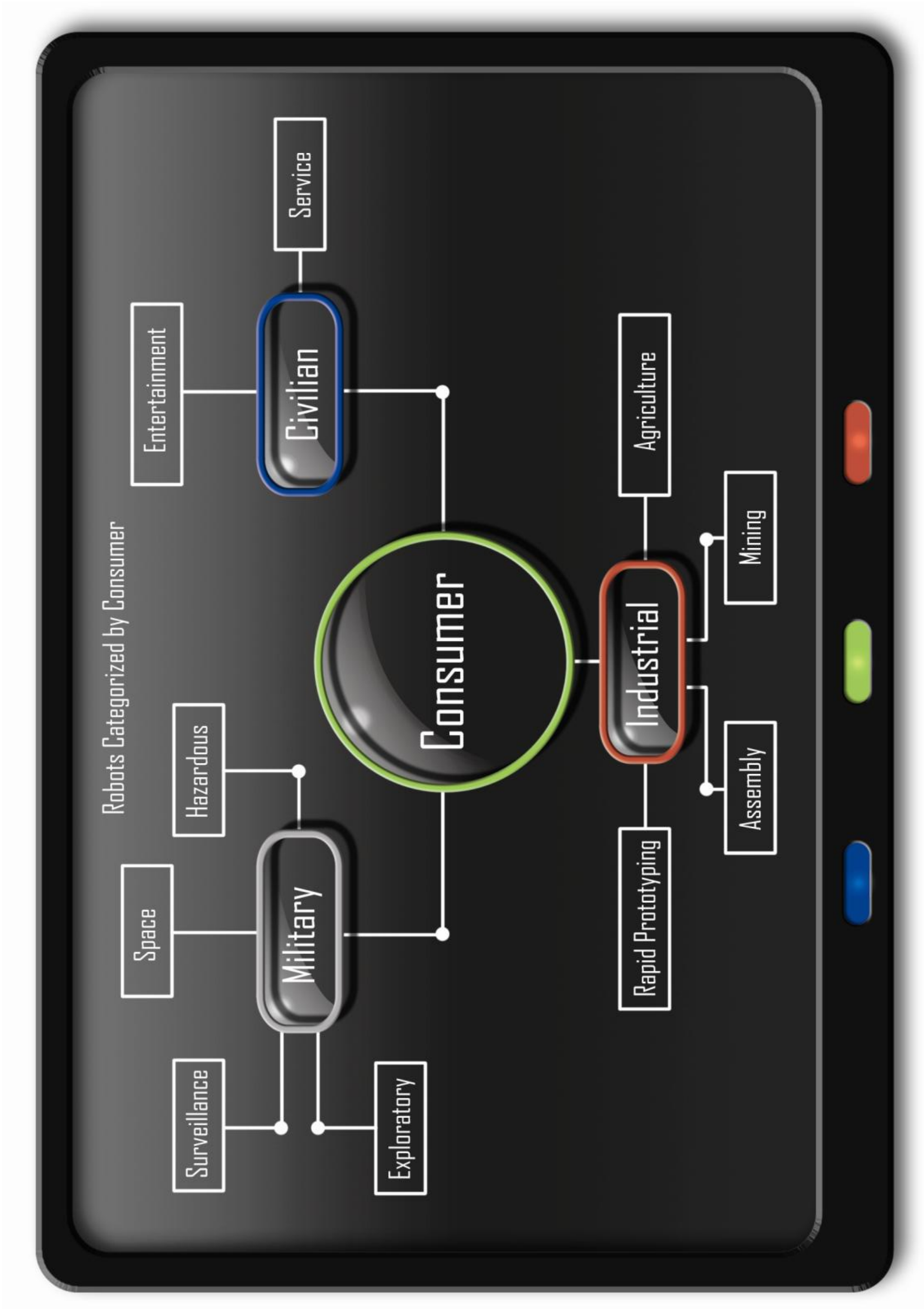


Figure 5 Robots categorized by the consumer

The TourBot can be categorized by all three methods. Its control type will be a fully autonomous with the ability to switch to partial in certain situations. As categorized by locomotion it will fall under the mobile category as a driving robot because its locomotion will be via wheels. In the consumer category its intended use will be by civilians as a service robot.

2.6 Asimov's Laws of Robotics

For decades science fiction has been a source of inspiration for designers and engineers in their development of robots. Although Isaac Asimov was not the first to conceive of non-threatening robots, he was the first to see the potential for robots to cause harm to humans. Asimov decided that there needed to be a safeguard, or set of laws that would govern the processes of robotic judgment. "In conjunction with another well known science fiction writer John W. Campbell, they formulated the three laws of robotics" (Clarke, December 1993).

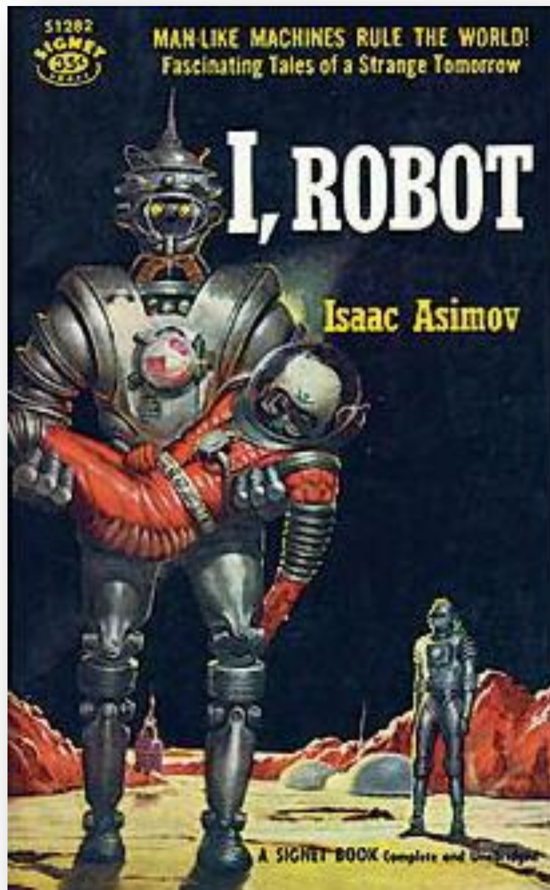


Figure 6: cover of Isaac Asimov's book *I, ROBOT*

First Law:

A robot may not injure a human being, or, through inaction, allow a human being to come to harm.

Second Law:

A robot must obey orders given it by human beings, except where such orders would conflict with the First Law.

Third Law:

A robot must protect its own existence as long as such protection does not conflict with the First or Second Law. (Asimov, 1942)

The three laws were first introduced to the public in Asimov's fourth short story "Runaround", and appear to insure the dominance of the human race over robots. The laws also prevent the use of robots for evil purposes. However after introducing the three laws Asimov noticed a conflict within the laws and issued a revised version in 1950.

The Meta-Law:

A robot may not act unless its actions are subject to the Laws of Robotics.

Law Zero:

A robot may not injure humanity, or, through inaction, allow humanity to come to harm.

Law One:

A robot may not injure a human being, or, through inaction, allow a human being to come to harm, unless this would violate a higher-order Law.

Law Two:

A robot must obey orders given it by human beings, except where such orders would conflict with a higher-order Law.

A robot must obey orders given it by superior robots, except where such orders would conflict with a higher-order Law.

Law Three:

A robot must protect the existence of a superior robot as long as such protection does not conflict with a higher-order Law.

A robot must protect its own existence as long as such protection does not conflict with a higher-order Law.

Law Four:

A robot must perform the duties for which it has been programmed, except where that would conflict with a higher-order law.

The Procreation Law:

A robot may not take any part in the design or manufacture of a robot unless the new robot's actions are subject to the Laws of Robotics. (Clarke, December 1993)

Although the laws were intended to be a literary device, they are considered common ground when discussing ethical questions about the future of robots. In March 2007, the South Korean government announced that it would issue a Robot Ethics Charter, setting standards for both users and manufacturers, later in the year. According to Park Hye-Young of the Ministry of Information and Communication, “the Charter may reflect Asimov's Three Laws, attempting to set ground rules for the future development of robotics” (Lovgren, 2007).

2.7 History

The notion of robots dates as far back as the ancient legends of the Iliad. The concept of the robot first appears as talking handmaidens of gold that were made by the hands of the Greek god Hephaestus. In reality the first robots to appear were known as automates, human like figures run by hidden mechanisms. These automates were used in churches and other places of worship to falsely provide evidence of a higher power.

2.8 Time Line

The time line below lists landmark achievement's in the history of robotics, followed by a visual timeline.

Date	Significance	Robot Name	Inventor
250 B.C.	Water clock with movable figures, first automata.	(Clepsydra)	Ctesibius of Alexandria
1495	Leonardo da Vinci designed and possibly built the first humanoid robot. The robot was designed to sit up, wave its arms, and move its head via a flexible neck while opening and closing its jaw. The design notes for the robot appear in sketchbooks that were rediscovered in the 1950s. It is not known whether or not an attempt was made to build the device.	Leonardo's Robot	Leonardo da Vinci

1865	First Steam Man apparently used to pull things.	Steam Man	John Brainerd
1868	Steam Man, capable of standing upright, running and walking, had the strength of three horses.	Dederick’s Steam Man	Zadoc P. Dederick
1885	Electric Man which is more-or-less an electric version of the Steam Man.	Electric Man	Frank Reade Jr.
1893	It was the figure of a man, constructed of iron, and fitted with internal mechanism, which, when put in motion by steam, was intended to cause the figure to move much as a human being walks.	Moore's Steam Man	(Prof.) George Moore
1893	Boilerplate was a mechanical man developed by Professor Archibald Campion during the 1880s and unveiled at the 1893 World's Columbian Exposition. It was built in a small Chicago laboratory, and was originally designed as a prototype soldier for use in resolving the conflicts of nations. Although it was the only such prototype, Boilerplate was eventually able to exercise its proposed function by participating in several combat actions. In the mid-1890s, Boilerplate embarked on a series of expeditions to demonstrate its abilities, the most ambitious being a voyage to Antarctica. Boilerplate is one of history's great ironies, a technological milestone that remains largely unknown. Even in an age that gave birth to the automobile and aero-plane, a functioning mechanical man should have been accorded more significance.	Boilerplate	Professor Archibald Campion
1897	Radio-controlled submersible boat.	Tesla’s Sub	Nikola Tesla
1912	Electric Dog, designed by two American experts in radio-controlled devices, John Hammond Jr. and Benjamin Miessner. The robot had Selenium cell 'eye' which could detect light which could detect light for maneuvering around objects.	Electric Dog	John Hammond Jr. and Benjamin Miessner
1937	Westinghouse creates ELEKTRO a human-like robot that could walk, talk, and smoke.	ELEKTRO	Westinghouse
1948	Elmer and Elsie known as the turtle robots. The robots were capable of finding their charging station	Turtle robots	W. Grey Walter

	when their battery power ran low.		
1951	Electric squirrel, contained four sense organs and a brain of six relays, hunts for nuts or small round objects.	Squee	Edmond C. Berkeley
1952	A small digital computing machine mounted on wheels, which is able to explore mazes made of toy train track and "learn" the correct path to a predetermined goal.	The Maze Solving Computer	Richard A. Wallace
1953	a mechanical man built from discarded aircraft parts is operated by remote control.	Garco	Harvey Chapman
1955	First design for a mechanical walking vehicle.	Teal	Peter Holland
1960	American Machine and Foundry (AMF Corp.) markets the first cylindrical robot.	Versatran	Harry Johnson and Veljko Milenkovic.
1961	First industrial robot in use. It was used at the General Motors factory in New Jersey. It performed spot welding and extracted die castings.	UNIMATE	George Devol
1961	It was build with dozens of transistors, and when its batteries ran low it would seek black wall outlets and plug itself in.	&quto;Beast &quote	The Johns Hopkins University
1961	Capable of anything from house work to handling radioactive materials or fighting fires.	MM47	Claus Scholz

1962	Robot capable of painting art.	Robot arm	Raymond Auger
1962	A walking robot designed for the Surveyor Project to explore the Moon.	Lunar walker	Aerojet General
1963	The Rancho Arm is created and is the first computer controlled artificial robotic arm, it was designed as a tool for the handicapped. It was developed at Rancho Los Amigos Hospital in Downey, California.	Rancho Arm	
1965	An air-powered robot arm called Orm. Orm is the Norwegian word for snake.	Orm	Victor Scheinman and Larry Leifer
1968	The tentacle arm was capable of lifting a person.	Tentacle Arm	Marvin Minsky
1968	The first computer controlled walking machine created by at the University of South Carolina.	Phoney	Mcgee and Frank
1968	General Electric four legged walking truck. The first manual controlled walking truck. It could walk up to four miles an hour. Designed for the U.S. ARMY.	Walking truck	R. Mosher
1969	First successful electrically-powered, computer-controlled robot arm.	Stanford Arm	Victor Scheinman
1969	First biped robot. Computers were used to stimulate artificial muscles connected to the frame.	WAP-1	Ichiro Kato
1970	First mobile robot controlled by artificial intelligence.	Shakey	SRI International
1971	(Mobile Environmental Response Vehicle) built by Peter Vogel to demonstrate his theory on artificial	MERV	Peter Vogel

	intelligence.		
1972	Could walk on flat surface as well as descend and ascend a staircase or slope. It could also turn while walking.	WAP-3	Ichiro Kato
1973	V.S. Gurfinkel, A. Shneider, E.V. Gurfinkel and colleagues at the department of motion control at the Russian Academy of Science create a six-legged walking vehicle.	Hexapod	V.S. Gurfinkel, A. Shneider, E.V. Gurfinkel
1973	First full-scale anthropomorphic robot in the world. It had a system for controlling limbs, vision, and conversation! It was estimated that it had the mental ability of a 18 month old child.	WABOT I	Ichiro Kato
1974	It assembled small-parts using feedback from touch and pressure sensors.	The Silver Arm	David Silver
1976	Shigeo Hirose from the Tokyo Institute of Technology creates the Soft Gripper. It conformed to the shape of the grasped object.	Soft Gripper	Shigeo Hirose
1978	It had snake-like abilities. The Oblix eventually became the MOGURA robot arm used in industry.	ACMVI (Oblix)	Shigeo Hirose
1980	A six-legged robotic insect.	Robot III	Robert Quinn and Roy Ritzmann
1980	It used a micro-computer as the controller. It could take one step every 10 seconds.	WL-9DR	Ichiro Kato

1982	It was indented to be a home companion. It had an alarm clock, and it could sing several songs. Additional programs were stored on 250 cartridges.	Hero Jr	Heathkit Corporation
1983	Had more degrees of freedom then its predecessor. It could walk laterally, turning and walking forward as well as backward. It could take a step every 4.4 seconds.	the WL-10R	Ichiro Kata
1983	Odetics Inc. unveils a six-legged walking robot called Odex 1.	Odex 1	Odetics Inc.
1984	Reads music and plays an electronic organ.	WABOT II	Ichiro Kato
1985	It was controlled by a hand-held remote control or through programs stored on magnetic tape.	Omnibot 2000	Tomy Kyogo Company Inc.
1985	Was a programmable robot. It had infrared sensors, remote audio/video transmission, bump sensors, and a voice synthesizer. It had software that could enable it to learn about its environment.	RB5X	General Robotics Corp.
1985	Waseda Hitachi Leg-11 (WHL-11) is a biped robot capable of static walking on a flat surface. It was able to turn and could take a step every 13 seconds.	WHL-11	Hitachi Ltd.
1986	EO Honda's first walking robot, Walking by putting one leg before the other was successfully achieved. However, taking nearly five seconds between steps,it walked very slowly in a straight line.	EO	Honda
1988	The first HelpMate robot goes to work at Danbury Hospital in Connecticut, delivering medicines.	HelpMate	HelpMate Robotics
1988	A two legged human sized pneumatic powered	Shadow	David

	walking robot.	Biped Walker	Buckley
1989	An autonomous four-legged machine. It weighed 1.5kg and could carry a load of about 150g.	Attila II	Robotics Corp.
1989	First biped walking robot which was able to walk on a terrain stabilized by trunk motion. It could walk at a rate of 2.6 seconds, up and down stairs. This robot could take a single step every 0.64 seconds.	WL12RIII	Kato
1990	First dynamic movement at 1.2 km/h mimicking human walk.	E2	Honda
1990	Dr. William Bargar and Howard Pual of Integrated Surgical Systems Inc. and the University of California at Davis develop the Robodoc. It performs a hip-replacement operation on a dog (1992 on a human patient).	Robodoc	Dr. William Bargar and Howard Pual
1992	First autonomous locomotion model	E5	Honda
1993	Robot autonomous control of balancing when going up and down stairs of slops or stepping over obstacles.	E6	Honda
1994	Dante explores Mt. Erebrus, Antarctica. The 8-legged walking robot was developed at Carnegie-Mellon University. However, the mission fails when its tether breaks. Dante II explores Mt. Spurr, Alaska. This is a more robust version of Dante.	Dante II	Carnegie-Mellon University
1994	First humanoid robot with arms and torso, capable of turning on and off switches and grabbing door knobs.	P1	Honda

1996	Created at MIT, the robot is used to study how fish swim.	RoboTuna	David Barrett
1997	NASA's PathFinder lands on Mars. It is a robotic rover that sends images and data about Mars back to Earth, while it roams the planet.	PathFinder	NASA
1998	This robot is a pet toy which communicates with its owner. It uses a variety of sensors to react to its environment.	FURBY	Tiger electronics
1998	Robotic creature that socially interacts with people. It uses cues from the person it interacts with as a basis for its interaction.	Kismet	Dr. Cynthia
1998	Campbell Aird, is fitted with the first bionic arm called the Edinburg Modular Arm System (EMAS).	EMAS	Prosthetics Research and Development Team at Princess Margaret Rose Orthopedic Hospital in Edinburgh.
1999	Electronic dog.	Aibo	Sony
1999	Personal Robots releases the Cye robot. It performed a variety of household chores, such as deliver mail, carry dishes, and vacuum	Cye	Probotics Inc.

2000	Sony unveils humanoid robots, the Sony Dream Robots (SDR) at Robodex. SDR is able to recognize 10 different faces, expresses emotion through speech and body language, and can walk on flat as well as irregular surfaces.	QRIO	Sony
2001	MD Robotics of Canada builds the Space Station Remote Manipulator System (SSRMS). It was successfully launched and has begun operations to complete the assembly of the International Space Station.	SSRMS	MD Robotics of Canada
2001	Omron releases their cat, NeCoRo, as a competitor to Sony's Aibo. It comes with Mind and Consciousness (MaC) technology, which enables the cat to generate feelings.	NeCoRo	Omron
2002	Honda creates the Advanced Step in Innovative Mobility (ASIMO). It is intended to be a personal assistant. It recognizes its owner's face, voice, and name. Can read email and is capable of streaming video from its camera to a PC.	ASIMO	Honda
2002	Vertical Unmanned Aerial Vehicle (VUAV) is a short-range, shipboard deployable unmanned aircraft. The VUAV will allow the Coast Guard to extend the surveillance, classification and identification capability of its major cutters through its speed, range, and endurance and at a lower cost. This asset will be used to support maritime homeland security, search and rescue missions, enforcement of laws and treaties including illegal drug interdiction, marine environmental protection, and military preparedness.	Eagle Eye	Bell Helicopter
2003	An unmanned autonomous helicopter developed for use by the United States armed forces. Provides reconnaissance, situational awareness, and precision targeting support.	MQ-8 Fire Scout	Northrop Grumman
2005	The Korean Institute of Science and Technology (KIST), creates HUBO, and claims it is the smartest robot in the world. This robot is linked to a computer via a high-speed wireless connection; the computer does all of the thinking for the robot.	HUBO	Korean Institute of Science and Technology
2005	Unmanned aerial vehicle (UAV) which the United States Air Force describes as a MALE (medium-altitude, long-endurance) UAV system. It can serve in a reconnaissance role and fire two AGM-114 Hellfire missiles.	MQ-1 Predator	General Atomics
2005	Quadruped robot to serve as a pack mule to	Big Dog	Boston

	accompany soldiers, known as "the world's most ambitious legged robot" is designed to carry 120 pounds (about 54.43 kg) alongside a soldier at three miles per hour (about 1.341 m/s), traversing rough terrain at inclines up to 45 degrees.		Dynamics
2006	Unmanned aerial vehicle (UAV) used by the United States Air Force as surveillance aircraft.	RQ-4 Global Hawk	Northrop Grumman
2011	The XM156 Class I Unmanned Aerial Vehicle (UAV) is a platoon level asset that provides the dismounted soldier with Reconnaissance, Surveillance, and Target Acquisition (RSTA) and laser designation.	XM-156	Future Combat Systems
2011	The XM1216 Small Unmanned Ground Vehicle (SUGV) is a lightweight, manportable Unmanned Ground Vehicle (UGV) capable of conducting military operations in urban terrain, tunnels, sewers, and caves. The SUGV aids in the performance of manpower-intensive or high-risk functions (i.e. urban Intelligence, Surveillance, and Reconnaissance (ISR) missions, chemical/Toxic Industrial Chemicals (TIC), Toxic Industrial Materials (TIM), reconnaissance, etc.).	XM-1216	Future Combat Systems
2011	The Multifunctional Utility/Logistics and Equipment (MULE) Vehicle is a 2.5-ton Unmanned Ground Vehicle (UGV) that will support dismounted and air assault operations. The MULE is sling-loadable under military rotorcraft and features three variants sharing a common chassis: transport, countermine and the Armed Robotic Vehicle (ARV)-Assault-Light (ARV-A-L).	XM-1217 MULE	Future Combat Systems

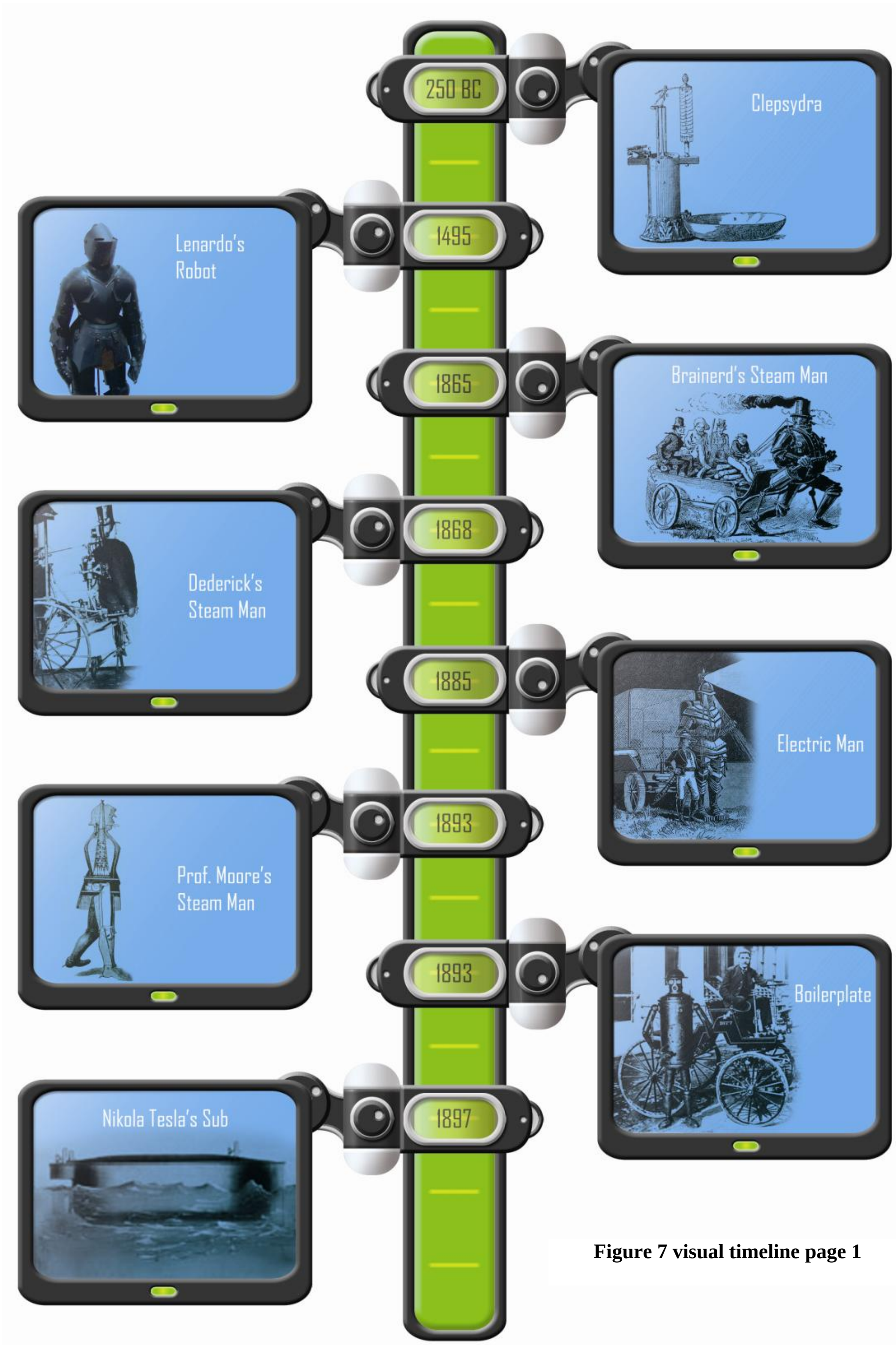


Figure 7 visual timeline page 1

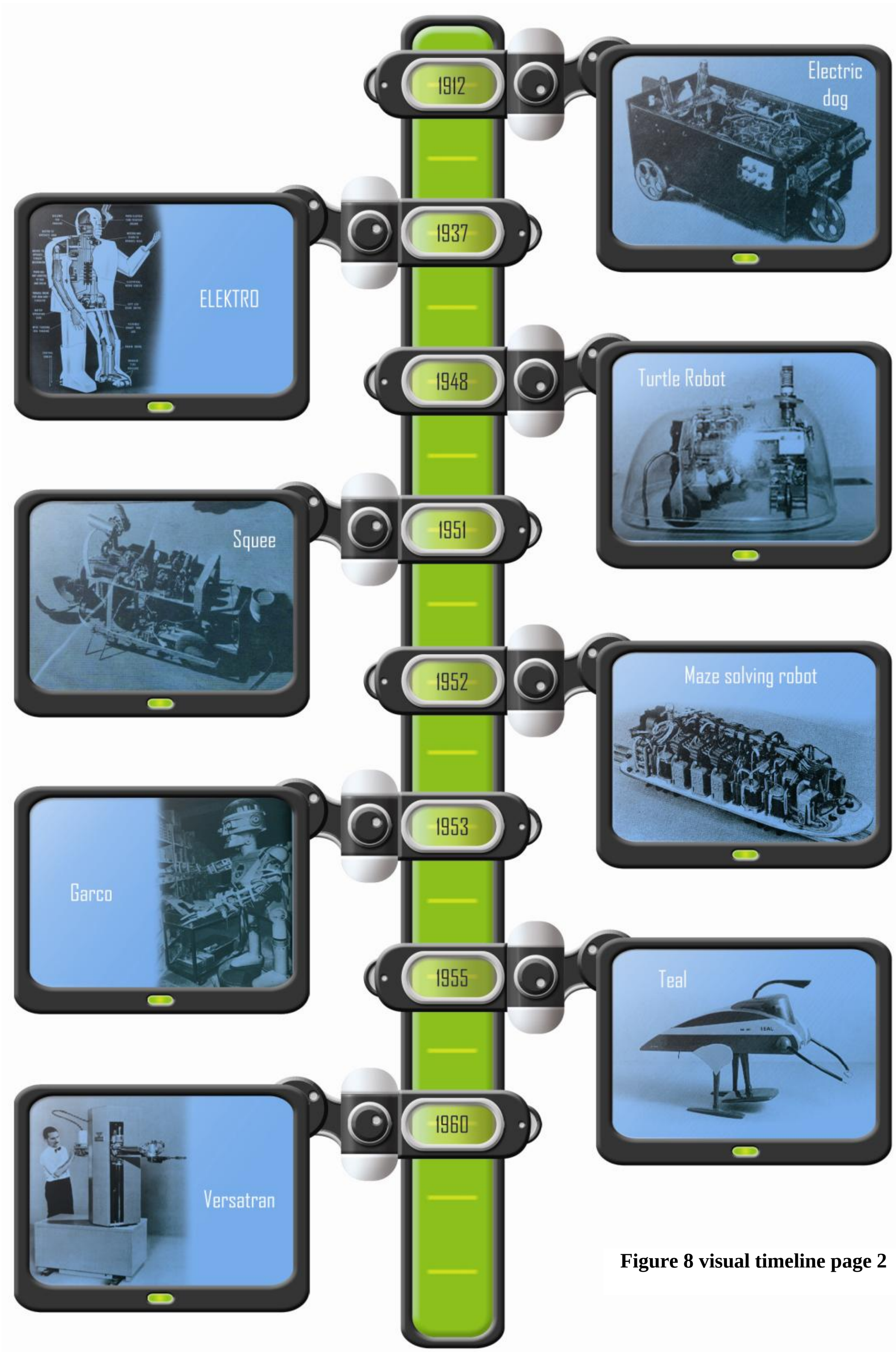


Figure 8 visual timeline page 2

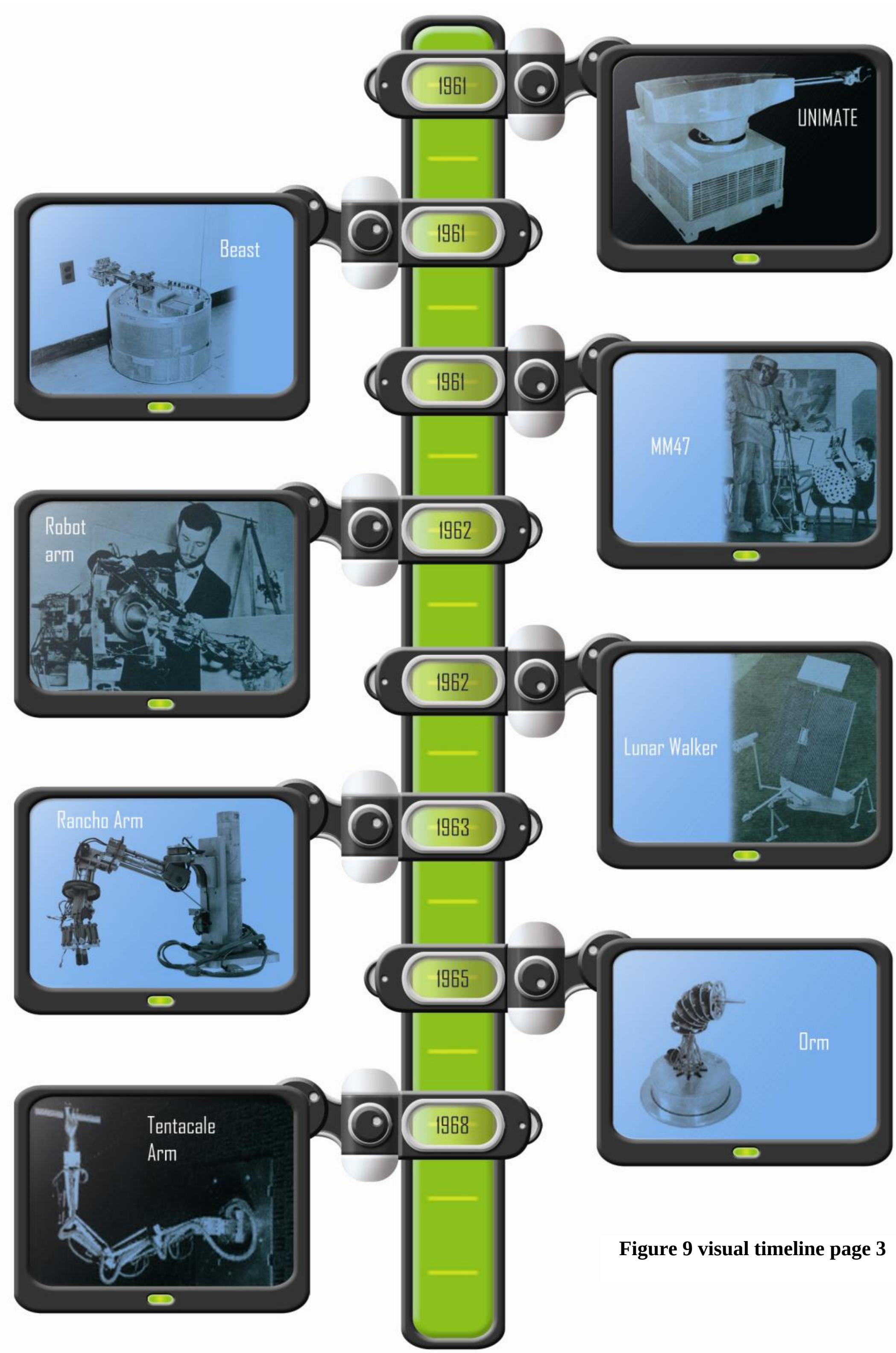


Figure 9 visual timeline page 3

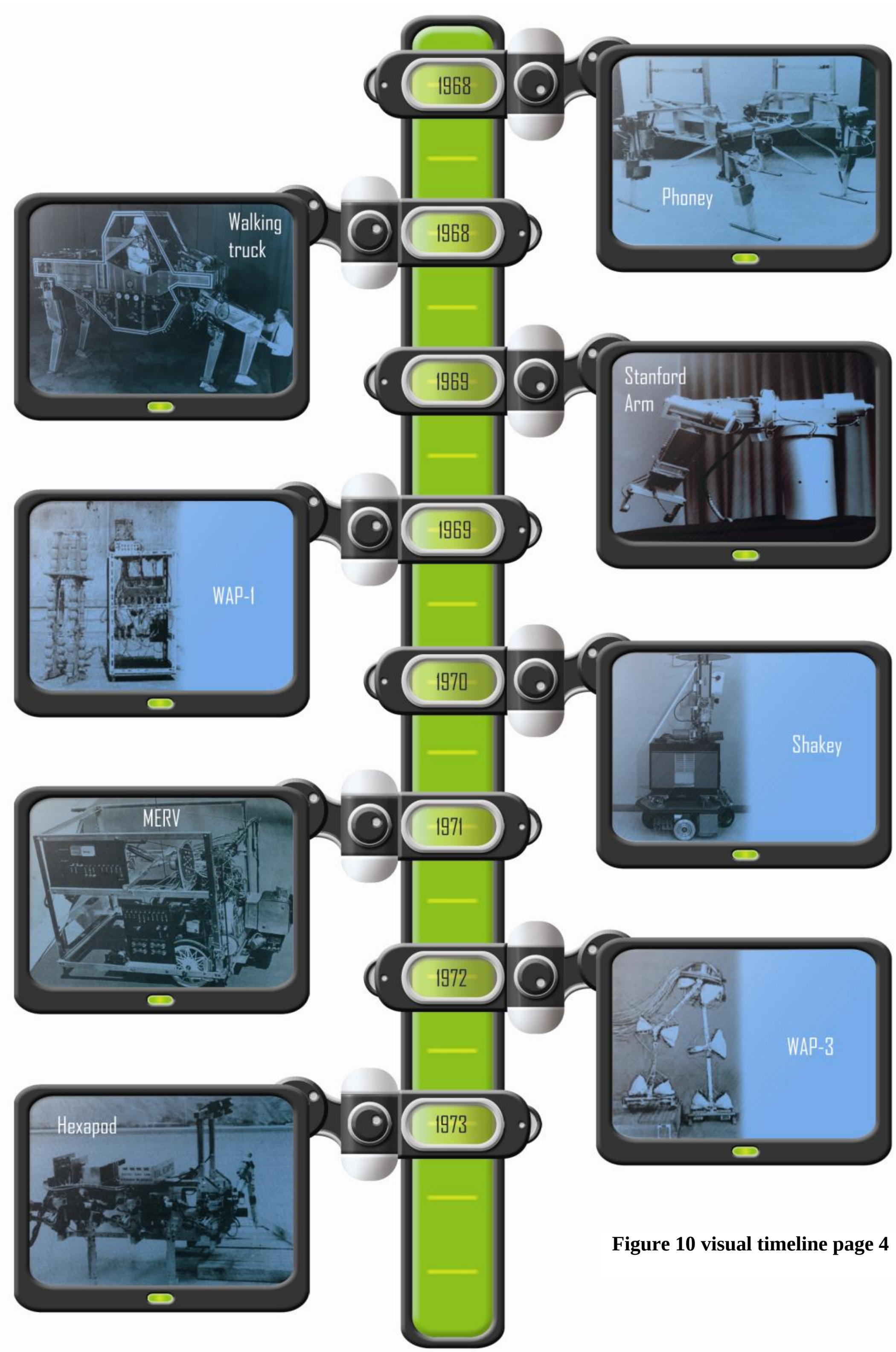


Figure 10 visual timeline page 4

Figure 11 visual timeline page 5

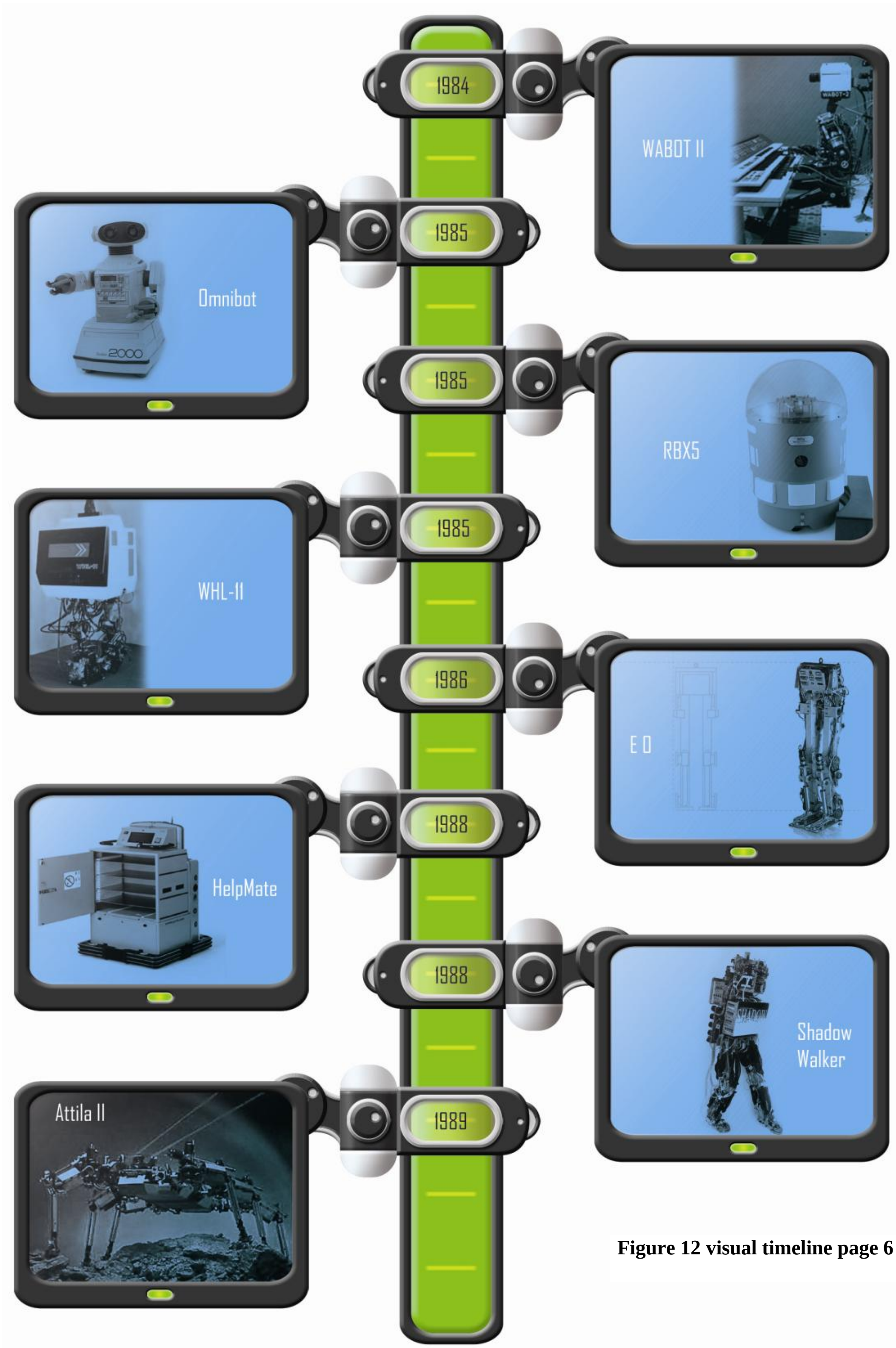


Figure 12 visual timeline page 6

Figure 13 visual timeline page 7

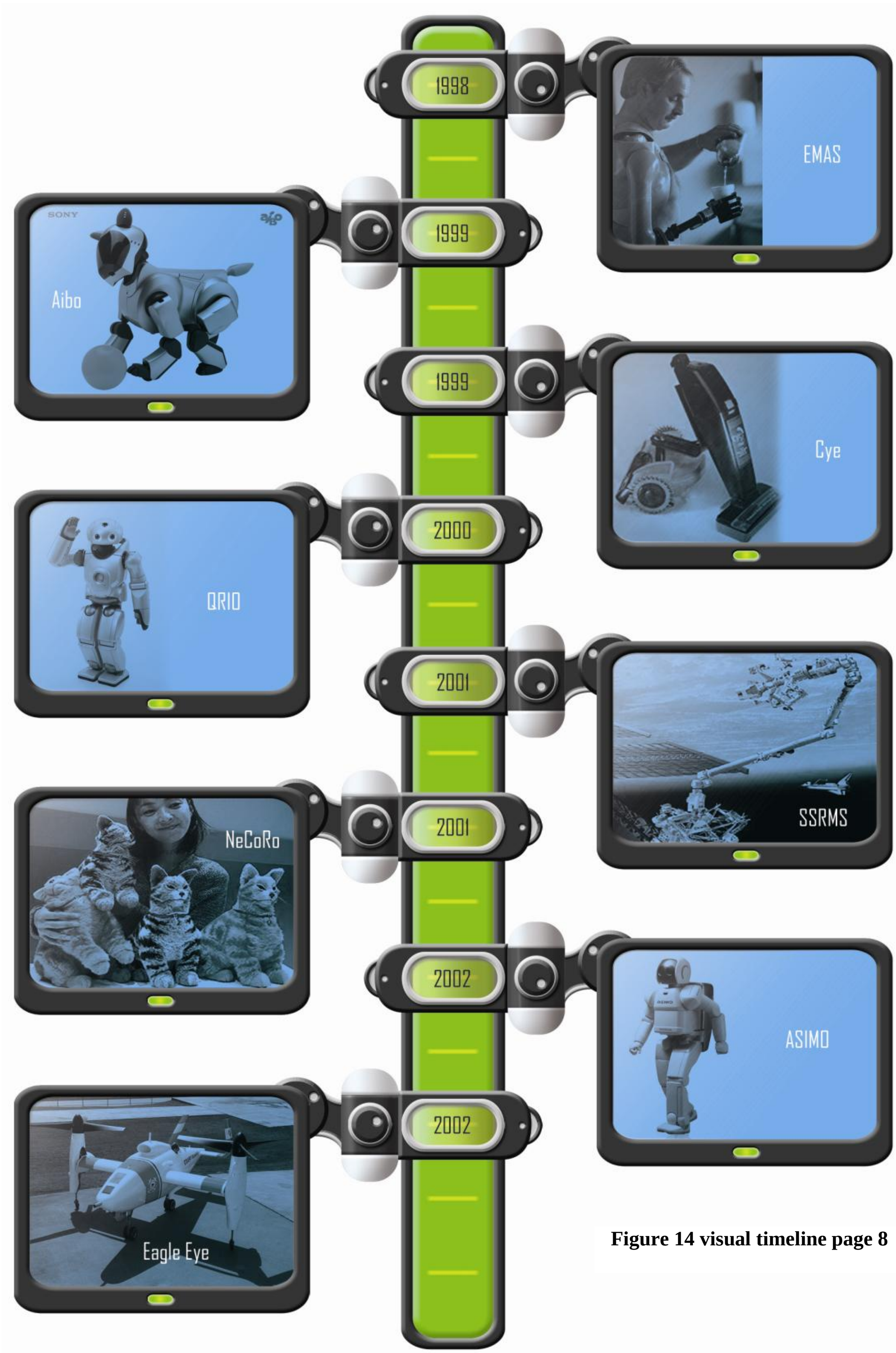


Figure 14 visual timeline page 8

Figure 15 visual timeline page 9

Timeline sources: (Buckley, 2009), (Currie), (Ranch), (Robotics Research Group), (UCLA), (Future Combat Systems), (Wikipedia, the free encyclopedia), (Boston Dynamics)

The timeline provides an overview of the progression of technology and design over time; it also helps to visualize the different trends of robots over the course of history. The years listed for all of the military robots are the dates at which they entered into service, the actual date of completion could not be obtained.

Chapter 3.0 Human Robot Interaction (HRI)

3.1 Definition

Human robot Interaction is a field of research that focuses on the interactions between humans (the users) and robots. This field of study is an "interdisciplinary process involving psychology, cognitive science, and engineering" (Kooijmans, Kanda, Bartneck, Ishiguro, & Hagita, 2007).

> *"Engineers study the HRI to develop and improve robots, while psychologists aim for a better understanding of human attitudes, roles, and expectations toward robots. The process is inherently entangled, since on the one hand, engineers require behavior frameworks developed by psychologist to help them analyze the HRI. Psychologists, on the other hand, need to be aware of the technical limitations and possibilities when developing robot behavior and creating observation frameworks."* (Kooijmans, Kanda, Bartneck, Ishiguro, & Hagita, 2007)

Research in this area focuses on natural human channels of communication, such as language and gestures, in order to generate a natural and more efficient way for the users to interact with robots.

3.2 Origins

Human Robot Interaction is a specialized area of study that emerged from Human Computer Interaction, which is a branch of Human Machine Interaction. Human Robot Interaction has been a topic of both science fiction and academic theory. Because HRI depends on knowledge of human communication, many aspects of HRI are continuations of human communications studies.

3.3 Goals

The methods by which humans interact with robots have become increasingly complex as new technologies emerge. Therefore, intelligent and sophisticated robots are often only technically successful, and the users find them confusing to use. Such robots are not used efficiently. This is where Human Robot Interaction studies come into play. One of the main goals of HRI is to develop interfaces generic enough to accommodate different types of environments. The interfaces are easy to learn and use, thus permitting the user to focus on the task at hand, rather than the tools of the interface. This will increase performance and productivity. Other goals include accelerating robot development and making robots the most accessible tools in homes and work places.

3.4 The Seven Principles of Human Robot Interaction

The principles of human robot interaction were developed by Michael Goodrich and Dan Olsen from the Computer Science Department at Brigham University in Provo Utah. In their article titled *"Seven Principles of Efficient Human Robot Interaction"* they claim the principles where uncover during their experiments and partly through experience in trying to design efficient interfaces.

Principle 1: Implicitly switch interfaces and autonomy modes

"*It is often desirable to change the way in which an operator controls a robot and receives information from the robot. Such changes are sometimes mandated by the environment and sometimes made at the discretion of the human; which autonomy mode and interface elements are selected depends on the context established by the environment, communication channel, or the operator"* (Goodrich & Olsen, 2003).

Principle 2: Let the robot use natural human cues

"People have extensive experience in accomplishing tasks and in interacting with other people. With this experience comes a set of natural expressions. Most often, scientists emphasize the naturalness of speech in supporting natural interactions, but natural language is an elusive goal and many other forms of natural expression are useful" (Goodrich & Olsen, 2003).

Principle 3: Manipulate the world instead of the robot

"The purpose of interacting with a remote robot is to accomplish some task in the world. Insofar as possible therefore, robot AI and interfaces should be designed so as to allow the task to be done, rather than drawing attention to the robot and the interface per se" (Goodrich & Olsen, 2003).

Principle 4: Manipulate the relationship between the robot and the world

"It is sometimes difficult to develop interfaces and autonomy that directly supports world manipulation. Under these circumstances, human attention may need to be drawn to the robot. When attention needs to be drawn to the robot, it is most helpful if this attention remains focused on elements of the world and the task. More precisely, information regarding the status of robot in relation to a goal state or information that relates robot pose to world coordinates is useful" (Goodrich & Olsen, 2003).

Principle 5: Let people manipulate presented information

"One primary purpose of an interface is to present information, primarily about the world, the relationship between the world and the robot, and about the robot In general, if information is presented to a user, the user should be able to

manipulate this information directly and thereby guide the robot or make progress on a task." (Goodrich & Olsen, 2003).

Principle 6: Externalize memory

"One of the difficulties with teleoperating a robot via a camera perspective is that the user cannot see where the "robot's shoulder are." A common occurrence in human machine interaction is when the user projects herself or himself into the machine so that the machine is an extension of the user. This greatly simplifies the task of keeping the correct mental models resident in working memory, but is limited if the sense of proprioception is missing. Without this sense, the user must either (a) maintain all relevant information in short-term memory and then integrate this information into a mental representation, or (b) consult other sensors and integrate all sensors into a consistent whole. Both are hard to do and both place burdens on short-term memory. This can make the task of guiding a robot all-encompassing" (Goodrich & Olsen, 2003).

Principle 7: Help people manage attention

"Attention appears to be a major bottleneck in cognitive information processing. Even if sufficient information is presented to a user, if their attention

is not on this information than incorrect decisions can be made. Thus, it is important for a user to properly manage attention" (Goodrich & Olsen, 2003).

3.5 Examples of Human Robot Interaction studies

Although there have been great advances in the field of robotics, vast amounts of work remains before robots can be integrated into the daily life of society. A few of the dominant challenges faced by Human Robot Interaction specialist today include;

- Formulating a framework for researchers that differentiate among the different categories of robots.
- Developing a system for analyzing sensor data from HRI studies.
- Robots being accepted as peers rather than objects.
- Building user trust.

The following studies address these issues and formulate interesting solutions.

The first article was written by Sebastian Thrun from the computer science department at Stanford University. Thrun suggests devising a "framework for researchers in HRI that differentiates between three main categories of robots which include industrial robots, professional service robots, and personal service robots" (Thrun, 2004). He expresses that the importance of this framework is due to the robots different capabilities, different user groups, and different contexts of use. "This framework will help the HCI community identify opportunities for research in Human Robot Interaction" (Kiesler & Hinds, 2004).

In the second article, *Accelerating Robot Development Through Integral Analysis of Human-Robot Interaction*, the authors first point out that humanoid robots possess great deal of sensors and actuators that are controlled by their artificial brain.

> *"One major engineering challenge is to process such acquired sensor information so that the robot can perform appropriate behaviors in certain situations. By studying sensor data triggered by a user's action or environmental condition, engineers can design a robot to anticipate this information and produce an appropriate reaction"* (Kooijmans, Kanda, Bartneck, Ishiguro, & Hagita, 2007).

The authors recognized the need for a tool to analyze data received by robots during HRI studies. They developed a software which they dubbed *Interaction Debugger* that features "user friendly navigation, browsing, searching, viewing, and annotation of data; it enables fine-grained inspection of the HRI" (Kooijmans, Kanda, Bartneck, Ishiguro, & Hagita, 2007). The software categorizes the data into modalities such as sound, vision, object positioning, person identification, and body contact with audio and video, which in turn lends its self to more efficient data analyses by researchers.

"Using this integrated approach one could, for instance, analyze which sensor values of a robot are triggered by certain human behavior, or if the internal states of a robot are activated in appropriate situations. From a psychological perspective, one could seek correlations between the distance from and behavior toward a robot or investigate such human attitudes as responses to body contact" (Kooijmans, Kanda, Bartneck, Ishiguro, & Hagita, 2007).

This software is a major accomplishment in the analysis of interaction data; it allows collaboration between robot developers and psychologist while conducting HRI research. This improves the effectiveness and efficiency at which we process data.

Challenges we face in the development of social robots is for the robot to be accepted as a peer and for robots to have the ability to detect humans rather than considering humans as obstacles. When analyzing this challenge one must consider the demographics of the user as well as the environment that the robot is in.

Figure 16: QRIO in a noisy environment

Some researchers suggest that children possess the ability to break such barriers in the development of humanoid robots. In citing studies that reflect this notion, the first conducted in the US was led by Javier Movellan from the University of California in San Diego. His team introduced four robots into a classroom of toddlers with their ages ranging from 18 months to two years old. The robots included in the study consisted of the SONY QRIO and ART's Robovie. The purpose of the study was to investigate the potential use of robots in early childhood education. The robots were programmed to interact with the children by giggling when they were touched and to lay down when their batteries ran low. The children interacted with the robots by touching them carefully on the face and arms, hugging them, helping them up when they fell, and covering them with a blanket when the robots laid down and also saying "Night Night". The team reported that some of the children even cried when the robot keeled over. In an interview conducted by Laura Parker from The Guardian news paper in London; Movelan says,

> *"One thing that became apparent to us was the importance of timing. When you get the timing right, magic happens. When you get it wrong, it disappears. Simply moving the robot's head too slow or too fast can make a difference on the appearance or disappearance of social behaviors towards the robot. We are working on robots that can automatically detect the different moods the classroom goes through and adjust their behavior accordingly"* (Parker, 2008).

The conclusion of the study reviled that the children treated the robots as social peers, as opposed to a mere object.

In similar study named “Interactive robots as social partners and peer tutors for children”, a team of specialist in Japan introduced two English speaking “Robovie” robots to an sixth grade elementary class with the purpose of teaching the children English. The robots used a vocabulary of about 300 sentences for speaking and 50 words for recognition. During an 18 day study the authors had to cope with the noisy environment of rambunctious children while studying the interactions and the effects of the interactions. At the start of the trial the children were given an English picture-word matching test and then given another after two weeks. In the post test results, the children showed improvement in their English skills; however the team had some other suggestion for future studies.

Figure 17: ROBOVIE interacting with children

“Further analyses indicate that the robots may have been more successful in establishing common ground and influence when the children already had some initial proficiency or interest in English. These results suggest that interactive

robots should be designed to have something in common with their users, providing a social as well as technical challenge" (Kanda, Hirano, Eaton, & Ishiguro, 2004).

Although the study was conducted over a short time period, the results demonstrated that children can overcome the operational properties of a robot, accepting them as peers and actually learning from their humanoid buddies.

The last article in this section is about building user trust. The authors hypothesize that relationships and trust between humans and computers can be initialized with conversational strategies.

> *"Humans use a variety of strategies to proactively establish and maintain social relationships with each other. Using small talk, intimacy through self disclosure, credibility through the use of expert's jargon, social networks through gossip, and "face" through politeness are all examples of this phenomenon. These relational strategies are important not just in purely social settings, but are also crucial to the establishment and maintenance of any collaborative relationship"* (Bickmore & Cassel, 2001).

Conversational strategies, such as those cited above, enable social relationships with the user in order to gain trust and ease cooperation during interaction. One example of an existing conversational agent is "Microsoft Bob the paper clip"; he achieves this affect by relating to users through social interaction. In another study listed in their article, Reeves and Nass conclude that computers who flatter the user or use humor were proved more likeable. Although the results of the study were minimal, they provide an interesting point of view on robots possessing personalities and engaging in social conversations with the user.

3.6 Conclusion of Human Robot Interaction

After reviewing the principles and research of human robot interaction, the TourBot needs to possess the ability to switch its control from autonomous to non-autonomous mode in certain situations may it be for safety or to suit the controllers needs. It is also important for the robot communicate with the user through natural human forms of communication such as language and gestures. Another important aspect is to let the user manipulate the information presented, this can be accomplished with the use of a touch screen LCD or voice commands that let the robot know what the user wants. Also the robot needs to attract attention to itself, this is an important asset because depending on how well the robot can maintain the users attention determines the how effective the TourBot serves as a tour guide.

Chapter 4.0 Universal Design

The principles of universal design are one of the most important aspects of this study. Applying these principles to the design of human interaction robots it will insure the design is usable by more than the majority of population. This is important because a tour guide robot has the opportunity to interact with humans with a wide range of abilities.

4.1 Definitions

Aside from understanding the meaning of design itself, there are three terms one must also review before understanding the definition of Universal Design. When used as a verb the word *design* refers to the thought process comprising the creation of an entity. (Erlandson, 2008, p. 15) This definition provides the true elements of design in its broadest sense. Design starts with identifying a problem, in which the designer conceptualizes the problem, by using a systematic approach or a thought process to solve. “The designer must have insight, an idea, or a thought as to the connections between a design concept and the needs or problems addressed by the proposed entity” (Erlandson, 2008, p. 15). Entity refers to the tangible end to the design process, which could be a product or a service.

There are three sub categories or specialized areas within design. Each term below addresses a specific area of design that derives from the needs or specifications of the entity.

- Accessible Design
- Adaptable Design
- Universal Design

4.2 Accessible Design

> *"Accessible Design is the design of entities that satisfy specific legal mandates, guidelines, or code requirements with the intent of providing accessibility to the entities for the individuals with disabilities"* (Erlandson, 2008, p. 18).

With the above definition one can conclude that accessible design focuses on legal implications set forth by laws such as the Americans With Disabilities Act (ADA), the Telecommunications Act 1996 section 255, and section 508 amendments to the Workforce Investment Act of 1998. Accessibility guidelines published by the United States Access Board provide specific design guidelines that relate to each of these laws.

4.2.1 Americans With Disabilities Act (ADA)

The Americans With Disabilities Act of 1990 states that "*The ADA prohibits discrimination on the basis of disability in employment, State and local government, public accommodations, commercial facilities, transportation, and telecommunications. It also applies to the United States Congress"* (Division, 2005). The act resulted in a set of guidelines for accessibility to public places and commercial facilities for individuals with disabilities. "*These guidelines are to be applied during the design, construction, and alteration of such buildings and facilities to the extent required by regulations issued by Federal agencies, including the Department of Justice, under the Americans with Disabilities Act of 1990"* (Department of Justice , 1994).

4.2.2 The Telecommunications Act (Section 255)

"The Telecommunications Act of 1996, a comprehensive law overhauling regulation of the telecommunications industry, recognizes the importance of access to telecommunications for people with disabilities in the Information Age. Section 255 of the Act requires telecommunications products and services to be accessible to people with disabilities. This is required to the extent access is "readily achievable," meaning easily accomplishable, without much difficulty or expense. If manufacturers cannot make their products accessible then they must design products to be compatible with adaptive equipment used by people with disabilities, where readily achievable" (United States Access Board, 1996).

The act also states that all manufacturers of telecommunication products must insure their products are "designed, developed, and fabricated to be accessible to and usable by individuals with disabilities" (United States Access Board, 1996).

Technologies covered under this bill include:

- Wired and wireless telecommunication devices, such as telephones (including pay phones and cellular phones), pagers, and fax machines
- Other products that have a telecommunication service capability, such as computers with modems
- Equipment that carriers use to provide services, such as a phone company's switching equipment.

4.2.3 Workforce Investment Act (Section 508)

Section 508 of the Workforce Investment Act (1998) is a set of requirements for federal departments and agencies regarding electronic and information technology. This section states "*individuals with disabilities who are Federal employees to have access to and use of information and data that is comparable to the access to and use of the information and data by Federal employees who are not individuals with disabilities; and individuals with disabilities who are members of the public seeking information or services from a Federal department or agency to have access to and use of information and data that is comparable to the access to and use of the information and data by such members of the public who are not individuals with disabilities"* (United States Department of Justice Civil Rights Division, 2008).

4.3 Adaptable Design

All products and services that are deemed accessible may not be for everyone. However, they can be made accessible with the use of modifications for individuals with specific disabilities. These modifications also known as accommodations illustrate the processes of adaptable design.

> *"Adaptable design features are modifications made to standard design for the purpose of making the design usable for an individual as needed"* (Erlandson, 2008, p. 18).

The principles of adaptable design focus on the development of modification devices that are to be used with an existing entity, for the purpose of being usable by persons with disabilities. The main difference between adaptable design and accessible design is that adaptable design is not regulated by law.

4.4 Universal Design

> *"Universal Design can be defined as the design of entities that can be used and experienced by people of all abilities, to the greatest extent possible, without adaptations"* (Erlandson, 2008).

The definition above illustrates that products encompassed by universal design standards, are to be usable by all people with or without disabilities. This is one of the main elements that set universal design apart from accessible and adaptable design. Universal design principles are geared toward everyone not just people with disabilities. Erlandson states that the usability of the product can be defined by five key elements.

- The use of the product should be easy to learn.
- Once learned the product can be used efficiently.

- The use of the product should be easy to remember.
- The product should have a low error rate.
- The product should have an enjoyable and rewarding user experience.

The overall usability of a product is determined by how physically and mentally accessible the product is by all users. Universal design principles differ from accessible and adaptable design because they are not mandated by law, and do not use modification devices. With the diversity of the human race, the probability that a single entity would be usable by all people under all conditions is very low. Every person is unique in age, size, abilities, and talents. For this reason universal design should be considered a process, rather than an achievement.

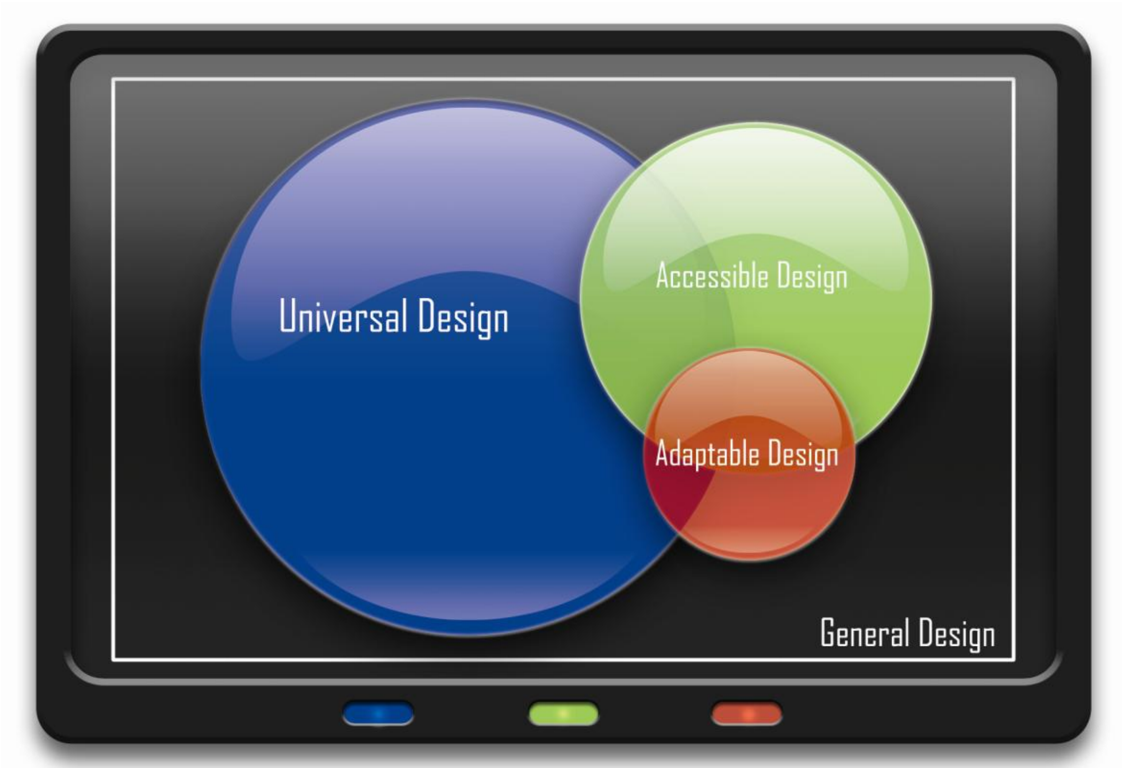


Figure 18 Design relationship diagram

The diagram above shows the relationships among three different types of design and how they each subside with one another within the realm of general design. The size or circumference of each circle represents the range of usability its products achieve, specifically the products derived from that particular design strategy. The overlapping areas between the circles represent the principles shared by universal design, accessible design, and adaptable design. (Erlandson, 2008, p. 19)

4.5 Principles of Universal Design

Universal design strives to be a broad-spectrum solution that helps everyone. The principles of Universal design bring existing practices from all aspects of the design community together in a unique way. There are seven principles listed by The Center For Universal Design:

Principle One: Equitable Use

The design is useful and marketable to people with diverse abilities.

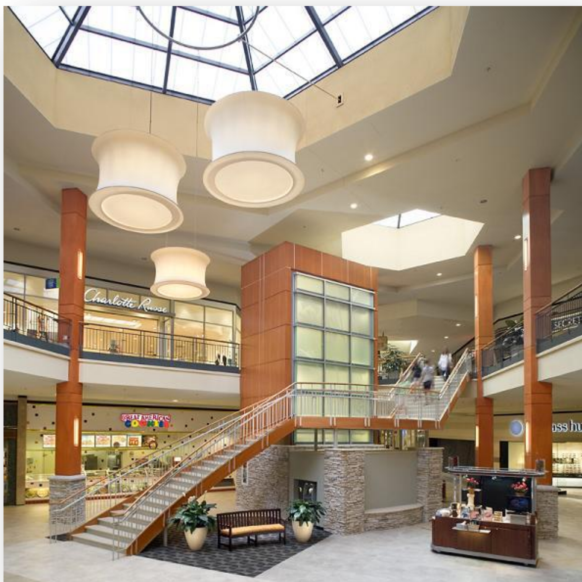


Figure 19 Elevator adjacent to escalators in shopping mall avoids segregating groups using different means of mobility (Mall Pictures)

- Provide the same means of use for all users: identical whenever possible; equivalent when not.
- Avoid segregating or stigmatizing any users.
- Provisions for privacy, security, and safety should be equally available to all users.
- Make the design appealing to all users.

Principle Two: Flexibility in Use

The design accommodates a wide range of individual preferences and abilities.

Figure 20 Large grip scissors accommodate use with either hand

(NC State University, 1997)

- Provide choice in methods of use.
- Accommodate right- or left-handed access and use.
- Facilitate the user's accuracy and precision.
- Provide adaptability to the user's pace.

Principle Three: Simple and Intuitive

Use of the design is easy to understand, regardless of the user's experience, knowledge, language skills, or current concentration level.

Figure 21 Kia's power seat control switch mimics the shape of the seat, enabling users to make adjustments intuitively.

(James, 2006)

- Eliminate unnecessary complexity.
- Be consistent with user expectations and intuition.
- Accommodate a wide range of literacy and language skills.
- Arrange information consistent with its importance.
- Provide effective prompting and feedback during and after task completion.

Principle Four: Perceptible Information

The design communicates necessary information effectively to the user, regardless of ambient conditions or the user's sensory abilities.

Figure 22 Dark background, contrast in color, and brightness on overhead sign contrasts with lighted ceiling. (designworkplan design blog, 2008)

- Use different modes (pictorial, verbal, tactile) for redundant presentation of essential information.
- Provide adequate contrast between essential information and its surroundings.
- Maximize "legibility" of essential information.
- Differentiate elements in ways that can be described (i.e., make it easy to give instructions or directions).
- Provide compatibility with a variety of techniques or devices used by people with sensory limitations.

Principle Five: Tolerance for Error

The design minimizes hazards and the adverse consequences of accidental or unintended actions.

Figure 23 The chain-break on a chainsaw locks the chain in the event in the event of a kickback, protecting the user from the chain. (Husqvarna, 2009)

- Arrange elements to minimize hazards and errors: most used elements, most accessible; hazardous elements eliminated, isolated, or shielded.
- Provide warnings of hazards and errors.
- Provide fail safe features.
- Discourage unconscious action in tasks that require vigilance.

Principle Six: Low Physical Effort

The design can be used efficiently and comfortably and with a minimum of fatigue.

Figure 24 Split, angled keyboard allows user to maintain neutral position from elbow to fingers. (ergoware, 2008)

- Allow user to maintain a neutral body position.
- Use reasonable operating forces.
- Minimize repetitive actions.
- Minimize sustained physical effort

Principle Seven: Size and Space for Approach and Use

Appropriate size and space is provided for approach, reach, manipulation, and use regardless of user's body size, posture, or mobility.

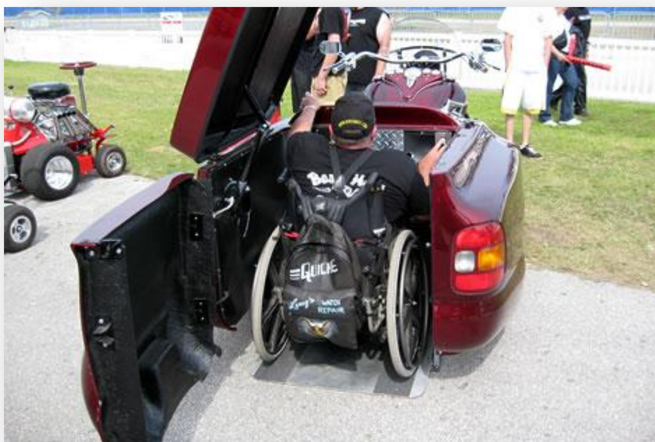


Figure 25 Motorcycle/Trike for the Handicapped, the door on the back of the motorcycle opens up wide enough to drive a wheelchair onto the lift for storage during transportation. (Crowe, 2008)

- Provide a clear line of sight to important elements for any seated or standing user.
- Make reach to all components comfortable for any seated or standing user.
- Accommodate variations in hand and grip size.
- Provide adequate space for the use of assistive devices or personal assistance. (NC State University, 1997)

4.6 Categories of Universal Design

The principles of universal design can be broken down into three categories. Some deal primarily with human factors, some focus on processes, and others go beyond human factors and processes.

Human Factor principles

The principles that focus on human factors deal with ergonomics, perception, and cognitive concerns. (Erlandson, 2008, p. 68) The principles that fall under this category are:

- Simple and Intuitive use
- Perceptible Information
- Low Physical Effort
- Size and Space for Approach and Use

Human factors rely primarily on the user. The person must be able to use the product regardless of their level of experience. The operating instructions must be easy to understand and the user should be able to use the product with minimal effort.

Process Related Principles

The principles relating to processes are:

- Flexibility in Use
- Tolerance for Error

A process is a method or series of actions for the purpose of achieving a goal. Processes relating to products deal mainly with usability or more specifically how the person uses the product. Therefore the processes support the product through flexibility of use and error management.

Transcending Principles

Transcending principles go beyond the principles of process and human factors. This principle is:

- Equitable Use

Products deriving from the principles of universal design should provide the same means of use for all users: identical whenever possible, equivalent when not. (NC State University, 1997) For a product to be equitable it should feature certain qualities. It should be aesthetically pleasing, marketable, and affordable to a broad spectrum of users. *"These design features and characteristics are generally true for any product or service, but is especially true for designers seeking to follow universal design principles"* (Erlandson, 2008, p. 69).

4.7 Conclusion of Universal Design

The principles of universal design are going to be a substantial influence on the design of the TourBot. It is very important that the robot meets the standards of all seven principles to enable it to be used by users with a vast range of abilities.

Equitable use: Provide the same means of use for all users: identical whenever possible; equivalent when not. The LCD screen is going to be located on of the arms so it has the ability to adjust the height of the screen to the user. In a situation when there is a group of people that has a wide range of heights the robot can either take an average of heights and adjust to it or adjust to the height of the shortest person and tilt the screen up to accommodate the taller individuals.

Flexibility in use: The robot can present data to the user by text on the screen (hearing impaired) and by audio (visually impaired), and move at a slower pace of the mobility impaired users.

Simple and Intuitive: The TourBot needs to be capable of utilizing natural forms of communication, in a variety of languages. The user can communicate with the robot verbally (simply by speaking to it), or nonverbally by reading text or by touching option buttons on the LCD.

Perceptible Information: The environment in Broun Hall is rather dark with brick walls and floors. For this environment the LCD should have a dark background with large light colored text for contrast, if a white background is used with dark text it most likely put strain the eyes of the users.

Tolerance for Error: For collision avoidance the robot should be equipped with a 360 degree sonar array coupled with the vision cameras. This will enable the robot to know its distance for objects anywhere around it during locomotion. Another failsafe that needs to be implemented into the design is a low battery protocol, once the robot detects its battery level diminish to 10 percent the it can either go back to the charging station and recharge, or if the robot decides it cannot make it back to the charging station it should find a place to lay down to prevent falling over on someone or something and signal the operator for assistance.

Low Physical Effort: To prevent fatigue and sustained physical effort the robot needs to adjust the LCD to a comfortable viewing height for the users, and maintain a walking pace during locomotion.

Size and Space for Approach and Use: This can also be accomplished with the variable height LCD to provide a clear line of sight, and make it comfortable to reach the touch screen for seated or standing users. The robot should also be small enough to fit through doorways and maneuver in crowded hallways, and be have an aesthetically friendly appearance.

Chapter 5.0 TourBot

5.1 Background of the TourBot Project

The TourBot project was conceived by Dr. Thaddeus Roppel in the summer of 2006 who stated “I was thinking about possible senior design projects for the upcoming Fall semester, and then enlarged my scope to think about it as on ongoing extracurricular activity” (Ropple, 2009). The purpose of the project is to provide an exciting extracurricular activity that will include both undergraduate and graduate students from various backgrounds. A goal associated with becoming involved in the activity is to help the students improve their marketability for employment. The TourBot project provides an ongoing source of senior design project activities, and makes a very high-profile E-Day display to generate publicity for the Electrical and Computer Engineering Dept., the College of Engineering, and Auburn University. Participants include students at the freshman level and every other level up to that of a PhD, industry personnel and any other person who expresses an interest. Involved in the project is Dr. Roppel as the sole faculty member accompanied by four undergraduates, two graduate students, and a senior design group that consist of eight students. The students involved incorporate a wide range of backgrounds and fields of study which include computer, electrical, software, and mechanical engineering, and industrial design. The project provides an outlet for the collaboration of people from various fields of study with their focus being a common goal.

5.2 Design Brief

The robot's function will be to give tours of Broun Hall located on the campus of Auburn University. The TourBot will have the capability of knowing its location and will be able to display multimedia presentations at predetermined stops during the tour. It will also interact with the tour group using voice and gesture (hand and body movement.) The following list is a summary of the TourBot's systems specifications provided by Auburn Universities TourBot program.

COMMUNICATION

- Data Presentation (Front End Software / User Interface / On Board Display)
    - Present multimedia
    - Meet power requirements
    - Reasonable size (weight, appearance from "x" feet, mutability, dimensions)
    - Sunlight visibility
    - Viewing angle

    - Temperature/humidity tolerance
    - Eye level presentation
- Accessibility
    - Closed captioning
    - Own voice (English language)
    - Voice recognition
    - Color blind access
    - Generic button interface

LOCOMOTION

- Traverse building options
    - Fit in door frames
    - Roll over door frame
    - Variable surfaces
    - Fit in hallway
- Speed
    - Fast enough for a human to slowly walk behind

    - Slow enough for manual wheelchair to follow

- Will not open doors by itself
- Will not move obstacles
- Ground clearance (1-5”)
- Balance
- Rigid Chassis (Smooth exterior / fully enclosed)
- Turning Must be zero point, to guarantee not hitting people/things when turning

NAVIGATION

- Follow predetermined path
- Avoid Obstacles
- Record path traveled
- Localization independent of surroundings (SLAM without GPS)
- Needs remote GUI administrative interface
- Needs on board user interface to allow tour participants to control pace and content of the tour
- Administrative functionality (setup waypoints / define floor plans of buildings)

SAFETY

- Avoid hitting people
    - Kids in tour
- Power outages
- Robot can function if confused about positioning (sanity check algorithm)
- Emergency Stop button
- Keep fire exits clear
- No sharp/ electrified components on exterior
- Periodic testing
- Emergency “911” call button
- Intrusion Detection

SOFTWARE

- Front End Software
    - Interface info needs to be readable (visibility)
    - Interpret response, prompt user, text /picture/ video display, sound
    - Display virtual map

- Back End Software
    - Control motors
    - Communication to front end software
    - Control Sensors

Things to keep in mind: Size and power constraints, serviceability / modular design, expansion capabilities

5.3 Design Goals

The design goals for the TourBot project are a direct result of research that was conducted in chapters three and four of this study. In order for the robot to be an effective tour guide for all users, it must meet the following criteria.

- Possesses the ability for users to interact with the robot, regardless of their experience or ability.
- Intelligently communicate with users through natural and digital channels of communication.
- Communicate necessary information effectively to users, regardless of ambient conditions or the users' sensory abilities.
- The ability to adjust to the needs of the users.
- Approachable and aesthetically pleasing.

It is important for the interface to facilitate easy interaction between the user and the robot, regardless of the user's experience or ability. The goal is for visitors to be able to utilize the robot without help or instruction. This can be achieved with multiple channels of communication and social dialog software. In order to isolate what channels are needed, one must review the abilities of the users. For this design, the robot needs to be as diverse as possible because it has the opportunity to interact with people with various abilities. The TourBot design will focus on three areas of user disability which are visually impaired, hearing impaired, and mobility impaired. While examining the users' disabilities the focus needs to be on their abilities. For visually impaired users the robot needs to be capable of communicating with them verbally. This can be achieved with audio speakers, a microphone, and voice recognition software. When interacting with hearing impaired users, communication will be more visual based. Visual communication can be accomplished in a number of ways one being that the user could read text on an LCD screen, and another being that the user could interpret the operating state or mood of the robot through facial expressions, color, and body gestures. To accommodate mobility impaired users the robot needs to be able to adjust the height of the LCD screen during interaction. Another variable that needs to be accounted for is the speed of the robot. It should be capable of moving at variable speeds. In communication and interacting with users, it is important for the robot to possess a friendly appearance. There are a number of aesthetic factors that contribute to a robot's appearance, such as size, shape, and color. If the robot appears to be aggressive it could intimidate users, and discourage them from interacting with it. According to the U.S. Department of Health and Human Services, the average height of a male is five feet nine inches tall and a female is five feet three inches. The average height of a person sitting in a wheelchair is three feet ten inches tall. (McDowell, Fryar, Ogden, & Flegal, 2008) Therefore the robot needs to be able to adjust the viewing height (center of the LCD screen) from forty six to sixty six inches from ground level. By tilting the screen up or down the robot could also accommodate users that are either taller or shorter than the heights previously mentioned.

5.4 Robot Tasks

Although this study will not address the actual construction of a fully functional robot, the following is a list of tasks that the robot must be capable of doing in order to be a successful tour guide.

- Attract users to itself
- Engage and maintain interest
- Autonomously navigate the second, third, and fourth floors of Broun Hall
- Utilize elevators
- Perform obstacle detection (pedestrians, random objects, doorways)
- Autonomously locate predetermined landmarks (doorways, artifacts)
- Give data presentation at predetermined landmarks
- Be self aware of battery level and autonomously dock with charger when needed

5.5 Product Comparison Research

The following chart is used to analyze the features of similar robots for comparison. The chart also helps to identify strengths, weaknesses, trends, and areas of opportunity.

		Visual Data Display	Adjustable Height	Variable Speed	Facial Expressions	Body Gestures	Audio/Verbal Comminution	Eye Contact/ Facial Recognition	Approachable/ Aesthetically Pleasing
Rhino		●		●			●	●	
Minerva		●		●	●		●	●	
Grace		●		●	●		●	●	
Robina				●		●	●		●
ENON		●		●	●	●	●		●

Figure 26 Product comparison chart

After reviewing the product comparison chart the results are as follows

- Visual data display – 4
- Adjustable height – 0
- Variable speed – 5
- Facial expressions - 3
- Body gestures - 2
- Audio / verbal communication - 5
- Eye contact / facial recognition - 3
- Approachable / aesthetically pleasing – 2

The higher numbers indicate trends and similarities, while the lower numbers indicate areas of opportunity. For the purposes of the design phase, the design should include the similarities and focus on the areas of opportunities. The areas of opportunities can be arranged by priority with the lowest number being the highest priority. The results indicate that adjustable height should be the highest priority, followed by body gestures, aesthetically pleasing, facial expressions, and eye contact.

5.6 Approach

The approach for designing a human interaction robot utilizes the research and the design brief completed prior to this section as a foundation. There are five steps in the approach that build upon one another and the result will be used as a guide during the design phase.

1. Task chart
    - The task chart is a list of tasks in order that the robot will complete during its function.
    - The chart helps the designer to get an idea of what tasks the robot needs to perform during its function.
2. Task map
    - The task map helps visualize the tasks in a sequence to make sure nothing was overlooked and sees the function as a whole.
3. Interaction chart
    - The purpose of the interaction chart is to break down the tasks to identify what hardware and software is needed to complete each task, and to meet the needs of the users.
4. Universal flowchart
    - The universal flowchart combines the information obtained from the three previous steps to visualize everything in the intended sequence and to

identify any additional tasks, hardware, and software that may be needed for the robot to complete its function.

5. List of Hardware and Software

    - Using the flowchart a complete list of the components, plus the hardware and software needed to operate the components can be generated to use during the design phase.
    - This gives the designer a complete list of functions, hardware and software that can be used while generating concepts. This streamlines the design phase and makes the designer more efficient.

The following figures illustrate the individual steps of the approach. Step one is the task chart (Figure 18), step two is the task flowchart (Figure 19), step three is the interaction chart (Figures 20-23), step four is the universal flowchart (Figures 26-30), and step five is the hardware/software chart (Figure 31).

STEP	TASK / INTERACTION DESCRIPTION
1	COUNTDOWN TO NEXT TOUR
2	BEGIN DATA PRESENTATION
3	VISITOR CHOOSES LANGUAGE
4	GREETING
5	BEGIN TOUR
6	OPEN DOOR
7	ENTER ELEVATOR
8	CONTINUE TOUR ON 3rd FLOOR
9	ENTER ELEVATOR
10	CONTINUE TOUR ON 4th FLOOR
11	ENTER ELEVATOR
12	CONCLUDE TOUR ON 2nd FLOOR / DOCK WITH CHARGER

Figure 27 Task chart

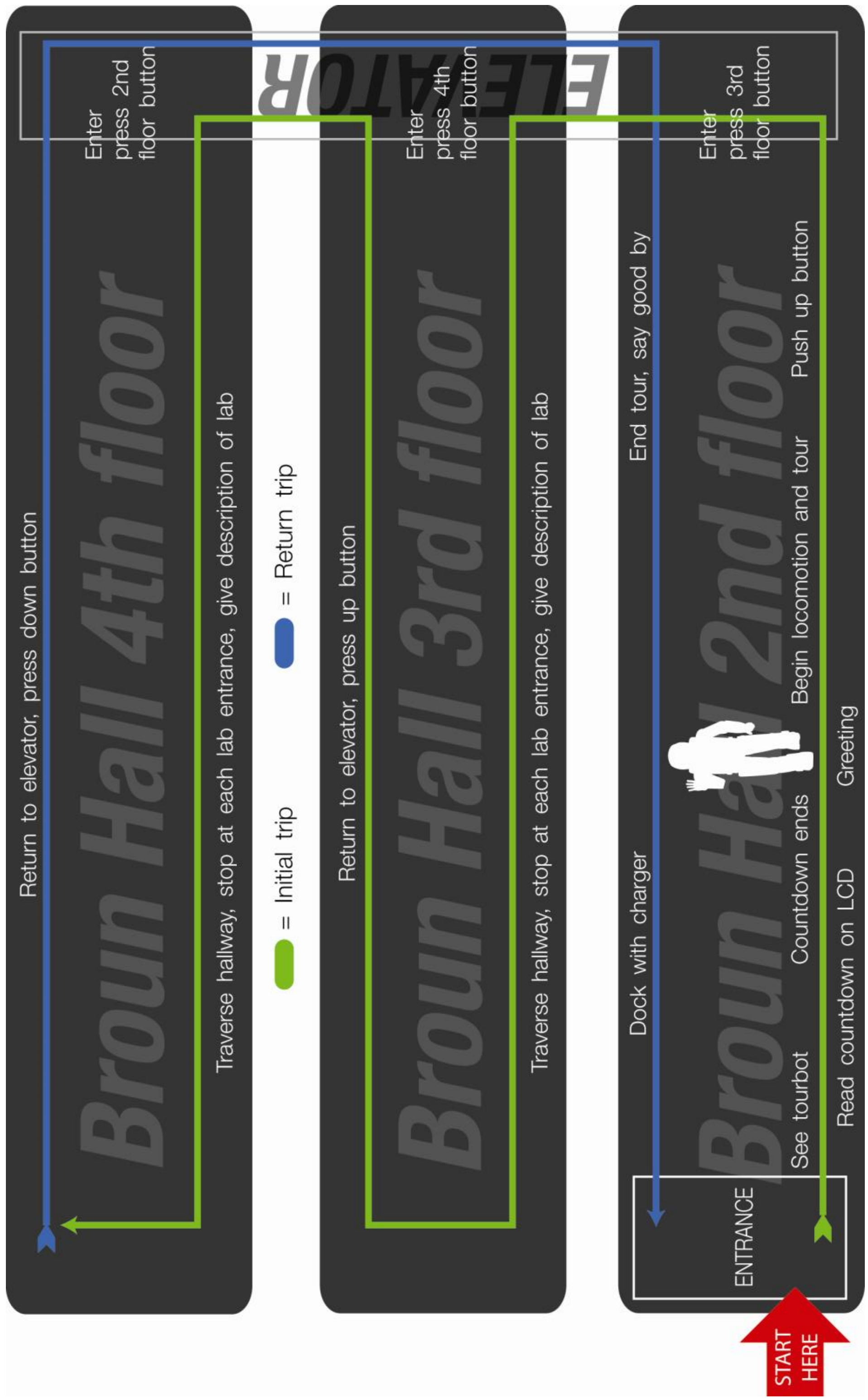


Figure 28 Task Flowchart

STEP	TASK	UNIVERSAL DESIGN	HARDWARE	SOFTWARE
1	COUNT DOWN TO NEXT TOUR		SPEAKER	AUIDO COUNTDOWN
			LCD	COUNTDOWN
			HEIGHT ADJUSTMENT ARM SERVO/CAMERA	VISUAL SCANING / SERVO POSITIONING
			CAMERA	SCAN FOR VISTORS
2	DATA PRESENTATION		SPEAKER	SPEECH
			LCD	TEXT
			HEIGHT ADJUSTMENT ARM SERVO/CAMERA	VISUAL SCANING / SERVO POSITIONING
3	CHOOSE LANGUAGE		SPEAKER	SPEECH/RECOGNITION
			LCD	TEXT
			HEIGHT ADJUSTMENT ARM SERVO/CAMERA	VISUAL SCANING / SERVO POSITIONING

Figure 29 Interaction chart page 1

STEP	TASK	UNIVERSAL DESIGN	HARDWARE	SOFTWARE
4	GREETING		SPEAKER	AUDIO GREETING
		LCD	LCD	GREETING TEXT
			HEIGHT ADJUSTMENT ARM SERVO/CAMERA	VISUAL SCANING / SERVO POSITIONING
			CAMERA	VISUAL SCANING
5	BEGIN TOUR		SPEAKER	SPEECH
		LCD	LCD	TEXT
			VARIABLE SPEED SWITCH	SPEED CONTROL
6	OPEN DOOR		SPEAKER	SPEECH/RECOGNITION
		LCD	LCD	TEXT
			HEIGHT ADJUSTMENT ARM SERVO/CAMERA	VISUAL SCANING / SERVO POSITIONING
			ARM/SERVO MOTORS/ CAMERA	BUTTON RECOGNITION PUSH BUTTON

Figure 30 Interaction chart page 2

STEP	TASK	UNIVERSAL DESIGN	HARDWARE	SOFTWARE
7	ENTER ELEVATOR		SPEAKER	SPEACH AUDIO
			LCD	TEXT
			ARM	HOLD DOOR OPEN
			ARM	PUSH 3rd FLOOR BUTTON
8	BEGIN TOUR THIRD FLOOR		SPEAKER	SPEECH
			LCD	TEXT
			HEIGHT ADJUSTMENT ARM SERVO/CAMERA	VISUAL SCANING / SERVO POSITIONING
				
9	ENTER ELEVATOR		SPEAKER	SPEECH/RECOGNITION
			LCD	TEXT
			ARM SERVO/CAMERA	VISUAL SCANING / SERVO POSITIONING
			ARM/SERVO MOTORS/ CAMERA	FIND AND PUSH 4th FLOOR BUTTON

Figure 31 Interaction chart page 3

STEP	TASK	UNIVERSAL DESIGN	HARDWARE	SOFTWARE
10	CONTINUE TOUR 4th FLOOR		SPEAKER	SPEECH
		LCD	LCD	TEXT
			HEIGHT ADJUSTMENT ARM SERVO/CAMERA	VISUAL SCANING / SERVO POSITIONING
		+		
11	ENTER ELEVATOR		SPEAKER	SPEECH/RECOGNITION
		LCD	LCD	TEXT
			ARM	HOLD DOOR OPEN
		+	ARM/SERVO MOTORS/ CAMERA	PUSH 2nd FLOOR BUTTON
12	CONCLUDE TOUR ON 2nd FLOOR / DOCK WITH CHARGER		SPEAKER	SPEECH/RECOGNITION
		LCD	LCD	TEXT
			HEIGHT ADJUSTMENT ARM SERVO/CAMERA	VISUAL SCANING / SERVO POSITIONING
		+	CHARGING STATION	DOCKING

Figure 32 Interaction chart page 4

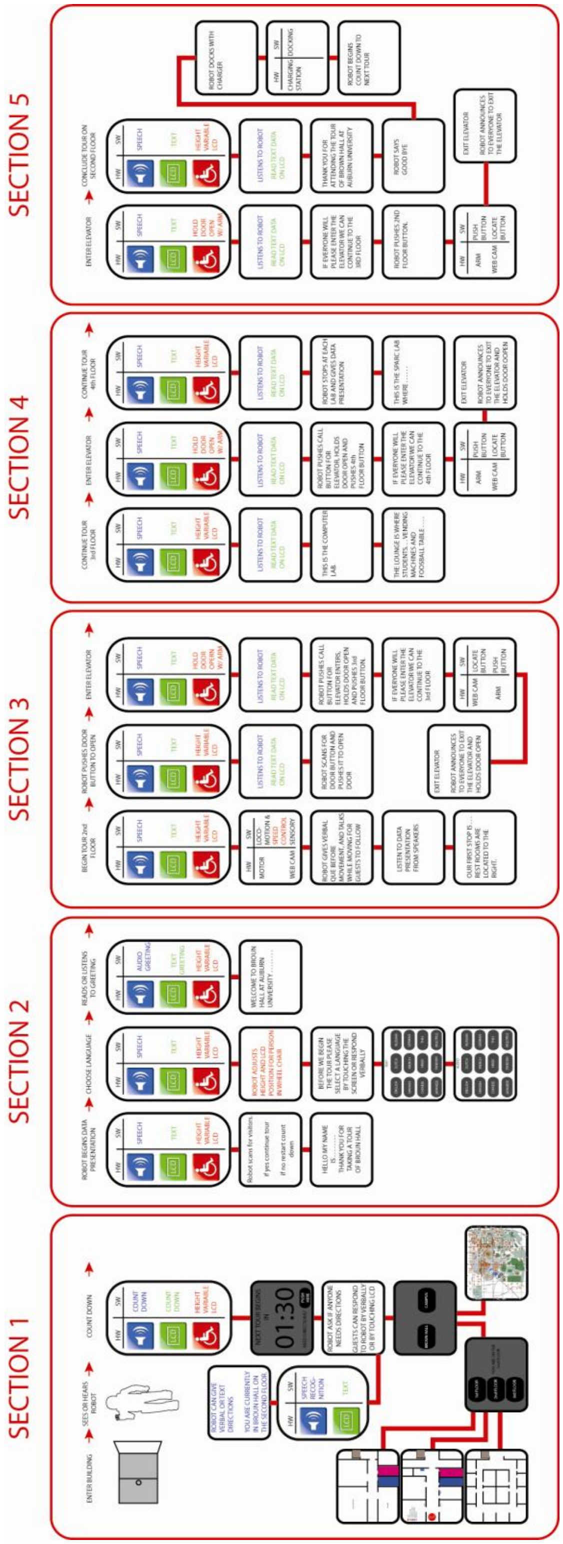


Figure 33 Universal flowchart full view

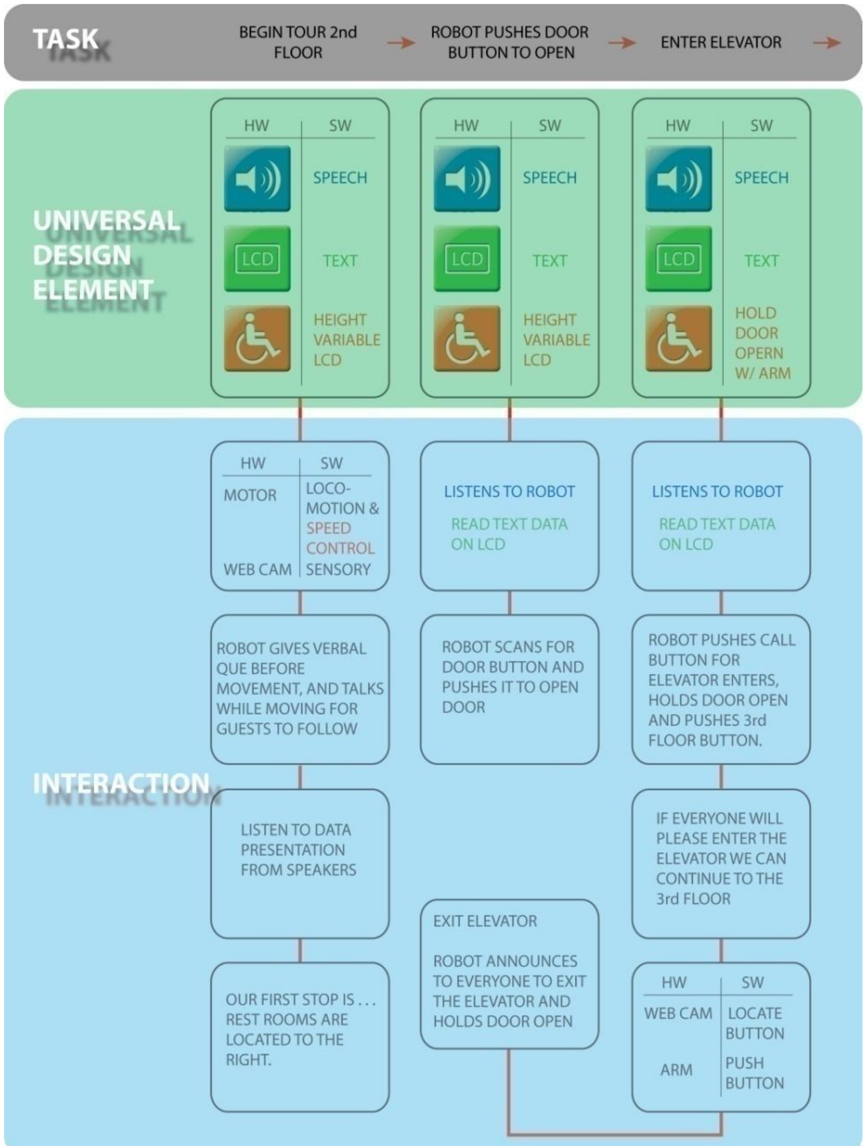


Figure 34 the three sections of information in the universal flowchart

The information contained in the universal flowchart can be divided into three sections, task, universal design element, and interaction. The task and universal design element sections possess the information obtained from completing the three previous steps of the approach. The interaction section is what needs to be completed during this phase.

UNIVERSAL FLOWCHART LEGEND

Figure 35 Universal design element symbols

Visually Impaired

Mobility Impaired

Hearing Impaired

HW = Hardware

SW = Software

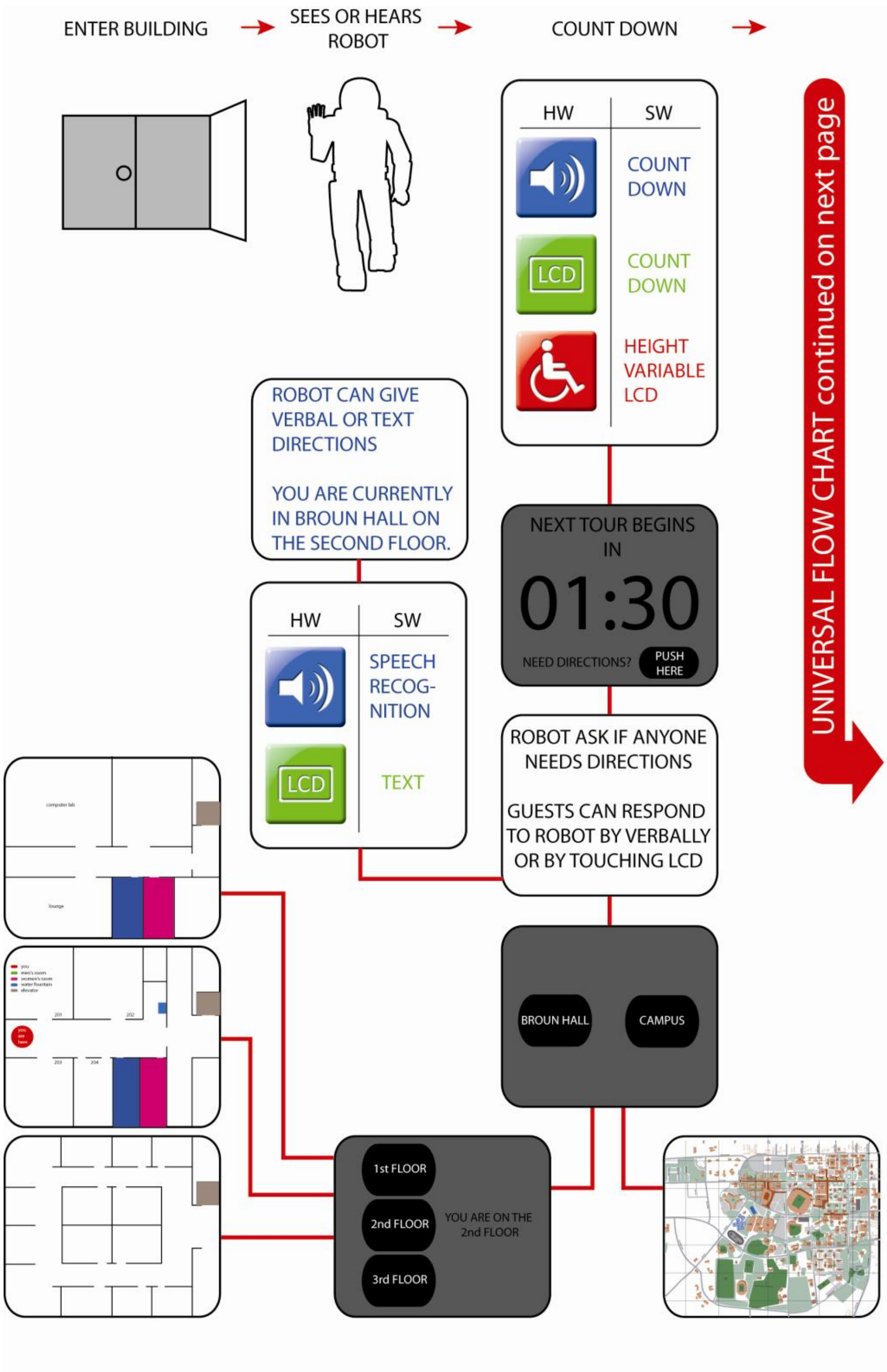


Figure 36 Universal flowchart section 1

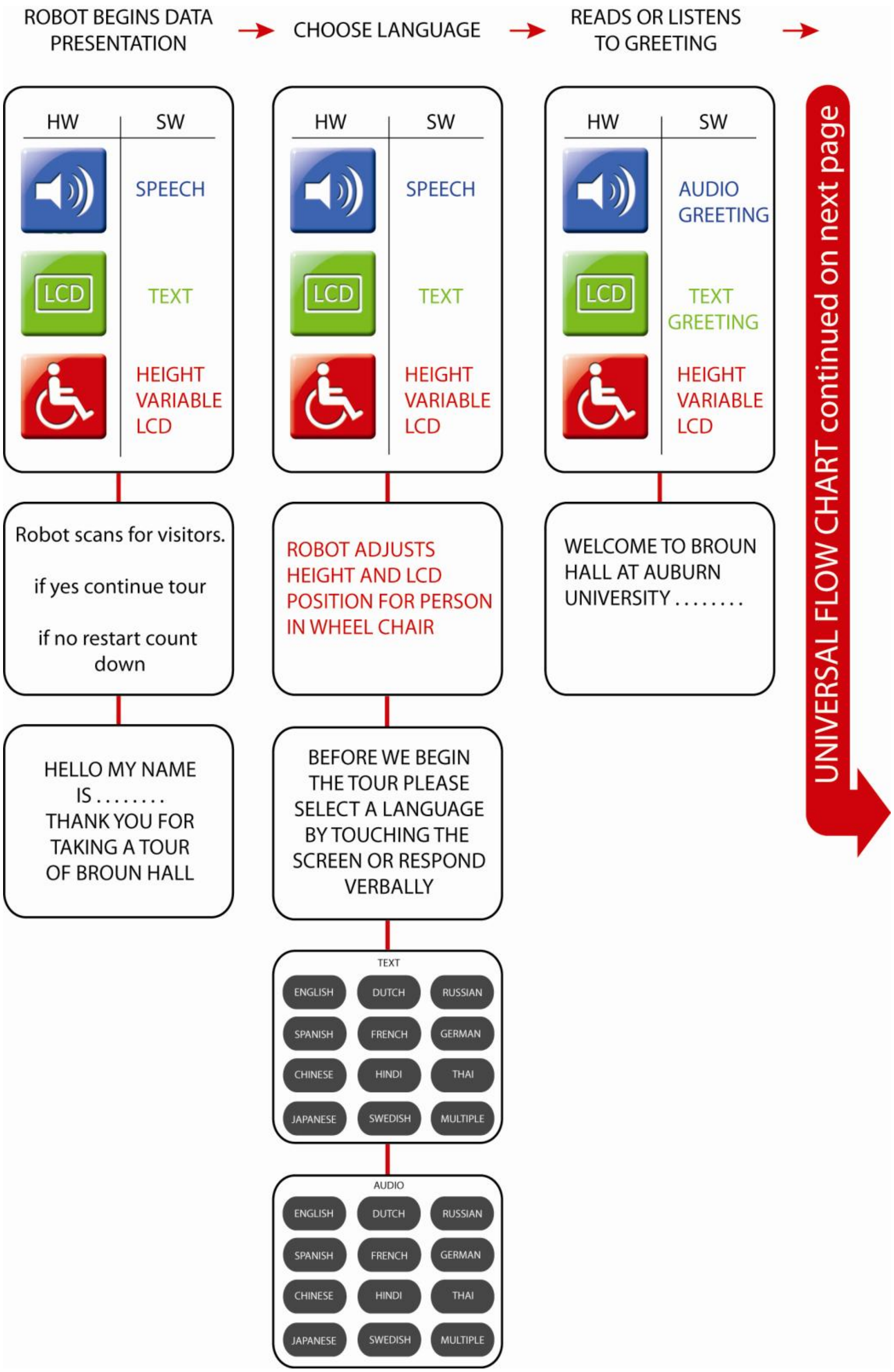


Figure 37 Universal flowchart section 2

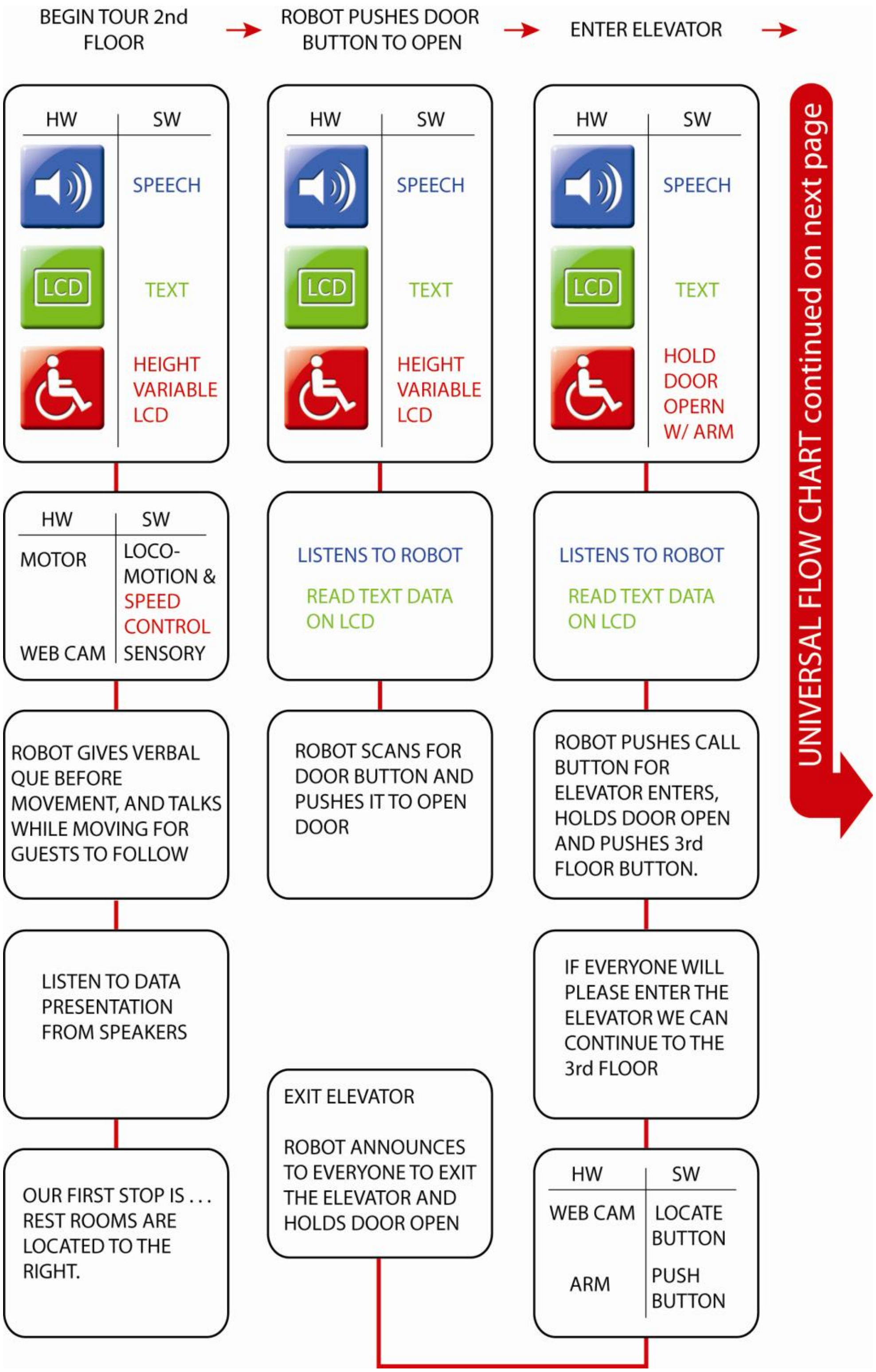


Figure 38 Universal flowchart section 3

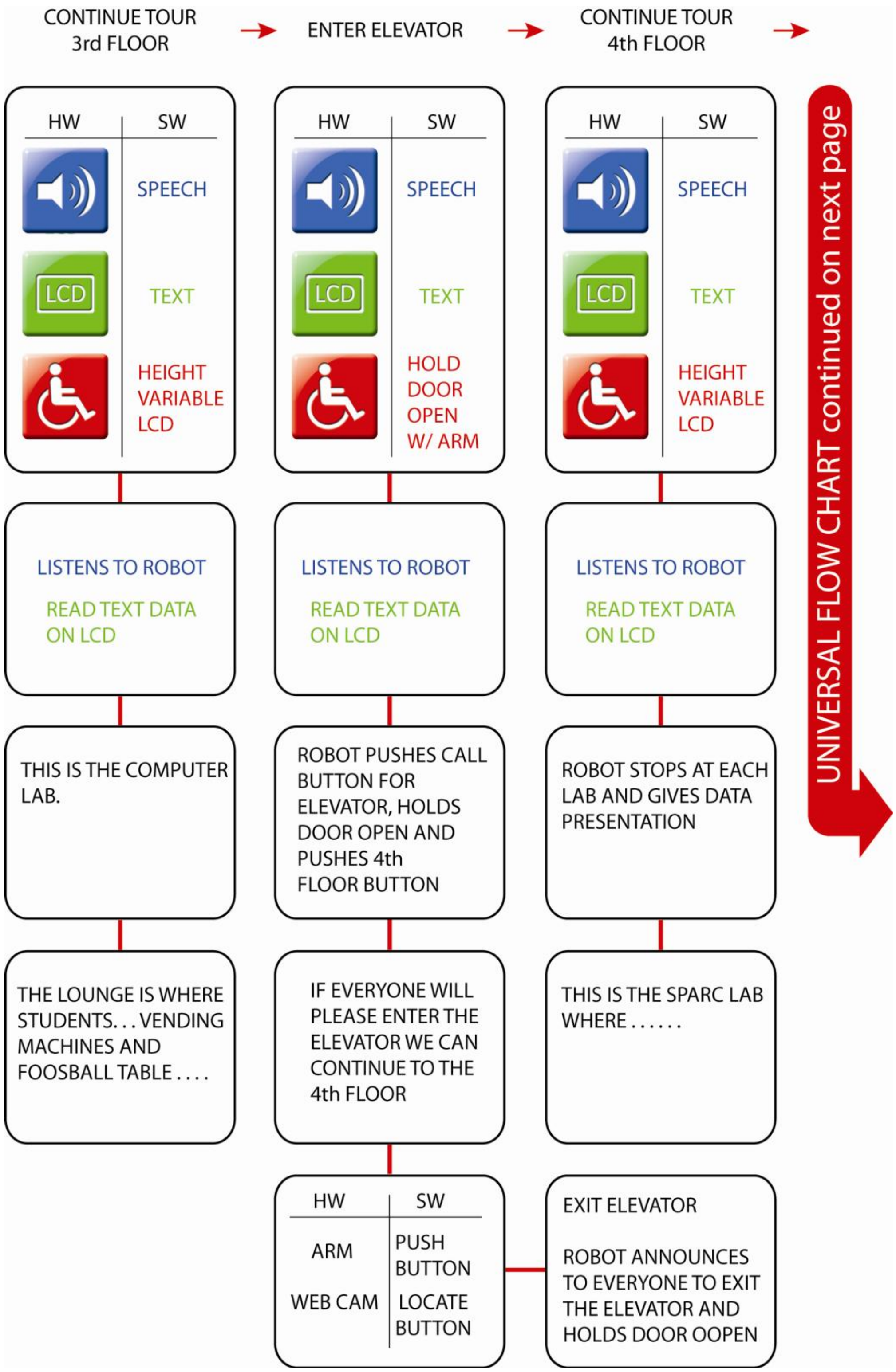


Figure 39 Universal flowchart section 4

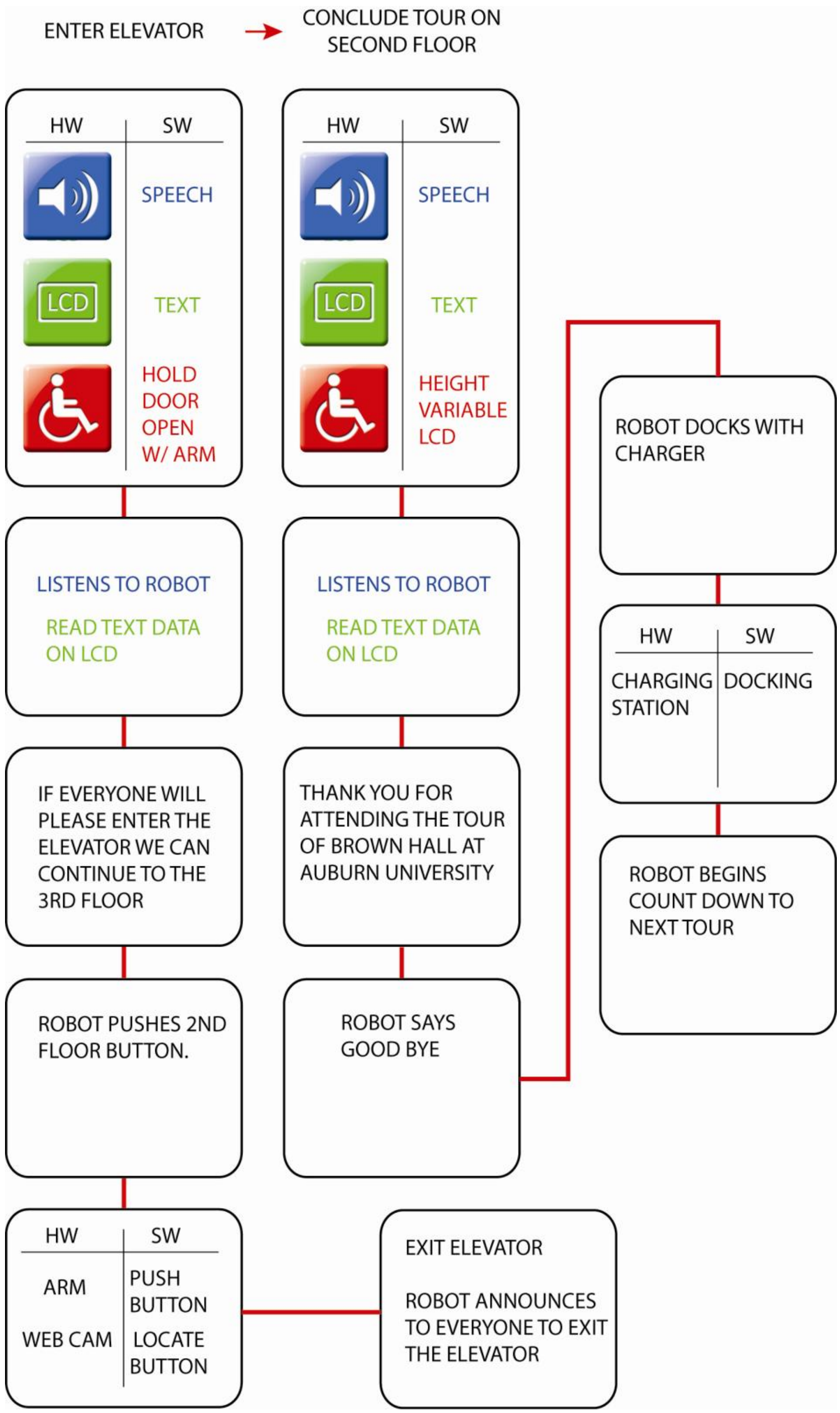


Figure 40 Universal flowchart section 5

	AUDIO	VISUAL DISPLAY	VISION / SENSORS	MANIPULATOR	BATTERY CHARGING
HARDWARE	SPEAKER	TOUCH SCREEN LCD	CAMERAS	ARM	CHARGING STATION
	MICROPHONE	ARM	SONAR	CONTROLLER MOTORS	
		CONTROLLER MOTORS		FINGERS	
SOFTWARE	AUDIO COUNTDOWN	TEXT COUNTDOWN	DEPTH PERCEPTION	BUTTON PUSHING	CHARGING
	AUDIO TOUR DATA	TEXT TOUR DATA	HEIGHT SCANNING	GRASPING	DOCKING
	AUDIO GREETING	TEXT GREETING	VISITOR SCANNING		
	SPEECH	SPEECH TEXT	FACIAL RECOGNITION		
	SPEECH RECOGNITION	HEIGHT ADJUSTMENT	ARTIFACT RECOGNITION		
	AUDIO DIRECTIONS	TEXT DIRECTIONS			
	MULTIPLE LANGUAGE	MULTIPLE LANGUAGE			
		MAPPING			

Figure 41 Hardware and Software chart

5.7 Human Interface Devices

The robot needs to be able to communicate with the user in order to be an effective tour guide. The following is a list of devices in which the robot will use to interact and communicate with the users.

- Touch screen monitor:

  One of the benefits of a touch screen LCD as opposed to a non-touch screen is that it provides an extra channel of interaction between the robot and the user. Touch is also a gesture of user trust. The touch screen makes information more accessible to the user. Touching the desired icon on the screen is easier than lining up text with a button on the side of a screen.

- Microphone:

  With the use of a microphone the robot will be able to hear the user give verbal commands, and use speech and language recognition.

- Speakers:

  Audio speakers allow the robot to communicate back to the user, through speech or tone of voice, especially when the user is visually impaired.

- Facial expressions: (LED lights behind a translucent material on face)

  There are many facial expressions that humans use to communicate with each other. Facial expressions generally represent the mood or state of mind that a person is feeling. The robot can use expressions to communicate happiness, sadness, anger, confusion, and even embarrassment. The TourBot will accomplish this with the use of different color LED lights that will light up behind a translucent material on the face and display the appropriate expression.

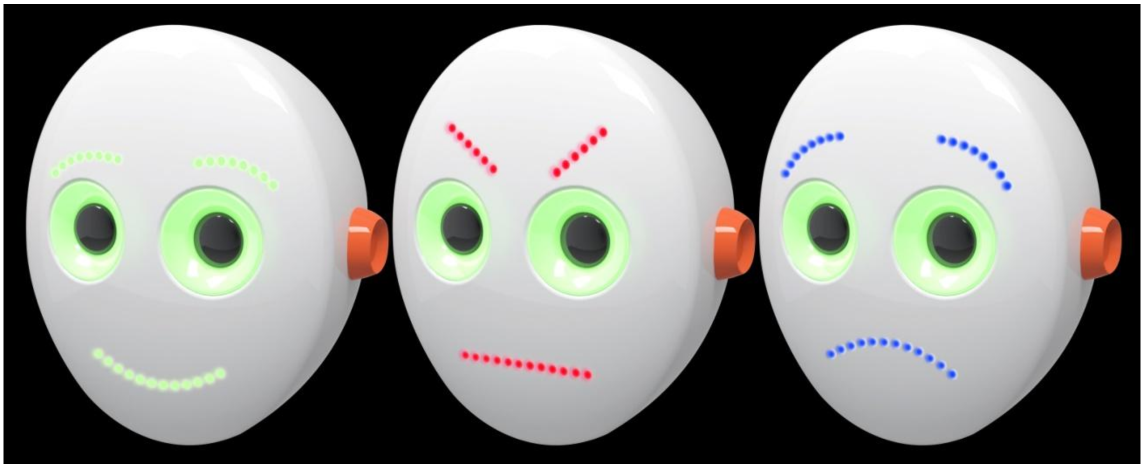


Figure 42 example of facial expressions with LED lights

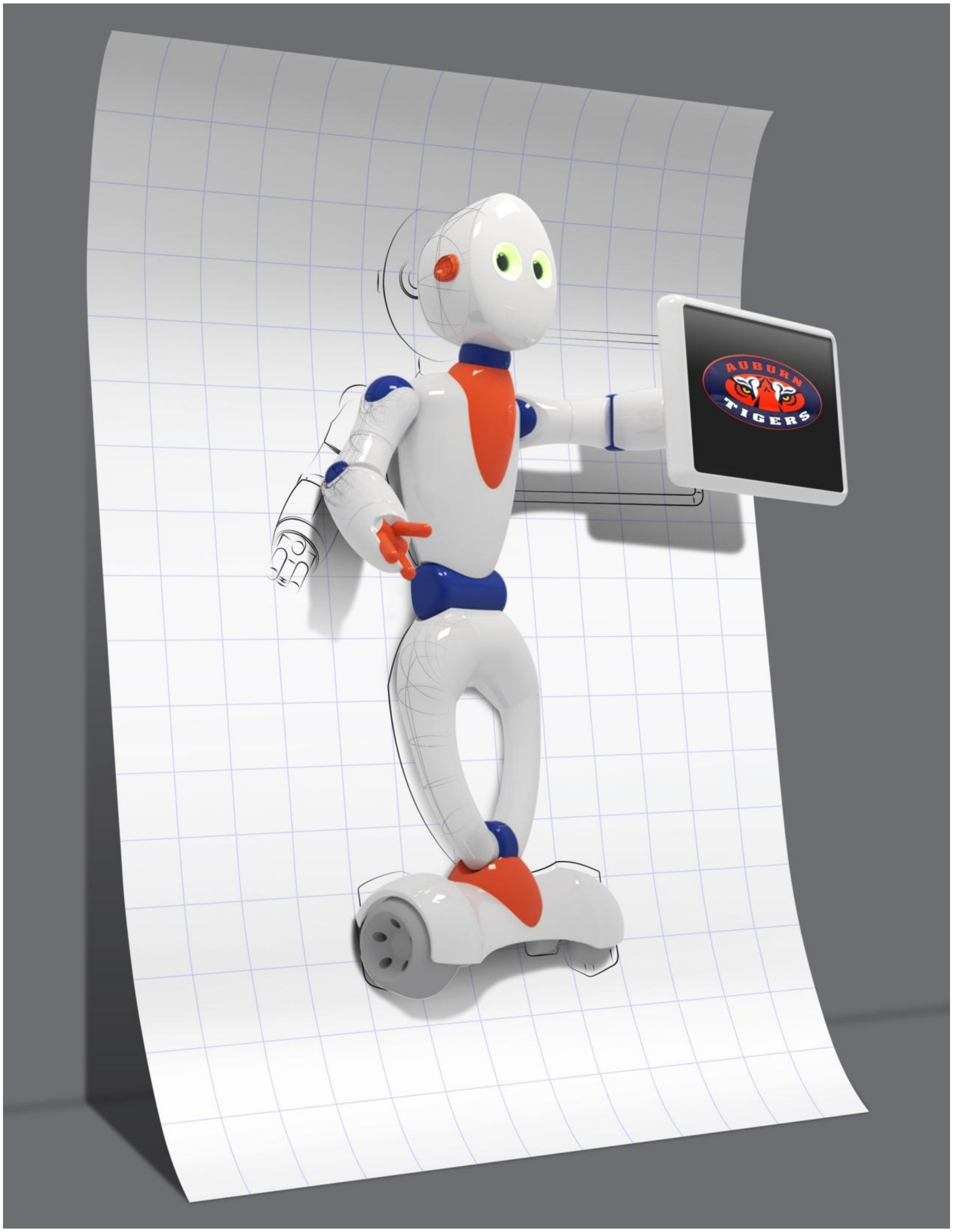
- Eye contact: (cameras)

  It is important for the robot to maintain eye contact with the user. It is a gesture that allows the user know who the robot is communicating with and gives the robot a sense of self awareness and intelligence.

- Body language: (limbs and posture)

  Body language is a non-verbal form of communication that is conveyed through the use of facial expressions and tone of voice. Body language can be used to communicate emotions and mental states. This is an important ability that will help the robot communicate more efficiently and seem more human like.

5.8 Concept Generation and Form Development



The first step of the concept generation and form development phase is conceptualizing the functions of the robot in a sketch. This is a very useful and common method that industrial designers use to visualize their ideas and to brainstorm. Sketching can be used to determine the mechanical functions as well as aesthetics before the actual building of a CAD model. In most cases, the first round of sketches is purely mechanical with the goal of incorporating all the functions described in the previous sections into a single entity. For example the robot needed to have an adjustable height LCD screen, the ability to show facial expressions, and the capability of fitting through a door way. The first concept was a starting point but there were still some key elements that needed to be introduced.

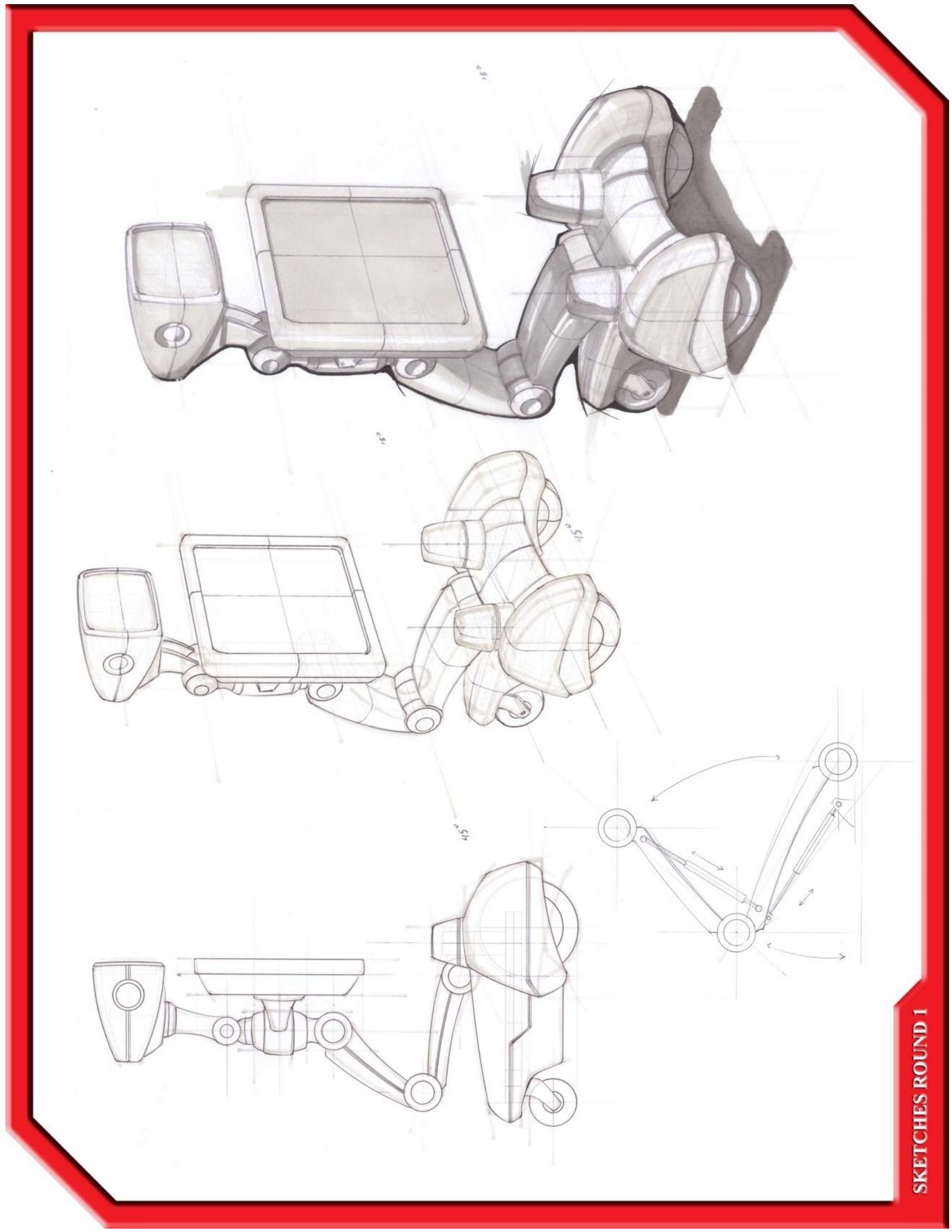


Figure 43 first round of sketches

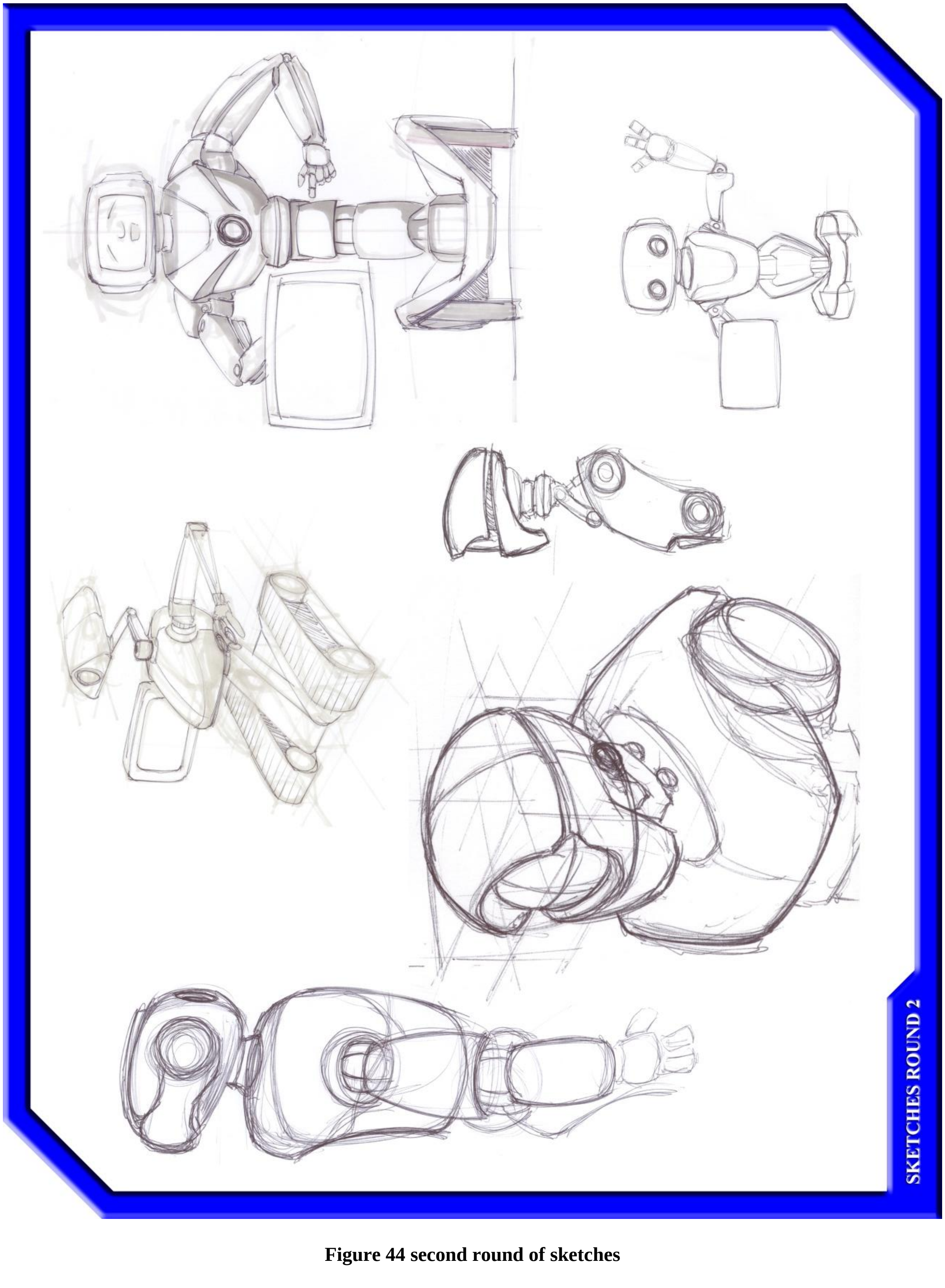


Figure 44 second round of sketches

The functions of the first concept (figure 32) shows the LCD screen being attached to the torso which is mounted on top of an arm. The arm was intended to be capable of variable height via linear actuators. The concept could also perform facial expressions with a smaller LCD mounted on top of the torso to be used as the head. The base was designed around an existing design provided by the Auburn University TourBot team, it had two wheelchair motors and a caster that provided locomotion and maneuverability. After reviewing the first concept it was noted that there was some key elements that still needed to be introduced. The concept was lacking the ability to open doors, push buttons (in order to operate elevators,) and perform body gestures. To accomplish these tasks an arm was introduced into the design, and after further examination it was determined that the LCD screen would be added to an arm, as opposed to being attached to the torso, to further enhance the robot's ability to perform gestures. It was also decided that rather than the robot having to adjust its overall height, it could adjust the height of the LCD and that would be sufficient. Another change that was made was the locomotion base. It was updated from a three wheel configuration to a two wheel that utilizes Segway technology. The sketch located in the top right section of figure 33 was selected for further development.

Figure 45 third round of sketches

The concepts illustrated in figure 34 include all of the functions mentioned in the previous round plus a few additions. The robot needed cameras for navigation and facial recognition so the idea of an LCD for the face was revised. There were two cameras added to the head and the face would now be constructed of a translucent material with LED lights behind it that would light up forming the facial expression desired. There were also further aesthetic adjustments made to the design. The sketch located on the right section of figure 34 was selected for further development in CAD (computer- aided design).

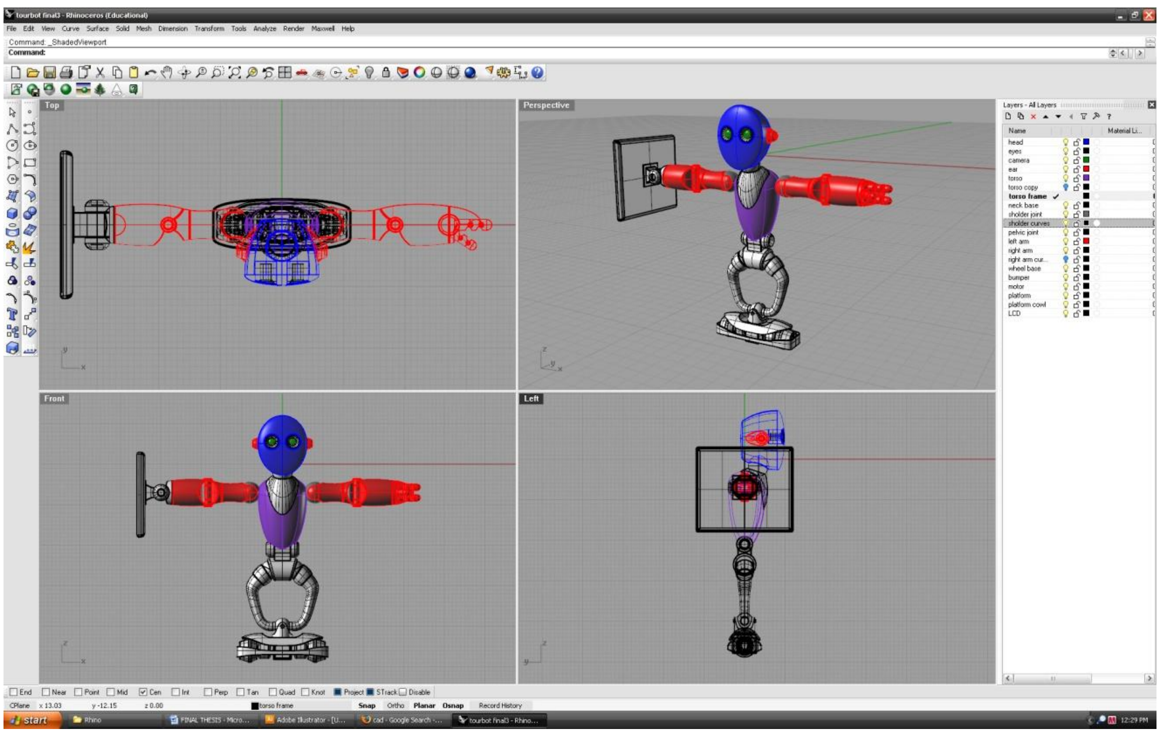


Figure 46 CAD screen shot

The software selected for the CAD phase was Rhinoceros 4.0 and SolidWorks 2008. After the first CAD model was completed the concept was printed out in full scale and mounted to foam core for review and user testing was conducted to test the adjustability of the LCD.

For the first phase of testing, a stand was constructed using PVC and wooden dowel rods. The purpose of the stand is to hold a foam core representation of the head and LCD screen to test the adjustability of height with different users. This test was made possible by inserting a wooden dowel rod (with holes drilled every inch) into the vertical piece of PVC. A nail was placed into the hole to hold the head or the LCD at the desired height so a measurement could be taken. After the stand was completed the model was ready for review by the members of the committee and willing volunteers.

Figure 47 testing stand with LCD and head

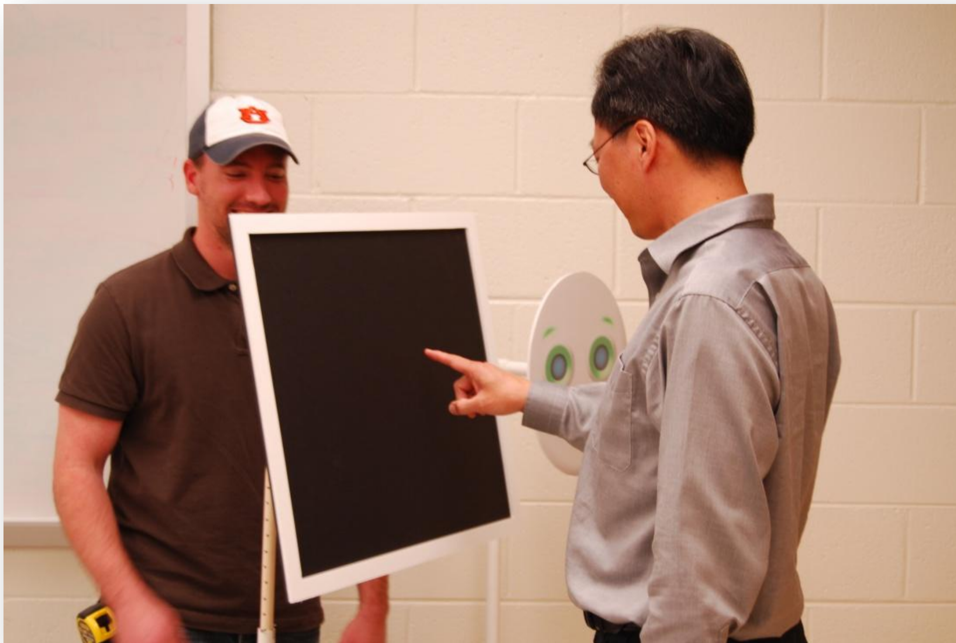


Figure 48 Tsai Lu Liu reviewing LCD height

After reviewing the model, the desired height of the LCD for a person standing is 50 inches, and for a person sitting in a wheelchair is 46 inches from the ground. Another area of concern that surfaced during the review was the size of the screen. It was suggested that a smaller LCD would be just as effective.

Figure 49 taking measurement of LCD height for person in wheelchair

Figure 50 full-scale foam core printout

After the first review, adjustments were made to the size of the LCD. A full scale representation was printed and mounted to foam core for another review. The subjects that were covered during the second review included proportions and aesthetics.

Figure 51 second review with committee

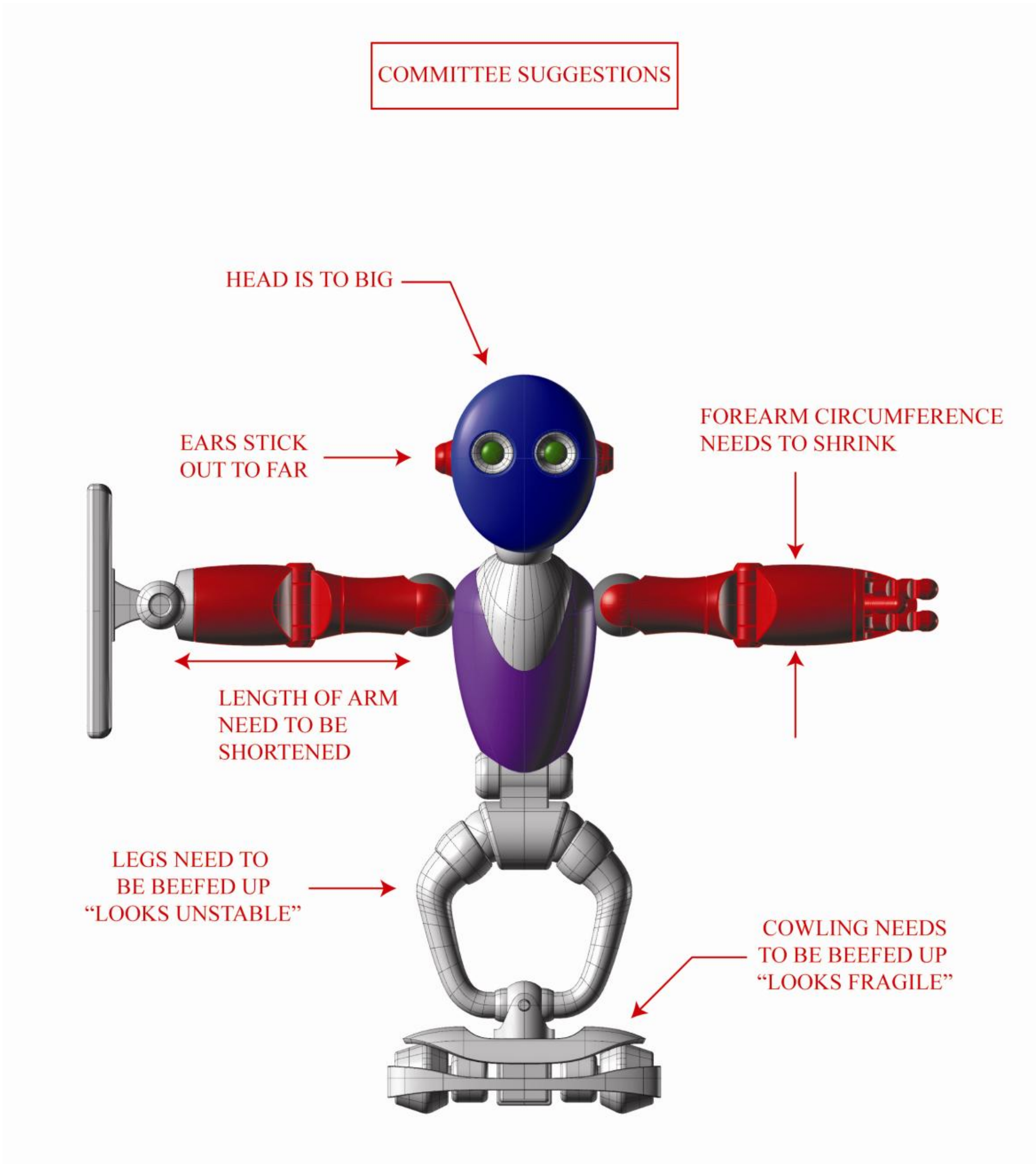


Figure 52 suggestions made by committee members during second review

Suggestions made during the second review (illustrated in figure 41) were taken into account and the changes were made to the CAD model. Below in figure 42 is the result of those changes.

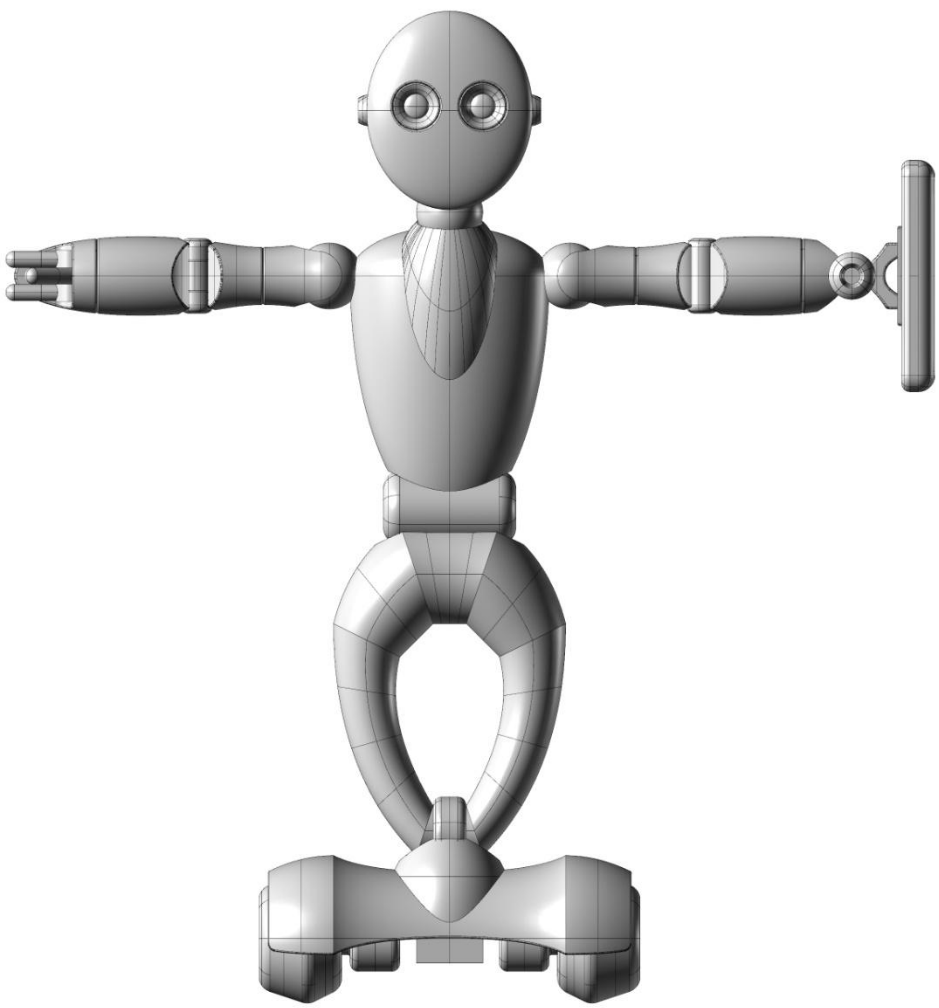


Figure 53 screen shot of CAD model after the committee's suggestions were applied

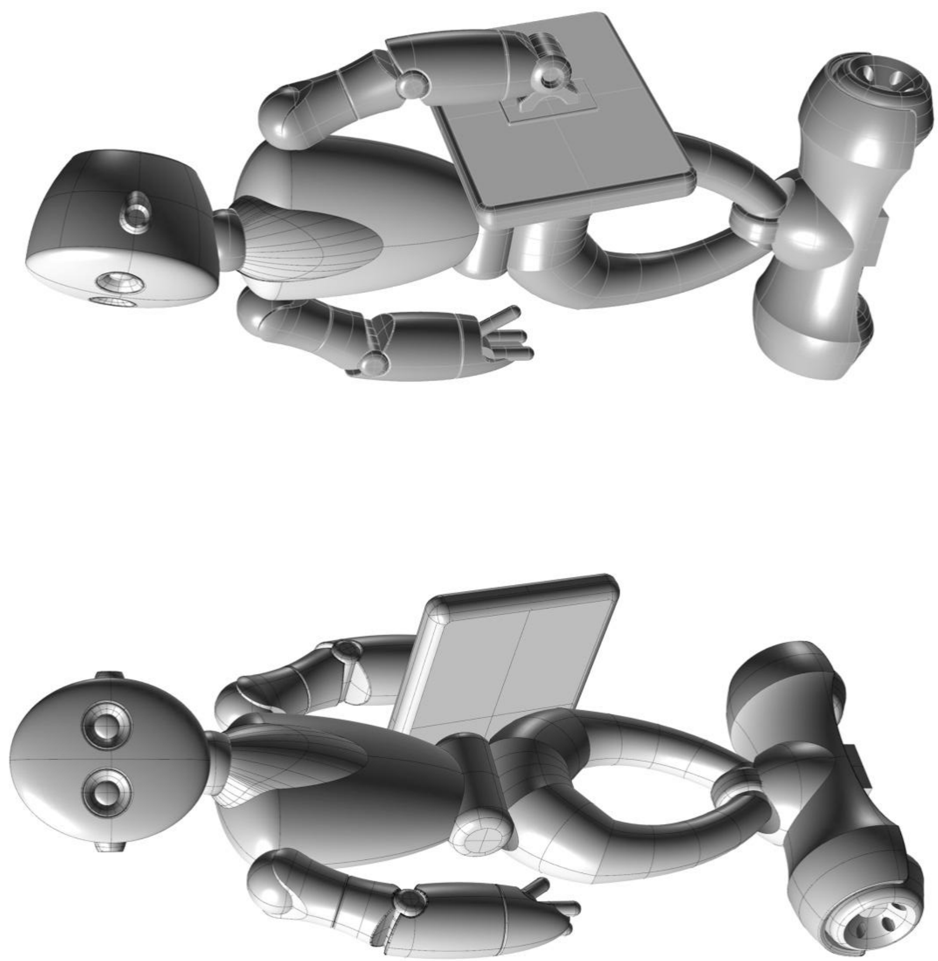


Figure 54 CAD model with arms down, this was a test to make sure the robot would still fit threw doorways.

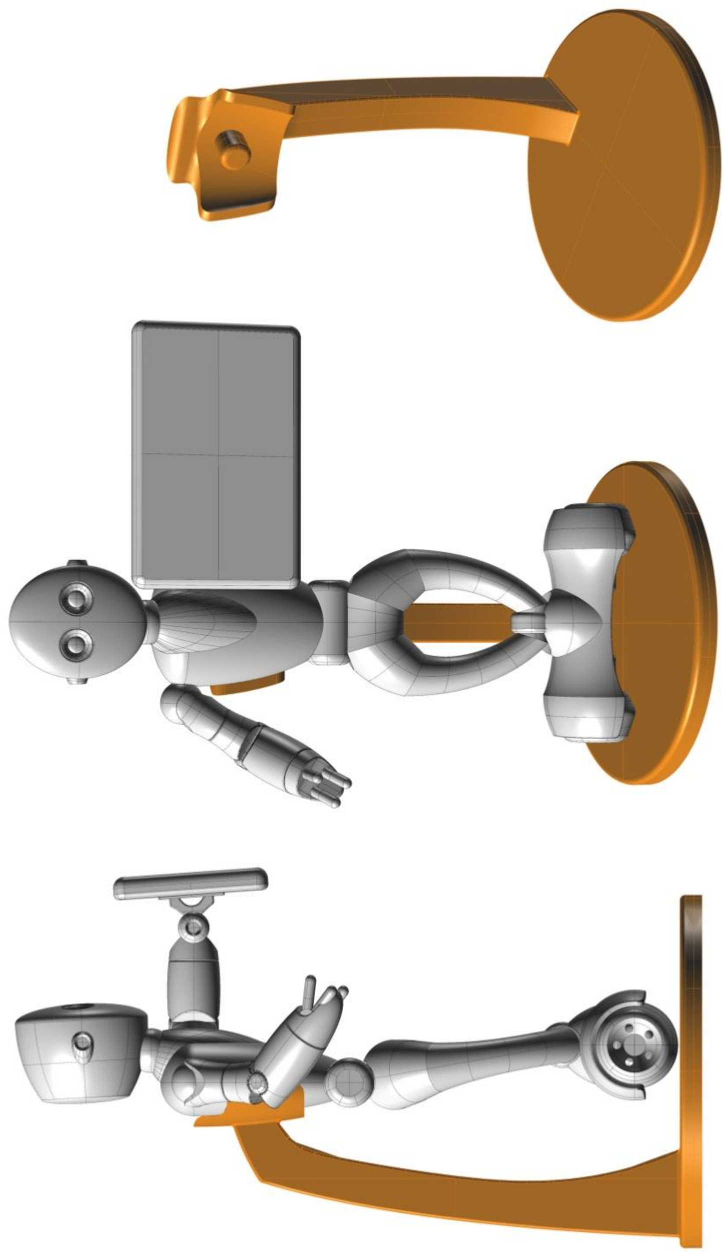


Figure 55 CAD model docked with charging base

An additional change was made to the LCD screen; it was switched to the left arm. This adjustment was made after research was conducted on handedness of the U.S. population. “90 percent of the population is right handed” (McCredie), and if the opportunity presents itself it would be a friendly gesture if the robot could shake hands with the user. With the new design in hand, it was printed out in full scale for a third review. The revised design received all positive responses from the committee and was approved for rapid prototyping. The method of choice for this phase was (FDM) Fused deposition modeling, it was the most cost effective and convenient process available at that time. Due to the cost of materials and lack of funding, a 1/5 scale model was produced. Once the model was finished printing it was sanded and finished to look as realistic as possible to serve as a visual aid during the thesis defense and review the mechanical functionality and aesthetics in 3D.

Figure 56 FDM model

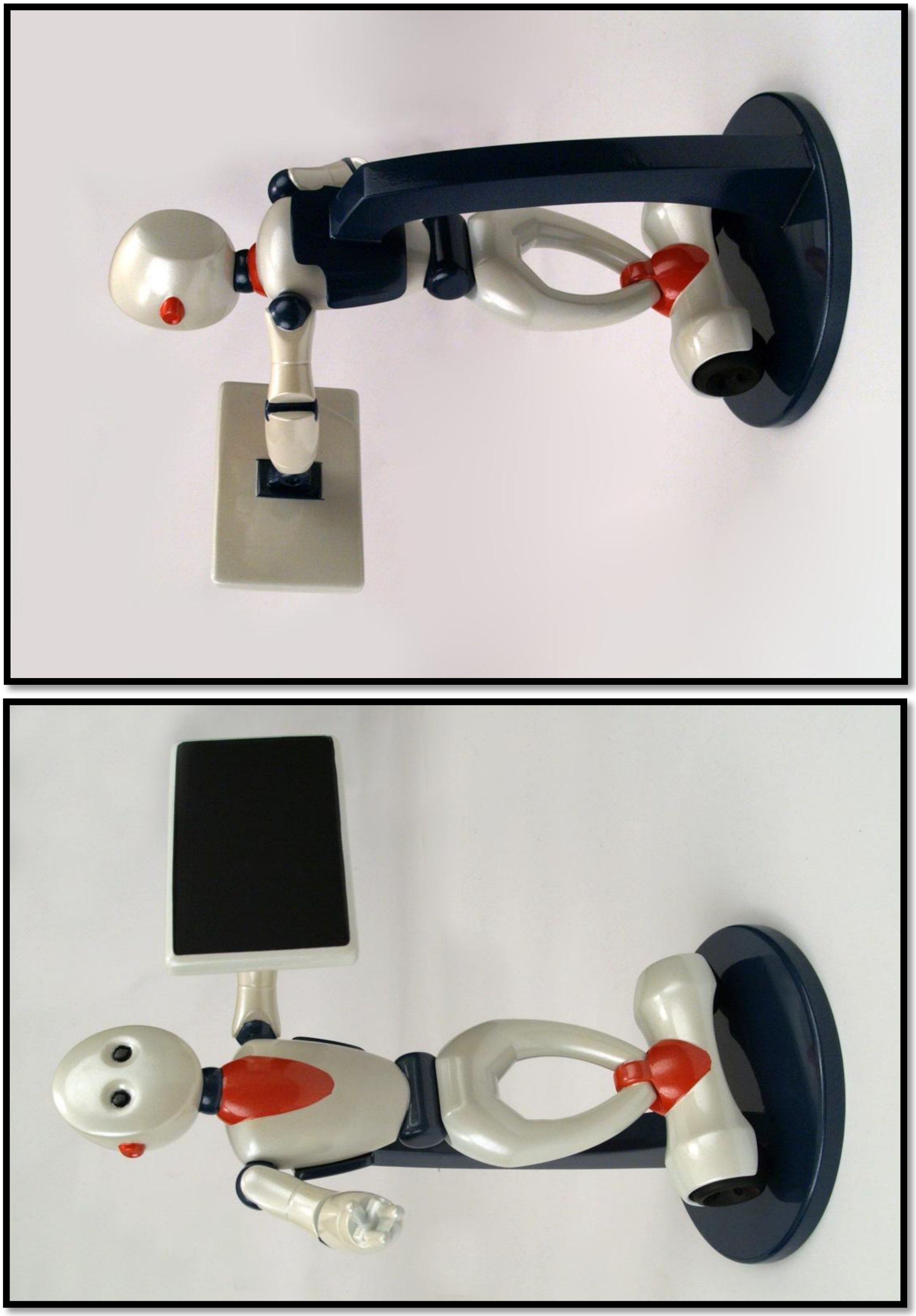


Figure 57 front and back view of the scale model

5.9 Conclusion

In the future there will be more robots designed to interact with humans. As technology advances, the pace at which human interaction robots are developed will continue to grow. However, people come in all shapes and sizes with a wide range of abilities and disabilities. The task of designing robots that interact with the greatest possible percentage of the population is difficult due to the inherent variety found in the human population: height, weight, ability. It is crucial that the needs of all potential users be taken into consideration during the design process. One of the main goals of the approach developed during this study is to ensure that the needs of the users are not overlooked. This will significantly increase the usability and broaden the range of users the robot is capable of interacting with during its function.

To address both human interaction and universal design, this study pursued an approach that consists of a five step process. The results of the five step approach proved to be a significant aid for designing the TourBot (as described below).

- The first step, developing a task chart, is a basic list of tasks or functions that the robot needs to perform during the tour of Broun Hall.
- The second step, a task map lays the functions out in the intended sequence to visualize the tour as a whole and determine if any adjustments need to be made.
- Third, the interaction map isolates the individual tasks to discover what hardware and software is needed to complete the function and apply the principles of

universal design to identify what is needed in order to meet the needs of the users with disabilities.

- The results of the interaction chart were then applied to the universal flowchart in a sequence of events to provide another overview of the tour and identify additional functions, hardware, and software that my need to be introduced into the design.
- At this point a list of hardware and software was constructed using the flowchart as a guide. The list was then applied to the design process.

The final concept reflects the results of the approach illustrated in figure 55. Depending on the function of the robot, the five step approach could be used in its entirety or adapted to help designers develop human interaction robots. Future applications of the five step approach can be applied to the design of other robots whose function includes interacting with humans with diverse abilities and enhance the opportunity for the robot to be useable by more than the majority of the population.

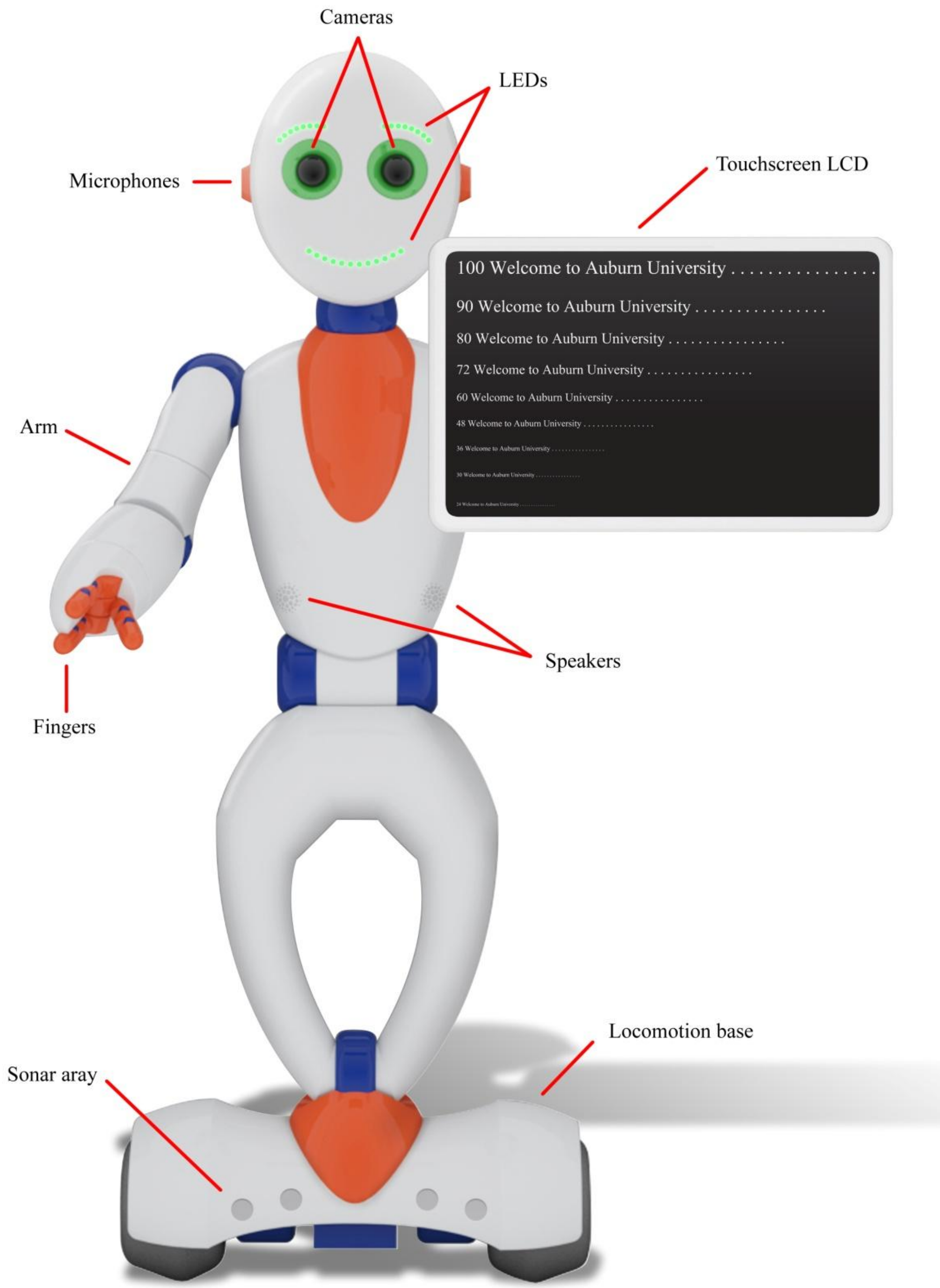


Figure 58 final rendering with description of hardware

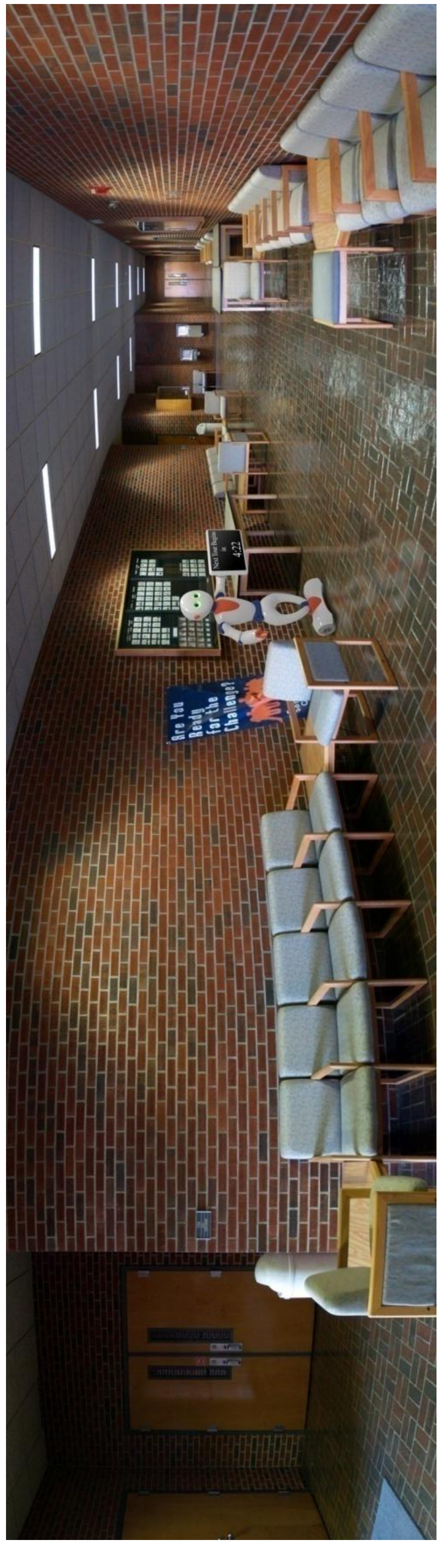


Figure 59 panorama of the TourBot in Broun Hall

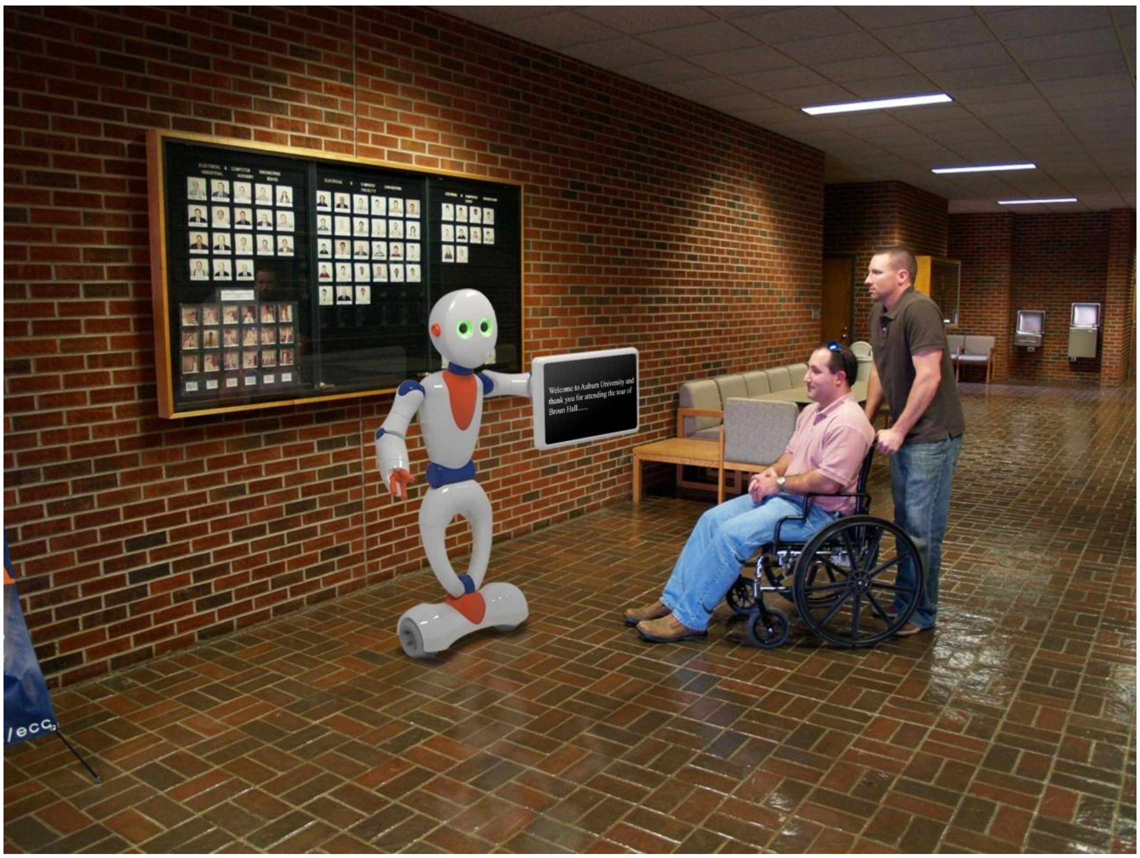


Figure 60 taking a tour of Broun Hall

5.10 Continued study

During the course of this study the approach was applied to a tour guide robot. In the future, additional testing will need to be preformed to assess the adaptability of the approach to the design of other human interaction robots. Also a full scale, fully functional prototype of the TourBot needs to be constructed to conduct user testing and test the effectiveness of the robot and its functions.

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