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Preliminary design of a ceiling-mounted fire extinguisher robot

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ABSTRACT OF FINAL PROJECT

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Abstract:

In this Thesis a fire robot was designed. The goal was to create a system which was able to extinguish a fire, but it had to be attached to the ceiling.

The first task was to consider an environment and to define qualitative requirements, obstacles and challenges affecting the robot. A cinema was chosen. The main challenges were: how the navigation of the robot could be, how many and what kind of sensors would be needed and how a fire fighting system could be created.

Later, new functions were added. The robot would send information and pictures about the situation inside the building to a fire station. When the robot detected a fire, it would send the report and it would also start to beep. With these tools, people and the fire brigade would be warned. Another interesting function was considered. The firemen could control the robot and take pictures from outside the building. More guesswork could be taken out of fire fighting.

Finally, possible materials, possibilities of communication, different power systems and safety measures were studied.

Keywords: fire extinguisher robots, ceiling robot, fire detection, fire fighting systems

Acknowledgements

I have added a lot of things and improved everything, but it is sure that this project would not have been possible without the work of Vasek Brabec. I also want to stress that the opinions done in the weekly research group meetings by the others students and the instructors were a great help to me. David Leal helped me a lot in the beginning, and he would have kept on doing so if I had needed. Tomi Ylikorpi, even from a distance, also did his best to help me. William Martin was a great adviser. I would also like to thank Prof. Halme for his work towards the end. He worked hard so I could finish everthing on time.

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1. Introduction

When a factory is going to be placed, many factors have to be taken into consideration. For example, it has to be near the suppliers, the clients, raw materials or the energy sources. Another important, and not easy, issue to consider is the layout of the factory. Machines and people have to interact as efficiently as possible. The answer is often small corridors and/or people with not enough space. Here is the solution. Robots working from the ceiling would increase the free space of the factory. And this is only one example, think about hospitals, where it is common to see five people and one machine around a bed. A *ceilbot* could be the solution, the ceiling is a wasted place, so seize it.

The author of this Thesis work was appointed to work in a research group in the Department of Automation and Systems Technology at the Helsinki University of Technology (TKK). This department was involved in developing service robot designs. The mission of the group was to take advance of a new solution: a ceiling-mounted robot.

The group was formed by eight students and a civil engineer. The engineer worked by himself and the students were divided into working pairs, assigning one different environment classification for each one of them. The pair in which the author was part of should try to find applications for a robot attached to the ceiling in their specific environment.

One pair was appointed to work in the Sports halls. They designed a robot capable to doing five different tasks: video recording, interactive player, virtual coach, cleaning the sports hall and catching balls. The robot was formed of four cables, four motors, four pulleys, one stabilizer and one arm.

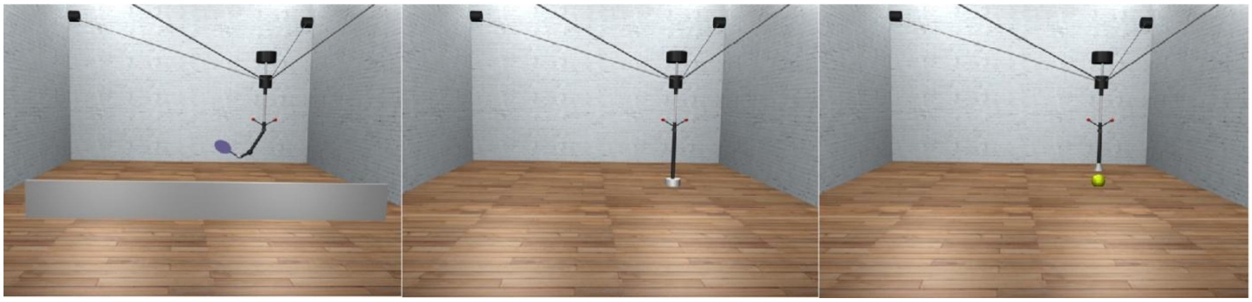

Figure 1: (from left to right) interactive player, playground cleaner and ball catcher (created by Guillaume Mercier and Massinissa Ait-Gherbi) [1]

Another group worked on a home cleaning robot. This robot was also designed to carry out different tasks: organizing misplaced objects, vacuuming, cleaning windows, giving water to plants and finding and bringing objects to the operator. In Figure 2 is shown the preliminary design of this robot.

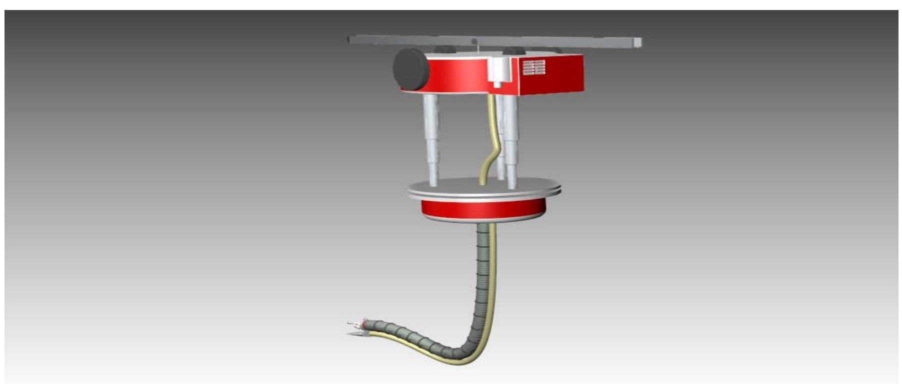

Figure 2: home cleaning robot (created by Juuso Kinnunen and Ville Rahikka) [1]

The third pair of students did not concentrate on one specific environment. They decided to study common tasks for all ceiling-mounted robots: location and mapping systems, sensors, and different alternatives for locomotion and attachment to the ceiling. They created an eye-catching possibility for locomotion (see Figure 3). The robot could move like a "monkey" grabbing pins on the ceiling. With this system, the *ceilbot* could go from room to room avoiding doorframes. They also studied the possibility of adding rails to make the system faster.

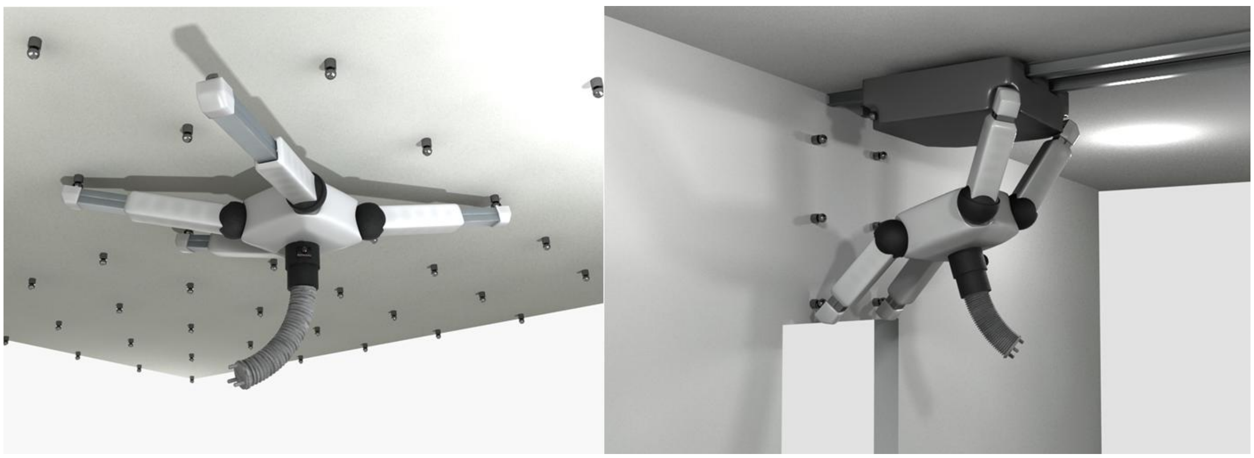

Figure 3: robot created by Juhana Leiwo and Marco Torti [1]

The first task was brainstorming about different robots in different environments. A lot of ideas came into the head, but finally the choice was a fire extinguisher robot.

This study contains the preliminary design of a fire fighter robot working from the ceiling, and all the possibilities that it entails.

1.1. *Ceilbot* applications

Each group had to think about a different environment. The author of this work was given the Industry and Entertainment environment category to work on. But lots of ideas appeared in different environments and they had to be shown to the other groups.

In the beginning some ideas could seem absurd, but maybe they would make the group find other ideas. Then, the author decided to fully document the research process, gathering together all innovative ideas and thoughts.

1.1.1.Industry

It is in this environment where there is the highest technology, and most likely where is easier to find new applications. Some tasks for this robot could be:

- Weld
- Drill
- Paint
- Assemble
- Transport
- Handle materials

1.1.2.Library

The ceiling robot could sort the books in a library. It would be useful especially in high difficult to access areas. The robot could have a barcode lector and a database.

1.1.3.Hospital

- Guide: The robot could have a rope/wire/telescopic arm with a speech recognition device at the end of the rope/wire. It could guide the sightless persons (or elderly people). They could say their need (dentist, ophthalmologist...), and the robot could guide them round the hospital. The device could bring a sound to alert other people. When the robot returns it should wind the wire.

Figure 4: a possible model of guide robot

- Nurse assistance: nurses often need help to move patients. Especially in hospitals, rooms are not very spacious. The possibility of adding a robot to the floor in most cases is impossible. A robot working in the ceiling, however, would be a good solution and most likely the only one. The *ceilbot* should be able to help with moving patients to other beds and turning them in their beds.

- Food supplier: another useful possibility could be using the robot to provide the patient with food. The food would arrive at the room in a little lift. It would come with a special tray and the *ceilbot* would only have to take the tray from the lift to the bed. The problem could be the feeling of loneliness. Very often they need to talk with someone more than only taking medicines. *Ceilbot* also could provide medicines, but only if it is sure that the patient wishes and is able to take it.

- <u>Surgery robot:</u> robotic surgery is the use of robots in performing surgery. Three major advances aided by surgical robots have been remote surgery, minimally invasive surgery and unmanned surgery. Some major advantages of robotic surgery are precision, miniaturization, smaller incisions, decreased blood loss, less pain, and quicker healing time. Further advantages are articulation beyond normal manipulation and three-dimensional magnification. Using the ceiling is always a good option as otherwise it is a waste of space. As already mentioned, in hospitals and, in this case, in operations where there are a lot of surgeons and nurses in a limited space it is a great advantage if we use the ceiling.

Figure 5: Da Vinci Surgical System [2]

1.1.4.Entertainment

- Cinema- Fight against piracy: Piracy is a topical subject, being a worrying issue for the film industry. The ceiling robot could detect cameras in the cinema and catch the pirates before the illegal copy ever reaches the streets.
- Cinema- Special effects: the *ceilbot* could sparkle, give off aromas or fog, throw confetti, etc. The robot would be programmed for each movie to do the different tasks in the right moments.
- Humour TV shows: in today´s world there are a lot of lucrative shows full of absurd humour. The *ceilbot* could throw eggs, a cake, water, a colour hair spray...
- Discos- wardrobe: the ceiling robot could take the jackets of those at the end and bring them to the high areas in the building. The area under the wardrobe is now useful. You get your ticket inserting a coin in a machine, and then you put your jacket on a hook. To retrieve your jacket, you can show your ticket in an optical sensor and it orders the robot to bring your jacket. With this tool it is not necessary for a person to be working and there is more floor space in the disco available for dancing.

1.1.5.Home

- Vacuum cleaner: there already exist different robots doing this task at ground level (*Roomba*), and at first it seems absurd thinking about a vacuum cleaner attached on the ceiling. But with this robot you can clean different levels, not only the ground level. It also could be useful, for example, if someone dropped something (cereals, a flowerpot…). It could detect it and clean up the mess.

Figure 6: Roomba [3]

- Arm to pick up: this robot would be useful mainly for people who for health reasons should not bend over or crouch down frequently. If they dropped something, the robot´s arm could pick it up from the floor.

1.1.6.Airport

- Loading the luggage: it is donkey work the task of transporting the luggage from the conveyor belt to the car which brings it to the plane. A *ceilbot* could help in these tasks.

1.1.7.Restaurant

- Waiter: a new concept of restaurant could be designed. The tables should be in fixed places. The waiter would be a ceiling robot. The robot with the help of a tray could take the customer the food/drink. As already commented in the case of the patients of the hospitals, in most cases we prefer human treatment. In some cases even this is the only thing you are looking for when you go to a bar.
- Cleaning: the design of the restaurant would be similar to the previous point. The *ceilbot* could fulfill different tasks: cleaning the table, removing the crumbs, glasses…

1.1.8.Garage

- Entrance: the robot could have a face recognition device. People would not have to use a key or a remote control, the robot would recognize them and let them in. The use of this robot is only for private parking. One challenge would be if people who try coming in are not the usual tenant (a friend, family).

1.1.9.Bank

- Security camera: the robot could follow the thief recording him. It should be able to distinguish the face and try to record his face. It should be small enough that thief is unable to see it. It could advance in a thin rail inside the ceiling. Big problem: how can the camera differentiate between a thief and a normal client?

1.1.10. Anywhere

In this section different robots which can be used in many places will be shown.

- Fire extinguisher: a *ceilbot* which is interacting with smoke detectors could localize the fire´s source and extinguish the flame. This robot is the main goal of this study, so it will be detailed in the next sections.
- Burning building: the robot could localize people inside the building and/or help them to go out.
- Changing lamps: there are a lot of high buildings where is not easy to reach the ceiling. The robot could change the lamps instead of us. One of the main challenges is that there are many different kinds of lamps.

After the study of the possibilities, the author finally decided to work on the fire extinguisher option. From here on, all the sections refer to this robot.

2. Fire Robot

The world of fire extinguishers is full of possibilities and is constantly under study. Numerous disasters have taken place over the years causing the destruction of forests and many deaths. There are a lot of ways to fight against the fire, but none is good enough to ensure the safety of civilians. Maybe this study can contribute in the search for solutions to address this problem. These were the reasons why the author finally chose this robot.

The robot is a fire fighter robot, so its task is monitoring of the room and the detection of the fire. For this function it uses commercially available smoke sensors in the room. The robot is waiting in its base position for the signal from the smoke detectors. In this base position it is connected to an electric plug, so it can charge its batteries. When the signal from the smoke sensors appears, at first the robot notifies with a sound beep signal any people in the room. At this moment the person who is in the room can cancel the procedure of the robot with the pressing of the stop-button. The robot takes pictures of the room with a camera and sends it to the fire station. And then the robot moves to the fire source. The robot has the first indication of the position of the fire in the room from the smoke sensors. For better localization it uses the smoke and heat sensors on its arm. The arm can move up and down, so the robot can estimate the best position for the use of the extinguisher. It also can turn. After arriving at the flame it uses the extinguisher and tries to stop the fire. The fire brigade is coming; when they arrive they can control the robot for taking pictures to know the situation in the building.

2.1. Detection

The building regulations of most countries in the world consider the combustibility of the materials which constructions are built of, that is their capacity to burn during a fire. These regulations also bears in mind the length of the fire-resistance, the emergency routes at the moments of collapse, and, particularly, the fire detection and extinction systems which can work individually or together.

The measures of performance of the fire fighting systems can be classified into actives and passives. The actives make reference to systems which are activated in the moment when a fire has been detected, to avoid larger damages and to preserve the safety of people, animals or damage to property which shall be in the place. Among these active systems there are the sprinkles of water or CO_2 and the assorted range of detectors. Among the passive systems, there are measures taken for the prevention of accidents, for example anti-fire doors and windows, utilization of non-combustible materials, etc. Especially in this chapter, different kinds of active systems are discussed in greater detail.

2.1.1.Heat detectors

It is definitely a thermostat, which opens a circuit according to the registered temperatures. There are several operational mechanisms, but definitively it distinguishes two: firstly, fixed-temperature heat detectors, which set when the room temperature exceeds the pre-established levels, setting an alarm or an extinguishing system. The most common fixed temperature point is 136.4°F (58°C). Recent technological developments have enabled the perfection of detectors that activate at a temperature of 117°F (47°C), providing increased time to escape; and secondly rate-of-rise heat detectors (ROR) which react to the sudden change or rise in ambient temperature from a normal baseline condition. Any sudden temperature increase that matches the predetermined alarm criteria will cause an alarm. This type of heat detector can react to a lower threshold condition than would be possible if the threshold were fixed. A typical alarm may sound when the rate of temperature rise exceeds 12° to 15°F (6.7° to 8.3°C) per minute.

2.1.2.Smoke detectors

There are several kinds of devices for detecting smoke, depending on the use and technology it is utilized. They are mainly devices which in view of the smoke detection produced by the combustion, they activate an alarm or an extinguishing system. There are ionic detectors, photoelectric, lasers, thermal and triple technology (optical + ionic + thermal). These detectors can belong to a fire detection network of the whole floor of a building, in airing pipes and individually in rooms. This last case refers the ones which work with batteries and which only activate a small alarm when the smoke is detected.

Figure 7: example of a commercial smoke detector

2.1.3.Infrared barriers

They fulfil the same task as the conventional smoke detectors, but in large premises. They are made up of an infrared light beam transmitter, and a receiver. With the presence of smoke in the air the light beam decreases, which is detected by the receiver in charge of activating the alarm. It is suitable for storehouses, hangars, warehouses and large premises.

2.1.4.Gas detectors

Gas detector systems perceive combustible or flammable gases concentrations in the air, like butane or propane, emitting signals even when the gas mixture is far from being dangerous.

2.1.5.Flame detectors

These systems are activated on detecting the radiation which are emitted by the flames. These systems of fire detection are suitable in areas with flammable liquids and gases of pure combustion like petroleum, polar solvents, kerosene and butane, where there is a fast growth of intense fire.

2.1.6.Manual station

This mechanism is a manual notice system, activated by a person in view of a fire. This system activates an alarm system for the evacuation of the occupants from a building. When the switch or handle is activated it can only return to its original off position with a key. This ensures that the system cannot be deactivated deliberately or accidentally.

Figure 8: manual station

2.2. Fire fighting systems

The methods of fire extinguishing change according to with the system and the element in charge required to smother the flames. Therefore, it is possible to find several types which are adapted to the kind of dwelling or building where they are used.

For smothering a fire, the system resorts to eliminating one or more of the elements of the fire´s triangle and/or or the chain reaction. There are four different ways to extinguish a fire: suffocation, cooling, fuel isolation or chain reaction inhibition.

- Suffocation: this method tries to remove the oxygen. For this purpose it uses blankets, throwing earth, etc. The special foams which are used for smothering fires by hydrocarbons also work in this way.
- Cooling: it tries to lower the temperature of the combustible materials to avoid them burning.
- Fuel isolation: this method prevents the fire propagation by adding barriers to avoid the fire reaches more combustible materials. The use of firebreaks or the felling of vegetation before the fire arrives in a forest fire are the most often used methods.
- Chain reaction inhibition: this way tries to stop the chain reaction using chemical substances. Extinguishers of chemical dust and of halogenated hydrocarbon work with this method.

2.2.1.Manual fire extinguisers

A fire extinguisher is a device which contains a pressurized fire fighting agent, so opening a valve the agent goes out through a hose which must be pointed toward the flame´s base. Generally they have a device that avoids an accidental start off; it has to be disabled before using the fire extinguisher.

There are a lot different sizes and types, from very small ones which are carried in cars, to larger ones which are called cart-mounted, also called wheeled extinguishers. The content of extinguishing agent varies from 1 to 250 kilograms.

The problem with these devices (except the largest ones) is that the agent runs out quickly. Its time of continuous download is from 18 to 20 seconds.

They are also distinguished by the fires that they are able to put out. Different classes of fire are shown in next table.

America	Europe/Australia	Fuel/Heat source
Class A	Class A	Ordinary combustibles
Class B	Class B	Flammable liquids
	Class C	Flammable gases
Class C	Class E	Electrical equipment
Class D	Class D	Combustible metals
Class K	Class F	Cooking oil or fat

Table 1: the different classes of fire

According to the extinguishing agent, the contents of fire extinguishers can be distinguished between:

- Air pressurized water: the extinguishers of water under pressure are designed for protecting areas where there is the risk of fires of Class A (solid combustibles). Typical applications: carpentry, furniture industry, hospitals, etc.
- Distilled water: used in areas with electrical equipment. They are also used in chemical fires or bacteriological risks. Typical applications: banks, museums, offices, hospitals, electronic industries, telecommunication centers, schools, etc. These first two options do not pollute the atmosphere (water does not affect the ozone layer and it does not produce global warming). There are no residues.
- Water and Aqueous Film-Forming Foam (AFFF): the AFFF is water-based synthetic foam. It often contains hydrocarbon-based surfactant. It has the ability to spread over the surface of hydrocarbon-based liquids. The extinguishers of water with AFFF

under pressure are designed to protect areas with solid, liquid and gaseous combustibles (America: Class B, Europe/Australia: Class B and C). Typical applications: chemical industries, petroleum industry, labs, transports, etc.

- Carbon dioxide (CO_2): they are placed in areas with liquid combustibles (Class B) and electrical equipment (America: Class C, Europe/Australia: Class E). Typical applications: industries, dwellings, transports, garages, aviation, etc.
- Ammonium phosphate, also known as "tri-class", "multipurpose" or "ABC" dry chemical: they are designed for protecting areas where could appear a fire from solid combustibles (Class A), liquid combustibles (Class B) or electrical current (America: Class C, Europe/Australia: Class E). They are more corrosive than other dry chemical agents. Typical applications: industries, houses, shops, transports, aviation, garages, etc.
- Dry chemical-BC: they are thought to be used in areas where there are liquid combustibles (Class B) and electrical equipment (America: Class C, Europe/Australia: Class E). Typical applications: industries, electrical equipment, dwelling, etc.
- Dry chemical-D: these extinguishers are designed to protect areas with risks of Class D (combustible metals like lithium, sodium, potassium and sodium alloys, magnesium and metal compounds). It is charged with dust composed of sodium borate. This compound is treated to make it resistant to the influence of extreme weather.

Figure 9: (left to right and from top to bottom) oil and fat fire, flammable gases, liquids burning and electrical equipment [4], [5], [6], [7]

There are some special extinguishing devices:

- Extinguishers of halogenated hydrocarbon (Class H): generally they are hydrocarbon derivatives, where some atoms are been replaced by halogens. Actually their manufacturing is prohibited because they deteriorate the ozone layer. Now new substitutive products which are not harmful to ecology are appearing. They are called Halotron fire extinguishers. They are environmentally friendly. These units are suitable for use in computer rooms, telecommunications and high-tech clean rooms.

- Extinguishers of Class N: they neutralize the gases formation by chemical agents or weapons of mass destruction introducing micropulverized dust with a neutralizer agent (specific antidote for each product).
- Automatic extinguishers: they contain an ABC agent with constant pressure and a sprinkler in the lower surface. The capsule of the sprinkler breaks when reach 68ºC. These extinguishers also have a valve which can be regulated manually.

Figure 10: (from left to right) CO_2 extinguisher, American water extinguisher, Class D extinguisher, car-mounted water extinguisher

2.2.2.Sprinklers

The water produces the triple effect of extinguishing the flames, cooling the surfaces to avoid combustion, and covering the place with water vapour which avoids the entry of oxygen which is esential for the combustion process.

Figure 11: sprinkler

2.2.3. Water conveyance systems

These are transporting pipes of water for the sprinkles or hoses. They work as feed source of them, from the tanks or pumps.

2.2.4. Fire fighting foam

These devices store a solution composed of water and frother agent. This equipment has a foam generation zone where the foam is produced when the solution mentioned go throught this zone. The function of the foam is cooling the oxygen surfaces, blocking the entry of oxygen, and restricting the flammable gases. The use of this method of extinguishing is common in zones of flammable substances manipulation like stores with tanks of fuel or paint.

2.2.5. Aerosol fire extinguisher

The aerosol is compossed of chemical elements which neutralize the combustible gases, and cooling agents in charge of absorbing the heat produced by the flames, and in this way it smothers the fire. This system provides advantages over the previous ones, it can be used in rooms with electronic machines like computers, phones or electrical appliances because it does not damage inside components, contrary to sprinklers or dust extinguishing.

2.2.6. Fire Extinguishing Ball

A good alternative to the common fire extinguishers is the fire extinguishing ball. In case of fire is enough with throwing it to the flames. When it is hot enough, it will explode covering everything around it with ABC dry chemical powder which will extinguish the flames. It is ideal in places prone to fires because it will also explode automatically if it reaches a hot enough temperature. The coverage area is about 5 square meters. In addition an alarm will sound (138 decibels) which will warn people that there is a fire. It is small and not very heavy (1,3kg), so it can be placed anywhere. It has a useful life of five years and it does not need maintenance [13].

Figure 12: fire extinguishing ball [13]

2.3. Fire fighting robots

This chapter tries briefly to show some researches about some robots developed to fight against fires. Some of them perhaps have a feasible entry in the market and others are simply academic research projects destined to remain in the laboratory.

2.3.1.OLE, The Fire Fighting Beetle

Robots can be either simple or, they can even have a personality. Some of them have been designed based upon the shape of animals or insects like this robotic beetle. OLE (short for "Off-road *Loescheinheit*," which means "off-road extinguishing apparatus" in German) simulates the displacement of a beetle, but with the work which a fireman would have to do.

The robot is equipped with tanks full of water or dust like that is used in fire extinguishers, but it has not to be carried where the fire is, it is autonomous and it is guided by a GPS chip. They have several intelligent feelers, infrared sensors, heat sensors and smoke detectors. It also possesses two antennas at the front to improve its navigation skills. With this system, it is easy for it from detecting small fires to the largest ones, starting to act by itself and simultaneously sending messages about the fire.

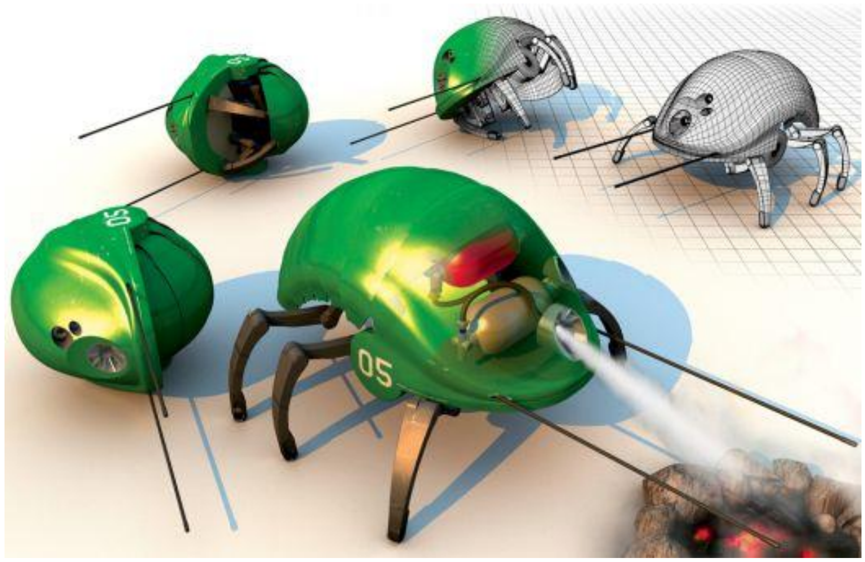

Figure 13: OLE, The Fire Fighting Beetle [14]

Their designers are from the Magdeburg-Stendal University in Germany. They have demonstrated in some tests that 30 OLEs could control a 7000 square meters area. A fire advances very rapidly, but this robot can reach a speed of 20 km/h. In dangerous situations it would roll like a ball to protect its circuits till it was in better conditions. It has been manufactured from fireproof material being able to bear temperatures up to 1300 degrees centigrade.

According to staff at the University of Magdeburg, the cost of an OLE unit is between 100.000 and 250.000 Euros; but annual forest fire damage in Europe alone is around 2.5 billion Euros [14].

2.3.2.AWARE project

Investigators from the University of Sevilla lead the European project AWARE, *Platform for Autonomous self-deploying and operation of Wireless sensor-actuator networks cooperating with Aerial vehicles*, where they have designed air robots which are autonomous, distributed, and having a capacity for cooperating between them, air robots to take part in case of disasters and fires. In this way the prototypes of helicopters could participate in tasks of civil protection and safety, because they are able to operate in places with difficult access and without communication infrastructures.

Although in AWARE the urban or industrial fires have been considered, it also contemplates the future application of the developed technologies for fighting against forest fires.

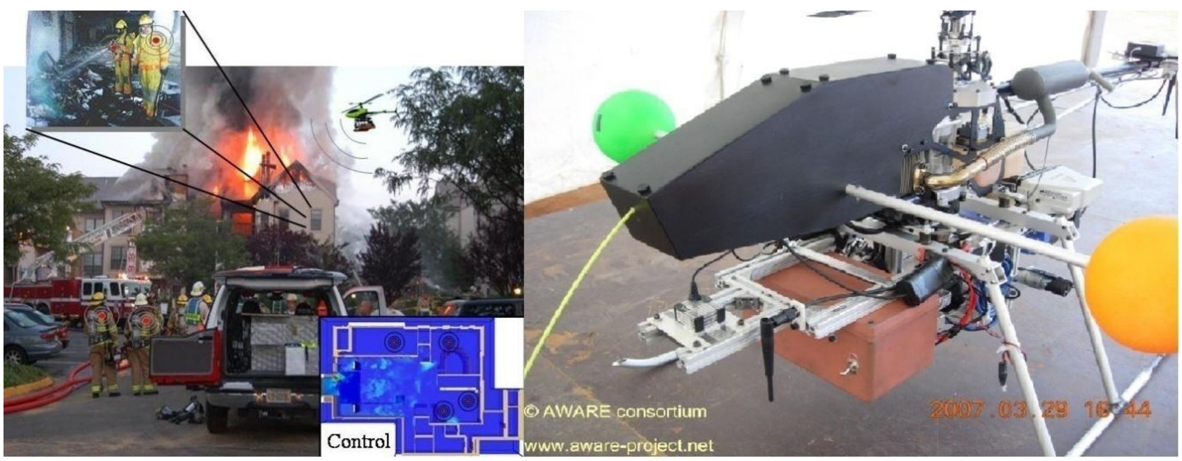

Figure 14: AWARE project [15]

In the actual project, the helicopter style prototypes of helicopters can spread cameras and take pictures of a fire in urban zones, transporting first aid equipment to the victims in inaccessible sides or record images of inside a volcano for a documentary.

Furthermore, the system operates with images from the helicopters adding dates from the sensor´s net which can be placed, for example, in the firemen´s clothes or being transported by vehicles, thanks to wireless technology. In this way, it combines the information from the air with which is contributed by the sensors. The air robot can also throw a node where it needs to collect the information.

Other of the features of the system is its distributed nature. In this way, all the nodes in the net operate one another, offering more trustworthiness, because the system does not depend on only a single station [15].

2.3.3.Fire Spy Robot

Most fires happens when there is nobody at home to avoid them, nevertheless in South Korea a robot has been developed which is able to smother fires when they are still small.

This robot is called Fire Spy, and it is able detect by means of images and sounds, as well as monitoring the room temperature or the air quality when a fire appears. It activates alarm sensors using wireless technology. It is even waterproof. Its diameter is 12.5 cm and it weighs 2 kg. It can tolerate temperatures of 500 degrees Celsius for a period of an hour.

Figure 15: Fire Spy Robot [16]

These robots are very useful in houses, because they are constantly monitoring the house and in case of detecting some fire, they act and send remote messages about the state of the house.

The Spy Robot is the work of Hoya Robot. For the time being it is under development, but it will be available in the stations of Daegu, South Korea [16].

2.3.4.Guardians

In the future, the autonomous robots will be the first to go into a building full of smoke or toxic gases, helping in this way the fire brigade in emergency cases.

Guardians, which is an investigation project from the European Commission, has a clear mission, which involves in building an automaton capable of resolve dangerous situations, increasing the safety and velocity of the tasks, and in this way saving lives.

Figure 16: leader of the group [17]

This robot will gain special prominence in low visibility conditions and in toxic or flammable atmospheres. The swarm of robots is managed commanded by an automaton which assumes the function of leader. They use wireless communication to interact with each other and with the central station.

Actually is under development. The end date is 31.01.09 (total duration: 38 months) and the project will cost 3.4 million euro [17].

2.3.5. Autonomous Fire Guard

This robot would be a good ally when larger fires occur, those which last days and days, consuming houses, forests and human lives. In the words of the designer, the mission of this robot is mopping-up: "Mopping-up is the most repetitive, exhausting, hard and dirty phase of the suppression operations. The main purpose of the mopping-up phase is to cool down hot and smoldering materials in the area after taking control of the fire to make sure that the fire is extinguished completely". To accomplish this task, the Autonomous Fire Guard is equipped with laser scanners, infrared cameras and radar to manage through the intense smoke. It has been built with interchangeable modules, each for a different task.

It is an autonomous robot, so it will have to be able to work without any human assistance. For this mission, it uses several sensors interacting with each other and with the environment.

It has been designed by Aydin Mert in collaboration with Husqvarna [18].

Figure 17: Autonomous Fire Guard [18]

2.3.6.Robot SACI

The robot SACI, developed in 2004, is a remotely control robot, which has one of the most modern fire fighting cannons, with the capacity for mist generation, solid stream or foam with a limit pressure of 125 psi throwing streams up to 4200 liters/minute, working till 120 m from the operator with 3 degrees of freedom (like the solid stream reaches a minimum distance of 60 meters, it means that the fireman will be able to be till 180 meters of distance from the incident).

Currently, SACI is the robot with most capacity of volume of flow in the world, becoming until 21 times superior to similar available models.

It has been created by a Brazilian company called Armtec [19].

Figure 18: on the left SACI 1.0, on the right SACI 2.0 [19]

2.3.7. "Candle robots"

There are many robots which can navigate a maze looking for a candle, find it and extinguish it. They have similar features, and they do not need to be explained singularly. There are several regional contests like The Trinity College Fire Fighting Home Robot Contest where a lot of different robots are shown.

Figure 19: (from left to right) "Flameout" (Ted Larson), "Lego NXT" (Scott´s Project) and model created from Rovio robot by a student [20], [21], [22]

2.4. Challenges

The target of this chapter is to identify the main challenges that are encountered in the building of the robot.

2.4.1.Environment

The robot could be used in many different places. For this study a cinema/theatre was chosen for investigation. A lot of tragic events have occurred over the years in cinemas or theatres causing many deaths or the destruction of heritage buildings. The floor in ramp was an aditional obstacle which added interest to the work. For this study, a square room, 30 meters wide by 15 meters tall, will be considered.

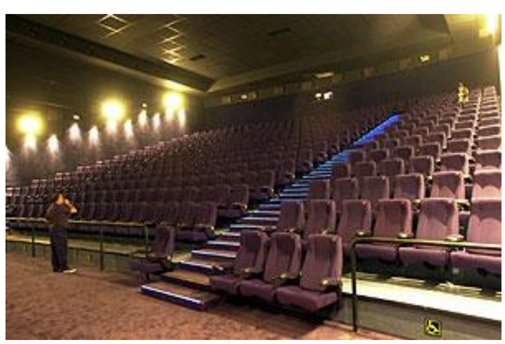

Figure 20: conventional cinema in Bilbao (Spain) [24]

2.4.2. Navigation

One challenge is in performing the motion of the robot on the ceiling avoiding lamps, walls, projector, etc. The robot must be able to both navigate with and without any human assistance.

2.4.3. Sensing

The robot needs some way to determine the position of the fire, the walls, people, etc.

2.4.4. Fire fighting arm

The fire must be extinguished. The *ceilbot* must have a tool for extinguishing the blaze.

2.4.5. Taking pictures

One of the most important features of the *ceilbot* is that it can take pictures inside the building helping the fire brigade to know the situation inside, the characteristics of the fire, if there is somebody trapped, etc.

2.4.6. Sound signal-stop button

When the robot receives the signal from a smoke sensor, it will start to move and sounds an alarm. In this way the alarm will warn people that there is a fire and, if necessary, they will be able to stop the robot with a simple switch on the wall.

2.4.7. Sending information to fire station

The fire brigade must know that there exists a fire. They will go to the building to check the situation. They will be able to control the *ceilbot* and to take pictures if it is necessary.

2.5. Structure of the robot

2.5.1. Possibilities of motion

This section is devoted to describing some options of how the navigation of the robot over the ceiling could be.

- Vacuum: one possibility for the motion could be by using suction cups. With a vacuum system the suction cups are activated or deactivated alternately making the robot advance. One example is shown in Figure 21. The idea was to build a shelf in a corner where the robot would wait for the signal of the smoke sensors. In this shelf, the robot would be charging its batteries and it would not need to be sucking at all times to remain on the ceiling. But in the motion, it requires a lot of energy .And a major problem with this *ceilbot* could be an energy failure. If the energy to the robot stops, the robot will fall down causing damages to everything that lies beneath it. Another problem could be that it makes too much noise. But it could be a possibility for the fire robot.

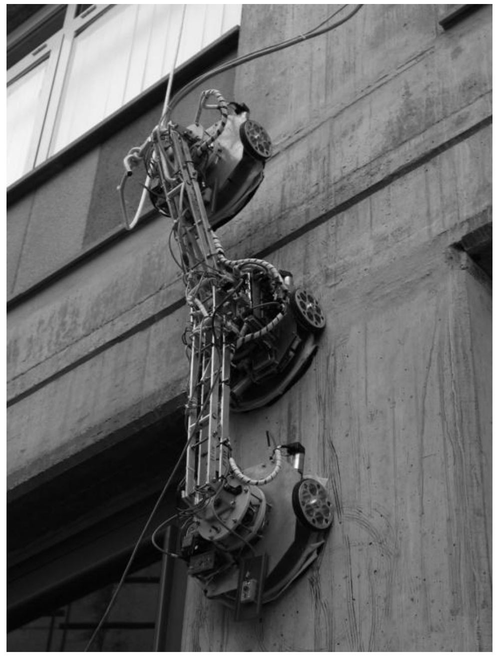

Figure 21: Robot Alicia3, example of vacuum system [25]

- Permanent magnet: using permanent magnets it would not be necessary to consume as much energy as in the previous case. The problem would be that it would have to build a suitable ceiling where the robot could remain with permanent magnets. An energy failure also can be dangerous in these robots. With regard to the fire robot, this ceiling could be a problem. If the fire heats the ceiling too much, it could damage the contact between the robot and the ceiling and it would heat the robot. TRIPILLAR is a robot which navigates thanks to magnets [38]. It needs ferromagnetic surfaces. Figure 22 shows its motion. There are not safety devices. If something fails, the robot will fall down. The fire robot will probably have to work interacting with people. Therefore, it will have to have the safety measures needed to make a fall impossible.

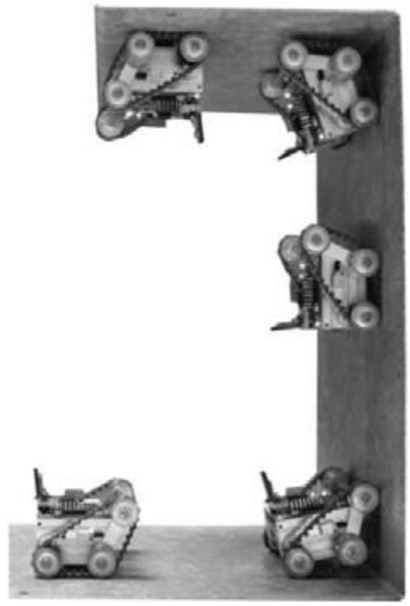

Figure 22: TRIPILLAR [38]

- Rail: another possibility would be to add rails to the ceiling. With the rails the navigation is limited. As we will see later the robot´s arm is designed with only two degrees of freedom (vertical and turn), then the motion of the *ceilbot* over the ceiling must be able to reach anywhere. These obstacles made the author rule out this option.
- Beams: the group appointed to work in the Sports Hall showed me the possibility of attaching the *ceilbot* with wires. I thought that also it would be a good option for my robot. But I changed wires into beams. This option requires building a beam´s system, but it is simpler than building a new ceiling for the magnet-robot. With beams, I only need small motors to make the robot move, and the weight of the *ceilbot* is supported by the beams. Finally I chose this option.

In the Figure 23 it is shown how the motion would be.

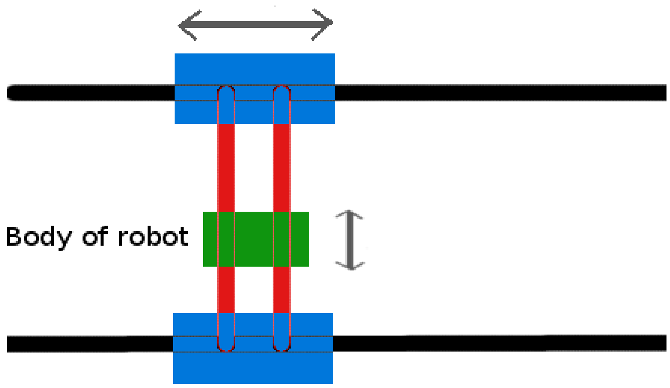

Figure 23: beams system

2.5.2.Frame of the robot

It corresponds with the green box according to the picture above. Inside, there will be one motor to move the robot along the red beams. It will contain two additional motors: one to move the pulley which makes the arm go up and down; and the other to turn the arm. There will also be the microcontroller, a memory, communication devices (Bluetooth and GSM) one battery, the pulley and the bottle of fire extinguisher.

The approximate dimensions are 0.5x0.5x0.25 m^3.

2.5.3.Fire extinguisher system

In the chosen environment, fires that could appear would be those caused in textile, wood or paper. Therefore an extinguisher for Class A fires was required. For health reasons, finally, a water extinguisher was chosen. The reason for doing so explained in more detail in the section devoted to safety.

Figure 24: water extinguisher label

The water extinguishes the fire by cooling, absorbing heat from the fire to evaporate itself. The amount of heat that the water absorbs is very large. Generally, it is more effective if it is used pulverized, because it evaporates more quickly, so it absorbs more heat. The water, when it is pulverized, increases its volume 1600 times.

The *ceilbot* will arrive at the flame quickly. Therefore, the use of a bottle of 9 liters of water will be enough. This bottle has a discharge time of approximately 1 minute. In this time, the robot can extinguish the blaze, or at least delay the spread of the fire. The approximate dimensions of the chosen bottle are 180 mm (diameter) and 600 mm (length).

The bottle is placed on the body of the robot. It is placed diagonally. Locating the centre of mass as well-balanced as possible was the reason for choosing this position.

It will be necessary to have some kind of valve in charge of making the bottle of the extinguisher open/close.

One different possibility could be to add a system to connect the robot with constant pressure water. This system can work indefinitely. The problem is that it is not as efficient as a bottle of extinguisher. If the robot is fast enough, it will be able to arrive at the flame and be success using the mentioned bottle. Another possibility could be that the *ceilbot* works simultaneously with sprinklers. If the robot was built waterproof, it could work simultaneously with them.

2.5.4.Arm

The arm of the *ceilbot* is shown in the Figure 25. The arm works as a pipe and the arm can turn thanks to a motor. It is composed of several cylinders. The number of cylinders will depend on the height of the ceiling. A cable is tied to the smallest cylinder. The motor connected to the pulley makes it go up and down. The gravity and the pressure of the extinguisher will do the rest. The turn motion is got thanks to another motor. The memory of the robot will contain a database where the microcontroller will be able to determine the distance to the floor from the position of the robot on the ceiling.

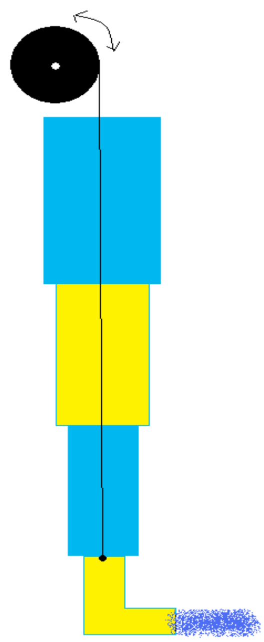

Figure 25: arm

2.5.5. Motors

Most of them have been already mentioned. It is only necessary now to present the other two motors which are inside the blue boxes (see Figure 23). Each of these motors will have its own battery. They will have to move simultaneity.

2.5.6. Sensors

There are not often changes in the ceiling. Then, the robot will have programmed the map of the ceiling. Therefore, sensors to avoid unanimated objects like lamps, projectors or walls are not necessary. It will need some sensors to interact with people in case that there was somebody in the room at the moment that the robot started to move.

- <u>Smoke sensors in room:</u> these sensors are permanently on the ceiling and they are used for the basic localization of the fire. The number of sensors depends on the size of the room. More sensors are better for better localization and the key point is the early detection of fire. The robot can only put out a small fire and when the fire appears, it is necessary to react as quickly as possible. These sensors are connected by wires with the *ceilbot* when it is plugged into the rest position. The robot would be programmed to know which sensor is sending the signal. With this, the *ceilbot* has a first approach about where is the flame, and it will go fast in the right direction.
- <u>Heat and smoke sensor:</u> these two sensors are placed on the arm, and they are used for the accurate localization of the flame. The heat sensor is used for nipping the fire in the bud. It would be programmed using a temperature algorithm. It is necessary to estimate the source of the flame very accurately, because the extinguisher bottle is small and with bad estimation we cannot be so

successful. We also win time knowing the approximate height. Using the coordinates where the fire is, the microcontroller knows the height of the seats in the cinema or the theatre. Then it would start go down waiting for the signal from the heat sensor to stop.

- Infrared sensor: in the vertical movement of the arm, it can find obstacles. This sensor will make the robot stop where the arm can reach the source of the flame without crashing into anything.
- Motion detector: the robot, in its way to find the flame, could collide with people who might be still trapped in the building. For this task a motion detector should be located on the lateral surface of the arm.
- Camera: camera is used for taking pictures of the room and in the remote-control of the *ceilbot*. This camera will have to be able both to take pictures in the first moments of a new fire, which will be sent to the fire station, and also to record when the room will be full of smoke, making it possible for firemen to see through the camera and display the situation inside on their own devices.

2.6. Materials

This section shows the possible materials to use in the building of the system robot-beams.

For the study of the different possibilities in the construction of the beams, a spreadsheet was used. This helped the author to get some findings.

- First study

According to the design shown in Figure 26, the author had to estimate the maximum deflection both in the beams placed on the left and the right (longitudinal beams:"LB"), and the beams where the robot is supported (transversal beams:"TB").

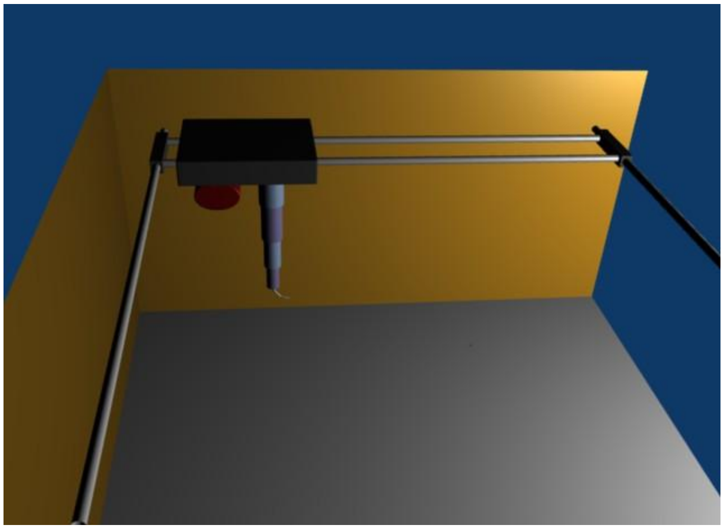

Figure 26: first system beams-robot

The first thing to be done was considering how the LB could be attached. The beams had to support the weight of the TB, the robot and their own weight.

Some basics solutions might seem feasible:

- Putting supports in the extremes of the beams attached to the walls.
- Putting supports in the extremes of the beams attached to the ceiling.
- Putting supports in the extremes of the beams attached to four columns in the corners of the room.
- Putting several supports attached to the ceiling.
- Putting several supports attached to several columns.

These ideas were shown in the meeting obtaining many and interesting suggestions. Too much material was being used and the torques were too great. Solid beams were being used, so they could be changed to hollow beams. And perfect fixed joints had been put, and this was the reason for having big torques. These joints could be changed to simple joints.

With the improvements the final prototype was designed.

- <u>Second study</u>

In addition to these two changes, fixed supports for simple supports and solid beams for hollow beams, another important change was done. The robot was not too heavy, so it was enough the two transversal beams were changed to only one. The weight of the beams was affecting the system to a greater extent.

To calculate the deflection in the beam, the Mohr Theorems were used:

- 1st Mohr Theorem:

$$\theta_B - \theta_A = \int_{x_A}^{x_B} \frac{M_f(x)}{EI_f}\, dx \qquad (1)$$

- 2nd Mohr Theorem:

$$\Delta_{B|A} = -\int_{x_A}^{x_B} \frac{M_f(x)}{EI_f}(x - x_A)\, dx \qquad (2)$$

Additionally, the formulas of the second moment of inertia for the different sections of the beam were necessary:

- Rectangular (Solid):

$$\boldsymbol{I = \frac{1}{12} ab^3} \qquad (3)$$

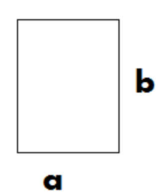

Figure 27: parameters of rectangular solid beam

- Cylindrical (Solid):

$$I = \frac{1}{64}\pi d^4 \qquad (4)$$

Being "d" the diameter of the beam.

- I-Beam:

$$I = \frac{bh^3 - 2\frac{b-tw}{2}h1^3}{12} \qquad (5)$$

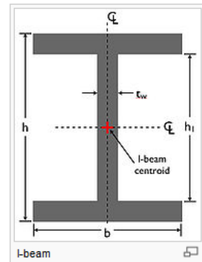

Figure 28: parameters of I-Beam

(Note: the position of the beam would be which appear in the picture)

- Rectangular (Hollow):

$$I = \frac{BH^3 - bh^3}{12} \qquad (6)$$

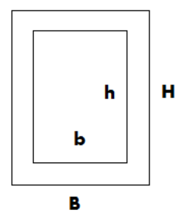

Figure 29: parameters of rectangular hollow beam

- Cylindrical (Hollow):

$$I = \frac{\pi}{64}(D^4 - d^4) \qquad (7)$$

Being "D" and "d" the external and internal diameters respectively.

Similar dimensions were chosen for the different beams:

- Rectangular (Solid):
  - $a = 10$ cm
  - $b = 15$ cm
  - $I = 2.81E\text{-}05\ m^4$

- Cylindrical (Solid):
  - $D = 15$ cm
  - $I = 2.48E\text{-}05\ m^4$
- I-Beam:
  - $b = 10$ cm
  - $h = 15$ cm
  - $h_1 = 10$ cm
  - $t_w = 2$ cm
  - $I = 2.15E\text{-}05\ m^4$
- Rectangular (Hollow):
  - $B = 10$ cm
  - $b = 8$ cm
  - $H = 15$ cm
  - $h = 10$ cm
  - $I = 2.15E\text{-}05\ m^4$
- Cylindrical (Hollow):
  - $D = 15$ cm
  - $d = 11$ cm
  - $I = 1.76E\text{-}05\ m^4$

An appropriate weight for the robot was estimated to be 25 kg, considering that the bottle chosen for the extinguisher weighed approximately 13 kg.

The length of the beam corresponds with the width of the room, which was deemed to be 30 meters.

The characteristics of the materials chosen were:

	Steel	Aluminum	Carbon Fiber
Young Modulus (N/m^2)	2.00E+11	7.00E+10	5.31E+11
Density (kg/m^3)	7850	2700	1740

Table 2: characteristics of the materials for the beams

All these characteristics are only indicatives. The materials will change their properties depending on, for example, the alloys. Or the carbon fiber will have a different Young Modulus depending on the way the fibers are woven. But all the changes produced by these variations will be easily calculated using the spreadsheet that was created.

The first task was to calculate the deflection characteristics for the different beams. To estimate the maximum deflection of the beam, the robot was placed in the middle of the beam. It was considered that the joints between the beam and the wall allowed the beam to rotate but no vertical deflect. With these hypotheses, the Mohr Theorems were used to estimate the deflection of the beam. Considering in each case the appropriate Young modulus, moment of inertia and mass for each different beam.

Table 3 and Table 4 show the next characteristics for three different materials and five different shapes for the beam:

- Mass of the beam (m): according to the section and the material, the mass of the beam was calculated. When the deflection was calculated, the mass of each beam was considered like a distributed force.

- Forces supported in the extremes (R1 and R2): in this step, the robot was placed in an extreme to estimate the maximum force that the wall would have to support. This force would correspond with the mass of the robot and the half weight of the beam (R1). R2 would the other extreme, which only would support the weight of a half beam.
- Maximum deflection of the beam (V): as already mentioned, to estimate the deflection, the robot was placed in the middle of the beam. And it was calculated with the Mohr Theorems.

	RECTANGULAR (SOLID)	CYLINDRICAL (SOLID)	I-BEAM
m(Steel)(kg)	3532.5	4159.51875	1648.5
m(Alum)(kg)	1215	1430.6625	567
m(CF)(kg)	783	921.9825	365.4
Steel:			
R1(N)	17912.5	21047.6	8492.5
R2(N)	17662.5	20797.6	8242.5
V(mm)	2.23E+00	2.97E+00	1.38
Aluminum:			
R1(N)	6325	7403.3	3085
R2(N)	6075	7153.3	2835
V(mm)	2.24E+00	2.97E+00	1.42
Carbon Fiber:			
R1(N)	4165	4859.9	2077
R2(N)	3915	4609.9	1827
V(mm)	1.94E-01	2.56E-01	1.25E-01

Table 3: masses, reactions and deflection for different materials and different sections

	RECTANGULAR (HOLLOW)	CYLINDRICAL (HOLLOW)
m(Steel)(kg)	1648.5	1922.622
m(Alum)(kg)	567	661.284
m(CF)(kg)	365.4	426.1608
Steel:		
R1(N)	8492.5	9863.11
R2(N)	8242.5	9613.11
V(mm)	1.38E+00	1.95E+00
Aluminum:		
R1(N)	3085	3556.42
R2(N)	2835	3306.42
V(mm)	1.42E+00	1.99E+00
Carbon Fiber:		
R1(N)	2077	2380.804
R2(N)	1827	2130.804
V(mm)	1.25E-01	1.75E-01

Table 4: masses, reactions and deflection for different materials and different sections

As can be seen from the tables, any deflections exceed 3 mm. This is reasonable against a span of 30 meters. It could be even greater.

So the main issues to consider would be, firstly, the weight which is able to support the walls and, secondly, the prices of the materials.

The solid beams (rectangular and cylindrical) would be totally ruled out according to the amount of material that they need, and the forces that it entails. They are which produced greater deflection owing to the high weight they have.

Take a look at the columns of the I-Beam and the hollow rectangular beam. They have exactly the same characteristics for the dimensions chosen. Both use less material, produce less forces and have less deflection than the cylindrical beam. So any of them would be a good choice.

The last step would be choosing a material. There is a noticeable different between the weight of the beams made of steel and the other two materials. But the price of the carbon fiber is significantly higher than the other materials. We should know the weight which the walls are able to support and the current price of the materials in the desired shape at the moment the building of the robot was started.

Another possible solution could be making the beams of wood. It does not seem a good idea, however, when thinking that the robot will be used to extinguish a fire. The use of some special fireproof isolation could allow some kinds of wood to be able to resist more than some metals without losing the beams mechanical properties.

One other option would be using some kind of lattice. These types of structures are frequency used for long spans.

Figure 30: different kinds of lattices [26], [27]

To make the arm, we need to know different properties of the materials used. The arm is not going to be subjected to large forces. It has to be as light-weight as possible, but strong enough to resist the pressure of the extinguisher. It also has to be heat-resistant. It is going to be the part of the robot which is going to stay nearest to the flame. The aluminum has a low melting point (660°C), but it could be enough in most cases.

The frame of the robot could likewise be made with aluminum. It could be reinforced with some thermal isolation. It is important to protect the devices inside the frame as well as the bottle of extinguisher.

The new model is presented in Figure 31. We observe that the robot now moves along only one beam. This picture shows a rectangular beam, but it can be of many different shapes as commented before. Another observation is how the beam is attached to the wall. It is now not necessary to have longitudinal beams, so it can take advantage of a projection on the wall. The projection could contain bearings, for example. And it must allow the beam a slight rotation to avoid large torques. The bottle of extinguisher is now not visible because it is inside the frame of the robot.

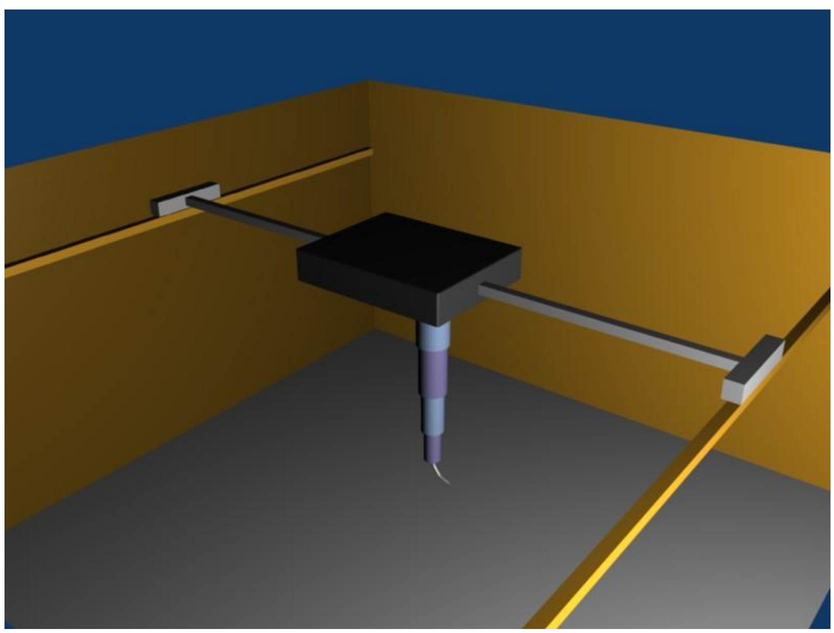

Figure 31: possible model with rectangular beam

2.7. Power system

First of all, it is necessary to know where energy is needed. In response to Figure 23, we have two linear movements. According to the picture, the horizontal movement is carried out by the robot and the two red beams, then the most energy will be required in this movement. The vertical movement only has to overcome the weight of the robot.

These were the movements of the robot; now it is time to consider the motion of the arm.

The arm has two movements: up-down and turn. It has already been explained how the vertical movement in the arm was achieved by using a pulley. What is then needed is a motor which moves this pulley. This motor must be able to turn in both directions to make possible the up and down movement. When the arm is going down, both the gravity and the pressure of the extinguisher will help the motion, decreasing the energy required. For turning the arm, it will be necessary to use another motor. The energy needed here it will be limited.

- Possibilities of power systems:

The next sections introduce and discuss four different ways to feed the robot: pneumatic, hydraulics, electrifying the beams and by using batteries.

- <u>Pneumatic:</u> This technology uses compressed air as a way of transmitting the energy needed to move and make the mechanisms work. The air is an elastic material so, on applying a force, it is compressed. It keeps this compression and it will return the energy accumulated when it is able to expand, according with the ideal gases law.

Some of the advantages are:

- The air is easily collected and is abundant.
- The air does not have explosive properties, so there is not risk of sparks.
- The actuators can work in easily adjustable and reasonable high velocities.
- The work with air does not damage the circuit components because of water hammers.
- Overloads do not cause dangerous situations or damage permanently the equipments.
- Changes in the temperature do not affect significantly.
- Clean energy.
- Immediate changes of direction.

The main disadvantages are:

- In large circuits, there are significant energy losses.
- It requires of special installations to recoup the air previously used.
- Pressures which it usually works with do not enable applying great forces.
- High levels of noise generated by the download of air to the atmosphere.

- Hydraulics: The hydraulics is in the area of physics and the engineering which is in charge of the study of the mechanical properties of the fluids. All this depends on the forces which intervene with the mass (force) and its drive.

Some advantages of this system are:

- It enables working with high levels of forces or torques.
- The oil used in the system is easily recoverable.
- Working velocity is easily adjustable.
- Compact installations.
- Simple protection against overloads.
- Swift changes of direction.

The disadvantages are:

- The fluid is more expensive.
- Losses of load.
- Technical personal for maintenance.
- Fluid very sensible to contamination.

The movements carried out by the robot have too long span (~30 meters). It is, therefore, not a good idea to use pneumatics or hydraulics. One possible option will be using pneumatic pistons moved thanks to induction. These systems have cylinders without piston rods. Inside these cylinders there is a magnet with ring shape. In the part outside of the cylinder there is a slide which also has a magnet. With these systems, longer strokes can be achieved than conventional systems, but the system built for this Final Project requires still too long strokes for these [28].

Another issue to deal with, for the particularity of the environment, is the temperature. In hydraulics, to get an optimum working life of both the oil and the hydraulic system, a maximum working temperature of 65ºC is recommended. For nylon tubes used in pneumatic the maximum temperature gets on for 90ºC; and polyethylene-based tubes the maximum temperature is close to 80ºC [29].

The group GIDAI, Department of Transports and Projects Technology of the University of Cantabria (Spain), estimated the temperature of two different environments exposed to fire. The first one was an industrial establishment constituted by an independent building with a gable roof. The dimensions were 18x50 meters and 10 meters tall in the highest point. It considered that the establishment was used to manufacture and store paint. The second environment studied was an enclosure of an office building. In this case, the volume and the height are much smaller than the previous enclosure. The office studied has a surface of 84 square meters and 2.5 meters tall. It is obvious that the robot designed in this project could be everywhere. According to the dimensions, a cinema could look like the first one. The thing is that the maximum temperatures estimated were approximately 180ºC in the factory and 800ºC in the office. This is an attempt to demonstrate that these temperatures are far from the ones which can be resisted by pneumatic or hydraulic systems [30].

- Electrified beam: electric power will be the energy-source of the robot. Electricity is necessary for the motion, the sensors, the control and the communication. Without enough energy the system will not be able to complete its mission.

  The advantages for this system will be:

  - Electrifying the beams, the system is at all times connected to the current.

- The robot will not need to be charged.
- It will not have problems with the capacity limits of energy from batteries.
- Not using batteries also reduces the weight of the robot.

Some disadvantages are:

- Shutdown of electricity: when there is a fire, there can be a power cut caused by human or by the fire itself (the fire can destroy the electrical system of the place).
- Energy losses caused by the use of long wires along the beams.

In Figure 32 we can see the way to feed the first model (with electrified beams).

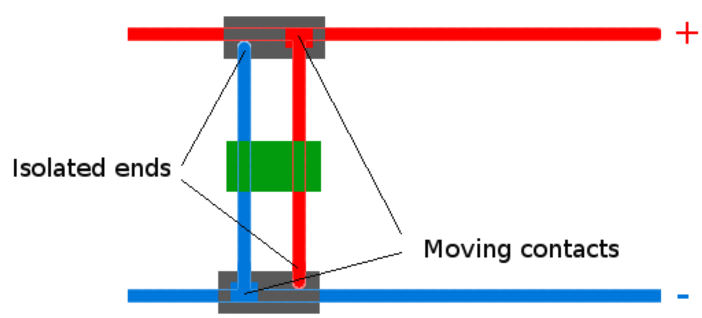

Figure 32: electrified beams for the first model

For the final model, we would need to use special tracks in the beam (see figure 33).

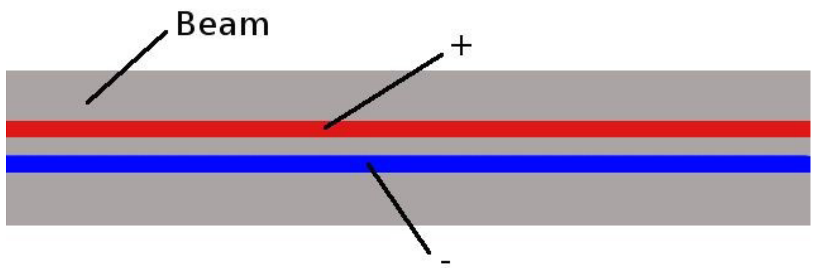

Figure 33: special electrified tracks in the beam

- Battery system: another option to supply energy to the robot would be adding batteries in specific places. It would be necessary to estimate if only one central battery on the body of the robot is necessary, or more batteries: one for the robot and two more for each motor in the sides (which move the beam along the projections on the wall). If only one battery placed in the frame of the robot was chosen, it would have to be larger in size, so heavier. And it would have to be supported by the beam. But if three batteries are used, the two which are placed at the extremes of the beam will be held by the walls. The communication between each motor and each battery will also be better.

  It was decided to use this system, so it will be explained in detail.

  So, finally, there will be one battery feeding the devices inside the body of the robot (three motors: the one which moves the robot along the beam, the one which makes the pulley works and the one which turns the arm; and the pair memory-microcontroller); and two more feeding the motors in each side of the beam.

  All batteries will be charged in the rest position. When the robot will be waiting a signal from a smoke sensor, it will be plugged in. There will be three similar connections. The connections will be:

  - Two between the batteries of the extremes and the wall.

- One between the inner battery and the box connected to the wall.

This can be seen in Figure 34. The arrow in the corner shows the contact between the box, which contains one battery and one motor, and the wall. There will be another identical connection in the other extreme of the beam. The second arrow shows the contact between the robot and the mentioned box. Notice that in the picture the robot is slightly separated from the box to allow us see the contact with the wall. This box will have an inner circuit which will connect the battery inside the robot with the plug on the wall.

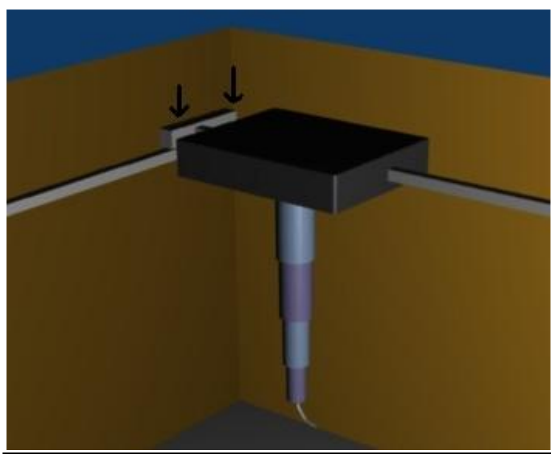

Figure 34: resting-charging position

The robot will have to be receiving voltage but it has also to be connected with the smoke sensors. The Figure 35 shows one possible system plug-socket. We can see three connections: two, which feed the batteries with voltage, and one more for the communication with the sensors.

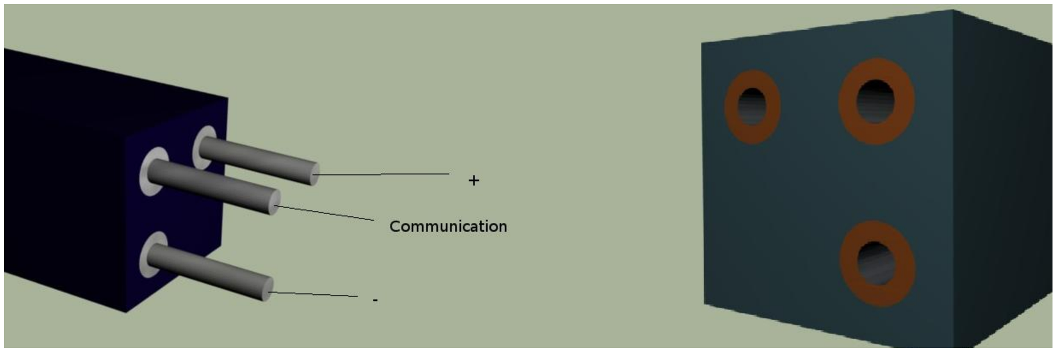

Figure 35: possible plug and socket

The advantages that the use of the batteries entails:

- The robot would be autonomous. It would not need to be connected to anything once the batteries were charged.
- The robot would still function cases of power cut (very probable situation in our case).

The disadvantages would be:

- The weight of the batteries.
- Energy limited by the batteries.
- Heat discharges batteries.

It could use many kinds of batteries. It should calculate the energy and autonomy required for a specific velocity and acceleration for the robot. And with these specifications it will be able to choose the batteries which fulfill the requirements better.

Some examples of batteries with some specifications are shown in Table 5:

	Car	Motorbike	Li-Ion (laptop)	Li-Ion (military)	Accumulators (drill machines)
Voltage (V)	12	12	10-25	26	9-14
Capacity (A·h)	40-60	From 3	Till 7-8	14	From 1

Table 5: characteristics of different kinds of batteries

There are many different batteries for many different purposes. Some batteries are shown in Figure 36:

Figure 36: (from left to right) lead-acid battery, laptop batteries and accumulator for drill machine

2.8. Communication

It is now time to discuss in detail the communications of the system.

2.8.1.Communication with voltage and smoke sensors

As discussed in the previous chapter, the robot, in its resting position, will be plugged into the wall. In this way, it will charge its batteries and it will be connected with the smoke sensors of the ceiling awaiting the signal from them.

2.8.2.Communication with fire station

The task of the robot is to put out the fire in the room, but this is a very demanding task for only a robot. So it is also necessary the fire brigade comes to the place, even though the robot may have been successful in extinguishing the blaze. It is necessary to have an inspection of the fire by the fire brigade or other institutions after the fire. It will be necessary to know the causes of the fire. If an arson crime has been produced, or if the fire has been caused accidentally, or by negligence. All this information will be useful, for example, for insurance companies. On the other hand the *ceilbot* cannot be successful with the fire and it most probably will need the help from the fire fighters. Therefore, there is a need to inform them. And the best way is by using mobile communication, because the wires in the room can be destroyed by the fire, so wired communication cannot be used. Furthermore, mobile communication is available everywhere and, of course, the microcontroller with the GSM module is available too.

When the robot senses a fire in the room, it will immediately notify the fire brigade. It will send a message to the fire station. This message could be an MMS with some pictures about the situation in the cinema and other data (info about robot, address...).

2.8.3.Communication with fire fighters

When the robot senses a fire in the room, it will immediately contact the fire brigade. The fire brigade already knows that there is a fire, the address of the burning building and the situation inside the cinema.

When they arrive at the cinema, they will be able to control the robot and display the situation. The user interface must be simple and fast, as the fire fighters are facing a critical situation. The robot will have in its memory a map of the room. Fire brigade will have a special control device. They will move the robot taking the pictures they want. The communication between the robot and the remote control device will be based on Bluetooth technologies.

This functionality is very helpful. There can be people trapped inside the building or a danger of building collapse. With this system, firemen know what they will face before they go inside. More lives will be saved. More guesswork will be taken out of firefighting. The response will be swift and decisive.

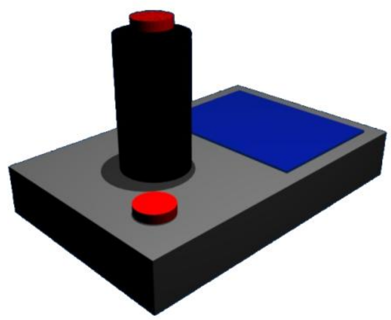

Figure 37: possible joystick for remote control

2.8.4.Communication with people inside or outside the building

When the robot receives the signal from the smoke sensors of the ceiling, it starts to beep warning people in the surrounding area that there is a fire. The robot sends a message to the fire station, but people who have heard the alarm can also call the police or the fire brigade.

If people in the cinema can put out the fire without the help of the robot or there has been an error and the robot is not necessary, they will be able to stop the robot with a simple switch on the wall. The robot will be probably moving, so this switch will have to be connected to the Bluetooth device to be able to stop the robot.

Another issue, which will be covered in the chapter about safety, is the sensors that the robot has attached to its body to avoid colliding with people while in motion. With motion detectors placed in the arm, the robot will be able to do its tasks while interacting with people.

2.8.5.Communication with fire

As already commented, when the robot is plugged there is an indirect communication between the fire and the robot through the smoke sensors of the ceiling.

When the robot is looking for the best position to extinguish the fire, it needs sensors to know where this position is. It will have to extinguish the blaze while it is still small and containable. It has an approximate idea from the first smoke sensor which sent it the signal. And it also knows the approximate height of the source of the flame thanks the map in its memory. But it needs to nip the fire in the bud. For this task, it will have a smoke sensor and a heat sensor placed in the nozzle.

Figure 38 shows a diagram of the mentioned communications. Notice that some arrows are unidirectional and some of them are bidirectional.

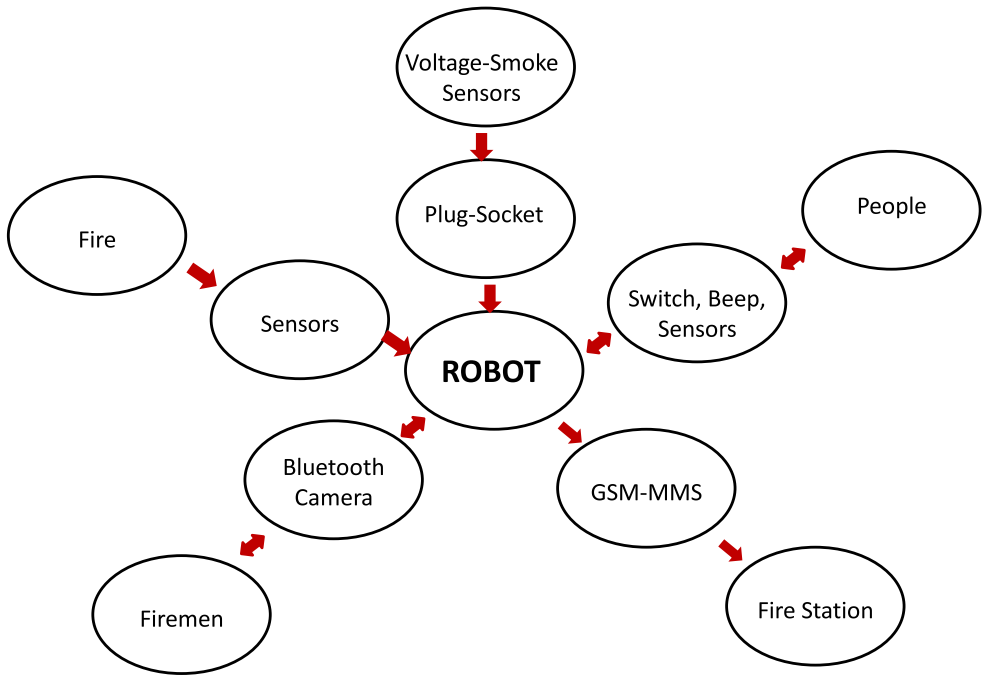

Figure 38: communication diagram

2.9. Safety

Any project must consider the safety subject as a prime issue. Asimov stated in his tale "Runaround" in 1942:

- "A robot may not injure a human being or, through inaction, allow a human being to come to harm."
- "A robot must obey any orders given to it by human beings, except where such orders would conflict with the First Law."
- "A robot must protect its own existence as long as such protection does not conflict with the First or Second Law."

In response to these laws, I can differentiate three main issues to consider in this section: people, robot and environment.

2.9.1.People

People are in first place. Mainly, the *ceilbot* is thought to help when nobody is in the cinema. Because, allegedly, if there is someone in the place, he can take an extinguisher from the wall and call the fire brigade informing about the facts. But it can also help people to extinguish the fire. Then, it is necessary to consider how the robot interacts with people.

It is not a normal situation. The cinema would probably be crowded with people and the exits could be blocked. Trapped people would start to panic with all that it entails.

One thing to consider is the possibility that the robot collides with people in its motion to reach the flame. The frame of the robot will be on the ceiling being impossible to collide with anyone. The problem would appear when the arm went down. At this point, we have two possibilities. The robot can move over the ceiling and get longer its arm when it will be just above the flame; or the fastest solution, the arm could go down simultaneity with the body motion. If the possibility that nobody were in the cinema is considered, then probably the best option would be the second one; but considering safety for people, it is necessary to study the possibility of people, for example, running along the corridors. For this goal, the arm would have some motion detector. Thanks to this sensor, the robot could avoid people in its path to the flame.

In the selection of extinguishers, it must always be considered the possible risks for human health. Generally, the manufacturers put visible warning labels about extinguishers which could contain toxic or breakdown steams. Sometimes, nevertheless, the danger is not in the extinguisher but in the place where it is going to be used. This problem can be addressed by placing warning signs, having long-range devices, installing special ventilation or providing artificial respiration to the employees of the zone.

All water-based extinguishers only can be used for Class A fires, apart from the AFFF models, which are used in Class B fires. If water-foam models are used in Class B fires, blazes can be produced, fire can be spread or operators can be damaged. If water-based models are used over electrical equipment or in the proximity to electrical equipment, the jet of water can transmit an electric shock to the operator.

Although CO_2 is not toxic by itself, it is not breathable when it is used in amounts large enough to extinguish a fire. If a CO_2 extinguisher is used in an area without enough ventilation, it dilutes the oxygen and anyone who remains in the area can lose consciousness and even die because of lack of oxygen. Anyway, a dense cloud of CO_2 can cause the disorientation of people. Another problem is the temperature of the CO_2 inside the bottle (≈-76ºC). A directly stream would cause the death of a human.

Dry chemical models are not considered toxic, but they can irritate if they are breathed for prolonged periods. The most irritant product is the monoamonic phosphate, and after this the potassium-based agents. The least irritant is the sodium bicarbonate. If it downloads dry chemical extinguishers in a closed area, they can reduce visibility and cause disorientation.

Dry chemical agents do not conduct electricity. They can block the filters of the fitting-out or air cleaning systems, if they are discharged in their proximities. The polyvalent chemical agents (based on monoamonic phosphate) have an acid nature and if they are mixed with water, even in a small amount, they will corrode some metals, unless it is cleaned quickly.

The initial download of the agent of an extinguisher has a considerable strength; if it is thrown in short distance against a small fire of liquid or flammable fat, it can give rise to a considerable spread before reaching to control it.

The extinguishers which contain Halon have only a slight toxicity in normal conditions. Nevertheless, products from its breakdown can be dangerous. When these extinguishers were used in areas without ventilation (small rooms, wardrobes and other closed places), it must avoid to breathe the vapours or gases produced by thermal breakdown.

It must be stressed that practically all fires emanate toxic products of breakdown and some ignited materials generate high toxicity gases. Until the fire has been extinguished and the area has been completely aired, it is important to stay out of the zone, or use artificial breath devices [32].

In the environment considered, a cinema, the fire would appear in ordinary combustibles (textile, wood), fires of Class A. For these reasons, finally, a water extinguisher was chosen.

Another question to consider is that my robot is attached on the ceiling. This new solution is precisely able to make use of the space under the robot, making it necessary to ensure that all parts and devices in the robot are completely fixed, being impossible that they fall down injuring people or the environment.

As already commented, there exists the possibility of stopping the robot with a button placed on the wall. If the fire is quickly controlled by people, anyone will be able to stop the robot.

Another safety measure is the alarm. When the robot receives the signal from the smoke sensor it starts beeping warning people that there is a fire.

2.9.2.Robot

According to the third law of Asimov, it is necessary for the robot designer to consider the safety of his robot.

The robot must move along the beams considering the different levels of the seats in the cinema and without colliding with anything. It will have to avoid obstacles like lamps, loudspeakers, etc in its motion. The beams will be previously placed considering all kinds of obstacles both on the walls and on the ceiling. The different heights will be programmed in the microcontroller and stored in the memory. The robot will be able to know the distance from its position to the floor (the seats) with only one coordinate. The arm will have an infrared sensor to avoid colliding when it is going down.

As mentioned before, all parts of the robot will have to be attached to the robot with high accuracy and considering all the accelerations or forces that could appear.

Another issue to consider in this specific environment would be the high temperatures that can appear in a situation with a fire. The robot must be protected against this enemy. The frame of the robot, the arm and the beams will be built with some metal. Then, they will be able to resist during a long time before lose their mechanical properties. For example, the yield point in structural steels keeps 85% of its normal value till temperatures of approximately 427°C (800F).

It will not, however, be the same with the devices inside the robot (microcontroller, memory, batteries) or with the bottle of extinguisher. For example, the plastic parts will not be able to resist temperatures above ~80°C. The working temperature for batteries is from -40°C to 70°C, and it is approximately the same for the rest of the electrical devices. For conventional extinguishers the working temperature is from -20ºC to 60ºC. It should add a thermal isolation over the surfaces of the frame of the robot to protect the inner circuits and the bottle of extinguisher.

At first, the system should be needed never. Then, it is going to be without being used for a long time. The robot has to be ready when it was required. It is very important an accuracy and frequent maintenance, both of electrical devices and the bottle of extinguisher. It is also a prime subject the fact that batteries go flat with high temperatures. This has to be considered at the critical moment of when the robot is needed [34].

Figure 39: tasks for monthly maintenance of an extinguisher [34]


DO NOT REMOVE

ATTACH TO HOME FIRE EXTINGUISHER
INSPECT EXTINGUISHER MONTHLY AND
INITIAL MONTH & YEAR INSPECTED

DO NOT REMOVE

MONTH	2007	2008	2009	2010	2011	2012
JAN.						
FEB.						
MAR.						
APR.						
MAY						
JUNE						
JULY						
AUG.						
SEP.						
OCT.						
NOV.						
DEC.						

RECHARGE IMMEDIATELY AFTER USE
HAVE YOUR EXTINGUISHER REGULARLY SERVICED
BY A QUALIFIED SERVICE PERSON

Figure 40: example of inspection tag [34]

2.9.3.Environment

It has already been mentioned indirectly the things to consider to protect the environment.

For example, it was noted that the robot must not collide with anything on the walls or the ceiling. This problem would be resolved by placing the beams so the robot, in its motion, did not come up against anything. The same would be applied to the arm. Of course, it is also necessary to fixed with accuracy all the parts of the robot to avoid them fall down breaking seats or anything.

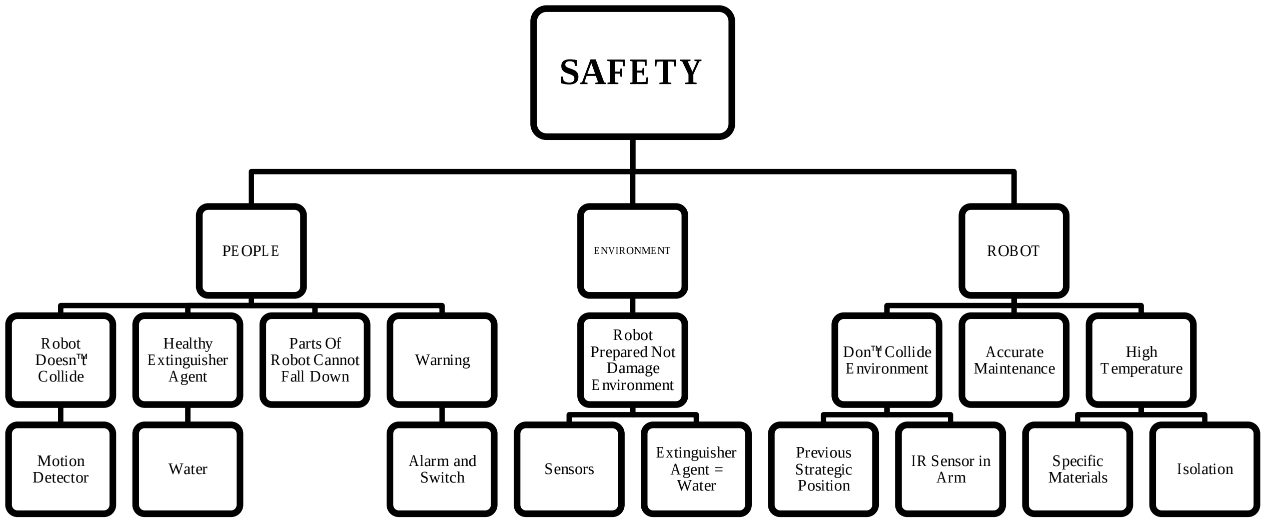

Figure 41: diagram of safety measures

3. Conclusions and future work

The robot designed in this project has not been built but it has drawn many conclusions and it could be developed with a few steps more.

It is clear that this robot is not confined to a cinema. It could be placed in many different areas as offices, garages, hotels, sport halls, hangars, libraries, malls, etc. Even outside using columns to support the robot, for example, in cultivations.

Apart from the mentioned tasks for the robot, the system also gives us the chance of knowing how the fire started. It has not stated when the robot would take the first picture, but it could be recording always and, for example, erasing the videos every two hours if nothing happens. In this case, we could know the reasons which cause the start of the fire. We would also know where and when the fire exactly starts. With this it could avoid the repetition of the same events leading to the fire. Likewise it could look for liable parties. If there has been negligence, or sabotage, etc. All these things would be useful for insurance companies.

It has been commented that maybe the *ceilbot* would not be useful if there were people in the room. It is necessary to add, that maybe the fire will not be at ground level making it impossible for a man with a commercial bottle of extinguisher to reach the flames. In this case, the system designed in this project would be a great help.

One of the possible issues to consider in the final develop of this robot could be the way to hide it, for example, behind a suspended ceiling. In this way the robot would have to break the suspended ceiling with the arm when it is time to act. The easy way would be to put a box in the resting place, maybe with a curtain. According to the dimensions of a cinema the dimensions of the robot are not excessively large.

When the time comes to construct the robot, one of the most important issues is the motion of the beam with one motor in each side. It is not easy to make them work simultaneously.

The robot has been designed only for a single task. But with some easy modifications could be used for other tasks. For example, removing the bottle of extinguisher and adding a tank with water, insecticide or pesticide, it could be useful in cultivations or anywhere with flowerpots. The tank could also contain food for pets. It could be placed in a farm, for example. Another possibility could be to change the extinguisher for some spray with colour to paint something; or some product of protection, for example, in planes.

4. References

[1] Ceilbot website, Helsinki University of Technology:

http://autsys.tkk.fi/en/Ceilbot/Files (accessed October-December 2009)

[2] Webpage of Intuitive Surgical, Inc. (designers of Da Vinci Surgical System):

http://www.intuitivesurgical.com/index.aspx (accessed 28.10.09)

[3] iRobot homepage (designers of Roomba robot):

http://www.irobot.com/ (accessed 28.10.09)

[4] Kitchen burning:

http://www.martinboroughstar.co.nz/?p=331 (accessed 10.11.09)

[5] Flammable gas:

http://commons.wikimedia.org/wiki/File:Flamme-gaz-p1010035.jpg (accessed 10.11.09)

[6] Flammable liquids:

http://www.hamiltontn.gov/emergencyservices/fsphotogallery.htm (accessed 10.11.09)

[7] Computer burning:

http://www.the-iss.com/2009/04/an_open_letter_to_an_incompete.php (accessed 10.11.09)

[8] SEGURIDAD BARRIOS, company devoted to safety and security in dwellings:

http://www.seguridadbarrios.es/incendios.html (accessed 04.11.09)

[9] Webpage about use and rules of manual extinguishers:

http://www.cdaf.es/normativa/mnzenith/ELEXTINTOR.htm (accessed 04.11.09)

[10] G. D. M. MERKOR S. L. (company of safety in fires) homepage:

http://gdm-merkor.com/Ventas/extintores.htm (accessed 02.11.09)

[11] Webpage about fire extinguishers:

http://www.fire-extinguisher101.com/index.html (accessed 09.11.2009)

[12] Miliarium.com, Civil Engineering, Building and Environment:

http://www.miliarium.com/monografias/incendios/Metodos.asp (accessed 11.11.09)

[13] Siam Safety Premier Co. (Fire Fighting Ball designers): http://www.ssp.co.th/ (accessed 09.11.2009)

[14] Magdeburg-Stendal University homepage, designers of OLE: http://www.hs-magdeburg.de/ (accessed 12.11.09)

[15] Aware Project webpage: http://www.aware-project.net/ (accessed 13.11.09)

[16] Hoyarobot homepage, designers of Fire Spy Robot: http://www.hoyarobot.com/ (accessed 14.11.09)

[17] Sheffield Hallam University webpage, designers of Guardians robots: http://www.shu.ac.uk/research/meri/mmvl/research/projects/guardians/ (accessed 14.11.09)

[18] Aydin Mert webpage, designer of Fire Guard robot in collaboration with Husqvarna: http://www.aydinmert.net/ (accessed el 14.11.09)

[19] Armtec company, designers of SACI: http://www.armtecbrasil.com/ (accessed el 16.11.09)

[20] Ted Larson webpage, designer of Flameout: http://www.tedlarson.com/robots/firefighter.htm (accessed 17.11.09)

[21] Scott´s Robot Projects webpage, designer of Firefighting NXT:

http://www.freewebs.com/robotprojects/firefightingnxt.htm (accessed 17.11.09)

[22] Webpage where a student shows his creation of the Rovio fire extinguisher:

http://www.robocommunity.com/forum/thread/15894/Rovio-fire-extinguisher/ (accessed 16.11.09)

[23] Official web of Rovio:

http://www.wowwee.com/en/products/tech/telepresence/rovio:rovio (accessed 16.11.09)

[24] Website of the digital version of El Mundo (Spanish newspaper):

http://www.elmundo.es/elmundo/blogs/cineclu/index.html (accessed 20.11.09)

[25] DIEES-Università di Catania (Alicia robots designers): http://www.robotic.diees.unict.it/robots/alicia3/alicia3.htm (accessed 12.12.09)

[26] ORCHARD, Scaffolding & Building Equipment:

http://www.orchardhireandsales.ltd.uk/aluminium-beam-temporary-roofing-corrugated-sheets.htm (accessed 29.11.09)

[27] Grupo TYPSA webpage, Civil Engineering:

http://www.typsa.com/2_2n_estructuras_trabajos.html (accessed 29.11.09)

[28] Webpage about pneumatic and hydraulics:

http://www.sapiensman.com/neumatica/mapadelsitio.htm (accessed 16.11.09)

[29] Datasheet of pneumatic circuits by Vignola:

http://www.vignola.cl/pdf_secciones/02/2-08-01.pdf (accessed 02.12.09)

[30] Group GIDAI, Safety in fires, Investigation and Technology:

http://grupos.unican.es/gidai/art%C3%ADculo_Comparativa%20MSCI_1.pdf (accessed 2.12.09)

[31] Rabino Pablo, Webpage about the building industry and the unsubsidized and used housing (in Spanish), June 2008,

http://www.elmercadodelavivienda.com/sistemas-de-deteccion-y-extincion-de-incendios.html (accessed 04.11.09)

[32] Webpage about extinguishers:

http://saludseguridadyalgomas1.blogspot.com/2007/10/selecci n-de-extintores.html (accessed 17.11.09)

[33] AING Proyectos, Engineering against fires, Engineering of installations:

http://www.aingproyectos.es/extincion.html (accessed 02.11.09)

[34] Windsor Fire & Rescue Services website:

http://www.windsorfire.com/divisions-prevention-home-fire-extinguisher-guidelines (accessed 13.11.09)

[35] Blender homepage:

http://www.blender.org/ (accessed October-December 2009)

[36] Wikipedia website:

http://www.wikipedia.org/ (accessed October-December 2009)

[37] Gimp homepage:

http://www.gimp.org/ (accessed October-December 2009)

[38] Laboratoire de Systèmes Robotiques (LSRO), Mobots group

Ecole polytechnique fédérale de Lausanne (EPFL):

http://infoscience.epfl.ch/record/141404/files/Clawar2009-FR&PS.pdf (accessed 13.12.09)