A SMARTER FIRE SPRINKLER

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ABSTRACT

The following describes an application model of a robotic fire guard, an automated fire extinguishing system for detection and localized handling of potential outbreaks using an Infra-Red (IR) camera and a turret mounted dispenser. The acquired IR image is processed and the sources of heat isolated, the turret is successively aimed towards the fire by a targeting control system before releasing the fire suppressant. A proof of concept has been built using retail components and a commercial viability study has been performed pointing out its market potential.

***Index Terms*—** Fire sprinkler, active fire protection

1. INTRODUCTION

More than a hundred years ago, following a series of devastating fires that claimed many lives and destroyed entire businesses, textile mills in New England began using fire sprinkler systems in order to protect assets and personnel in case of such events. Most public and commercial buildings have since benefited from fire protection of sprinkler systems [1].

Since its creation in 1812, fire sprinkler systems have not undergone significant improvements besides the creation of an automated activation method (soldering iron at first) patented by Philip W. Pratt in 1872. Although the main concern related to the use of such device remains to this very day, the extensive water damage resulting from an activation (figure 1), often surpassing the fire damage, in case of small, easily controlled outbreaks.

This work presents an alternative to the conventional fire sprinkler, one which employs IR sensors alongside actuators and a targeting control system to locate and suppress outbreaks in a localized fashion. This intelligent fire guard (patent pending) presents the advantage of reducing water damage, desirable when protecting environments containing sensitive equipment or documents.

A model was build using the Lego Mindstorms NXT and an Infra-Red camera. In addition to the working prototype, which uses water as extinguishing agent, the project included a commercial viability study, considering the advantages and eventual added costs of the project implemented as a marketable product.

Figure 1: Activated sprinkler.

2. IMAGE ACQUISITION AND PROCESSING

Many fire detection systems are based upon IR sensors, usually detecting wavelengths in the mid-IR range, from 3-50µm. For its close relation to heat, IR is often referred to as "thermal radiation". Despite not the only radiation emitted by hot objects, it is often used to read temperatures in sensors and image processing applications.

The use of IR cameras to obtain temperature readings is well known to the industry and science. To detect a potential fire, one needs only to know the approximate combustion temperature of involved materials, or merely the amount IR radiation emitted by regular burning objects. This can be determined by a simple calibration using a lighter or a candle. Nevertheless, false fire detections may occur when sources containing bright IR components are present, such as heaters, lasers and LEDs.

Most CCD cameras are able to operate in the IR spectrum. In fact, IR filters are often mounted alongside optical components in order to remove IR interference, otherwise noticeable as bright spots on the image. As the interest here is the IR component itself, filtering all visible components can be performed by adding red, green and blue filters, or an IR pass-through [2].

The captured monochromatic image will map the intensity of IR radiation to each pixel with values ranging from 0 to 255. The hot spots can then be easily determined applying the desired threshold. As the points of interest may span several pixels, further image processing may be required in order to track the central points of each region in the image, such as masks, averaging and erosion, for instance.

For sake of simplicity and availability, in the prototype a camera from a Nintendo Wii remote control was used. The WiiMote camera comes with an IR pass filter and a built-in image processor, configured to capture 1024x768 pixel images and track up to four simultaneous sources [3].

3. THE CONTROL SYSTEM

Using the Lego Mindstorms NXT 2.0 platform, the camera was mounted alongside a water turret in a movable stand, capable of spherical displacement with two degrees of freedom and ranges of 360° (rotating base) and 180° (turret lift). The NXT comes with actuators and a programmable microcontroller (NXT brick) containing USB and Bluetooth interfaces.

The programming was done using LeJOS, a Java port for NXT [4]. Based on the readings received from the camera's image processor, three different tasks may be performed:

- Scan: Search for hot spots in the near surroundings;
- Target: Aims the turret to the nearest located point;
- Trigger: Activate a solenoid valve releasing water.

In the case of no detection, the system enters scan mode. In this mode the turret slowly rotates its base 180° back and forth, quickly swinging the turret 180° in order to monitor the surrounding area. The speed of each actuator was adjusted considering the camera aperture and detection speed, the entire semi-sphere in range can be imaged in close to 30 seconds. When one or more points are detected, the control automatically switches to targeting mode [5], optionally emitting a buzz sound.

The water nozzle and the camera are aligned in such fashion the water hits the region central to the image.

When in targeting mode the points detected by the image processor are ordered by distance to the center of the image, then the two actuators are used to align the nearest point with the center, placing the source of detection right under the effect zone, within the reach of the water nozzle. The system constantly adjust the position of turret by a delta factor (see figure 2), as performed in PID controllers, using as feedback the camera reading and the cosest detected point. The distances *Dx* and *Dy* are given by:

$$\begin{bmatrix} Dx \\ Dy \end{bmatrix} = \begin{bmatrix} Cx \\ Cy \end{bmatrix} - \begin{bmatrix} Px \\ Py \end{bmatrix}$$

The distance vector $\vec{D}$ is then corrected (correction factor always smaller than motor-step/pixel ratio) and have its X and Y components applied to each actuator in order to bring the point *P* to the region near *C* (*Cx*=512, *Cy*=384), in which the water can hit the source of emission.

Once the point is within the effect zone, a solenoid valve is activated releasing the fire extinguishing agent. A simplified block diagram is presented in figure 3.

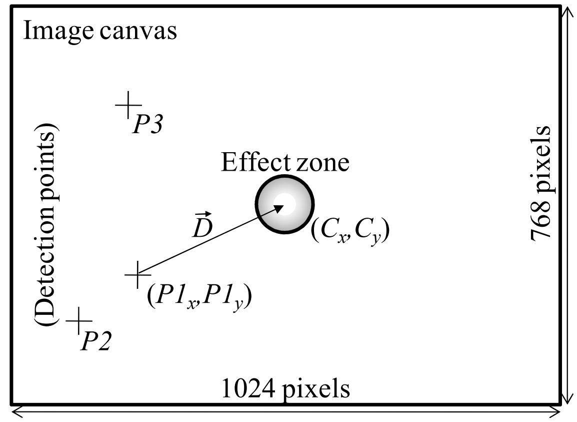

Figure 2: Captured image schematics.

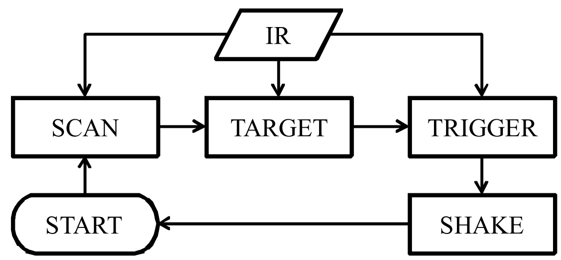

Figure 3: Simplified diagram.

Even after the target point is centralized, a small variation is outputted to the actuators in the ±*X* and ±*Y* directions in order to produce a shake, increasing the area hit by water, thus the effect zone, represented as the central circumference in figure 2. This effect zone may be adjusted in area, shape and position to a variety of settings, for instance to compensate for water pressure, distance to target, inclination and the effects of gravity. However, for sake of simplicity, none of the previous adjustments were implemented for being considered unnecessary at this point, as the tests were performed in a controlled environment of limited dimensions. Just a few steps in random directions needed to be sent to the actuators to increase the effect zone.

Once the current heat source is no longer detected in the central area, the system assumes it has been suppressed, the solenoid valve is deactivated and the next point in proximity is targeted. The procedure is repeated until all heat sources have are no longer detected, the system finally returning to the scan routine.

4. COMERCIAL VIABILITY

Although its technology is more than a 100 years old, fire sprinkler system is the single most employed active fire suppression system in use today. The main reason for its traditional, persistent popularity can be attributed to its constantly diminishing costs and wide availability of manufacturers, products and services worldwide. Another good reason may be due to lack of suitable alternatives.

Perhaps the lack of alternative products is what lead many to adopt systems with regular sprinklers even for environments containing sensitive equipment (industrial machinery, electronic appliances, computers), furniture (wooden, leather, textile), documents, books (libraries) or high-voltage (transformers, distribution boards, power stations), where the results of activating such measures could be as devastating as the fire itself. For such scenarios, a product based on the described prototype or presenting similar characteristics could have a significant market potential, as water hazard is minimized by just replacing some key sprinklers in the system with smart sprinklers. However, the inclusion of smart protection would add considerably to the cost of the installation, a known issue concerning choices made by consumers when purchasing appliance upgrades. To have a better idea of the relation between cost and protection, we need to compare each of the options from an economic perspective.

According to Stacy et. al. [6], the current cost of Sprinkler Systems usually range from 8 to 22 €/m^2, what answers for around 1% of the total construction cost. In locations where the installation of sprinkler systems became mandatory for new buildings (including residential), prices dropped abruptly, reaching close to 5 €/m^2, as the related costs were incorporated into the cost of construction. This shows a close relation between popularity and low prices, in accordance to free market rules. It is safe to assume that the same would apply to smart devices, is natural to expect a reduction to competitive prices as the technology grows in popularity. But at first we must consider current costs.

For the proposed device, starting with the cost of the implemented prototype, we estimate around €300 in total: €250 the price of the Lego kit alone, a €35 WiiMote and another €15 in parts, including the solenoid valve, hoses, wires and support. The prototype had its working range curbed by a series of factors, on top, the water pressure and limited camera sensitivity, what reduced the detection and suppression range to a radius inferior to 3 meters. To make a safe approximation, if similar devices were to be combined in a grid, the operability range of each one is around 2m^2, resulting in an approximate cost of 150 €/m^2. In fact, the cost could be reduced to well under €100 by using retail parts, such as generic CCD or IR camera, step motors and a microprocessor (still accounts for most of the cost, Arduino or PIC considered). Even in case production costs eventually drop under €50 per unit and the coverage area can be increased to over 3m^2, the most optimistic estimative would yield around 16 €/m^2.

Considering the case in study is not a replacement for Fire Sprinkler Systems altogether, but merely an alternative for replacement of individual fire sprinklers, most of the related installation costs would remain, such as piping, pumps, etc. Clearly the costs of including smart sprinklers in the system would add up, increasing proportionally to the smartly protected area.

Table I: Comparison chart.

Sprinklers	Standard	Smart
Added cost	0	+ 16 to 150 €/m^2
Water damage	Spread	Localized
Detection and response	As heat/flames reach the ceiling	Early with first IR emission spotted
Powering	Not required	Required

When taking into account the potential water damage that can be adverted and the capacity of early suppression of small flames, in opposition to traditional sprinklers, activated only when the heat has reach the top of the room, the smart alternative clearly provides added protection, particularly interesting in small, sensitive spaces.

5. CONCLUSIONS

In this project we employed control systems and actuators as well as digital imaging to propose a new solution to an old problem. A prototype was assembled (presented in figure 4) using available components, demonstrating successfully the suitability of the proposed alternative to replace conventional fire sprinklers. Upon activation the water damage in minimized in opposition to the extensive water damage caused to electronic equipment, furniture, books and paperwork by conventional sprinklers.

Many regulations worldwide demand fire prevention systems to be installed in offices, public buildings, schools and, for some regions [6], even residences, despite potential water hazard caused to cases aforementioned, for which the proposed model could be offered as a better alternative.

The main differential of the proposed model is related to a key factor in controlling fire: Quick response. Tests carried out by the Building Research Establishment (BRE) of the United States determined that unless a fire is tackled within the first two to three minutes, it is ‘highly unlikely’ it can be controlled, saving the building and its contents. Sprinkler systems respond just as quick as the heads are activated by the heat of flames, what implies the fire has been raging long enough for it to affect the high of the ceiling. Most heads are activated by temperatures above 70°C, only then delivering water indiscriminately over the entire area, not considering the nature of the fire, either extinguishing it or keeping it under control until the Fire and Rescue Service arrives [6].

The high cost of the prototype is a consequence of the parts used, common only in academic environments. It must be clear that these components were selected for their ready availability and prototyping simplicity, not taking into account economic factors. Given the option of economy over simplicity, using parts suitable for manufacturing, the costs would have been inferior to a €100. The estimated cost drops dramatically when considering the use of industrial processes, what would yield an additional cost per protected square-meter ranging from €16 to €50.

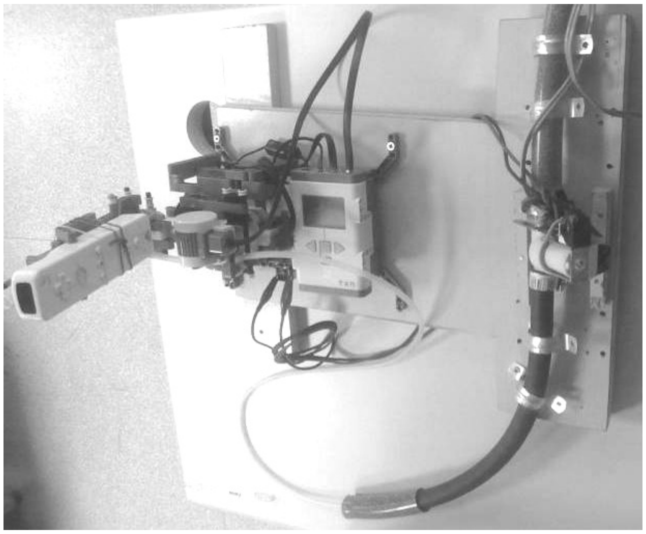

Figure 4: Prototype assembled using the Lego Mindstorms NXT 2.0, a WiiMote and a solenoid valve.

Nonetheless the increase in cost comes with added protection, not only against early fires but minimized water damage, strongly indicated when water hazard is a predominant issue.

The final conclusion pricewise is that, complying to many commercial protection and insurance products available, the price-benefit ratio is apparently low, until one eventually need it. The consumer decision to invest in safety is usually risk based, a decision not only involving a financial cost, but a potential toll in property and lives.

Fire sprinklers will surely remain the active fire suppression technology of choice for protecting property, assets and improving safety at work and home for many years to come. However, considering different scenarios, given more alternatives, comparing costs and benefits, consumers may have diverging ideas about the price of protection, given a choice.

6. REFERENCES

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