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PyroShield - A HVAC fire curtain testing robot

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ABSTRACT

Fire curtains (or dampers), as found in HVAC ducts, are drop-down thermally triggered fire-resistant barriers designed to block the spread of fire and smoke. Regulations stipulate regular mechanical drop-down testing as a visual inspection may not identify rust or jamming which may prevent a curtain from falling. Currently it is difficult to test these curtains as many HVAC ducts are small (340 mm × 330 mm) and access hatches often don't allow direct external access to the thermal fuse. Hence complete testing may require the temporary (and expensive) removal of plaster walls, floors or ceilings. This paper describes a pair of tele-operated robots which are designed to mechanically test the operation and serviceability of the fire curtain. Significant experimentation has demonstrated that the testing procedure requires a skilled operator and can be performed typically within a 15 minute timeframe without the expense of renovation and remediation procedures.

1. Introduction

Densely populated high-rise buildings can be dangerous places when a fire is present. The three worst (in terms of loss of life) hotel fires (Winecroft 1946, Dupont Plaza 1986 and MGM Grand Hotel 1980) are often cited as case studies and have significantly shaped fire and building design codes [1]. Findings from these fires (along with others) have noted that these buildings have long egress times when only stairs are allowed (20–30 min), that the majority of the deaths caused by these fires are from smoke inhalation (often spread through HVAC ducts) and that malfunctioning or non-existent fire suppression increased the severity of the fire and smoke [1–3].

There are two types of fire protection which are now commonly in place for buildings; active and passive. Active fire protection systems are designed to detect and suppress the fire, such as smoke alarms and sprinkler systems. Passive fire protection is designed to stop the spread of fires, containing them to a single area; including technology such as fire curtains, fire walls, and fire doors. Fire walls are installed inside buildings to help stop the spread of fires, by containing them to a smaller area. These walls are made from fire resistant materials and block the spread of fire and smoke for a rated number of hours. In large buildings HVAC ducting breaks through these fire walls reducing their ability to contain a fire by allowing the fire and smoke to travel through the ducts.

Fire curtains (also called fire dampers) are designed to be installed in these ducts where the fire wall is located to strengthen the fire protection of the building [2,4]. Fire curtains are designed to reduce the spread of fire and smoke throughout a building. Traditional fire curtains (see Fig. 1) have two main elements. A fusible link that is hooked under the curtain which holds the curtain up, and the curtain itself which is made from steel blades to form a concertina and drop down under the force of gravity. The link is designed to break in half when temperatures reach 71 °C [5]. The curtain then drops and blocks the duct so that the fire and smoke cannot pass through. Fire curtains are rated based on how long they can survive the extreme temperatures found in a fire before failing. Typically a fire curtain will have a 1.5 to 4 h rating [5].

In Australia standard AS1851-2005 stipulates that fire curtains need to be inspected every 5 years [6,7]. However due to their location in air ducts, which are typically small (340 mm × 330 mm is a standard size), and their placement under floors, in ceilings, and behind walls they are often impossible to reach to test by hand.

To test the curtain it must first be visually inspected to check for any obvious defects. The fusible link must then be removed or released (it can be unhooked at either end). The curtain must then fall down to prove that the air duct can be blocked, and that the curtain hasn't rusted or jammed open. It is then lifted back into place and the fuse reattached, ready to prevent the spread of fires in the future [6,8].

Robot solutions are becoming increasing popular in solving issues related to both building maintenance and building construction. Maintenance robots tend towards more inspection and tele-operated roles like pipe or duct inspection [9]. In contrast construction robots have very wide applications in research particularly in areas of 3D printing and assembly [10–12].

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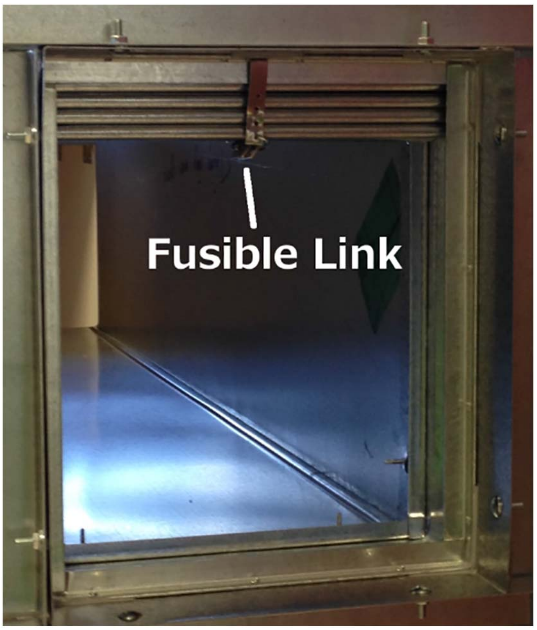

Fig. 1. Typical steel fire curtain.

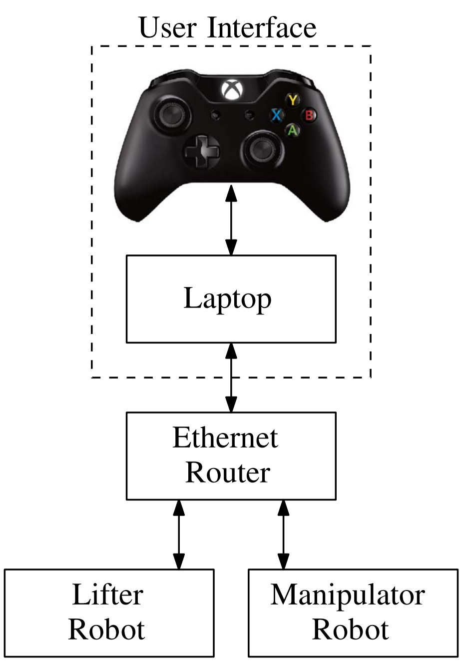

Fig. 2. System top level architecture.

This paper describes a decoupled testing solution consisting of a pair of purpose designed tele-operated robots. One robot is a manipulator robot which is used to physically connect and disconnect the fuse from the curtain. The second robot is a lifting robot which allows the curtain to be lifted back into place and holds it in place whilst the thermal fuse is re-attached. This collaborative robot approach facilitates greater flexibility for the operator in manipulating curtains - adding additional degrees of freedom without increasing complexity.

The novel contribution of this paper is the use of tele-operated robots in HVAC ducts, not merely for visual inspection, but to actually mechanically test the operation of fire curtains. The proposed solution reduces the reliance on expensive renovations to access difficult curtains whilst providing adherence to relevant safety inspection standards. The robots, which were purpose designed for this application, demonstrate an expanded scope in building testing as the only current means of curtain testing involve manual testing which in some cases requires costly renovations.

This paper is structured as follows: Section 2 provides a review of related research and developments relating to HVAC inspection. Following this, Section 3 provides an overview of the proposed dual-robot curtain testing system with the testing procedure and evaluation described in Section 4. Concluding remarks are then provided in Section 5.

2. Related research

This section provides a background to existing technologies used for HVAC duct inspection and maintenance. HVAC duct inspection robots are extensively used by industry to monitor the condition of ducts. These robots traditionally are small tele-operated platforms which use CCTV (Closed Circuit Television) to facilitate a visual inspection of the duct surfaces [13,14]. Traditionally these robots would be used to integrate blockages, leaks and visual defects (rust, discontinuities, etc.) and in some causes perform localised cleaning within the system [15].

More advanced sensor packages have been employed on some of these HVAC robots allowing them to measure thermal performance [16] and perform flow rate diagnostics [17]. Limited research has also been conducted to allow robots to autonomously traverse HVAC ducts and to perform image processing to facilitate feature recognition [18].

These robots are widely used for HVAC inspection as they follow a relatively simple design and can easily fit in the tight spaces (typically 340 mm × 330 mm) which inhibit direct human inspections.

Although these robots are widely used for duct inspection and could be used for the visual inspection of a fire curtain, they don't facilitate actual operational curtain testing as mandated by the relevant standards [6,8].

The inadequacy of visual-only inspection become apparent as many of the failure modes (latent rust, jamming) are not apparent upon visual inspection but become very apparent upon attempted mechanical actuation. As a result, many buildings will have regular and periodic fire alarm and emergency equipment tests but the cost involved with HVAC curtain testing is very prohibitive which may result in non-compliance. Functional fire curtains are an important safety mechanism within buildings by attenuating the flow of smoke, reducing fresh oxygen flowing into a room which fuels fires and maintaining the integrity of fire-walls which are broken up via the HVAC ducts.

3. Implementation

The duct inspection robotic system, PyroShield, as presented in this paper consists of two tele-operated robot platforms that go beyond simple visual inspection–allowing fire curtains to be mechanically tested and reset. Traditionally this mechanical inspection can be very expensive to perform as building layouts often don't facilitate easy removal of HVAC access hatches and may require expensive removal of plaster or wall surfaces to access each hatch. This inspection process needs to be repeated every 5 years leading to very expensive compliance costs.

The prototype proof-of-concept design decouples the two main areas of functionality (lifting and fuse handling) into two separate robots. This decoupled approach provides two extra degrees of freedom (rotation and forward/back motion) to the fuse handling manipulator robot (effectively giving a total of 7-DOF) whilst allowing the lifting robot to remain stationary as it holds the curtain (Fig. 11).

These robots each include a Raspberry Pi to provide embedded control functionality which is tethered to a router using an Ethernet cable. Besides overcoming wireless issues related to electromagnetic shielding through a steel duct, these cables also provide a means of extraction in the case of robot failure whilst inside a duct. The top level system architecture is pictured in Fig. 2. Communication (control and