A Research Platform for Drone Assisted Firefighting with AR Path Visualisations

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Abstract

This paper, through the use of a HoloLens Head Mounted Display (HMD) and a Tello EDU Drone, presents a research tool as well as two expert reviews, aimed at exploring path visualisation using augmented reality for firefighters in their efforts to find and rescue people in danger. Drones have seen some usage in the field of firefighting, especially in the context of high-rise fires and plantation fires. So too has Augmented Reality (AR) devices historically been used in the context of providing firefighters with thermal visioning information, how ever, not much research has gone into combing the two technologies in a firefighter/rescue worker centric context. We discuss the implications of our findings both during the development of the research tool and as a result of our expert reviews in the future work and discussion section respectively. Lastly a short conclusionary take on the work will be presented to the reader, summarising the work described in the paper.

Keywords

AAU, Aalborg, University

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1 Introduction

It lies within the nature of working as a firefighter or a rescue worker, that one also has to work during periods of intense stress [12], time is, in other words, of the essence and time saved, is time the firefighter in question does not have to spend in impending danger. As such an interesting problem domain arises in trying to minimise the amount of time spent, for example, inside a burning building in order to save survivors, this problem domain can be summarised by the following problem statement:

> *"How do we best minimise the amount of time firefighters have to spent in hazardous situations?".*

While there have been development of AR solutions usable for firefighters serving during fires as well as no small amount of drone solutions serving to stake out an ongoing fire for possible Points Of Interest (POIs), there have yet to be many solutions combining the two technologies. Beyond that, the solutions developed thus far, with regards to drones, have yet to fully utilise the possibly autonomous capabilities offered by drones.

This paper will describe the development of a research platform using AR as well as autonomous drones in order to aid research in the area of firefighting in house fires. The paper will furthermore also feature expert reviews of said research platform by professionals. With regards to the structure of the paper, related work will follow in the following section. The related work section is divided into areas of importance to the research platform, namely: 'Drones in Firefighting', 'Mixed Reality in Firefighting', 'Drone Visualisation' and 'Drone Pathfinding'. Next a section covering the implementations of the research platform as well as any considerations to be had in the context of implementation. Lastly the paper will cover a discussion section, allowing the reader to get a in-depth look into the consequences of choices made, during the development of the research platform as well as a conclusion tying the work together, and summarising our work.

2 Related Work

In creating systems for use in stressful situations, clear and obvious directions are often needed, in fact, in the paper 'Vigilance Performance Modelled as a Complex Adaptive System with Listener Event Graph Objects (LEGOS)', stress is shown to have a direct impact on factors such as reaction time and vigilance, we in this paper stipulate that this must necessarily be especially true in life-or-death situations where failure to understand the correct usage of any given system in time could potentially lead to the loss of human lives. As such, an important area of focus for the project

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should be to ensure that the usability of the system is up to par with the users requirements, even during times of heavy stress and confusion[10].

Drones in firefighting

Using drones for hazardous assignments has already been thought of and is widely used in many areas, for example the usage of drones has been used in order to relay important information to rescue personnel during wildfires as well as high-rise fires[14].
3D Robotics' have developed an API, "DroneKit", which features both piloted and some autonomous flight capabilities, such as GPS and camera control[14]. Most fully developed systems, how ever, does not feature autonomous path finding and exploration, something which would indubitably serve to free up resources in the context of, for example, fire rescue work. In the paper 'Autonomous Drones for Assisting Rescue Services within the context of Natural Disasters', Histogram of Gradients (HOG) is used in order to detect survivors during disasters[11]. The very same system also used a 'Rao-Blackwelissed particle filter', in order to extrapolate movement direction of the detected survivors[11]. Lastly the paper very explicitly remarks on the importance of the manipulation of such systems not requiring any special skills, seeing as such requirements would be detrimental to the successful integration of the system into rescue teams.

Mixed Reality in firefighting

The Qwake's C-Thru Heads-up display allows firefighters to substitute the use of handheld thermal vision cameras with a single AR display device allowing for seamless navigation through dark and smoke filled rooms as well as thermal visioning helping firefighters in seeking out survivors of a fire in real time. The Qwake's C-Thru device also allows for live streaming of anything the wearer is watching providing whoever is responsible at the scene of the fire with valuable on-scene intel[13].
The paper 'Using Serious Games and Virtual Simulation for Training in the Fire Service: A Review' reviews the development of serious games and virtual simulation applications with the purpose of being utilised for training in the fire service. The paper refers to such applications as 'serious games' and claims that as of the the publishing of said paper (2014), gaming technology was not capable of completely and faithfully encompassing the very dynamic and varied real world scenarios that firefighters could possibly be facing while performing their work[6].
In the paper 'Finding Our Way In The Dark: A Firefighters Augmented Reality Heads-Up-Device' Google Glasses as well as edge-detection technology is used in order to develop a Glassware application which enables firefighters to have an augmented view during low-visibility environments. The paper claims that the most contributing factors to low visibility is heavy smoke, heated air, and transient flames[5]. The paper 'Handheld Augmented Reality Indoor Navigation with Activity-Based Instructions' presents a novel design of AR interfacing in order to support indoor navigation through the use of arrows in order to infer directional information[3]. In order to convey a path, the paper 'Human pacman: a wide area socio-physical interactive entertainment system in mixed reality' uses little yellow spheres, inspired by the target objects one is tasked with collecting in the well known computer game 'Pacman'[2]. It is possible that using similar spheres as a metaphor for those aforementioned target objects might infer direction.

Drone Visualisations

The paper 'Multi-view Augmented Reality with a drone' presents an exploratory research effort into AR applications where the users of said systems are able to control alternative viewing positions based on a drone, the paper then presents the resulting system specifications of a system which offers multi-view AR as well as a demo application in which the user can switch between first and third person view. The results of the paper serves as evidence to the applicability of a system offering alternate viewing experiences[1].
In the conference paper 'Augmented Reality Based Thermal Drones for Victim Detection' a system such as the one presented in the introduction to this section is presented. The paper proposes the use of thermal imaging, drones as well as AR in order to provide aid rescue workers in locating and rescuing victims. The results of the paper show that the described approach enhances the efficacy of rescue workers in terms of time and amount of humans located[4].

Drone Pathfinding

Autonomous movement capabilities necessitates pathfinding algorithms. In the paper 'An algorithm for on-the-fly K shortest paths finding in multi-storey buildings using a hierarchical topology model' the exploration of buildings with complex vertical and horizontal features are presented. The approach is based on computing several shortest paths using building information models implemented using directed multigraphs[8].
The paper 'Distributed path planning for building evacuation guidance' presents a distributed path planning approach meant to provide guidance for reliable and efficient building evacuation in emergency situations. The approach involves networked sensors, information sharing and distributed computation[15].

An interesting concept seems to arise when one combines

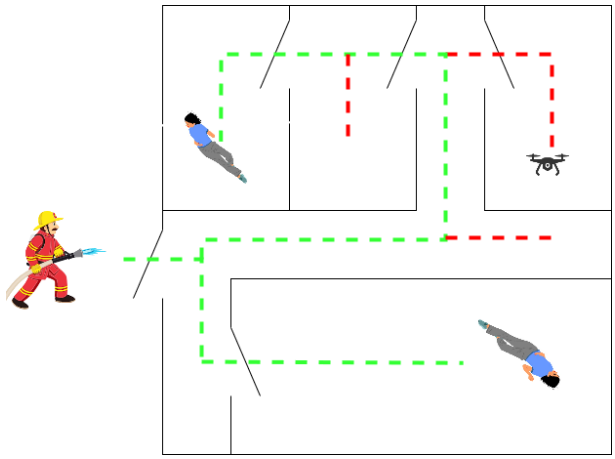

Figure 1: A visual representation of a drone assisting in finding survivors

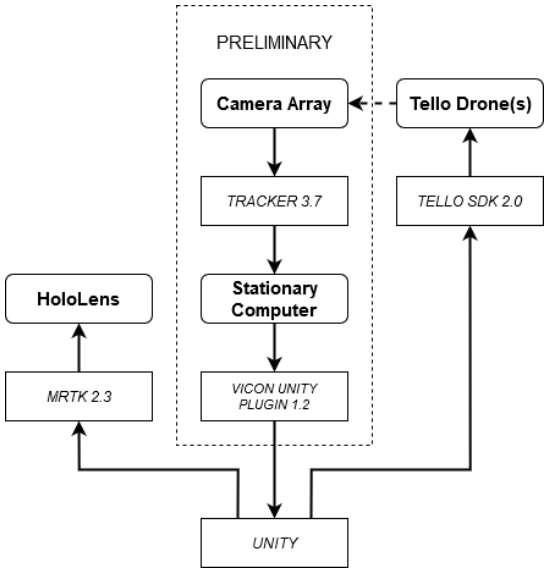

Figure 2: The different components used in order to construct the system.

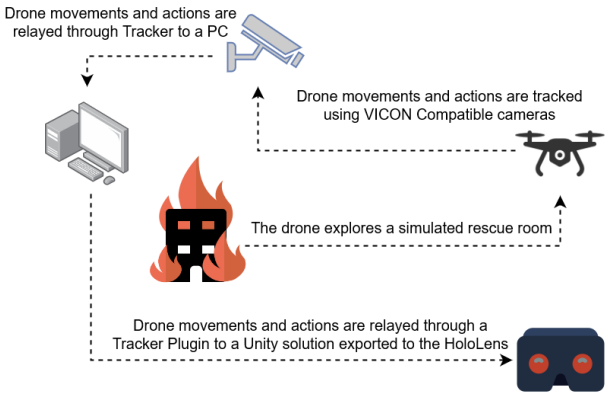

Figure 3: The flow of information in the system.

the fully autonomous capabilities of drones with the hands-free operations of AR in that the resulting piece of technology would allow for a safe, automated, handsfree, search and rescue tool which could potentially help save human lives during a disaster. And while research into such systems has already been conducted, considerations such as User Interface (UI), Human Computer Interaction (HCI) and path finding remains interesting avenue of research which remains in its infancy.

3 System

It is dangerous for firemen to enter burning buildings, in such cases the firemen in question are forced to make difficult choices. Do they enter the burning building and hope to find survivors? and if so, where are the survivors most likely to be found?

Due to the nature of burning buildings, rescuing people from fires is as much a matter of time issue as it is of weighing the risks of entering the burning building. Therefore employing the usage of drones in order to scout a burning environment would ensure that the risk to human lives are minimised, and depending on the amount of drones employed the time necessary to find survivors could even be lessened.

Vision

The base idea is to have a building explored by autonomous drones reporting the position of survivors to a AR HMD or application, enabling the real time visualisation of paths leading to survivors for firefighters. As visualised in Figure 1 one or more drones are sent in to search the building providing real-time instructions to firefighters such that they can get to a survivor as fast as possible while avoiding dead ends. We propose a system that can track the drone's position, in our example we suggest utilising the Vicon system with Vicon cameras as well as the Vicon Tracker software as can be seen in Figure 2. The flow of the system is shown in Figure 3. As we get to the point where it is possible to get very precise positional information in small spaces the Vicon system could be omitted which would result in less equipment being required and therefore less setup. The goal is to make the system as intuitive and fast to use as it should be competitive with the speed of which current operations are done.

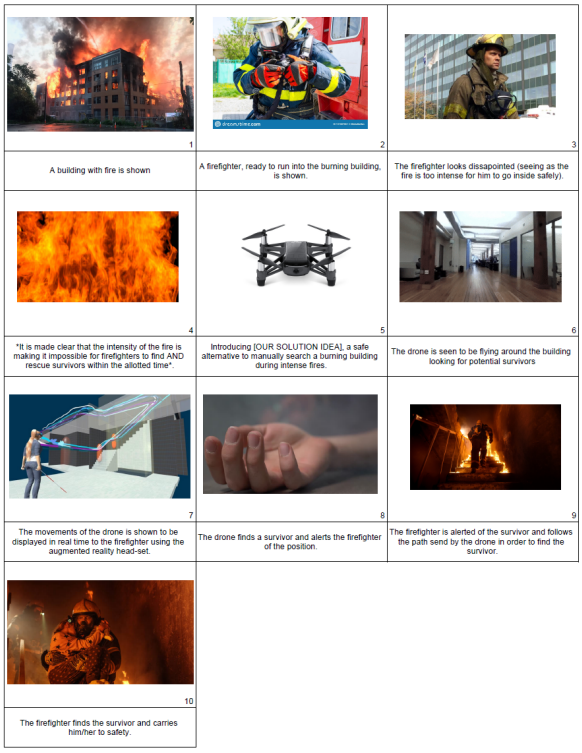

Figure 4: Storyboard of a demonstrational video made for the purpose of showing our vision for the system

Consider the following scenario

Based on our storyboard in Figure 4, a potential scenario can be derived. A fireman at the place of a burning construction puts down a drone in front of him, the drone takes off into the air and heads inside the burning building.

Inside the building, the drone navigates through the rooms of the building searching for people that may be trapped inside by the flames. Upon detecting a person the drone will alert the fireman observing the situation from the outside that a person has been found. The drone supplies a path that will become visible using the fireman's AR HMD and the fireman can enter the building, going straight for the person in distress and lead them out of the building.

Meanwhile, the drone continues to look for additional people and the fireman spends as little time inside the building as possible in order to stay out of potentially dangerous situations.

Technologies

Augmented Reality

AR is a concept in which you augment the real world, usually through the use of holograms but any change to the real world.

Compared to Virtual Reality (VR), in which you create a virtual world that may not correspond to the real world, AR does rely on the real world environment in which the user experiences it.

In addition to VR and AR there also exists a third concept, Mixed Reality (MR). MR can be seen as a branch of AR as, generally, all MR is also AR, however, not all AR is MR. In order for a AR application to be considered MR it has to have the ability to interact with the physical objects in the real world environment, while a pure AR environment does not.

HoloLens

The HoloLens is a MR HMD developed by Microsoft which utilises the Windows Mixed Reality platform. Here we will focus on the AR capabilities of the HoloLens as that will be the focus of this project. The AR capabilities of the HoloLens makes it able to show visual objects, called holograms, which the user can see, and interact with, in the real world. The HoloLens contains a custom built Microsoft Holographic Processing Unit, based on Intel 32-bit architecture. The specifications does not state clock speed of the device, but it can be assumed to be on the level of a Windows Phone. As for memory, the HoloLens comes with 64 GB flash memory for apps as well as 2 GB of RAM. There is support for both WiFi and Bluetooth LE on the device[1].

Vicon Tracker

In order to perform extremely precise object tracking, Vicon has created a tool aptly called Tracker which provides real-time data with minimal latency. Vicon furthermore also offers a Unity plugin allowing for direct data transfer between their own Tracker software and Unity, enabling real time translation between real time coordinate systems and virtual ones. Tracker itself is claimed to be able to process data in as little as 1.5ms, at more than 500 frames per second using their own proprietary cameras[2]. Vicon offers a variety of different cameras[3], the cameras are optical motion capture cameras made specifically for observing objects and movement in a space covered by a set of cameras. The objects are tracked using indicators on the tracked objects in a certain pattern unique to a given object such that they are distinguishable from each other. Before using the Vicon system there is a calibration step in which a special wand is used together with the cameras in order to define the center of the area in which objects are tracked.

[1]https://docs.microsoft.com/en-us/hololens/hololens1-hardware
[2]https://www.vicon.com/software/tracker/
[3]https://www.vicon.com/hardware/cameras/

Unity 3D

Unity3D is a powerful tool for many use cases. While being initially developed for the purpose of game development, it has, since then, been used in areas, not necessarily game related, such as AR and VR. Unity 3D is, as the time of writing, the preferred, and suggested, way of developing for the Microsoft HoloLens. During the development of our system, Unity underwent a transition period of their AR and VR implementations where they are separating the features from the engine itself. This means we had to make a choice whether we wanted to use the new system or the legacy system. In order to make a decision we looked into both options. The benefit of using the new system would be the fact that it would be compatible with future versions of Unity and therefore easier to maintain going forward should the system be continued in the future. However, we discovered that, at the time of writing, the new system lacked the sufficient documentation to set it up and thus we would have been required to invest a lot of time into figuring the system out for ourselves. As none of us had previous experience with AR and the workflow hereof we decided to setup the legacy system in the current implementation of the system until the new system is more mature. Using the legacy system means that we will have the resources we need to set it up as well as getting help if we encounter issues. The downside is the fact that it is a legacy system and therefore will need to be updated in later versions of Unity if the project is continued at a later time.

Method

For the purpose of improving the platform we will be proposing a heuristic inspection that could be performed on iterations of the system as it is being developed. This is aimed to help guide the direction of the project while ensuring the system will perform as expected. We will also be conducting a study in the form of an expert review in order to get a better understanding of the problem domain and get new insights into potential issues from experts in the field of drones and firefighting.

Inspection

The heuristic inspection will be focused on the evaluation of essential features of the platform that we have implemented as well as an evaluation of how those features could be improved by conceptual features that were not implemented in this version of the platform but is assumed to provide additional value to it. In our case we will utilise a modified set of heuristic inspection criteria formulated by one Gerhardt Powal whom developed the criteria specifically for human computer interaction, anchored in the cognitive sciences. The following is a list of those criteria[7].

- Automate unwanted workload.
- Reduce uncertainty.
- Fuse data.
- Present new information with meaningful aids to interpretation.
- Include in the displays only that information needed by the operator at a given time.
- Practice judicious redundancy.
- Reduce danger to the individual firefighter.

The first criteria aims to reduce the amount of 'low-level' cognitive thinking required to complete a task, thus freeing up cognitive resources for 'high level tasks'. Reducing uncertainty refers to the way information is displayed to the user and ensuring that the data shown is clear and obvious in order to reduce decision time and the chance of failure.
The criteria of fusing data refers to, where applicable, fusing multiple low level data sets into higher level summation data sets, reducing the cognitive load of understanding said data. The fourth criteria aims to present new information in ways that are familiar to the user, in order to make the newly provided information easier to absorb, thus reducing cognitive load.
Names and labels should be representations of the conceptually related function in order to improve recollection and recognition. Similar to fusing, Grouping data aims to reduce the cognitive load of understanding data by grouping relevant data together for example within a screen.
Where applicable one should prefer to use colours and graphics in order to limit the amount of raw data driven tasks, this reduces the amount of time necessary to be spent on assimilating data.
Extraneous data should where applicable not be shown to the user, allowing the user to concentrate on critical assignments more easily. When displaying data to the user, the format of data should encompass varying formats and/or levels of detail in order to better accommodate a varying user base.
In spite of the focus of many previous criteria seemingly limiting the redundancy of shown data, the tenth criteria is included in order to handle the sometimes necessary inclusion of more information than may be needed at any given time, in order to be consistent.[7]

Expert Assessment

In order to ensure the usefulness of a research platform in this field, we include some expert assessment of the platform. The profile of the experts includes firefighters, drone operators and general rescue workers. In order to perform the expert assessment we created a video demonstrating the platform as well as a use case of the system proposed by the platform. This video is shown to the experts and they

will provide feedback. The video will be a visual representation of the scenario described earlier in section 3. Before making the video we developed a storyboard covering the interesting points of interest that the video should include, this storyboard can be seen in Figure 4. The main points covered during the expert assessment will be the viability of the system, exploratory questions widening our understanding of the problem domain and confirming our own initial suspicions on the topics of the questions. The expert review is conducted in the form of an qualitative interview to gather feedback directly from users working in the fields of interest of the problem domain as part of an empirical contribution as described by Jacob O. Wobbrock and Julie A. Kientz.[9] Our findings from these expert reviews will be discussed together with our remaining results.

Our Implementation

The implementation for the research platform is developed as two separate applications. One for controlling the drone and one responsible for the HMD information and path visualisation. The two systems communicate over a TCP connection where the drone is sending updates to the HMD. These updates include a video feed from the drone to the HMD as well as path information to visualise a path.
On the HMD side of things we have functionality to visualise paths and on the drone side of things we have some functionality for using OpenCV as a means to detect survivors. As these functionalities were experimented with at the start of the project, they are, at the time of writing, separate experiments and not coupled as a system

The drone application is capable of relaying a path, in the form of a sorted list of coordinates, through the TCP connection to one or more connected HMDs. It is also responsible for all communication to and from the drone. Although the vision is for the drone to be autonomous, the current implementation only supports manual control. Experimental support for relaying the video feed from the drone over the network has been included but, at the time of writing, has not been fully implemented in the current system. The drone also has a very basic OpenCV implementation for detecting people by analysing the video feed from the drone. There is more work to be done on this feature and in the current system it has not been tested.
The application on the HMDs is responsible for all the visualisation that is being shown to the wearer based on input from the drone application. Current functionality includes the ability to generate visualisations for paths given a list of coordinates.

In addition to the two-part system described above, we developed a separate system, a prototype, that was used in the making of a demonstrational video. The focus of this system was to allow us to easily set up environments that represents the look and feel of our vision. We also used this system in order to test different visualisations, based on findings in our related work, that were included in the video. The visualisations include spheres and arrows both of which have been found to infer direction.
The video, which can be found on YouTube[4], goes through a potential use case of the vision, in the main part of the video we show the implementation using spheres. Later in the video we show a side by side comparison of the spheres and arrows in order to get insights into which of these visualisations would be preferred and why as we had some initial thoughts on the matter and wanted to compare that to the expert assessments.

4 Results

The following sections will cover the results of expert reviews performed with a professional fire master and firefighter as well as a second person, who is an expert in the field of drone technology. The system presented in the concept video was generally well received and received praise both from the firefighter and the drone expert, how ever as can be seen in Figure 5 which covers the results of more strictly structured questionnaire type questions, the system does not, in the mind of the firefighter, seem to adequately help alleviate stress nor improve the safety of firefighters performing their job.
During an initial conversation with one of the interviewees, we discussed the implications of the system, to which he pointed out that no matter the cost to personal safety, from the firefighters side, the firefighters are, and will always be, sent inside the burning building immediately, with no time to wait for a drone to report the position of a survivor. As such the purpose of the system described in section 3 changes slightly from enabling firefighters to locate survivors while not even necessarily being in the building, to enabling concurrent use with firefighters in order to minimise time spent inside a burning building while searching for survivors.

The following sections will cover information learned directly as a result of less strictly structured parts of the expert reviews. The sections will be divided into issues to do with the drone, firefighter and context of the system respectively.

Issues and Concerns for the Drone

The size of the drone
The interview with the drone expert yielded interesting considerations with regards to the size of the drone. While a small drone is generally more effective at entering smaller

[4]https://www.youtube.com/watch?v=XIiL5Lnt7QA

spaces as well as generally easier to pilot, larger drones are more often made of more durable materials like metals or carbon fiber which becomes relevant in that the drone in this case runs the risk of bumping into various debris while searching the building, larger drones are also generally more stable in violent air conditions than smaller drones.

Drafts of air

Pointed out by both the firefighter and the drone expert is the fact that the atmosphere inside burning buildings can be filled with turmoil and violent air drafts posing a hindrance to the flight of drones.

Battery performance in high temperatures

A concern addressed during the interview with the drone expert has to do with lithium batteries' varying output discharge depending on the temperature of the lithium battery.

Issues and Concerns for the Firefighter

Spheres versus arrows

With regards to the two different path visualisations presented in the concept video, the spheres and the arrows, the drone expert mentioned that while the spheres posed a more easily recognisable figure, the arrows might prove more capable of inferring direction, something that he deemed to be essential in the work of firefighting. When interviewing the firefighter though, this proved not necessarily to be the case, as he remarked that direction, and the inference of direction within the scope of this system, isn't necessarily important seeing as the firefighters would never enter a burning building without their fire hose, which is tangentially used to infer direction of travel in that they would always just be able to follow the hose back out of the building. With regards to the question of spheres versus arrows how ever, the firefighter had no preference on the matter.

Augmented reality components and their movement

A concern first raised by the drone expert and later addressed by the firefighter was the concern of moving parts within the scope of augmented reality. The drone experts concern was that too much movement might prove distracting as he thought that firefighters probably instinctively saw unnatural movement as a sign of danger. When inquired on the subject how ever, the firefighter did not see moving parts as a problem or a distraction as he could not imagine having trouble distinguishing between augmented reality and actual reality.

	Firefighter	Drone Expert
The system automated work for the firefighters, easing their workload.	3 – 4	6
The system seemed easy to understand and use.	6	6
The information displayed to the firefighter was clear and orderly.	5 – 6	6
The information displayed to the firefighter was easy to understand.	6	5
The system improved the safety of the firefighters.	1	7
The system will alleviate stress in the business of firefighting.	3	N/A

Figure 5: The figure displays the results of the rating part of the interviews conducted with the drone expert and firefighter.

Human pilot versus Autonomous piloting

With regards to human piloted drones, the firefighter pointed out that having human pilots eliminates the need for HMD-side gestures completely. The firefighter deemed gestures to be a strenuous distraction which could prove troublesome in complete darkness, which is especially true when the firefighters are engaged in other activities.
On the other hand, the firefighter thought that autonomous drone control posses less of a distraction thus freeing up resources with regards to rescue work.

Stress as it relates to firefighting

The firefighter could readily recognise stress as an important and detrimental factor in firefighting, in fact he had an acquaintance whom had just entered early retirement due to Posttraumatic Stress Disorder (PTSD), remarking that stress is certainly a very serious and ongoing subject in the field of rescue work as a firefighter.

Information overload

Information overloading was a concern raised in both interviews, met with very varying opinions. The drone expert thought that the system should be very wary of showing too much information at any one time as it could prove distracting and even dangerous if not handled correctly.
On the other hand the firefighter thought that there was no such thing as too much information and if, at any point, too much or trivial information was displayed it would be no trouble for the firefighter to simply ignore it.

Issues and Concerns for the Context

The problem of doors

One interesting point yielded by the interview with the firefighter arose when he told us that it was not uncommon to experience closed doors while searching for survivors, a fact that would most likely be detrimental to the work of the drone if encountered. In addition to doors being problematic for navigation the firefighter also explained that obstacle avoidance in general would be beneficial as to ensure that firefighters will not have to worry about the drone being stuck either because of an obstacle or as a result of colliding with one.

Multiple drones
Both the firefighter and the drone expert posed the very interesting idea of having multiple drones operating within the system at the same time, this is something that the drone expert thought would be more easily controlled through the use of human piloting, remarking that ".. it is possible to make the system so simple that a firefighter could control multiple drones at the same time.".

Already existing firefighting drone solutions
During the drone expert interview, he mentioned that autonomous drones are currently being used in the field of mining, in order to autonomously explore mining shafts, allowing for mining personnel to remain completely safe whilst exploration is underfoot. The drones work by having non predetermined paths computed in real time whilst exploring.
The firefighter told us that a certain unit of firefighters exist in the Copenhagen branch of the Danish Emergency Management Agency whose sole responsibility it is to use drones for firefighting purposes. The main responsibilities of this branch seemed to cover exploration and surveying of plantation as well as high rise fires from outside in.

Notable technologies for future work
Through the interview with the firefighter we were pointed towards the delivery of thermal information being essential in already existing technologies aiming to aid firefighting and that amongst the information displayed to the firefighter through our system, thermal information was of the utmost importance.

Extra ideas
During both interviews several good ideas was discussed such as using sound as an alternative interfacing additions in order to infer information to do with everything from hazardous gasses, amount of survivors, the condition of the survivors and general information relevant to pathing. Likewise colour was suggested for much of the same reasons.

5 Discussion

To evaluate our work we will discuss the topics of our problem domain and the considerations that we have made in the development of our research platform and the knowledge we have obtained in the process. We will also propose our thoughts on future work, that could be beneficial for adding additional value to future iterations of this research platform as well as a potential final system.

The Implementation
The system as is, will make a good base for future iterations, as it applies the knowledge we have gathered over the course of the project. However, due to the fact that Unity is in the process of deprecating the old AR Application Programing Interface (API) that is currently built in, as well as due to the documentation for the new API being a lot more descriptive and thorough, it might be worthwhile investigating opportunities to switch the implementation to the new APIs, if possible. If that is not possible it may be worthwhile to start over using the new APIs entirely, depending on how much progress has been made since this initial experimentation.

Implementation of Augmented Reality Headset
A HoloLens are not durable enough nor made of the necessary materials in order to survive the hazardous environments found inside a burning building, implicitly agreed during the interviews has been the understanding that the final solution would involve the augmentation of fire resistant faceguards or facemasks with AR capabilities.

Drone Size and Choice of Material
The drone used in the current implementation needs to be made of more durable materials, during the interviews it was implicitly agreed upon that the current drone was an abstraction of the final fireproof drone which could be used in an actual implementation. The final drone should probably be made of fire retardant materials such as ceramics or steel yielding a more fire resistant drone than is currently the case. The changing of material also poses the restriction of more powerful rotors and thus more yield from the power supply.

Lithium Batteries in Varying Temperatures
The fact that a change of material might very possibly increase the power yield necessary to be generated by the power bank is only worsened by the fact that lithium batteries change their output discharge depending on the temperature of the batteries. In order to combat this, redundant power supplies might solve the problem of having an insufficient amount of power available while the use of voltage surge protectors might be able to help overcome the risk of internal power surges. Further research into the precise variation in discharge in lithium batteries is needed in order to more fully understand this problem.

Spheres versus Arrows
With regards to the case of spheres versus arrows, being used for path visualisation, the interview with the firefighter seems to suggest that either type is equally good at conveying directional information. The interview with the drone expert how ever addressed some valuable points, in that arrows

by their mere shape can infer direction, an attribute that spheres does not possess, unless augmented with tangential features such as colour, animation or sound. That being said we deem arrows to be the superior path visualiser provided that measures to ensure visibility, such as arrow size and height above ground, is put into place.

Information Overload
While the drone expert felt very strongly about the dangers of having too much information displayed at any given point in time, the firefighter seemed much less passionate about its importance and postulated that too much information would simply lead to the users of the system ignoring the superfluous information. These are two very impactful and very contrasting opinions and while both participants provide valuable insights from each of their respective fields of expertise, further reviews involving firefighters from drone focused branches of the Danish Emergency Management Agency might be able to produce a more nuanced point of view on the matter.

Stress and Firefighting
Stress seemed a very important and current problem in the field of firefighting, and since the firefighter did not feel as though the system did much to help alleviate stress during the workflow of firefighting, the system, as well as the firefighters, could benefit from directing at least some of the development focus on alleviating stress, in that the reduction of stress could possibly increase effectivity reducing the amount of time spent in close proximity to hazardous environments.

Human Piloting versus Autonomous Flight
While the original intend of the system was to implement autonomous flight, the expert reviews have since then brought light upon the much simpler yet possibly just as effective use of human piloting in order to search the burning building using drones. On one side there is the added advantage of lower development time and an all around much simpler system to maintain with regards to a human piloted control system, and on the other hand is the potential of totally hands free searching of a building, freeing up resources which could potentially save human lives.

The Problem of Doors
While closed doors pose a, perhaps, insurmountable challenge in the way of surveying a building in its entirety for survivors, the system is still able to search paths not cut off by closed doors. Perhaps the usage of the system could entail a reduction of scope for the firefighters to only check paths where doors are closed, leaving the open doors to the drone system.

Obstacle Avoidance
With regards to drone navigation, several obstacles might present themselves while navigating, such as tables, chairs electronics etc. Generally speaking many obstacles one would encounter inside a burning building has flat surfaces, which makes the use of sonar a potentially viable solution for detecting these obstacles, first proposed by the drone expert, sonar very likely would prove suitable for the purpose of obstacle avoidance in the system, provided that autonomous flight is chosen as the drone control system.

Limitations

The limitations section will cover areas of the research platform where the current work is not perfect, but adequate for the purpose of serving as part of a research platform. The limitations section covers the drone autonomy, fire resistance and positioning.

The drone is not currently autonomous, it is instead in its current implementation controlled by a person in real time through a PC and a live video feed. This is something that in future iterations of the research platform should be changed both in order to distinguish the research platform from already existing solutions on the market and in order to free up resources in any one given fire department. We have considered the usage of OpenCV in order to implement image recognition enabling the recognition of survivors. In the current iteration of the research platform, the drone itself is not fireproof, this, while not crucial to the development of firefighting aids, still presents a challenge in that the research platform will not necessarily provide precise data in actual fire hazardous environments. Future iterations of the research platform should consider using a more durable drone in order to better acquire data in realistic firefighting environments. In order to survive inside the hazardous environment of fires, firefighters use masks and various other kinds of headgear, this poses a problem for the current HMD in that it offers no fire protection what so ever. The implementation of the augmented reality device into the already used headgear of firefighters would improve the research platforms ability to provide accurate and useful data.

Future Work

The future work section will cover concerns needing resolution, in order to fully satisfy the requirements of the system described in section 3.

As of right now the only camera attached to the drone is

pointing straight forward and is totally static with respects to the drone frame. This is inadequate for the purpose of locating survivors in that the camera should be at an angle to better locate survivors of a fire who would most likely be lying down on the floor in order to avoid the toxic fumes and heat associated with fires.

In some situations, the firefighters at the scene of a fire might wish to take direct control of the drone or for it to perform certain actions. This could be implemented through the use of new gestures which would need to be implemented.

As of writing this, the server is not able to receive data from the HMD. In order for the HMD to communicate with the drone, necessitated if the aforementioned gesture suggestion is to be implemented, two way communication must be implemented. This can be handled by complimenting the current TCP connection system with an initial handshake as well as complimentary mirrored drone-side receive functionality.

Future research regarding the exploration of path visualisation using augmented reality for firefighters in an effort to find and rescue people in hazardous environments should involve exposing potential users of the system to the actual research platform directly, this could lead to crucial HCI minded contributions. Due to the 2020 COVID-19 pandemic, actually exposing potential users directly to the research platform has proven difficult and even problematic, alas future iterations of the research platform could, with very little adaptation, be exposed to a potential user base. We suggest future researchers pursuing the exploration of this problem domain to perform co-design sessions or user studies in order to receive more detailed cognitive feedback. We imagine that the precise nature of the proposed user review would borrow from the principles of heuristical inspection already specified in section 3 by Jill Gerhardt-Powals. We stipulate that such user reviews would reveal data not found during our presented expert reviews.

6 Conclusion

We have developed a research platform allowing people interesting in exploring the problem domain of technologies aiding firefighting. We also conducted two separate expert reviews, one with a drone expert and another with a firefighter. The two expert reviews yielded valuable information regarding the problem domain.
During the development of our system we furthermore encountered some limitations as well as suggestions for future work which should be a point of focus for future iterations of the system.
The research platform is able to provide valuable information in the ongoing effort to explore the realm of technologies aiding firefighting, the research platform is Open Source and is able to aid future research in said field. Furthermore the expert reviews aided in the understanding of firefighting, drone systems, augmented reality systems as well as any combination thereof.
With regards to the problem statement,

> *"How do we best minimise the amount of time firefighters have to spent in hazardous situations?"*

We feel that our findings specified in section 4 and section 5 has contributed significantly towards the end goal of creating a system able to minimise the amount of time firefighters have to spent in hazardous environments enabling researchers to build upon our work in order to find the optimal solution.

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Appendices

Contextual Interview Questions

Can you explain the system in the video you just saw?
Can you talk about three, or more, of what you deem to be the most important considerations to be had, regarding such a system?

What would you say were the main considerations behind having the drone be autonomous?
What would you say were the main considerations behind having the drone be controlled by humans?
Which hindrances can you imagine arising in constructing an autonomous drone able to navigate a burning building?
Do you know of current drones that exist for this type of work? (Rescue work in hazardous environments) In your mind, what would be the best way to interact with the drone through the augmented reality headset? (for example hand gestures, voice, handheld controller, etc)
In your mind, what would be the best way to symbolise the path travelled by the drone? (we used arrows and spheres, do you have a preference for either of these?)
Can you imagine any other visualisations that would be more helpful?
How would you signal, through a augmented reality headset, the location of the drone?
How would you signal, through a augmented reality headset, the location of a survivor?
How would you signal, through a augmented reality headset, a path?
How would you signal, through a augmented reality headset, danger?

The following statements are to be considered and rated on a scale of 1-7, 1 meaning that you very much disagree with the statement and 7 meaning that you very much agree with the statement.
The system automated work for the firefighters, easing their workload.
The system seemed easy to understand and use.
The information displayed to the firefighter was clear and orderly.
The information displayed to the firefighter was easy to understand.
The system improved the safety of the firefighters.

The system will alleviate stress in the business of firefighting.
I know or have heard of people suffering from stress related debilitation's within the field of firefighting.

Glossary

API Application Programing Interface. 8
AR Augmented Reality. 1–5, 8

HCI Human Computer Interaction. 3, 10
HMD Head Mounted Display. 1, 3, 4, 6, 7, 9, 10
HOG Histogram of Gradients. 2

MR Mixed Reality. 4

POIs Points Of Interest. 1
PTSD Posttraumatic Stress Disorder. 7

UI User Interface. 3

VR Virtual Reality. 4, 5