Assessment of human and multiple UAVs interaction in police clearing operations

Cong Xu
Iowa State University

Follow this and additional works at: https://lib.dr.iastate.edu/etd

Recommended Citation
Xu, Cong, "Assessment of human and multiple UAVs interaction in police clearing operations" (2020). Graduate Theses and Dissertations. 18250.
https://lib.dr.iastate.edu/etd/18250

This Thesis is brought to you for free and open access by the Iowa State University Capstones, Theses and Dissertations at Iowa State University Digital Repository. It has been accepted for inclusion in Graduate Theses and Dissertations by an authorized administrator of Iowa State University Digital Repository. For more information, please contact digirep@iastate.edu.
Assessment of human and multiple UAVs interaction in police clearing operations

by

Cong Xu

A thesis submitted to the graduate faculty
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

Major: Industrial Engineering

Program of Study Committee:
Richard Stone, Major Professor
Kyung Min
Beiwen Li

The student author, whose presentation of the scholarship herein was approved by the program of study committee, is solely responsible for the content of this thesis. The Graduate College will ensure this thesis is globally accessible and will not permit alterations after a degree is conferred.

Iowa State University
Ames, Iowa
2020

Copyright © Cong Xu, 2020. All rights reserved.
# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Chapter</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>ACKNOWLEDGMENTS</td>
<td>iii</td>
</tr>
<tr>
<td>LIST OF FIGURES</td>
<td>iv</td>
</tr>
<tr>
<td>LIST OF TABLES</td>
<td>v</td>
</tr>
<tr>
<td>ABSTRACT</td>
<td>vi</td>
</tr>
<tr>
<td>CHAPTER 1. INTRODUCTION</td>
<td>1</td>
</tr>
<tr>
<td>CHAPTER 2. METHODS</td>
<td>7</td>
</tr>
<tr>
<td>2.1 Participants</td>
<td>7</td>
</tr>
<tr>
<td>2.2 Equipment</td>
<td>7</td>
</tr>
<tr>
<td>2.3 Setting</td>
<td>8</td>
</tr>
<tr>
<td>2.4 Experimental Procedures</td>
<td>8</td>
</tr>
<tr>
<td>2.5 Assessment Tools</td>
<td>11</td>
</tr>
<tr>
<td>2.6 Dependent and Independent Variables</td>
<td>12</td>
</tr>
<tr>
<td>CHAPTER 3. RESULT</td>
<td>13</td>
</tr>
<tr>
<td>3.1 Target Identification &amp; Time Difference</td>
<td>13</td>
</tr>
<tr>
<td>3.2 NASA-TLX score</td>
<td>13</td>
</tr>
<tr>
<td>3.3 Complexity score of SART</td>
<td>15</td>
</tr>
<tr>
<td>3.4 Informal interview</td>
<td>16</td>
</tr>
<tr>
<td>CHAPTER 4. DISCUSSION</td>
<td>18</td>
</tr>
<tr>
<td>CHAPTER 5. CONCLUSION</td>
<td>24</td>
</tr>
<tr>
<td>CHAPTER 6. FUTURE WORK</td>
<td>26</td>
</tr>
<tr>
<td>REFERENCES</td>
<td>27</td>
</tr>
<tr>
<td>APPENDIX A. IRB APPROVAL</td>
<td>30</td>
</tr>
<tr>
<td>APPENDIX B. INFORMED CONSENT</td>
<td>31</td>
</tr>
</tbody>
</table>
ACKNOWLEDGMENTS

I would like to express my deepest thanks to my major professor Dr. Richard Stone who offered me the opportunity of my master's program, supported me in my research, guided me, and showed the path of my career.

Special thanks to my committee members Dr. Min and Dr. Li. I understand this is a hard time due to the COVID-19, but you supported me through such a difficult period with your encouragement and wisdom.

I would also like to thank all the ATHENA Lab members for their help and company and thank Erik Danford-Klein, Colten Fales, and Fatima Mgaedeh for your emotional support and thesis consultancy.

Besides, I would also like to thank the department faculty and staff for giving me the greatest Iowa State University adventure experience in Ames, Iowa.

Last, thank you, my beloved parents, Hengjian Xu and Hui Yan, for your unconditional love and support, and I love you.
LIST OF FIGURES

<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Figure 1.</td>
<td>Experimental Drone</td>
<td>7</td>
</tr>
<tr>
<td>Figure 2.</td>
<td>Layout of the experimental setting</td>
<td>8</td>
</tr>
<tr>
<td>Figure 3.</td>
<td>Procedure of the drone study</td>
<td>9</td>
</tr>
<tr>
<td>Figure 4.</td>
<td>Lead office sending a command to drone operators and corporate with drones</td>
<td>10</td>
</tr>
</tbody>
</table>
LIST OF TABLES

Page

Table 1. Summary of all the ANOVA F-test of each catalog ................................................................. 14
ABSTRACT

Unmanned aerial vehicle (UAV) or drone technology is developed maturely these years, and drone assists humans in various fields. Especially, it is a great solution for law-enforcement operations. Officers usually work individually or with a small group during the clearing operation, which may encounter uncertain events or surprising ambush from the hostile target and respond to the potential threat swiftly and appropriately.

An assistant drone can support law-enforcement officer has the potential to increase the safety and reduce the number of casualties by detecting and spotting hostile target in advance during the operation. Drone swarms (multiple UAVs) are more efficient than a single drone in the searching process, and swift clearing operation means less possible injuries. Hence, this study is aiming to find an effective and intuitive single operator interface for multiple swarm law-enforcement operations based on the previous study. In a simulated environment, this study reconducted single monitor single drone trails as the benchmark, and both of single monitor swarm and multiple monitors swarm trailed are tested against each other and are assessed their effects on cognitive workload. The cooperation time and target identification are recorded, and officers completed a survey that included adjusted NASA-TLX survey, modified SART survey, and informal interview questions to determine the optimal setting.

Although the result showed single monitor swarm is more complex and uncomfortable to use, the target identification result proved single monitor swarm is a stable and safe interface setting with smoother operating pace. According to the informal interview, participants have no complains and are willing to work with drone in the future, but they suggest a mature and implemented drone technology in the future, so the drone or drone swarms can be a part of puzzle of clearing operation in the future.
CHAPTER 1. INTRODUCTION

Unmanned aerial vehicles (UAVs), also known as drones, are a pilotless flying object that can operate through autopilot or can be controlled by a human operator. Some are small unmanned aircraft (sUAVs or drones) “weighing less than 55 pounds on takeoff, including everything that is on board or otherwise attached to the aircraft (Federal Aviation Administration).” According to the United States Federal Aviation Administration Title 14 Part 107, these small UAVs are designated as “sUAVs” and will be labeled as such in this thesis, whereas “UAV” indicates any craft larger than 55 pounds. In aviation history, the first vehicle with no on-board crew or passenger was made in World War I. Other such unmanned aero craft like cruise missiles paved the way to allow UAVs technology to evolve rapidly through World War II and the Cold War. During these periods, the UAVs developed abilities to deliver real-time information, detect designated targets, assistant frontline troops, and assault the enemy with on-board weapons (Blon, J.D, 2010).

Although UAVs have been successfully applied and deployed in the military field since the 1910s, at the civilian level, the UAVs were not fully developed due to the current limitations of UAV technology and the lack of communication between humans and the UAVs. Currently, the consideration of safety is the primary problem, such as potential collisions of UAVs hitting unmanned or manned flying objects (like airplanes) and ground targets, (like humans and property) (Stephen, B. H, 2015). However, in the last decade, UAVs technology has improved rapidly due to the advantage of drones. Because the UAVs can quickly respond to the orders to search certain areas, deliver support, and feedback real-time massage with limited operator exposure to the hazards and risks (Greenwood et al., 2020).

However, in the last decade, UAVs technology has improved rapidly thanks to the
advantage of drones. UAVs can quickly respond to the orders to search certain areas, deliver support, and feedback real-time massage with limited operator exposure to the hazards and risks (Greenwood et al., 2020).

Due to the characteristics, the UAVs can be suitable tools for the law-enforcement agency to deal with a wide variety of situations. Though a helicopter can achieve the same tasks as drones do, the material and operating costs of a helicopter are significantly higher. According to the U.S. Department of Justice data, the average price of the helicopter is near 30 times more than the cost of sUAV, and the average operating and maintenance cost is near 16 times more for the helicopter than for the cost of sUAV (Valdovinoset al., 2016). Besides the cost, the applications of sUAV are a versatile tool and sUAVs can assist operators under multiple situations when the helicopter’s strength is limited because drones not only can be operating in natural disaster rescuing, heavy snowfalls and strong winds searching, but also can locate building firefighter, police, hostage, suspect, and terrorist in a building or a room (González-Jorge et al., 2017).

Further, law enforcement care about more than costs and technological advancements. Specifically, law enforcement agencies are urged to have a safer approach to execute building clearing operations by using drones in the form of sUAVs. The objectives of building clearing operations are occupying critical areas as footholds for further actions, determining inimical objects and friendly targets, eliminating threats with minimum force, and evacuating personnel equipment. During these processes, under a high-stress environment, law enforcement agencies face dangerous and uncertain situations and require not only physical preparation but also mental concentration (Texas Association of Police Explorers, 2004). To reduce the potential injuries of law-enforcement agencies that many may face, drones are an optimal solution for the police
department to deal with low budgets, limited human resources, and temporary operator’s loss. Since the implementation of drone technology, drones exhibit the capability to capture detailed images and search large areas (Hernandez et al., 2014), cooperating with other drones (Hernandez et al., 2014), and autopiloting within an indoor environment (Mac et al., 2018). Despite the advancement in drone automation, there are few research studies focused on law enforcement application, and, explicitly, building clearing operations. Although the related human-robot interaction research was developed in the military, in Chen et al. (2008) study, the military-purposed UAV interfaces were examined through the NASA Task Load Index (Hart & Staveland, 1988) and a Simulator Sickness Questionnaire (Kennedy, Lane, Berbaum, & Lilienthal, 1993). The result shows one of the problems of the human-robot interface that multiple asset workload is statistically higher (p < .005) than a single asset workload (Chen et al., 2008). The study is limited to the military-purposed, outside, and long-range distance drone simulator. The uncertain and uncleared indoor situation causes blind spots during the clearing operation. The potential hazards and lethal ambushes threaten the lives of the law-enforcement officers (Greenwood et al., 2020). To solve the indoor hazards of law-enforcement clearing operations, Schnieders et al. (2019) tested a single drone to support the law-enforcement agencies in a simulated building clearing operation. Schnieders et al. (2019) argued that, due to the improvement of microchips of drones, drones are able to move indoor environments with high quality of streaming and maneuverability capability; drones fit into law-enforcement clearing operations. Their research shows that a single operation drone provides clearer target information without a law-enforcement agency present in the designated room physically. Schnieders et al. also indicate that the mental workload of law-enforcement has no negative influence with fewer targets missing in the simulated operation area. More importantly, the study
showed 0 missing hostile target in drone assistance among all the participants (Schnieders et al., 2019). The result is crucial because the safety is the most considered factor in the clearing operation.

On the other hand, because of the improvement of the cutting-edge drone technology, it is now possible to control multiple UAVs in a tight formation as a single drone swarm. Multiple drone swarms are more capable of clearing large areas, simultaneously, with less amount of fuel and time (Jones et al., 2010). In theory, with the approachable method, drone swarms are able to autopilot and auto-search to complete the objectives and cooperate with other UAVs in the swarm (Kunming et al., 2020). Faster searching speed is critical in clearing operation, because less operation and reaction time means less injuries (Hontz, 1999).

A problem with utilizing drone swarms is the cognitive load when an operator uses more than one drone at a given time. Due to the characteristics of drone swarms, as mentioned by Chen et al., the operator of drone swarms receives information and executes the orders instantaneously and continuously. The result of this mental workload is significantly higher than the workload of watching a single asset (Chen et al., 2008). The study verified by Dixon et al. (2003) demonstrated that an individual has a higher fail rate when controlling two or more robots at the same time (Dixon et al., 2003; Roldán et al. 2017). In operation, the operator collects the data from the drones, interprets and decodes the data by accessing the interface. Next, they would have to make the decision, and commanded the drone through interface order. Suitable interface and auxiliary instruments can help reduce the mental workload during the multiple UAVs operation (Roldán et al., 2017).

Although studies have indicated that the NASA-TLX score is an engineering approach which can provide the quantitative and qualitative information (Chen et al., 2008; Dixon et al.,
2003; Roldán et al., 2017), however, this information is limited and narrowed as they don’t take into account the direct feedback from the participants. By following human-centered design, participants’ needs are one of the primary objectives for satisfactory design. As implementation of human performance design principles, the interface should support the users’ normal and “flexible multimodal communication pattern”, minimize the mental workload, and align with users’ real work training (Oviatt, S., 2006).

In human-computer interaction, another key factor is the trust between humans and computers. In the book, *Engineering psychology & human performance*, the study mentioned the trust between human and computer influence the users’ reactions with the information from the system (Wickens et al., 2000). This study showed that trust can affect the performance of human-machine interaction, especially in the case of fully automated machine work. This study also mentioned the human-human model presented by Rempel, Holmen & Zanna (1985), and extended it to human-machine model. The human-machine model presented the user as a “supervisor” of the machine and verified there was a relationship between human-machine interaction. In Rempel, Holmes & Zanna (1985) model, a human-human trust system was created based on predictability (dominating in the early relationship), dependability (dominating in the later stage of the relationship), and faith (dominating in the “mature interpersonal relationship”).

Furthermore, Muir (1994) indicated the dynamics model of trust, which was adopted from Rempel, Holmes & Zanna (1985), was related to the work experience of the machine operator. Muir’s (1994) also mentioned that providing examples can increase the trust between humans and machines. However, empirical tests were lacked (Muir, B. M., 1994). Later, Hancock et al. (2011) pointed out human-related factors, robot-related factors, and environmental factors which are factors of human-computer trust. The study was an empirical
analysis that considered and provided 69 correlational and 48 experimental studies through meta-analytic methods. The results of Hancock et al. (2011) showed robot-related factors and environmental factors were affected and associated with trust. Moreover, little evidence showed that the human-related factors were associated with trust. This study proved dependability and predictability which affect the trust between humans and machines from Muir (1994) human-computer trust model. The Muir’s model was adopted from Holmes & Zanna (1985) human-human trust model. Instead of engineering approaches to access the interface interaction between humans and UAVs, it is critical to ask the special group of the users’ opinions and to learn the focus groups of users’ communication patterns. In this study, we addressed this problem by conducting informal interviews with each law-enforcement officer to better understand different scenarios. Through the interviews, the trust related topic questions are covered.

The previous studies investigated the optimal solution of multiple UAVs supporting highly trained law-enforcement agencies in building clearing operations while focusing on the effectiveness of clearing. This was accessed by operator feedbacks in three different scenarios: (1) single monitor single drone, (2) single monitor swarm, and (3) multiple monitor swarm.

The NASA Task Load Index (Hart & Staveland, 1988) and the Complexity score of Situation Awareness Rating Technique (Taylor, R. M., 1989) were recorded and analyzed from each situation: (1), (2), and (3).

The goals of this study were to discuss the trust issue through informal interviews and to verify [1] single monitor swarm and multiple monitors swarm required same mental workload as single monitor single drone; [2] by accessing results of the experiment, the single monitor swarm is the optimal interface setting.
CHAPTER 2. METHODS

2.1 Participants

Participants were trained law-enforcement officers and had the ages between 22 to 63 (M = 33.0, SD = 12.7). The participants served as law enforcement officers with experience ranging from one to 43 years (M = 6.1, SD = 13.0). The participants’ clearing operations training experience was around one to 43 years (M = 6.0, SD = 13.0). There were ten participants in total. Six out of ten participants conducted a real clearing operation. Eight out of the ten participants were male, and two out of the ten participants were female. Participants completed 40 runs of the experiment in total, and each performed four runs.

2.2 Equipment

The setting of the drones, which recorded the videos, was quadcopter and the weight was around 80 grams and each contained an 82.6-degree field view with a 720p HD transmission capacity camera. The camera features 5-megapixel (2592 x 1936) photos. The size of the drone is 3.9 in x 3.6 in x 1.6 in, and the max speed is 8m/s. See Figure 1 below.

Figure 1. Experimental Drone
Multiple standard 24-inch monitors were used in accessing the pre-recorded video from drones.

2.3 Setting

The scenario started with the participant who took the role of a regional law-enforcement officer. The test environment was formed by a looped hallway, and seven individual rooms off the main hallway, as Figure 2 shown below. Each room was furnished, and all participants were made familiar with the building and inside layout before the experiment. In order to randomize the study, the in-room objects were differentiated after each designated session.

Figure 2. Layout of the experimental setting

2.4 Experimental Procedures

Upon arrival, the participants were asked to complete an informed consent form and a pre-survey. This survey was to find information about the previous experience related to building clearing operation, drone operation, and personal demographic information.
Figure 3. Procedure of the drone study

Firstly, each participant watched two pre-recorded single-drone feed videos separately by using a single monitor. A video was recorded by the control group, and there were no targets hidden or covered in any of the rooms in the footage. Another video was recorded by the experimental case where a target was hidden or covered in a random room, and the subject had difficulty in detecting the target. Participants were instructed to call out if they found a target and marked on a printed map of the experimental area if they confirmed the target was found. Participants were asked to finish the full video even if they already found and marked a target on the map. If the participants did not find and mark any target, they were informed to mark the “No Target” on the post-survey.

After the first two videos were completed, half of the participants were assigned to the multiple monitors with a single drone feed group, and half of the participants were assigned to the single monitor with multiple drones feed groups. Both groups had a control case and an experimental case. In the multiple monitor group, the participants were asked to watch three monitors at the same time, and each monitor was feeding the video from separated drones. There
were two runs in the three monitors with a single feed experiment, and the participants were instructed to mark the target if they saw a hostile target, or they marked “No Target.” As with the multiple monitor group, the participants were asked to watch a single monitor with three feeds simultaneously and marked target or “No Target” after the videos were completed.

All the videos were filmed and pre-recorded in the same building as shown in Figure 2. The reasons of pre-recording are because we try to eliminate variables in the videos, so participant would watch the same drone operator in the recorded video. And, in the video, the drones were followed the command verbally by the lead officer who presented in the video. The drone entered each room and scanned the room, no more than 40 seconds, and then the officer followed the drone. The lead officer held an orange “bluegun”, which is a plastic pistol, and the officer and drones, as a group, searched the rooms in the designated building, as Figure 4 shown below.

Figure 4. Lead office sending a command to drone operators and corporate with drones

In the experiment, the participant is the lead officer who can access the videos from drones and make the decision to call out and mark the target. In a real-life scenario, the lead officer will
watch the drones’ feeds, so missing a target will cause a potential hazard to all law-enforcement officers present.

After finishing four runs, each participant was asked to complete a post-survey, which includes modified versions of the NASA-TLX Index (Hart & Staveland, 1988) and the Complexity score of SART.

### 2.5 Assessment Tools

**The NASA-TLX Index:**

An assessment tool of mental workload allows the users to self-evaluate subjective performances when humans are interacting with the machines' interface system. The score is based on the weighted average of six subcategories, which are mental demand, physical demand, temporal demand, frustration, effort, and performance (Hart & Staveland, 1988). NASA-TLX is generally used in various industrials, which involved with a human-machine interface such as spaceship control (Zhang et al., 2009), planes interface (Yiyuan et al., 2011), construction machine (Akyeampong et al., 2014), etc.

**Situation Awareness Rating Technique:**

The SART is a situational awareness assessment tool that can evaluate the situational awareness from seven aspects: complexity, alertness, concentration, division of attention, information quality, familiarity, and spare mental capacity (Taylor, R. M., 1989).

Although situation awareness information can be provided through the SART to us, we try to narrow the scope of the study, because a complex interface would cause a problem in clearing operation.
2.6 Dependent and Independent Variables

Dependent Variable:

- Correct/incorrect target (error) calls in each trail
- Operation Time
- NASA-TLX survey score
- SART Complexity score

Independent Variable:

- Number of Monitors
- Number of drone feeds on each monitor

For the study, the recorded videos were randomized by orders which certain videos were not presented again and making sure the videos were distributed and watched evenly among participants. This order ensures no-bias present among the recorded videos and allows all variables were performed by each participant.
CHAPTER 3. RESULT

3.1 Target Identification & Time Difference

40 rounds of this experiment were conducted in total. Participants located, called out, and marked a potential target in a specific room correctly within 35 runs. In total, there was one run where the participant failed to find any targets in any room, and there were four runs with misidentified targets where participants located and marked a target in a different room from where the target was located. Half of the runs were using a single drone. Only two out of 20 runs, occurred where the participant marked the target in a room incorrectly, with 10% error rate in total. In the single monitor swarm, which were 10 runs in total, there was one incorrectly identified (type I error, marked target in a wrong room) target, with 10% error rate in total. In the multiple monitors with single drone feed trails which were 10 in total, there was one incorrectly identified (type I error, marked target in a wrong room), and one was a completely missing target (type II error), with 20% error rate in total.

In time difference, single drone required average operation time is approximated 5 times as multiple drones (three drones) average operation time.

3.2 NASA-TLX score

Each catalog was computed individually by using the one-way ANOVA single factor analysis (α = 0.05) to other trails. Both single monitor and multiple monitors swarm are comparing to the single monitor and single drone. The summary of each catalog is showed in Table 1.
Table 1. Summary of all the ANOVA F-test of each catalog

<table>
<thead>
<tr>
<th></th>
<th>Mental Workload</th>
<th>Perceived Difficulty</th>
<th>Pace of Task</th>
<th>Insecurity Stress</th>
<th>Complexity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single Monitor Swarm</td>
<td>p = .0273 &lt; .05 mean &gt; single drone</td>
<td>p = .0003 &lt; .05 mean &gt; single drone</td>
<td>p = .0992 &gt; .05</td>
<td>p = .1589 &gt; .05</td>
<td>p = .0085 &lt; .05 mean &gt; single drone</td>
</tr>
<tr>
<td>Multiple Monitors Swarm</td>
<td>p = .2659 &gt; .05</td>
<td>p = .0060 &lt; .05 mean &gt; single drone</td>
<td>p = .0357 &lt; .05 mean &gt; single drone</td>
<td>p = .9106 p &gt; .05</td>
<td>p = .1389 p &gt; .05</td>
</tr>
</tbody>
</table>

3.2.1 Mental Demand

By using ANOVA, the results showed that using a single monitor with multiple drones’ feeds is more mentally demanding than looking at a single monitor with a single drone feed [F(3,16) = 3.966, p = 0.0273]. However, there were no statistically significant in mental demand between looking at a single monitor with single drone feed and multiple monitors each with single drone feed [F(3,16) = 1.449, p = 0.2659].

3.2.2 Perceived Difficulty

The results showed that using a single monitor with multiple drone feeds is more difficult for participants to perceive than looking at a single monitor with a single drone feed [F(3,16) = 11.679, p = 0.0003]. Unlike the mental demand result, there were statistically significant in perceived difficulty between looking a single monitor with single drone feed and multiple monitors each with single drone feed [F(3,16) = 6.020, p = 0.0060] which means looking at multiple monitors feeds is more difficult than watching a single monitor with single drone feed.
3.2.3 Pace of Task

The results presented that participants perceived in a more rushed pace when the participant was watching the multiple monitors with single drone feeds compared to the single monitor with single drone feed \( F(3,16) = 3.636, p = 0.0357 \). The results also suggest that the single monitor with multiple drones’ feeds is not a statistically significant \( \alpha = 0.05 \) threshold but something different \( F(3,16) = 2.471, p = 0.0992 \).

3.2.4 Insecurity Stress

Results suggest that insecurity and stress had no statistical significance between both the single monitor with multiple drone feeds, compared to a single monitor with single drone feed \( F(3,16) = 1.972, p = 0.1589 \). Same as the single monitor with multiple drones’ feeds, there was no statistical significance between multiple monitors with single drone feed and single monitor with drone feed \( F(3,16) = 0.177, p = 0.9106 \).

3.3 Complexity score of SART

Table 1 showed the calculated Complexity score of SART. Although SART is different from the NASA-TLX and even overlapped each other on some level, the situation awareness complexity is the only catalog that was assessed by using the one-way ANOVA single factor analysis (\( \alpha = 0.05 \)) to other trails.

3.3.1 Complexity

Results suggest that looking at a multi-monitor swarm feed is more complex than watching a single drone feed \( F(3,16) = 5.529, p = 0.0085 \). There was no significant correlation found in complexity from viewing multiple monitors swarm feed compared to a single drone feed \( F(3,16) = 2.160, p = 0.1327 \).
3.4 Informal interview

Based on survey and interview, law enforcement generally loath to trust the drones due to the general trust, which is between human, and robot limitations of drones, although they agreed about drones can deliver clear and accurate information in each unsearched room. One participant mentioned that, “I think there were circumstances where maybe we would've wanted more of an angle or like a lower angle to...” Seven participants mentioned the camera angle limited the version of the search area which they want a wider angle to expend the vision.

In terms of the comfort level of working with drones, seven officers mentioned that they do not have enough experience or any related training with drones or cooperating with drone operators. Four officers out of the seven officers suggested that they are preferring work with a human, for example, additional officers or drone operators. One participant said, “I would rather have a second person than a drone, but if it was just me and someone else running the drone, I’d rather have the drone than just be alone…”

Automated drones were not trusted among participants. Five participants suggested that they preferred a drone operator to help rather working with a fully automated drone. One mentioned about working with automated drones but with a drone operator who can supervise the automated drone, and the participant said, “You’re losing a set of eyes… you’re just trusting a computer at that point, not another person. So, I’d probably feel more comfortable with a person [at] the end of it, not a computer.”

Generally, officers preferred to use a drone or drone swarms to search over a large and open area or high places. One participant mentioned that using a drone or drone swarms is a safer way to complete the clearing building operation, and said, “You can see the majority of the room and see that nobody is in there, and then I can go check the smaller spaces…. A lot safer than
somebody just standing in the middle of the room, and as soon as I come around the corner, they’re shooting at me.”
CHAPTER 4. DISCUSSION

The study focused on the discussion of trust between humans and computers and verified two hypotheses: [1] single monitor swarm and multiple monitors swarm required same mental workload as single monitor single drone; [2] by accessing results of the experiment, the single monitor swarm is the optimal interface setting.

According to the result of NASA-TLX, hypothesis [1] was tested by this study’s result, where a single monitor with multiple drones feeds mental workload was statistically significant different [F(3,16) = 3.966, p = 0.0273] comparing single monitor with a single drone feed. There was no statistically significant mental demand score difference between participant looking a single monitor single drone feed and multiple monitors swarm [F(3,16) = 1.449, p = 0.2659].

Our study verified that single monitor swarm would increase the mental load of the operator during the clearing operation. For a single monitor swarm, the result is the same as the previous studies’ findings (Dixon et al., 2003; Chen et al., 2008; Roldán et al., 2017).

However, interestingly, in the case of single monitor swarm, even participants think they require a higher mental workload. The target identification has no difference from the result of single drone. Both setting had a 10% error, and both were type I error.

In the opposite way, multiple monitors swarm not require a higher mental workload but had a 20% error rate with 1 type II error. The type II error is unacceptable because this means a potential injury or death for a or even more law enforcement officer in clearing operation.

There are a few potential reasons that could cause additional cognitive overload. Firstly, in a high-stress circumstance, such as clearing operations, the participant needs to send the commands to drone swarms, to perceive the information from drones, to make decisions, and to cooperate with sUAVs. During this process, participants can be easily distracted and tend to miss
important details. This leads to the result of the target identification test because at least one misidentification or missed target in both drone swarm cases. Although we followed the procedures in the same environment setting as the previous study, the first reason explained why the result difference. Our result also aligned with the results of Dixon et al. (2003), as their study mentioned, the operator’s performance declined after the operator commanded two robots or more. Secondly, although law-enforcement officers can send the command to the drones, the law-enforcement participants were not trained on how to collaborate with drone swarms before. Since this was the first time the participant used the drone swarm in the clearing operation, the participant required additional cognitive load to cooperate with the drones. This reason can be applied to all the trails. Thirdly, a lousy interface layout would require an extra mental load. Chen et al. (2008) suggested the current system in their study, which has a poor interface setting, and participants usually had saliency effects and the anchoring heuristic. This explained why participants thought about looking at a single monitor with multiple drone feeds that required high mental demand because participants would choose a feed as the main screen or focus and would miss the detail in the other two feeds. Additionally, they would prefer multiple monitors due to participants treating each monitor separately rather than one monitor, and eliminating the saliency effects and anchoring heuristic. This could explain why multiple monitors swarm, even with less mental workload, still has one type II error.

Nevertheless, although the multiple monitors swarm showed no statistically significant difference in terms of mental demand, the target identification result had one type II error. This may due to the saliency effect that mentioned previously. Notably, type II error is very dangerous in law enforcement clearing operation.
The result of the perceived difficulty of both cases showed statistically significant difference. This means multiple monitors swarm feeds \(F(3,16) = 11.679, p = 0.0003\) and single monitor swarm feeds \(F(3,16) = 6.020, p = 0.0060\) were harder to perceive than a single monitor with a single drone feed. Both of single monitor swarm feeds \(F(3,16) = 1.972, p = 0.1589\) and multiple monitors swarm feeds \(F(3,16) = 0.177, p = 0.9106\) showed no statistically significant difference in irritation/stress.

Although the perceived difficulty is higher in both swarm groups, the error rate of single monitor swarm is same as the multiple monitors swarm with same insecurity/stress level.

Besides, participants' self-rated pace of task results showed no statistically significant difference \(F(3,16) = 2.471, p = 0.0992\) when using the single monitor swarm feeds. On the contrary, the results showed for the multiple monitors swarm feeds \(F(3,16) = 3.636, p = 0.0357\) showed a statistically significant difference compared to single monitor with a single feed. The results of the Complexity score of SART showed that watching single monitor swarm \(F(3,16) = 5.529, p = 0.0085\) is more complex than watching multiple monitors swarm \(F(3,16) = 2.160, p = 0.1327\).

As the results mentioned, since both single monitor swarm feeds and multiple monitors swarm, feeds are harder to perceive, but both have the same stress or frustration level as single monitor single drone.

With regard to the hypothesis [2], although the single monitor swarm is more complex and uncomfortable to us, even require additional workload, in terms of target identification result and pace of work, a single monitor swarm is the preferred interface setting. This due to the type II error that occurred in the multiple monitor swarm group. In the clear operation, a complete miss a target usually causes the injury and even death.
In addition to the quantitative analysis, informal interviews provided us more information. In the direct feedback from the participants, there was no one complained about the drone assistance in the clearing operation, and they were looking forward to working with drones. However, they had their considerations and comments about how drones should be changed to suit the clearing operation. Some participants worried about the information and feedback back and forth between participants and drones, especially fully automated drones. Due to the current drones and human interaction model, communication is a big problem that is related to the topic of dependability and predictability. According to Hancock et al. (2011), dependability and predictability are critical robot-related factors in human and machine trust. These two factors represented the reliability of robots based on the robot’s capability. In the study, instead of giving feedback from the drones, the participant had to perceive the images/footage from the drones’ feeds. After receiving the feedbacks, participants should decode the image, which basically is analyzing the video, making the decision, and sending the next command to the drone. This pattern was mentioned in Hocraffer and Nam (2017). This is different from human and human interaction because law enforcement would communicate the feedbacks through the language directly. The law enforcement officer who received the information verbally does not need to decode the image but gets the decoded information from the law-enforcement officer who detects the room and sends the feedback to him/her. To conquer this question, self-detect drones would be a solution for the future due to the capability of decoding the image and sending it to the officer directly, a concept developed by Cooper and Goodrich (2008).

Besides the technical issue, in the informal interview, training is another reason which caused the potential problem between human and drone. Seven officers mentioned that they
would be better trained or had experience with the drone before the clearing operation. As Chen et al. (2008) mentioned, since there was no related training before, the law-enforcement officers would follow their own communication pattern rather than a new path. An inefficient communication was made through lack of training, and, consequently, the dependability and predictability of the drone swarm were decreased, so an untrusting relationship was formed. However, all feedbacks are positive because the suggestions showed law enforcement officers who are willing to build the bridge between officers and drones towards future clearing operations.

In addition, in a Hancock et al. (2011) study, the environment was another factor which majorly influenced the trust between human and drone and was verified through the experimental and empirical analysis. In this study, the building was a familiar building for all the participants, so the physical environmental factor would help form trust between participants and drones. Curiously, environmental factors, mentioned in the Hancock et al. (2011) study, contained culture, communication, and shared mental model as sub-factors. Although personal training is human-related, it did not affect the HRI trust directly. Personal training would influence the group mental model, which includes culture and communication patterns. Since all the participants were from the same region, the training process would form the same personal behavior and culture and communication patterns. This reason also explained why seven out of ten law-enforcement officers thought about training with drones before the operation.

In this study, there were a few limitations. Seven out of ten participants mentioned the drone field of view is limited, which is 82.6 degrees. In comparison, average human eyes’ binocular field view is 120 degrees with an additional 60 - 70 degrees accounting for peripheral vision (Sukhatme, 2011). The drone had no ability to precisely locate itself, so participants
would need to remember the location and be forced to determine the position of the drone in the environment.
CHAPTER 5.  CONCLUSION

This study assesses the impacts of single monitor swarm feeds’ and multiple monitors swarm feeds’ interface setting on target identification, operator mental load, and human-machine truth by using multiple drone swarm feeds in a regional law-enforcement building clearing operation. Twenty participants completed forty runs and identified targets correctly in thirty-five runs. Both single monitor single drone and single monitor swarm had a 10% error rate, and all were type I error. However, multiple monitors swarm had a 20% error rate, and one type II error occurred.

Adding additional drones reduced the amount of time, which law enforcement officer is exposed in a dangerous environment, in a clearing operation approach. Because of the safety reason, drone and drone swarm is the future of law-enforcement operations. Because drone or drone swarm can fly through those fatal funnels as I mentioned before. And, they will save the law enforcement officer life at an affordable cost. Although the optimal drone swarm interface is setting demand more mental workload, single monitor swarm setting provides a safe and stable approach with a smoother working pace.

Despite there were no complaints about cooperating with drones, and they were looking forward to working with drone or drone swarm, participants gave the considerations and comments towards the future work and drone design. They mentioned the inefficient communication in the trails due to the model of perceiving images, decoding the information, making decisions, and sending a command to the drone. The communication pattern did not fit the daily law-enforcement communication pattern, which was formed during the law-enforcement personal training. The technique issues also reduce the dependability and predictability because the limited camera angle provided less information, and the interface
cannot provide the map for the operator, which increases the complexity in operation. Despite those suggestions, 70% of participants were willing to train with drones, which have mature technology and working with them in the future.
CHAPTER 6. FUTURE WORK

There were few limitations mentioned in the discussion which can help us to build off in the future.

This study can be extended if the drone can fully be automated, searching the room and establishing the map which can be sent back to the operator. The drone can highlight the object in different colors and direct feedback to the operator, reducing the amount of law-enforcement officer cognitive decoding time. The drone’s camera field view angle should be updated to human size, and a thermal camera can be used to identify the targets.

In the future study, a group of participants should train with drones and get familiar with human and drone interaction patterns before the clearing operation. The environment can be changed to an unfamiliar location, which is different from this case, where all participants knew the layout of the building before the study. This change would help researchers to have a better understanding of the environment as a critical factor in the trust of human-machine interaction.
REFERENCES


the impact of immersion and prediction. Sensors (Switzerland), 17(8), 1–25. https://doi.org/10.3390/s17081720


APPENDIX A. IRB APPROVAL

IOWA STATE UNIVERSITY
OF SCIENCE AND TECHNOLOGY

Institutional Review Board
Office for Responsible Research
Vice President for Research
2410 Lincoln Way, Suite 201
Ames, Iowa 50014
515-294-4566

Date: 2/23/2018
To: Thomas Michael Schnieders
304 Black Eng

CC: Dr. Richard T Stone
3004 Black Engineering

Zhongjun Wang
616 Billy Sunday Rd. Unit 201

From: Office for Responsible Research

Title: The Effect of Human Robot Interaction on Trust, Situational Awareness, and Performance in Drone Sweeping

IRB ID: 18-016

Approval Date: 2/23/2018
Submission Type: New

Date for Continuing Review: 2/22/2020
Review Type: Expedited

The project referenced above has received approval from the Institutional Review Board (IRB) at Iowa State University according to the dates shown above. Please refer to the IRB ID number shown above in all correspondence regarding this study.

To ensure compliance with federal regulations (45 CFR 46 & 21 CFR 56), please be sure to:

- Use only the approved study materials in your research, including the recruitment materials and informed consent documents that have the IRB approval stamp.
- Retain signed informed consent documents for 3 years after the close of the study, when documented consent is required.
- Obtain IRB approval prior to implementing any changes to the study by submitting a Modification Form for Non-Exempt Research or Amendment for Personnel Changes form, as necessary.
- Immediately inform the IRB of (1) all serious and/or unexpected adverse experiences involving risks to subjects or others; and (2) any other unanticipated problems involving risks to subjects or others.
- Stop all research activity if IRB approval lapses, unless continuation is necessary to prevent harm to research participants. Research activity can resume once IRB approval is reestablished.
- Complete a new continuing review form at least three to four weeks prior to the date for continuing review as noted above to provide sufficient time for the IRB to review and approve continuation of the study. We will send a courtesy reminder as this date approaches.

Please be aware that IRB approval means that you have met the requirements of federal regulations and ISU policies governing human subjects research. Approval from other entities may also be needed. For example, access to data from private records (e.g., student, medical, or employment records, etc.) that are protected by FERPA, HIPAA, or other confidentiality policies requires permission from the holders of those records. Similarly, for research conducted in institutions other than ISU (e.g., schools, other colleges or universities, medical facilities, companies, etc.), investigators must obtain permission from the institution(s) as required by their policies. IRB approval in no way implies or guarantees that permission from these other entities will be granted.

Upon completion of the project, please submit a Project Closure Form to the Office for Responsible Research, 202 Kingland, to officially close the project.

Please don’t hesitate to contact us if you have questions or concerns at 515-294-4566 or IRB@iastate.edu.
APPENDIX B. INFORMED CONSENT

Informed Consent

The Effect of Human Robot Interaction on Trust, Situational Awareness, and Performance in Drone Sweeping Operations

This document describes a research project. It has information to help you decide whether you wish to participate. Research studies include only people who choose to take part – your participation is completely voluntary. Please discuss any questions you have about the study or about this form with the project staff before deciding to participate.

Introduction
The purpose of this study is to investigate how a drone affects trust, situational awareness, and performance in drone sweeping operations.

This training is completely optional but will count towards Story County Sheriff’s Office mandatory active shooter scenario training. Participants may choose to complete the active shooter scenario training and opt out of having their data collected for this study.

Inclusion Criteria
Law enforcement personnel above the age of 18 who can legally give consent and do not have conditions which would inhibit a sweeping operation of a 2-3 story building are invited to participate in this research study.

Description of Procedures
The procedure of this study is as follows:

1) Introductory briefing about the study
   a. Review informed consent form
   b. Explain the experiment
   c. Complete pre-experiment survey

2) If you agree to participate, you will perform the tasks in a 2-3 story building. You may be put on a team with other participants. Some teams will be given a quadcopter to assist in the sweeping operation task. The quadcopter will be able to fly and will have a video camera attachment to relay the aerial information to the team. Participants will not be flying the quadcopter. A trained quadcopter operator will be remotely piloting the quadcopter. One or more team members will be asked to wear pedometers to track the number of steps taken. Audio communication between officer(s) and drone operator will be recorded by the research team. In addition, the research team may take notes of the operation as it proceeds.
A principle investigator will explain how to perform a sweeping operation of a 2-3 story building. This task will involve tactical movement through a 2-3 story building where participants will attempt to identify a target. The target may or not be present. In the event that the target is present, the target will be a member of the research team and will be hidden somewhere within the building.

a. Group 1
   i. If you are assigned to this group, you will be placed in a team of two. You and your team member will perform the sweeping operation to identify and locate the target.

b. Group 2
   i. If you are assigned to this group, you will be placed in a team of two with a third team member who will be operating a quadcopter. You and your team member will perform the sweeping operation to identify and locate the target. The quadcopter operator will be providing information remotely to your team during the sweeping operation. The drone will be used to enter each room to be swept before the team.

c. Group 3
   i. If you are assigned to this group, you will not have a second on the ground team member but will have a quadcopter operator working remotely. You will be performing the sweeping operation to identify and locate the target. The quadcopter operator will be providing information remotely to you during this operation. The drone will be used to enter each room to be swept before you.

3) Following the experiment, you will be asked to complete a post-experiment survey and an informal interview. The audio of the informal interview may be recorded.

These activities are expected to last 240 - 350 minutes.

**Risks or Discomforts**

You will not be engaging in tasks that exceed normal building sweeping operations as expected in standard Story County Sheriffs' Office training. You will only walk around the experiment area. The research team assumes the participant has had experience in building sweeping operations.

**Benefits**

If you decide to participate in this study, there may be no direct benefit to you. It is hoped that the information gained in this study will benefit society by providing valuable insights for human-robot interaction in team environments.

**Costs and Compensation**

You will not have any costs from participating in this study. You will not be compensated for participating in this study.
Participant Rights
Participating in this study is completely voluntary. You may choose not to take part in the study or to stop participating at any time, for any reason, without penalty or negative consequences. You can skip any questions in the pre- and post-survey that you do not wish to answer.

If you have any questions about the rights of research subjects or research-related injury, please contact the IRB Administrator, (515) 294-4566, IRB@iastate.edu, or Director, (515) 294-3115, Office for Responsible Research, Iowa State University, Ames, Iowa 50011.

Research Injury
Injury will be treated following standard Story County Sheriff’s Office protocol. The participant will be escorted immediately by one of the research team members to Mary Greeley Medical Center and an injury report will be filed to the Story County Sheriff’s Office.

Confidentiality
Records identifying participants will be kept confidential to the extent permitted by applicable laws and regulations and will not be made publicly available. However, federal government regulatory agencies, auditing departments of Iowa State University, and the Institutional Review Board (a committee that reviews and approves human subject research studies) may inspect and/or copy study records for quality assurance and data analysis. These records may contain private information.

To ensure confidentiality to the extent permitted by law, the following measures will be taken: participants’ names will be replaced with their participant number and names will not be collected other than for informed consent reasons. Participant names will be associated with a code and key. Participant information will not be stored with the key and the key will be destroyed after data analysis has been completed. Only the research team will have access to the data and study records. Physical copies of the informed consent forms will be kept with one of the principal investigators and stored in a locked filing cabinet. The room of the principal investigator will be locked when the principal investigator is not in the room. The electronic data will be stored on a password protected external hard drive.

Audio recordings and field notes will be stored on an encrypted drive. Only the research team will have access to the encrypted drive. Specifics about the audio or who any identifying information will not be shared. Generalization of communications by all participants may be used for research purposes (i.e. 97% of participants developed a certain entry point plan, etc.).

Questions
You are encouraged to ask questions at any time during this study. For further information about the study, contact one of the principal investigators: Thomas M. Schnieders (tms@iastate.edu) or Zhonglun Wang (zhonglun@iastate.edu). Alternatively, you may contact the supervising faculty: Dr. Richard T. Stone (rstone@iastate.edu).
Consent and Authorization Provisions
Your signature indicates that you voluntarily agree to participate in this study, that the study has been thoroughly explained to you, that you have been given the time to read the document, and that your questions have been satisfactorily answered. You will receive a copy of the written informed consent prior to your participation in the study.

Participant's Name (printed) ________________________________

-------------------------------------------------------------

Participant's Signature Date