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The Effect of Asynchronous Data on Pilot-Controller Communication in a Dynamic Environment with Subject-Matter Experts

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THE EFFECT OF ASYNCHRONOUS DATA ON PILOT-CONTROLLER COMMUNICATION IN A DYNAMIC ENVIRONMENT WITH SUBJECT-MATTER EXPERTS

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Integrating Unmanned Aerial System (UAS) into controlled airspace may introduce communication challenges if there are time delays associated with the distribution of a common surveillance source of those UAS. Termed "information asynchrony" by Yuan et al (2012), an earlier, static image study showed large time delays had an observable impact on controller-pilot communication, but the effect was not present for time delays of less than 1 minute. A follow-up study is being conducted using an online ATC-flight simulator with professional pilots and controllers as participants. Effects on communication are being analyzed objectively through measurable characteristics of communication breakdown, and subjectively through trial questionnaire and survey. Limited results to-date showed no observable effects on pilot-controller communication with time delays of less than 100 seconds and illustrated the challenge of identifying measures robust to the inherent variability in working methods and communication styles.

Civil applications of Unmanned Aerial Systems (UAS) such as security surveillance, disaster response and aerial photography are steadily increasing. The Federal Aviation Administration's 5-year roadmap on the integration of UAS into National Airspace stated that more research will be needed on procedures and operating rules for UAS (FAA, 2013). Smaller, non-cooperative UAS, that do not have the capacity or desire to participate in traditional surveillance techniques (such as secondary radar, or ADS-B) are generating significant public and research interest. New technologies, procedures and operation rules being developed will need to take into account how surveillance data about these vehicles is distributed to both pilots and controllers. Asymmetric time delays, termed "information asynchrony" by Yuan et al (2012), can occur in the distribution of any surveillance data from a common source to a pilot and a controller. Challenges can arise if different surveillance sources are used, or there are time delays associated with the distribution of a common surveillance source.

Yuan et al (2012), in a preliminary study using static pictures and naïve university students as participants, showed that longer time delay values had a clear effect on pilot-controller communication. The operator with the most up-to-date information had a consistently better communication experience with less frustration, better communication effectiveness and performance. However, the method used had several limitations including the lack of time pressure on participants as a result of static radar displays, and the use of university students as participants lacking professional experience, knowledge and judgement.

In order to investigate the effects of information asynchrony at shorter time delays and address the previous study's limiations, a follow-up, dynamic study, with subject-matter-experts as participants has been developed and data-collection is ongoing. This paper reviews previous works on asynchrony, describes the experiment design and presents findings to-date.

Previous Work

There has been significant work in the past on asynchrony in the control loop with a majority of findings showing that latency in feedback can have detrimental effects performance such as increased errors and movement time in tasks involving target acquisition and telemanipulation (MacKensie 1993, Currie & Rochlies, 2004, Lum et al, 2009). This is also true in collaboration tasks, for example, where latency caused increased time to completion, and over and undershoot errors over targets during multiple robot manipulator control tasks, as well as collaboration breakdowns from jigsaw-puzzle task (Allison et al, 2004, Gergle et al, 2006).

In aviation, numerous studies have also looked into data asynchrony topics and found similar degradation effect on pilot-controller communication causing misunderstandings and degrading operator's performance. For example, Nadler et al. (2009) found increasing transmission delays on air traffic control communications can cause communication blocks and thus lapses in transfer of critical information due to simultaneous transmission between pilots and controllers. This was one of the identified causes to the Tenerife disaster (Nalder et al., 2009). Also, actual incidents such as the crash of a Eurocopter AS350 and Piper PA-32-360 due to NEXRAD weather imagery of more than five minutes old also serve as examples of the degradation effects of time delays (NTSB, 2011).

However, a limitation in these studies on asynchrony was that they were conducted with a singlular delay in the feedback loop, such as a delay in operator responding, or a one-way propagation delay in transmission. Little research has been done to date in the case of two or more parties receiving data from the same source with different latency applied. For example, surveillance data on non-cooperative objects (UAS, birdflocks) may be passed to a System Wide Information management (SWIM) architecture, where data may be processed through different system paths to be delivered to pilots and controllers. Each path will have different amount of inherent latency due to hardware, software, human operations and cognitive complexity in information processing (Yuan et al, 2013, Yuan and Histon, 2014). Consequently, pilots and controllers may have a different situation awareness due to the presence of information asynchrony; this would be expected to affect their communications (Yuan & Histon, 2014). Understanding the conditions (e.g. amount of time delay) that trigger such effects is important for the design of future surveillance distribution systems affecting the integration of UAS into controlled airspace.

A Dynamic Study of Information Asynchony

To address this challenge, a dynamic study utilizing experienced subject matter experts has been developed. The study uses a simulated environment to provide time pressure and is recruiting professional pilots and controllers as subject-matter experts. The research objectives of the follow-up study include: 1) to identify any observable effect of information asynchrony on pilot-controller communication applied to non-cooperative surveillance data, and 2) to identify if the effects differ between the pilot versus controller role, and 3) to identify if the effect depends on whether a participant is in the role that is ahead (no time delay applied) or behind (experiencing the applied time delay).

Methodology

In the study two subject matter experts are paired together to perform in an online simulator session while sitting at home using own choice of computers. One participant assumed the role of a pilot while the other assumed the role of a Terminal (TRACON) controller. By live-streaming a video broadcast of simulator displays, participants were provided a dynamic, real-time navigation display and ATC radar display for pilot and controller participants, respectively. They were instructed to communicate with each other to resolve a potential traffic conflict in each trial. In each trial a time delay value was applied to only the non-cooperative objects on one of the pilot or the controller's display.

Experiment Setup, Task Details, Scenario Design, and Time Delay Choices

A schematic of the experiment setup is shown in Figure 1. The experiment moderator interacts with the pilot and controller participant on the web from a physical lab room through Google Hangout. The web platform delivers the required simulator video feed separately to each participant.

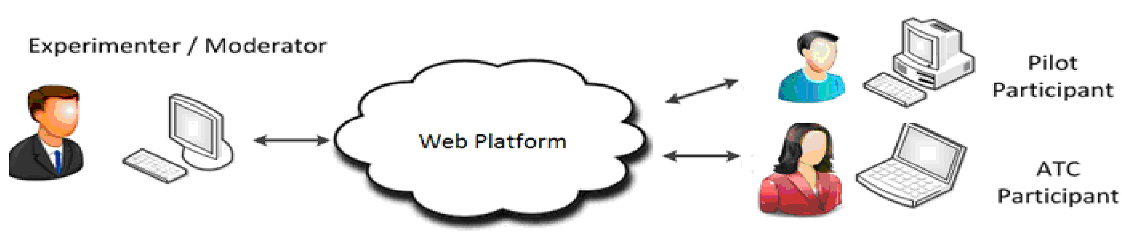

Figure 1. Experiment Setting in an Web Environment.

Participants began each trial reading a brief paragraph on the traffic situation of the scenario, customized for their respective role. Participants monitored their respective display and communicated with each other following standard procedures as they would do their in professional work. The controller participant was responsible for the safety of all airline traffic, while the pilot participant was responsible for the safety of their own aircraft. The goal for both parties was to avoid colliding with non-cooperative objects including UAS and birdflocks. Surveillance data consisted of normal airlines traffic (cooperative), UAS and bird flock (both non-cooperative). For each scenario, there were eight cooperative and four non-cooperative surveilance object. No weather data were presented in the study. The moderator implemented all commands given by the controller to the pilot participant and "imaginary pilots" of other airliners on the simulator.

Five departure and five takeoff scenarios were designed and each uniquely and randomly assigned to nine time delay values of (96c, 48c, 12c, 6c, 0, 6p, 12p, 48p and 96p) applied for each participant pair. The time delays were in seconds and the "c" and "p" designate either controller or pilot participant's screen has the delay applied to the non-cooperative objects. Two additional generic training scenarios, one arrival and one departure, were designed as well. Thus, for a simulator session, there were two training and nine formal trials.

Participants and Training

The required audience for recruitment included active or retired commercial pilots with at least commercial licence (CPL) or above, as well as active or retired air traffic enroute or terminal (TRACON) controller. As of March 1st, five groups (five pilots and five controllers with ages between 27-65) have participated in the study. The effect of gender was not controlled due to very few female participants signing up. Participants were paired based on schedule availability and did not previously know or have worked with each other. Training preparation included briefing documents and two training scenarios for familiarization of simualtor procedures. The training scenarios were repeated depending on participants' experience and familiarization levels.

Data Collection

Objective Data. Audio transcripts were collected for each trial. The transcripts were analyzed for indications of communication breakdowns including the number of phrases: 1) expressing conflicting understanding, 2) asking for clarifications, 3) seeking confirmations, 4) expressing confusion with respect to the traffic situation, 5) spoken in an urgent tone, 6) making direct "interventional" commands. Timing data was also extracted from the audio transcript showing when and the length of particular phrase of interest.

Subjective Data. A demographic questionnaire was administered to gather information on the background of each participant. A self-rated post-trial questionnaire was administered at the end of each trial, with 7-point Likert scale "agree-disagree" self-rating questions on 1) confusion, 2) awareness of own traffic situation, 3) awareness of other's traffic situation, 4) communication effectiveness, 5) controller's satisfaction with the pilot's reaction to the initial resolution from controller, or pilot's satisfaction with the controllers' issued initial resolution, and 6) controller's satisfaction on pilots reaction to final resolution from controller, or pilot's satisfaction to a controllers' final resolution . A post-experiment survey was administered asking about participant's insight and professional experience with information asynchrony.

Other Data. Latency data was collected as the simulation was done online, by using an online clock broadcasted on the participant screen to count out loud while noting down the discrepency.

Preliminary Results

For space reasons only examples of the objective communications data analysis are shown. For each trial, one coder listened to the recorded audio data and determined the total number of communication events, coding them according to the six categories discussed above. Due to the limited number of participants, initial results are presented in the form of box and whisker plots to emphasize the spread in the data collected to date. Boxes show the inter-quartile range (Q1-Q3) while whiskers show the minimum and maximum observed values.

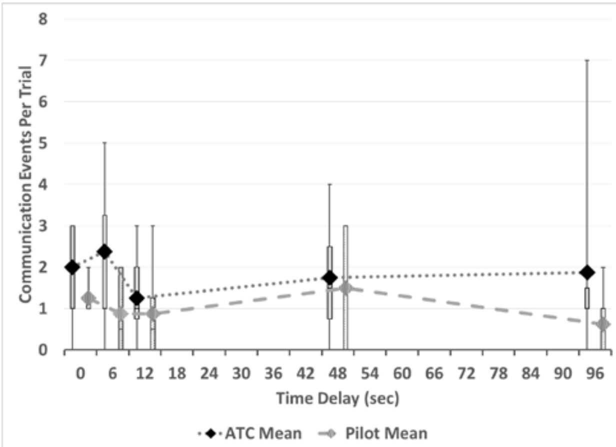

*Figure 2.*Communication rates per trial as time delay increases for pilot and controller.

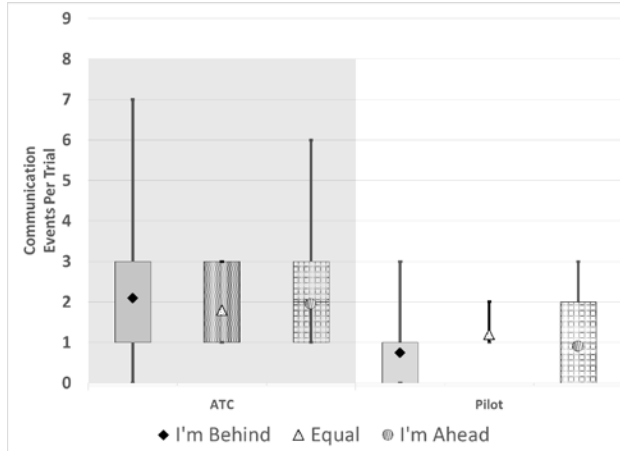

*Figure 3.*Communication rates per trial as time delay increases for pilot and controller grouped by behind , no delay, ahead.

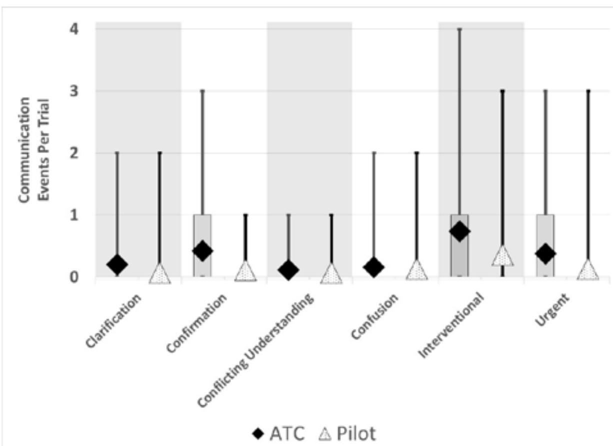

*Figure 4.*Communication rates per trial for pilot and controller grouped by individual types of communication events.

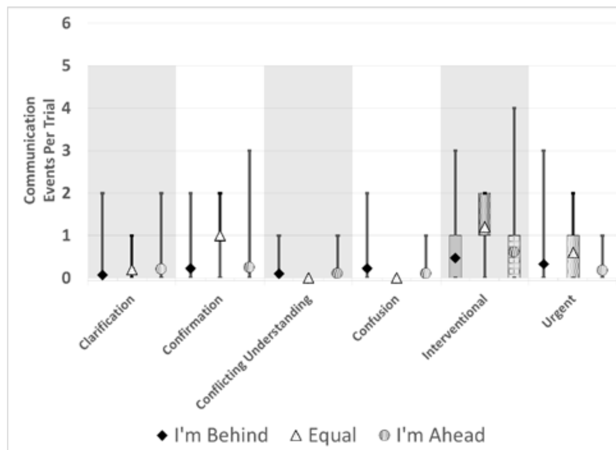

*Figure 5.*Communication rates per trial for each communication events overall, grouped by behind, no delay, ahead.

Figure 2 presents the average number of communication events per trial for all participants; results are shown separately for pilots and air traffic contollers. The time delay is in the x-axis and does not distinguish between which role (controller/ pilot) is experiencing the time delay. Three preliminary trends are found in the figure. First, the average number of communication events appears to be higher for air traffic controllers compared to pilots; this is not surprising given the traditional division of tasks between pilots and controllers.

Second, time delay does not appear to be having any impact on the total number of communication events, irrespective of the role (pilot / controller). This suggests the effects of time delay may be subtle, without causing dramatic changes in the communication behaviour. It may also be that the effects manifiests themselves more dramatically only in particular aircraft configurations (e.g. scenarios); this is an area that needs further investigation.

The relatively low number of events per trial suggests other, more sensitive, measures beyond the communication events analyzed so far also need to be considered. Alternatives such as examining each pairs event counts as a difference from the count in a baseline (no delay) condition will be considered in the future.

Third, the previous two points need to be considered relative to the wide spread in the results collected to date. There are wide absolute ranges (spread of whiskers) and large inter-quartile ranges in Figure 2. However,

Figure 3 also shows the challenges of representing low count discrete data with box plots as there are several places where the inter-quartile range is either non-existent (Q1=Q3) or the maximum observed value corresponds with Q3 and hence no whisker is visible. Alternative visualizations will be considered in future to show the spread of the observed rates.

Analyses are also being conducted to investigate the hypothesis that there may be differences in the effect of time delay depending on whether the participants is the one experiencing the time delay or not. A distinction is drawn for each participant between trials where they are receiving up to date data (e.g. not experiencing a time delay, "I'm ahead" in the following figures) and trials where they are receiving the delayed data (e.g. are experiencing a time delay, "I'm behind " in the following figures). As shown in Figure 3, results to date indicate there may be a slight effect for air traffic controllers with I'm ahead and I'm behind showing slightly higher average communication event rates. The situation is reversed for pilots, with equal time delays having the highest average communication event rate. What is also clear from Figure 3, is that the spread in the data collected limits the confidence in these effects until much more data has been collected.

In order to examine whether effects of time delay are limited to only a subset of the communication events, Figure 4 breaks out the rates of the individual types of communication events. Unsurprisingly, interventional events are the highest communication type for both air traffic controllers and pilots. When the rate of event types are examined with respect to time delay experienced (Figure 5), somewhat surprisingly interventional events are the highest in the no time delay ("Equal") condition. This is also true for the Urgent and Confirmation event types. More data collection, as well as examination of the association of specific scenarios with the no time delay ("Equal") condition, will be performed to investigate this further.

Discussion, Limitations, and Future Work

The limited results to-date showing no observable effect on pilot-controller illustrate the challenge of identifying measures robust to the inherent variability in working methods and communication styles. The limited results to-date showing no observable effect of time delay may point to several limitations of this study. First, only a limited number of pairs have been run. Second, it was very difficut to maintain a consistent procedure tailored to the collision designed into each scenario. This appeared to be due in part to the control strategies used by participants due to their different background, experience and training from region of work (e.g. Africa vs North America). Thirdly, the absence of the visual, out-the-window view for pilots, and the ability to listen to radio chatter from other aircrafts, limited cues for more accurate identification of object location and decision-making. Consequently, results to date have illustrated the challenge of discerning an effect due to the high variability in participant responses.

Finally, in a dynamic environment, it is now recognized that time delay may not have direct effect on communications. Rather, it has been recognized that time delay ultimately manifests itself in a difference in the physical location of an object on the display screen. Pilots and controllers directly observe the history and current positions of surveilled objects (assuming no out-the-window view) to form a mental model of the situation and behavior of the aircrafts (Reynolds, 2006). The change in physical location between displayed and 'actual' will be a function of the speed of the object; thus, rather than designing the experiment around consistent time delay values, it may be more appropriate to design for consistent screen distance impacts (e.g. pixel difference on the display screen as seen by participants). As screen distance depends on the speed of the non-cooperative object in question and the ratio of the size of the radar screen, limitations with online experiment environment, such as participants use of different monitors for the study, and fluctuating network latency, may have affected the accuracy of captured effect on communication mapped to each time delay measurement.

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