USE OF CONTINUOUS ZOOM ON ELECTRO-OPTICAL IMAGING SYSTEMS: COMPARISONS BETWEEN AUTOMATIC AND MANUAL TARGET TRACKING

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The use of continuous zoom in an electro-optical sensor system was investigated with respect to target tracking. Using a simulation of an operator-machine interface in an airborne multi-sensor surveillance system, targets were tracked by manually directing the sensor or by an automated tracker. It was hypothesized that frequency of using the continuous zoom would be higher in the manual tracking mode than in auto-tracking, and negatively correlated with tracking error. Sensor, and targets to be tracked, were either moving or stationary in three types of tracking scenarios. Results showed that the zoom function was used more often when tracking manually, although the way continuous zoom was used differed between the two tracking modes. Also, tracking error was lower when the zoom function was used in manual mode. Tracking error was additionally affected by whether or not the target and/or the sensor were moving or stationary. Results improve our understanding of the way complex sensor systems are used, and will assist in ascertaining whether providing a continuous zoom into optical imaging systems is of benefit to operators.

To enhance the capability of airborne search and rescue and surveillance multi-sensor systems are being developed in which several sensor types are housed in one gimball mounted on the undercarriage of an aircraft. Forward-looking infrared (FLIR) imagers and active-gated imagers (AGTV) are examples of sensors that are currently being developed in a multi-sensor suite. The integration of passive and active imagers results in adequate image contrast and resolution to support search and surveillance in degraded weather, where the effects of backscattering of light from haze, snow, or rain are problematic, as well as in low light, and in the presence of scattered light from street lamps. Thus, combining the capabilities of these sensors can effectively serve to extend search and surveillance operations beyond the limitations of conventional daylight.

Both sensors in the gimball are slaved together and view the same scene, and an operator-machine interface (OMI) depicts the images captured by the two sensors. The direction of the sensors is controlled by a single joystick and additional functionality is provided to the operator through a control panel.

Since the scene outside the aircraft is viewed on an interface with restricted field of view an airborne search using an electro-optical imaging system is very different from the traditional ‘out-the-window’ naked eye procedure. With sensors, locating and classifying an object of interest involves tracking a relatively small target on the interface image in a high vibration, moving vehicle. Thus, the image is continually changing and the operator may be viewing a scene very different from that seen by the pilot and other crew members looking out the window. The success of search and surveillance missions relies on accurate search and detection capability and it is essential to understand the factors that promote or hinder this process.

Although multi-sensor surveillance systems are intended to free operators from major environmental constraints and overcome the operational limitations of current low-light sensors, the added complexity of operating the sensor and controls and the challenge for operators to maintain situation awareness while viewing sensor images on an interface display, places high demand on the user. Furthermore, future generation multi-sensor systems will become more complex, supporting up to five sensors and including high-end technology enhancements such as Assisted Target Detection (ATD) and Mosaic Imaging (a form of image processing in which the resolution is high in the foveal field of view, and low in the surrounding peripheral area). A system that is difficult to operate increases the likelihood that attention will be diverted away from the task of the mission, jeopardizing the overall goal of the search and rescue or surveillance operation.

Auto-tracking

A primary objective throughout the design process of a complex sensor surveillance system currently being developed is to design an operator-machine interface that allows the system to be used effectively with a minimum of operator training and experience. An early recommendation, established through initial human engineering analyses, was to automate functionality where possible to alleviate workload demands on the sensor operator (McFadden & Shek, 1996). To this end a number of automated features were implemented, one of which is an auto-tracking function. When a target of interest is identified on the sensor image the auto-tracker can be activated to set the sensor to automatically track that specific target, thus freeing-up the operator to attend to other tasks and/or sensor image detail.

The alternative to auto-tracking is manual tracking, that is, using the joystick to directly control the direction the sensors are pointing to search an area of the scene or follow a target. Manual tracking may be more fatiguing for an operator since it requires constant control of the joystick and continual monitoring of the sensor position, but there are situations where it may be preferred over auto-tracking. For example, an operator may find manual tracking conducive to focusing attention on a specific search area or target of interest.

In short, electro-optical imaging systems can support two modes for tracking targets - automated and manual – both of which are used during search and surveillance missions. The objective of the planned study is to investigate differences between these modes when they interact with another feature of the multi-sensor surveillance system – continuous zoom.

Continuous sensor zoom

Although continuous zoom is available on electro-optical imaging systems research suggests that the function may not always be used by operators to its full potential. In a recent study investigating sensor field of view and operator performance, rather than using the entire span of field of view participants tended to limit use of the zoom to the extreme ends of the range available (Crebolder, Unruh, & McFadden, 2003). Also, during field trials operators have commented that zooming in and out using the continuous zoom on a sensor system is time consuming and they recommended that a rapid zoom out function be implemented. This sort of evidence questions the practicality of implementing a costly continuous zoom into a sensor surveillance system. However, preliminary work in our laboratory has also pointed to a possible benefit of having a continuous zoom. That is, operators might use the fine-tuning aspect on the zoom function as an aid in target tracking. Using a variable zoom to assist in keeping a sensor directly on target, may be especially useful if the target itself is moving. Overall, these initial findings suggest that further research be conducted to ensure that implementing the added complexity of a continuous zoom in electro-optical imaging systems is beneficial to an operator.

Objective

One objective of this study was to investigate whether the continuous zoom function is used differently under manual and auto-tracking conditions. We hypothesized that the zoom function would be used as a tool to support tracking a target in the manual condition but that it would be of little use when tracking was automated in the auto-track condition. As obvious as this latter statement may sound it is nevertheless necessary to provide statistical evidence supporting even the most basic assumptions since we do not know how operators use many of the tools provided to them in this relatively new application. Therefore, the usefulness of continuous zoom must be evaluated in the context of all possible functionality. There are other tasks in which it is perhaps more likely that continuous zoom would be used while in auto-tracking mode – such as a search task where the zoom function can be used to get a closer look at a target of interest. However, since the focus of this study is on target tracking, and two modes for target tracking exist, both modes are included in the analysis.

An additional objective of this work was to investigate tracking accuracy as a function of whether or not sensor and targets were moving or stationary. Three different scenarios were created to simulate various combinations of static and dynamic target and sensor. They were: i) target stationary and sensor moving; ii) both target and sensor moving; iii) target moving and sensor stationary. The first two scenarios were designed to simulate surveillance of ground targets from the air, the third was included to simulate instances where a sensor system is mounted at ground level and is stationary. We hypothesized that the moving target_moving sensor condition would be most challenging and that no significant difference between the other two conditions would be observed.

METHOD

Participants

Eighteen individuals participated in the study. Participants were civilian and military employees and undergraduate students from a local university. All were 18 years of age or older with normal or corrected-to-normal vision. Participants were reimbursed according to Defence Research and Development Canada Human Research Ethics Committee guidelines.

Apparatus

A prototype simulation consisting of a sensor image interface, sensor controls, and simulated airborne terrain was used (see Figure 1).

Figure 1. Simulator Workstation and Operator Interface

Though the simulation interface normally represents two sensor images only the upper window was required for this experiment and the lower window was blacked out. A second window in the top right area accommodated a 2-dimensional moving map display representing the terrain over which the aircraft was flying. The moving map also provided information regarding the location of the sensor footprint and the location of the aircraft. A main joystick, mounted at desk height, was used to control the direction the sensor was pointing (azimuth and altitude), and a trigger on the front of the joystick was used to mark, or 'designate', targets. Participants used the joystick to direct the sensor over the terrain and a cursor on the screen showed where the sensor was pointing. A secondary joystick on the left of the control panel was used to control the continuous zoom of the sensor. The zoom field of view ranged from 5° to 40°. The target stimulus, embedded in the ground terrain, was a 3D image of a white Hummer military vehicle from the FACETS models library (CG2 Incorporated, 2001). Hardware included a dual Intel Xeon 3.6GHz central processing unit with 4x1GB random access memory, using a 256MB Gforce 6800 video card, and running Windows XP Professional (Service Pack 2). The participant was seated 60 cm in front of a 20" liquid crystal display monitor that displayed the interface on the full screen.

Procedure

After a general introductory session to familiarize participants with the system and the task, 6 experimental sessions were conducted (2 tracking method conditions x 3 target/sensor movement conditions), counterbalanced for order across participants, and divided over 2 days. Each of the 6 individual experimental sessions was preceded by a practice session.

Within each of the 6 sessions eighteen targets were tracked. Each target tracking began with operator control disabled while the simulation aircraft flew to the general location of the target. The moving map display then blinked to indicate to the operator that he/she should take control of the joystick and place the cursor as close to the center of the target as possible. Once this task was accomplished the participant was to 'designate' the target using the trigger button on the joystick. For consistency, to ensure that target tracking always began from the same zoom level, the simulation would not begin until the operator zoomed out to the widest field of view (40°) at this time. This procedure initiated movement of the sensor and/or target and participants then began tracking by keeping the cursor as close to the center of the target as possible. In the case of auto-tracking the auto function was enabled automatically after the zoom out. In both manual and auto-tracking participants were in control of the zoom function once the tracking scenario began.

The tracking task ended when the target changed colour, from white to black, at which time participants were to again 'designate' the target, this time as quickly as possible. Although included in both manual and auto-tracking conditions, the target colour change was incorporated primarily to encourage participants to focus on the target during the auto-track condition when attention might otherwise wander. After the target had been 'designated' operator control was disabled and the aircraft flew to the next target. The duration of the target tracking times was varied and counterbalanced across the 18 targets (15, 30, 45, 60, 75 or 90 seconds). To control for potential bias in tracking the direction of movement of target and sensor was random within each condition with an equal ratio of clockwise to counter-clockwise.

In the manual condition participants were instructed to use the joystick to direct the sensor cursor so that it tracked the target as closely as possible, and to respond as quickly as possible to the target changing colour. In the auto-track condition participants were simply instructed to respond as quickly as possible to the target changing colour. Participants were also instructed to use the zoom as they wished in both conditions.

RESULTS

Field of view, and heading and pitch of the sensor were recorded at every time step amounting to ~20 samplings per simulation time unit (STU). Targets outside the range of the widest field of view (i.e., deviations greater than 20°) were flagged and inspected visually to determine a) if the target had been lost during tracking and not recovered or (b) if an incorrect object had been tracked. Two targets from the manual condition and two from the auto-track condition were subsequently removed from the data set.

Performance metrics

To look at the distribution of raw field of view values, ranges were created for every five degrees for each of the two tracking conditions (Figure 2). As seeen in Figure 2 field of view was set most frequently to the narrowest levels (5°- 10°) in the auto-tracking condition whereas in the manual condition the extreme settings of 5°- 10° and 35°- 40° were most often used.

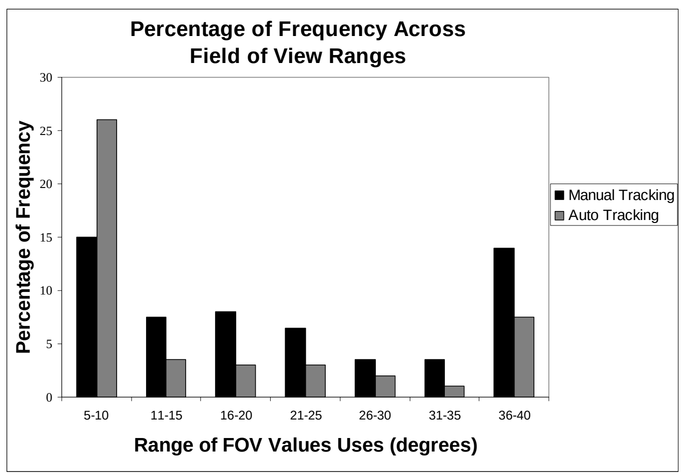

Figure 2. Percentage of total frequency of use of the continuous zoom use across field of view

Frequency of using the zoom function was determined by the number of times field of view was changed across time. Use was calculated using the following formula, where Δ represents the change in field of view over 10 STUs (simulation time units do not have equal intervals between samples) or approximately 500 ms:

$$\textit{Zoom Use} = \Delta\mathrm{FOV} / \Delta\mathrm{STU}$$

A frequency variable was calculated by assigning 1 to all Zoom Use values that were above a predetermined threshold, and 0 to all Zoom Use values below *(*Zoom

NonUse). The threshold value was determined through stability testing of the change in field of view and was implemented to control for inherent noise produced by the zoom lever on the control panel.

Zoom Use

Cell means for Zoom Use and Zoom NonUse for each mode of tracking (manual/auto-tracking) and each of the movement combinations (stationary target_moving sensor; stationary sensor_moving_target; moving target_moving sensor), for each participant were entered into a repeated measures analysis of variance (ANOVA). A significant effect of tracking mode was observed with zoom being used significantly more in the manual tracking condition (Mean Zoom Use = .128) than in the auto-tracking condition (Mean Zoom Use = .076) [F (1,17) = 9.39, p < .007, MSe = .007], as shown in Figure 3. In addition, a significant main effect of movement was found [F (2,34) = 5.49, p < .009, MSe = .026] showing highest Zoom Use in the moving sensor_moving target condition (Mean Zoom Use = .131, with no interaction between tracking mode and movement condition observed [F (2,34) = .393, p > .677, MSe = .002]

Further analysis revealed that the effect of movement was limited to the manual condition and that Zoom Use in the moving target_moving sensor condition was significantly higher than in the moving target_stationary sensor [$t_{(17)}$ -2.188 p < .044], and the stationary target_moving sensor conditions [$t_{(17)}$ -2.551 p < .022]. There was no difference in Zoom Use between the latter two movement conditions [$t_{(17)}$ -.473 p > .641]

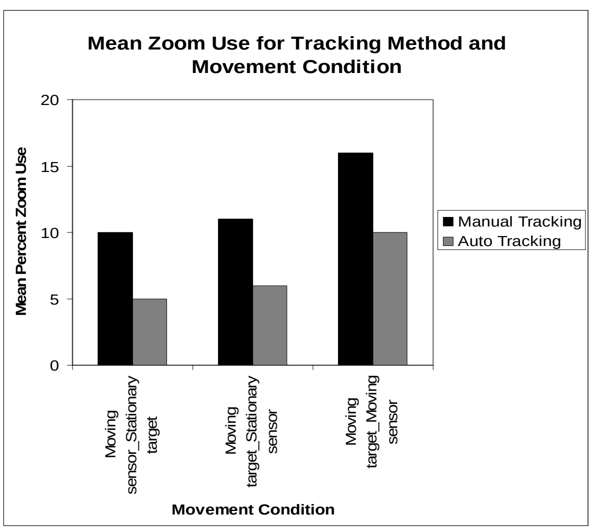

Figure 3. Mean FOV Use for Manual and Auto-tracking for each Movement Condition

Tracking deviation

Tracking performance was assessed by an absolute ground tracking deviation score representing the distance between the sensor cursor to the centre of the target. The tracking deviation score (Θ_{total}) was calculated using the following formula, where Θ_h and Θ_p are the heading (horizontal) deviation angle and the pitch (vertical) deviation angle respectively:

$$\Theta_{total} = (\Theta_h^2 + \Theta_p^2)^{1/2}$$

Mean deviation scores for each participant for each tracking condition and each movement condition were entered into a repeated measures ANOVA. A significant difference between tracking mode was observed in which overall deviation was greater in the manual tracking condition than in auto-tracking (manual M = 1.33; auto-tracking M = 0.24) [F(1,17) = 141.382, p < .0001, MSe = .223]. This difference was expected since little variation exists in system tracking. Consequently, the auto-track condition produced a baseline.

Further analysis was limited to manual tracking where tracking deviation in the moving target_moving sensor condition (M = 1.72) was significantly higher than in the stationary target_moving sensor (M = 1.09) and the moving target_stationary sensor conditions (M = 1.18) [$t_{(17)}$ = -5.401, p < .0001; $t_{(17)}$ -3.802, p < .001 respectively], as shown in Figure 4. No difference was observed between the stationary target_moving sensor and stationary sensor_moving target conditions [$t_{(17)}$ = -1.156, p > 2.63].

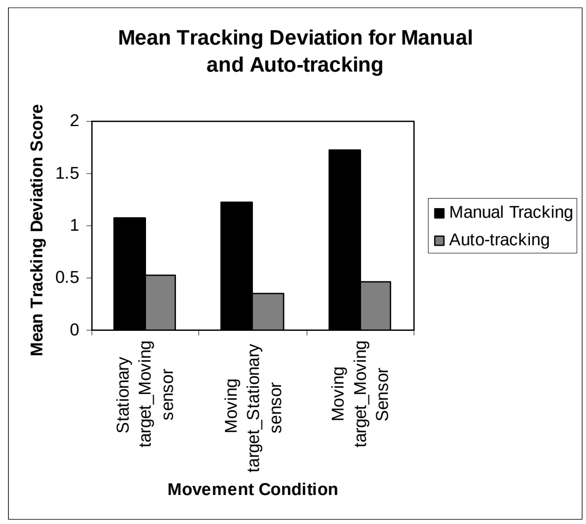

Figure 4. Mean Tracking Deviation Score for Manual and Auto-tracking for each Movement Condition

Analysis of Tracking Deviation and Zoom Use

For the manual tracking condition, cell means for tracking deviation for Zoom Use (Zoom Use/Zoom NonUse) and the three movement conditions, for each participant, were entered into a repeated measures ANOVA. A significant main effect of Zoom Use revealed that deviation error was less when zoom was used than when it was not [F(1,17) = 66.30, p < .001, MSe = .344]. Also a significant main effect of movement was observed [F(2,34) = 17.26, p < .0001, MSe = .059] with no interaction between Zoom Use and movement [F(2,34) = 2.174, p > .128, MSe = .094]. Zoom was used significantly more frequently in the moving target_moving sensor condition (M = .31) than in the stationary target_moving sensor (M = .14) [$t_{(17)}$ = -3.423, p < 004] or the moving target_stationary sensor conditions (M = .15; [$t_{(17)} = -3.598$, $p < .003$].

DISCUSSION

Frequency of use of continuous zoom in a simulated airborne sensor was examined as a function of tracking performance in manual and auto-tracking modes. Participants were required to track a target manually using a joystick to direct the sensor cursor over a target or to monitor auto-tracking, and report on a change in target colour. Preliminary work had suggested that operators may use a continuous zoom function on a sensor system like the one used in this simulation, as an aid to staying on target during tracking. If that is the case, we might expect continuous zoom to be used more frequently in the manual condition, and to be negatively correlated with tracking deviation where the operator has control of directing the sensor. These two hypotheses were supported in this study. Frequency of use of the zoom function was higher in the manual condition and tracking deviation was less when continuous zoom was used.

Although the continuous zoom was used less frequently during the auto-tracking condition the zoom function was not ignored entirely. Participants most frequently used the narrowest field of view (5°- 10°) suggesting perhaps that they preferred to be zoomed in to detect the change in target colour more easily. Note that the percentage of time the zoom function was used in the auto-tracking condition includes zooming in to an end point, which would include this 5°- 10° point. Differences in use of field of view as it relates to alternating between zooming in and zooming out, and as it relates to zooming in over a long range to reach a point and stay fixed at that particular field of view, need to be teased out in further analyses.

In manual mode the results generally support the trend noted in past research (Crebolder, Unruh, & McFadden, 2003) where operators were inclined to use the extreme field of view settings rather than intermediate values. However, though we hypothesized that the zoom function might aid in target tracking participants commented that they used the zoom function in the manual tracking task because of occasions when the target was in jeopardy of moving out of view on the screen if the field of view was narrow. By zooming out the target could be visually recaptured more effectively. Thus, though this experiment showed that tracking deviation was less when the zoom function was used the reasoning behind why that result was observed cannot be determined to support the conjecture that zoom use would directly aid in target tracking.

Tracking performance can obviously be affected by the instrument used to control tracking movement. Participants commented that the gain in the displacement joystick used in the study was relatively large and that movement of the joystick did not always transfer to movement of the cursor without considerable lag. Also, variables inherent to the airborne mission that undoubtedly impact human performance, such as vibration and poor lighting, were not simulated in this study. Future work will investigate the use of different types of controllers using search and tracking tasks within an environment that more closely simulates typical environmental characteristics of an airborne operation.

The objective of the current work was to investigate two aspects of sensor systems, tracking and continuous zoom, under various simulated scenarios. Findings showed that frequency of using the zoom function, and the range of zoom used, was not the same across both tracking methods. The observation that minimum and maximum field of view were used more frequently than intermediate settings, at least in manual tracking, questions the value of providing a continuous zoom function when in fact a less costly discrete mode of varying field of view might be sufficient. Secondly, tracking performance was related to frequency of using the zoom function. However, although we anticipated that the continuous zoom function might be used as an aid to keeping the sensor cursor centered on the target we cannot conclude from this study that this is in fact why participants used the zoom. There may be other, more practical reasons for using the zoom function, such as increasing field of view to keep a target in sight. The results offer insight into the way in which operators use these complex systems, and assist in determining the attributes of multi-sensor systems related to optimizing human performance.

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