Chapter 12 – SWE-2: SUPERVISORY CONTROL OF UGVs FOR TACTICAL RECONNAISSANCE

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12.1 DATES

1 December 2007 – 28 February 2008.

12.2 LOCATION

FOI, Linköping, Sweden.

12.3 SCENARIO/TASKS

The operator's task was tactical reconnaissance along the route of advance for a convoy to locate and neutralize mobile threats in a simulated urban environment. The convoy consisted of 15 vehicles that advanced along a fixed route that was about 1.7 km long. Along the convoy's route of advance were 28 mobile threats that either crossed or came near the route of advance. The operators performed the tactical reconnaissance using either six or twelve UGVs that autonomously searched for the mobile threats within designated areas, as well as detected and tracked the mobile threats. The operator controlled the UGVs by allocating them into search group and designating search areas for groups of UGVs. Detected threats were neutralized by simply clicking on the threat's icon in the control station's interface. Performance was measured by the number of hits that the mobile threats inflicted on the convoy when the vehicles were within weapon range.

Figure 12-1 shows an example of interface. The pane on the left was used for allocating UGVs into colour coded search groups and selecting groups for designation of search areas. Six search groups were available in both conditions, whether the tactical reconnaissance was performed using six or twelve UGVs. After selecting a search group, the operator drew the search area on the map to the right. The map could be scrolled and zoomed in and out any time during a trial. The position of the convoy vehicles, UGVs, and detected threats where indicated on the map. The detection of threats was also indicated by changing the icon colour of the corresponding UGV in the left pane and sounding an auditory alarm. Convoy vehicles that were recently hit by a threat were also indicated.

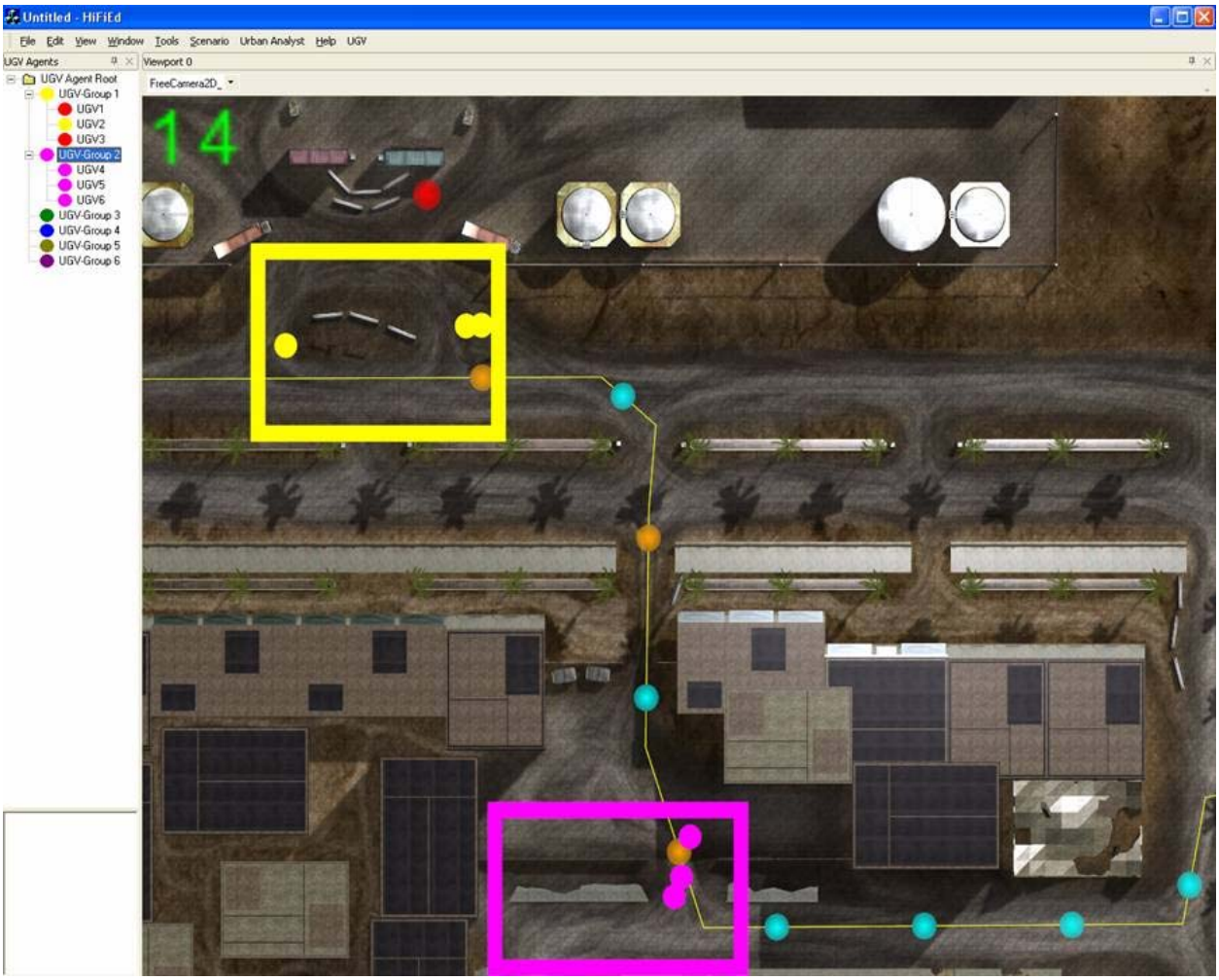

Figure 12-1: Example of the Operator Control Station. The blue circles indicate convoy vehicles. The yellow and pink circles indicate UGVs in colour coded search groups. The red circle (encircled in white for clarity) in the upper-left corner of the map in the industrial area shows a mobile threat approaching the convoy. The UGVs that detect the threat have a red icon in the left pane. Convoy vehicles that were recently hit by a mobile threat are shown with an orange colour.

12.4 TECHNOLOGIES EXPLORED

A partly autonomous search function for multiple UGVs was investigated that minimize the time for capture rather than guaranteeing capture [3]. The algorithm simplifies the search problem by composing the environment into convex cells where an UGV that enters the area of a cell can always detect any threats that are present within the cell. Initially, there is an equal probability that there is a threat within all the convex cells within a search area. Over time, however, these probabilities change depending on the connections between adjacent convex cells and which cells the UGVs visit. The algorithm prioritizes which adjacent convex cell to visit using a heuristic entropy function that minimizes the entropy over five consecutive cells starting from the UGV's current cell.

12.5 HUMAN FACTORS ISSUES EXPLORED

There are many potential applications for robotic systems that are only feasible if one or a few operator can simultaneously control several robots. One way to enable such multi-robot systems is to use partly autonomous functions where the robots can maintain an acceptable performance level even when unattended to by the operator. However, similarly to many automated systems, partly autonomous functions are most successful in applications that only require limited interaction between the operator and the autonomous function (e.g. [4]). Applications that require much interaction are more likely to have human-robot coordination problems. An important factor for the interaction are the dependencies between the task that operator performs and the task that the partly autonomous function performs. Tasks with only weak dependencies are more likely to be more suitable for multi-robot systems than tasks with strong dependencies [5].

The purpose of the study was investigate how the operators perceived the dependencies between the designation of search areas and the partly autonomous search function in a representative urban environment. With weak task dependencies, an increased number of UGVs for tactical reconnaissance should reduce the number of hits on the convoy without any significant effect on the operator's task. Weak task dependencies were expected since search tasks generally have weaker dependencies than other tasks, such as navigation [1]. Please see Svenmarck et al. [1] for more information about the study.

12.6 UNMANNED SYSTEMS USED

Six or twelve simulated UGVs.

12.7 SUMMARY OF ANY NATO COMMUNICATIONS/COLLABORATIONS/ INTERACTIONS

The results of the study have been presented at Task Group meetings, as well as at conference sessions arranged by Task Group members [1],[2]. The following table summarizes the extent of the NATO collaboration.

	Planning/Design	***Execution***	***Analysis***
Communication			*X*
Coordination			
Collaboration			

12.8 SUMMARY OF TD RESULTS

The results show that increasing the number of UGVs from six to twelve reduce the numbers hits on the convoy by 25%, due to a 26% increase in detected threats and a 33% increase in neutralized threats. Subjectively, the operators also reported higher situation awareness as measured by 3D-SART. More importantly, these benefits were achieved without any detrimental effects on the mental workload as measured by NASA-TLX. Overall, the operators used fairly large search areas and a uniform allocation of the number of UGVs into search groups.

12.9 LESSONS LEARNED

Typical issues in control of multi-robot systems can be investigated in a laboratory environment without experienced operators, although care should be taken when interpreting the results.

12.10 STUDY CONSTRAINTS/LIMITATIONS

The operators were college students and thus rather naïve towards the complexity of tactical reconnaissance.

12.11 CONCLUSIONS

The results show that partly autonomous functions can improve the operator to vehicle ratio in a military environment if there are weak dependencies between the task that the operator performs and the task that partly autonomous function performs. However, the task dependencies also partly depend on the operators' task experience, as well as the formal task properties. The operators' control strategy shows that they were rather naïve towards the complexities of tactical reconnaissance. More experienced operators may therefore find different task dependencies.

12.12 FUTURE RESEARCH NEEDS AND PLANS IN THIS AREA

One future research need is better theories for conceptual evaluation of task dependencies to reduce the need for empirical investigations when introducing partly autonomous functions. Future studies may also investigate suitable control strategies for comparison with operator performance, as well as to support the operators' control decisions. Finally, mixed-initiative control may be investigated by varying the operators' degrees of freedom in designating search areas. There are currently no plans for future research, however.

12.13 ACKNOWLEDGEMENTS

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12.14 REFERENCES

[1] Svenmarck, P., Andersson, D., Lindahl, B., Hedström, J. and Lif, P. (2009). Tactical reconnaissance using troops of partly autonomous UGVs. In *Proceedings of HCII 2009, 8th International Conference on Engineering Psychology and Cognitive Ergonomics* (pp. 326-335). San Diego, CA.

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