Adaptive training simulation using speech interaction for training navy officers

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ABSTRACT

An important element of the Royal Canadian Navy (RCN) Future Naval Training System Strategy is the deployment of technology enabled learning systems allowing for acquisition of knowledge and skills using a variety of shore-based multipurpose and reconfigurable simulators, as well as at sea embedded simulators. The RCN has a strong culture of one-to-one relationship between instructors and trainees while trainees use simulators. This close relationship allows for direct feedback to trainees, and individualized assessment. With the increased access of distributed learning opportunities in the form of part tasks trainers and serious games, trainees will benefit, and should be encouraged to acquire knowledge, and practice skills in a self-directed manner, outside the context of a supervised simulation session supervised by an instructor. However, the ubiquitous individual access to learning programs should continue to provide immediate feedback to trainees, and allow instructors and course developers to monitor learning. Fulfilling both objectives requires the relevant capture and analysis of learning events. In this context, our particular project focuses on Maritime Surface and Sub-Surface Officer (MARS) training using serious games, capturing learning event data to leverage them for adaptive training, and self-directed learning using learning assessment dashboards. The project is at an early development stage and aims to provide high realism for the officer of the watch (OOW) through speech interactions with simulated agents including a naval communicator, helmsman, range finder, commanding officer, and a guide ship. The training program focuses on the acquisition of conning skills. The paper presents some conceptual foundation for this program, as well as the first training module aimed at demonstrating the feasibility of a speech interaction interface for conning in the context of a manoeuvre scenario. The paper also outlines the intended adaptive training specifications to be implemented in a second project phase, and indicates areas of future work.

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INTRODUCTION

An important element of the Royal Canadian Navy (RCN) Future Naval Training System Strategy (RCN, 2015) is the deployment of technology enabled learning systems allowing for acquisition of knowledge and skills using a variety of shore-based multipurpose and reconfigurable simulators, as well as at sea embedded simulators. Simulators provide safe environments to acquire knowledge and skills required by the rapid changes of threat and associated operating environments. They also support a continuity of learning conditions from simple procedures and task acquisition by an individual, to distributed network simulations involving teams and units. However, simulators are often costly to acquire, maintain, and provide only a limited scheduled access to trainees. The increased prevalence of networked laptops and smartphones provides an opportunity to increase trainees' access to learning technologies. Training accessible through these devices would allow trainees to acquire knowledge and practice skills in a self-directed manner, outside the context of a simulation session. Currently, the RCN has a strong culture of a one-to-one supervision by instructors as trainees use simulators. This close relationship allows for direct feedback to trainees and for individualized assessment. Any ubiquitous learning system should continue to provide immediate feedback to trainees, while allowing instructors and course developers to monitor their learning. Fulfilling both objectives requires the capture and analysis of learning events.

There are many issues associated with the deployment of ubiquitous learning systems. Here are just some of them: hardware infrastructure required to provide just in time and easy access to training opportunities; knowledge transfer potential of part task trainers and serious games; adaptive training, and proper pedagogical support for both trainees and instructors. The current paper does not intend to discuss all of these issues, but rather focuses mostly on the conditions for knowledge transfer, and the progress we have made in demonstrating the feasibility of a serious game designed for RCN Maritime Surface and Sub-Surface Officers (MARS) training on communication and conning skills during a formation manoeuvre. The project started in December 2015, and is still at an early stage of development. The first phase of the project ended in March 2016, and the content of this paper discusses the analysis and observations made during this time period.

The first section of the paper presents some of the problems the project is seeking to solve. The following sections are devoted to addressing the different aspects of the problem statement, namely: 1) the relations between ubiquitous learning, training simulations, and serious games, and 2) the demonstration of the feasibility of a bridge simulation for officer of the watch (OOW) training. Finally, a conclusion outlines future work.

PROBLEM STATEMENT

One goal of the RCN-ULEARN project is to deliver to the RCN a proof of concept of a ship's bridge ubiquitous learning application which focuses on competencies and training requirements, self-paced part-task training support using serious game concepts, and learning analytics to foster self-directed learning in trainees and provide instructors with monitoring capabilities. Providing access to anytime, anywhere training opportunities carries the prospect of increase training efficacy and efficiency for personnel readiness. In the first phase of the project, the objectives are to reduce some of the technology development uncertainties. The following paragraphs present the main problems/questions the project was seeking solutions/answers to, as well as the objectives and actions undertaken towards resolution.

A second goal of this project is to help the RCN become a more informed customer with regards to ubiquitous learning solutions, simulations, and serious games so that it can more accurately identify its requirements. To this end, embedded throughout this paper are several instructional design, technical, and software development considerations that can inform future technology enabled learning procurement projects.

What could ubiquitous learning mean for the RCN, and how does it relate to trends in training simulation? The availability of ubiquitous learning options is one of the pivotal elements of the RCN future naval training strategy. In this project, we carried out a literature review on the topic to identify the main characteristics of ubiquitous learning, and how it relates to trends in training simulations. An answer to this question allows us to determine to the extent to which the technology developed can be considered ubiquitous.

What should a serious game for OOW training look like? It was initially decided to implement a relatively complex scenario whereby a trainee would manoeuvre his ship from astern to the starboard quarter of a guide ship as an early test of the feasibility of using speech to control a simulated ship and to interact with simulated agents on the bridge. Instead of designing a proof of concept around a simple task, we opted to develop a relatively complex simulation so that we could better assess the various success factors that make up a ubiquitous modern learning application. The analysis showed that given the nature of the learning objectives, effective speech recognition and synthesis were essential elements to meet the required level of fidelity for a gamified simulation. Furthermore, it was also identified that having a modularized architecture that integrates various applications for learning analytics, speech recognition, and image generation were also important elements for RCN ubiquitous learning solutions. Given the strong viability of the ubiquitous learning proof of concept designed in the first phase, the second phase of the project is looking at furthering this proof of concept by using gamified simulation to deliver instruction using adaptive learning principles. To this end, a serious game is being developed to instruct trainees, with no prior knowledge of conning, to learn a fundamental OOW skill, which is to con a ship so that it turns to port and starboard, and adjusts its speed (i.e. issue engine orders) using speech conventions.

UBIQUITOUS LEARNING, TRAINING SIMULATIONS, AND SERIOUS GAMES

Ubiquitous learning is a new educational paradigm made possible in part by the affordances of digital media, and mostly by mobile computing. Ubiquitous learning or u-learning is defined as a counterpart to the concept of ‘ubiquitous computing’ which seeks to put the needs and dynamics of learning ahead of the technologies that may support learning (http://ijq.cgpublisher.com). U-learning has been characterized as learning anywhere, anytime and as closely associated with mobile technologies (Education 2025, 2011).

The most significant role of ubiquitous computing technology in u-learning has been in the construction of ubiquitous learning environments which enable anyone to learn any place, at anytime (Yahya, Arniza Ahmad, & Abd Jalil, 2010), providing intuitive ways for identifying the right learning collaborators, the right learning contents, the right learning services, at the right place, at the right time, based on a learner's surrounding context (Ogata & Yano, 2004; Zhang, Jin, & Lin, 2005). Ubiquitous learning environments provide inter-operable, pervasive, and seamless learning architectures to connect, integrate, and share learning resources, learning contents, and learning services (Yang, 2006). A summary of u-learning definitions gathered by Yahya (Yahya et al., 2010) from a selection of journal articles and conference proceedings found considerable overlap between the definitions, and five key characteristics of u-learning:

- Permanency: Learners can never lose their work unless they purposely remove it.
- Accessibility: System access via ubiquitous computing technologies.
- Immediacy: Learners can retrieve their own data (performance, learning, remediation) immediately at any time.
- Interactivity: Learners can interact with peers, teachers, and experts efficiently and effectively through different media.
- Context-awareness: The environment can adapt to the learners’ real situation to provide appropriate learning information.

Trends in training simulation include high level of realism, interoperability, reduced hardware footprint (Frost and Sullivan, 2015; Rambeau, 2014), augmented reality, virtual reality, intelligent agents in simulation, live, virtual, and constructive (LVC) training, mobile solutions for military training, and on demand training solutions as a service (Lowendahl, 2015; Rambeau, 2014). In general, defence agencies have demonstrated greater adoption of simulations rather than games but gamification is having some impact in some countries, mostly in army training. To date, the emphasis for training has been placed on high-fidelity simulations, while serious games have low-to-mid levels of fidelity. These fidelity differences are correlated with other features, which as a whole produce different value propositions for high-fidelity simulations and serious games. Some important differences between serious games and simulations in relation to the use of serious games in ubiquitous learning are presented in Table 1 below. Both serious games and training simulations are intended to provide instructions, in contrast to games, which are purely for entertainment (Sauvé, Renaud, Kaufman, & Marquis, 2007).

Table 1. Training Simulations and Serious Games

Training Simulations	**Serious Games**
High(er) fidelity (perceived)	Low(er) fidelity (perceived)
High(er) cost	Low(er) cost
Specialized hardware	Common hardware
Limited access by trainees	Ubiquitous
May not be engaging	Engaging by design
Evidence of effectiveness	Limited evidence of effectiveness

The foregoing suggests that high-fidelity simulators would be ideal to support transfer to the real world. Indeed, there is evidence to support the use of simulators for skill and ability training in a multitude of contexts ranging from health and medical practitioner development (Cook et al., 2012) to pilot and flight training (Carretta & Dunlap, Ronald, 1998). However, differences in simulation design and in study methodology, as well as methodological flaws and the complexity of transfer produce a wide variety of transfer effectiveness results (Borgvall, Castor, Nählinder, Oskarsson, & Svensson, 2007; Brown, 2010; Carretta & Dunlap, Ronald, 1998; Cook et al., 2012). This is why it is necessary to understand the factors that support learning transfer so that individual simulations (or games) can be designed to maximize it.

Generally speaking, the accepted wisdom is that games increase learner engagement, motivation, and explorative behaviour, particularly for millennials and younger learners who have grown up playing video games (Abdul & Felicia, 2015; Boyle et al., 2016; Hainey, Connolly, Stansfield, & Boyle, 2011; Nadolny & Halabi, 2016; Phillips, Horstman, Vye, & Bransford, 2014; Whitton & Moseley, 2014). However, while there is some evidence of effective skill transfer in the case of simulations, there is minimal empirical evidence in the case of games (Stevens, Ortiz, Reinerman-Jones, & Maxwell, 2015). As with simulation research, methodological differences abound and the research appears to be problematic: worthwhile pedagogical metrics are lacking, assessment methodologies are weak, and data tends to be anecdotal or subjective rather than empirical and experimental (Hays, 2005; Stevens et al., 2015).

One of the critical underpinnings of learning, especially skill acquisition, is practice. The more time is spent performing the task, the more performance improves, as long as proper performance feedback is available. This suggests the best way to maximize the return on a computer-based training asset is to maximize the amount of the time trainees spend using it. Currently, the strong focus on mid to high-fidelity computer-based simulations for training requires expensive hardware and software to support visual (and sometimes motion) fidelity. Typically, the higher the fidelity, the more expensive the training system will be. The more expensive the system, the less accessible it is to trainees. And of course, since practice is crucial to performance improvements, the less accessible it is, the less it supports performance improvement. Consequently, even if high-fidelity simulations are potentially beneficial, the little amount of time a trainee spends using them limits their impact on learning. The intent underlying the new educational paradigm of ubiquitous-learning is to dramatically increase access to computer-based learning. Beside the need for reduced hardware footprints, and mobile solutions, the field of training simulation has been focusing mainly on high fidelity and has few common characteristics with ubiquitous learning. Serious games, on the other hand, have more in common to ubiquitous learning, mostly in regard to accessibility. The next section describes our efforts to develop a serious game for OOW.

A SERIOUS GAME FOR OFFICERS OF THE WATCH

The main objective of the project is to develop a serious game for the RCN (MARS) officers, capturing learning events data to leverage them for adaptive training, and self-directed learning using learning assessment dashboards. The system developed should provide high realism for the OOW through speech interactions with simulated agents including the naval communicator, helmsman, range finder, commanding officer, and guide ship. The training content consists of conning orders, and OOW manoeuvre scenarios or varied difficulty levels. The adaptive selection of the next training challenge is based on an assessment the trainee's achieved part task competencies or mastery level. The design, measurement, and assessment of trainees' performance using learning analytic methods are closely guided by subject matter experts and will be validated using human subject data.

The project started in December 2015, and is still at an early stage of development. The first phase of the project ended in March 2016, and the content of this paper covers mainly results obtained during this time period. The objective of this first phase was to demonstrate the feasibility of a serious game for executing a relatively complex formation manoeuvre. The mastery level required to accomplish through this manoeuvre is very high, and requires a good level of expertise in OOW manoeuvre communication protocol, as well as conning protocols and conning precision. The next subsection describes our efforts to develop this advanced scenario. The second phase of the project examined the other end of the spectrum. From April to the end of July 2016, the project focused on the development of gaming scenarios assuming no prior OOW related skills. A shorter subsection describes the current work.

Phase 1: Complex Manoeuvre Execution Using Speech Recognition

This section describes the software development efforts from mid-January to the end of March 2016. As part of the requirements analysis, the project conducted a product vision workshop in order to establish the scope of a minimal viable product. The vision workshop took place with key stakeholders from the RCN, the Canadian Army, two former MARS officers, and National Research Council Canada (NRC) staff. The outcome of the workshop identified the initial training scenario as well as the importance of speech recognition for the application. However, as is the case with an iterative design and development framework, requirements were not completely defined at the start of the project but were continuously updated and refined through interaction with the RCN and SimFront (http://www.simfront.com) who acted as the developer responsible for the speech interaction with Virtual Battle Space (VBS), and the implementation of speech recognition grammar. During the development of T4-WATCH (Phase 1 product name), SimFront managed requirements in close collaboration with the RCN and NRC. SimFront focused on leveraging its existing speech recognition and VBS2 simulation for training Royal Canadian Air Force (RCAF) air traffic controllers for the RCN training requirements. Alongside SimFront's developments, NRC ensured that requirements for providing adaptive training could be inserted at some point into the T4-WATCH application.

Figure 1 presents an overview of the intended behaviour of the system. The (OOW), who is the trainee, interacts with T4-WATCH by speaking and listening. The OOW can also look at the VBS rendering of the 3D simulation of ships and sea states, as well as press the keyboard or use the mouse (these leverage affordances of games, such as pedagogical context, fidelity and engagement). Information is shared between T4-WATCH and VBS to execute speech commands, as well as to the learning analytic modules, which offer adaptive training, and learning report services.

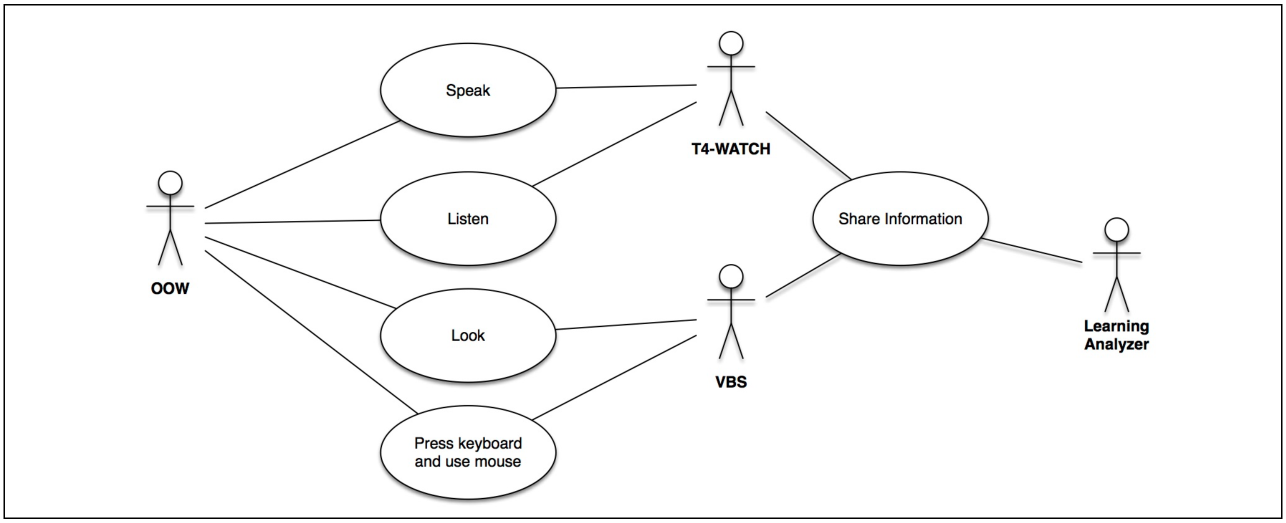

Figure 1. System behaviour model, where the OOW is a trainee, other agents are computer programs.

During the twelve weeks of software development, efforts were prioritized on demonstrating the feasibility of speech interaction with a simulated bridge crew to execute a manoeuvre. The manoeuvre identified for the demonstration was a formation manoeuvre in which the own ship was ordered to move from an initial astern station to a starboard quarter station in relation to the guide ship. Figure 2 presents an overview of the communication on the bridge, between the trainee (OOW), six simulated agents, as well as instruments available to plan and monitor a manoeuvre execution. The feasibility of the system was assessed through the subjective judgment of RCN MARS officers. The system was qualified as feasible if subject matter experts, upon using the system or observing a demonstration, would recognize the speech interactions on the bridge to have met the required level of realism. A dozen demonstrations were given to subject matter experts who confirmed the adequacy level of realism in the execution of the training scenario.

In addition to the subjective assessment of experts during demonstrations, SimFront (http://www.simfront.com) used positive speech recognition experience metrics in the course of software development to assess the quality of speech recognition. Five error measurements were taken with subject matter experts while performing the manoeuvring task in order to refine the speech recognition grammar. These measures were: 1) concept-error, when a trainee uses phraseology that is in the system and in scope, but the utterance is not recognized by the system; 2) fault-tolerant, when a trainee uses phraseology that is in the system and in scope and a concept error occurs, then the trainee can correct the concept error with a single repeat of the original phraseology, the second utterance is classified as a concept-pass; 3) input-error, when a trainee uses phraseology that is in the system and in scope, but the utterance is not recognized due to external factors that impact the quality of the signal input such as microphone setup, background noise, or partial press-to-talk interactions; 4) validation-error, when a trainee uses phraseology that is not in the system but should be in scope (undocumented valid requirement); 5) training-error, when a trainee uses phraseology that is not in the system and is not in scope. The data collected during speech recognition grammar development led to a significant reduction of validation-error. The development data also indicated a constant level of concept-errors under a 5% quality threshold with high fault-tolerance. A usability study with a subject matter expert not familiar with the system indicated no training-error, but repeated input-errors related to the use of press-to-talk procedures, which validate the need to prepare a trainee well to some of the technical factors involved in speech recognition technology or remove the necessity for the press-to talk button which brings technical challenges (e.g. increased computing power, increased input errors).

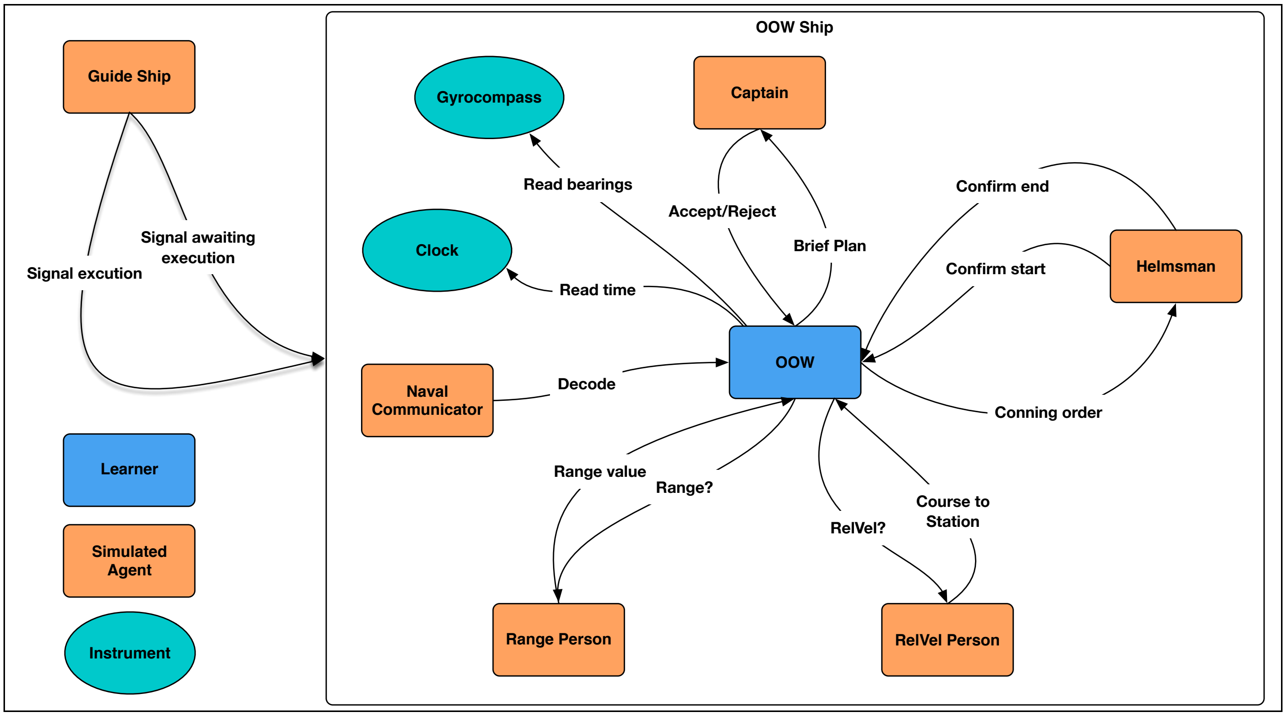

Figure 2. Communication flow during a manoeuvre.

A script for the manoeuvre scenario is given in Table 2. Each utterance is preceded by the name of the speaking agent. Utterances from simulated agents were produced through a speech synthesis application (www.acapela-group.com). CMU Sphinx (cmusphinx.sourceforge.net) was used for speech recognition of the trainee. The manoeuvre is a formation manoeuvre, in which the guide ship requests the OOW's ship to move from a station of 300 yards astern, to a station at 300 yards on the starboard quarter. The in-station speed is set to 10 knots, and the stationing speed is set at 20 knots.

Table 2. Bridge dialogue to execute the form manoeuvre.
The officer of the watch (OOW) is the trainee, all other agents are simulated.

Agent	Utterance
Guide ship	HMCS Montreal this is orca five eight. Signal awaiting execution form starboard one three answer.
Naval communicator	Officer of the watch, Nav comm.
OOW	Go ahead
Naval communicator	Signal awaiting execution form starboard one three five. We are to form on a relative bearing of starboard one three five from the guide orca five eight on a course of zero nine zero speed ten. When in station, the guide orca five eight will bear zero four five at three hundred yards. Signal awaiting execution, Sir.
OOW	Very good.
OOW	Range?
Range finder	Three hundred yards steady.
OOW	Captain Sir, Officer of the watch.
Commanding officer	Go ahead.
OOW	Signal awaiting execution form starboard one three five. Ships are to form on a relative bearing of starboard one three five. We are to take station on the guide's starboard quarter at standard distance. When in station, the guide will bear zero four five at three hundred yards. My plan for this manoeuvre is to use standard helm and to come right 40 degrees to a new heading of one three five and then come up to stationing speed. I will resume the guide's course at a key range of two hundred and eighty yards and speed at key bearing of zero four seven.

Agent	Utterance
Guide ship	Signal has been executed.
Naval communicator	Officer of the watch, Sir, Signal has been executed
Commanding officer	Get us into station.
OOW	Clear to starboard.
OOW	Starboard fifteen set speed two zero.
Helmsman	Starboard fifteen set speed two zero.
Helmsman	Speed two zero ahead set.
Helmsman	Fifteen of starboard wheel on sir.
OOW	Midships port fifteen.
Helmsman	Midships port fifteen.
Helmsman	Fifteen of port wheel on sir.
…	…
OOW	Stand by rel vel update.
Range finder	Standing by.
RelVel	Standing by.
OOW	Guide bears zero eight five. Range?
Range finder	Range 270 yards. At key range.
OOW	What is the course to station?
Helmsman	Speed one zero ahead set.
RelVel	Course to station one five two.
OOW	Set key range 270 opening.
Range finder	At key range.
OOW	Captain sir, in station.

The utterances required by the trainee (officer of the watch) being short, fall-back strategies are easily available. However, during the plan-briefing task, the officer of the watch must give a relatively long report with many possibilities for errors. The solution developed involves supporting the learning with a boilerplate form containing blanks for the OOW to fill in. Moreover, the OOWs could access a manoeuvring board to help them identify the missing values for the plan form. The board was based on the initial and final station coordinates, and the headings of the guide and OOW ships. Figure 3 shows an instance of this solution.

Figure 3. Manoeuvre planning task support using a form and manoeuvring board.

During the first phase of the project we developed a set of specifications for an adaptive training framework to be implemented in subsequent project phases. This framework is intended to conform to the Human Performance Modelling Language (HPML) being developed by the Simulation Interoperability Standards Organization (SISO). HPML will allow an explicit declaration of measurements and assessments independently of the software that will be performing them. The standard proposal aims, in particular, to decouple the code running simulations from the performance measurements and assessments to ensure interoperability and portability of performance assessments across simulations. This is particularly important for the RCN given that the future naval training strategy will require assessment of competencies across a variety of learning/training systems (serious games, part task trainers, team training simulators, etc.).

The task partition specification consists of applying predicates to performance log data to identify the specific tasks being performed by the trainee. For instance, a task partitions specification will categorize log data into such tasks as a signal awaiting execution, manoeuvre planning, signal execution, conning, and finally maintenance of in-station. By identifying relevant tasks in this way, performance measurements and assessments can be performed on specific tasks, thus characterizing individual trainee strengths and weaknesses in each task.

Using prototype code, NRC has shown the feasibility of making measurements and assessments of trainees performances of three types: a) conformance to a protocol sequence, for example when the planning brief to the commanding officer is done in the expected order b) accuracy of performance, for example when the plan values or change of bearing are correct, and c) efficiency in performance, for example when the OOW is able to brief the commanding officer in a reasonable time after the naval communicator's brief of the expected manoeuvre.

Our framework for competency assessment includes a Bayesian knowledge tracing models (Corbett & Anderson, 1994), which is a variation of hidden Markov models (Sande, 2013). Bayesian knowledge tracing has been applied mostly to skill acquisition by monitoring skill mastery to decide on the next step (Desmarais & Baker, 2012). It is important to note that the competency assessment at this level is not the same as when an assessment of performance is done on a measurement. In the latter case, judgment is done on a single measurement. In the case of competency assessment, relevant data is a series of prior measurement assessments to determine if a trainee has acquired or mastered a skill or not.

Phase 2: Conning Order Basics

The second phase of the project (April to July), was specifically centred on the development of an adaptive training game for learning basic conning skills. The game is currently structured as a series of increasing difficulty levels to master, from simply learning the meaning of starboard and port, to conning tasks demanding conformance to communication protocols and conning precision. As with the complex manoeuvre developed during the first phase of the project, the OOW interacts with simulated agents from the bridge. However, in the current simpler game, interactions are limited to the captain and the helmsman. The adaptive training model is relatively simple, determining mastery as meeting a threshold consisting of a number of consecutive successfully performed tasks. This phase also includes data collection with human subjects to measure the rate of learning and assess the suitability of the mastery thresholds used to advance users to the next, more difficult, game level. All performance data collected are recorded in an xAPI learning record store.

CONCLUSION

Overall, the maturity of the system after the first phase is not evenly distributed across its intended features. The speech recognition, speech synthesis components, and the control channel for steering the ship through voice are robust, as supported by experts' subjective judgments during demonstrations, and data collected during speech recognition grammar development. The latter allowed reducing significantly the number of validation-errors. The development data also indicated a constant level of concept-errors under a 5% quality threshold with high fault-tolerance. A usability study with a subject matter expert not familiar with the system indicated no training-error, but repeated input-errors related to the use of press-to-talk procedures, which validate the need to prepare a trainee well to some of the technical limitations involved in speech recognition technology. However, the other elements such as the learning dashboard, and adaptive training are at a prototype stage and will be inserted during the second phase of the project. Also being pushed to subsequent development phases is the issue of instructor interaction, when a specific deployment instance as a pilot project could be set with instructors in the loop.

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