TRAINING SYSTEMS DEVELOPMENT
AT
HMAS WATSON

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ABSTRACT

Surface Warfare training for Royal Australian Navy (RAN) personnel is undertaken at HMAS WATSON in Sydney. Individual operator, command team and task group level tactical training is conducted on a variety of systems, including functional simulators, Milspec equipment and CBT suites. Most of the smaller training systems have been developed at WATSON by personnel from the RAN and Serco Australia Pty Ltd, the major on-site engineering support contractor. Even though these training systems have been developed and built in-house at very low cost, they have proven to be extremely effective for shore based operator training.

This paper discusses two of the many in-house development projects completed at WATSON. Firstly, the recent development of a low cost, high fidelity emulator for the AN/SQS-56 sonar display console as fitted on the RAN's FFG-7 Class guided missile frigates and an associated scenario generator is described. The second project discussed is the development of a medium fidelity PC based Generic Radar Display Simulator that has been designed to provide shore based radar operator instruction for training functions that previously could only be carried out at sea.

Some of the lessons learned and the benefits and shortcomings experienced in using PC hardware and software development tools for these types of projects are discussed. A brief summary of the future directions for the in-house development work is also given.

ABOUT THE AUTHORS

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Andrew Weisz is the Contract Manager for WATSON's on-site Systems Engineering Contractor, Serco Australia Pty Ltd. He has been employed in that capacity since 1991, prior to which he was the Technical Director with a small SCADA (Supervisory, Control and Data Acquisition) System manufacturer for 15 years. Since he has been at WATSON, he has applied the Man-Machine Interface design experience gained in his previous position to the development of numerous Part Task Trainers for the Royal Australian Navy. In 1995 he was the recipient of a Commanding Officer's Commendation in recognition of his contribution to the development of training facilities at HMAS WATSON. Mr. Weisz has a Bachelor of Electrical Engineering degree from the University of New South Wales, Sydney Australia.

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INTRODUCTION

RAN Surface Warfare School

In recent years, the RAN in conjunction with the WATSON on-site Systems Engineering Contractor Serco Australia Pty Ltd, has undertaken the in-house development of Part Task Trainers to complement the major simulator based training systems. The in-house development of low cost Part Task Trainers for operator training was initially undertaken due to the ever increasing cost of the Milspec equipment used for this type of training in the past. Furthermore, experience at WATSON has shown a major limitation of the Milspec ship-fit equipment for training, to be the requirement for significant additional expenditure on stimulation hardware and software to enable the operational equipment to function in a realistic manner.

The limitations experienced with Milspec equipment for operator training, together with the relatively small number of operators to be trained on any one item of equipment, was making it increasingly difficult to justify the high cost of this type of training equipment.

Operator Training on Milspec Equipment

An example of Milspec ship-fit equipment previously installed at WATSON for operator training, is the MULLOKA Sonar Set as fitted to the DE Class destroyers of the RAN. The equipment was installed at WATSON for a cost of approximately six million dollars. Experience however showed that the equipment was very labour intensive to maintain, expensive to operate (high power consumption, with special three phase and 400Hz power requirements) and most importantly, only possessed very limited scenario generation capability. While it obviously provided good training for operators in basic usage of the Sonar Set, it lacked the capability to generate realistic sea conditions, realistic contacts and passive sonar sounds, such as biologicals and propeller cavitation.

Training with Simulators

The first experience with low cost PC based simulators at WATSON was the in-house development of an emulated Global Positioning System (GPS) Navigation unit. The system was developed to be used in conjunction with the full motion Ship's Bridge Simulator that is used for Navigation and Officer of the Watch training. The system consisted of a standard Intel 386 PC fitted with a touch screen, emulating the Keypad and Display of a Magnavox GPS Navigation unit. The PC was interfaced to the Bridge Simulator computer via an RS-232 9600 baud simplex serial line, enabling ship's position to be displayed in Latitude/Longitude, as well as providing all the navigational calculations available on the actual GPS.

This early development project confirmed the point made by people such as Brown & Rolfe [1] about the importance of concentrating on the training requirement instead of the technical requirement. The success achieved with this $3,000 emulator developed in three months, lead to the undertaking of a more ambitious project.

With the difficulties in justifying the multi million dollar cost of a new shore based sonar trainer, together with the desperate need for some FFG sonar training capability, the in-house development of a low cost PC based high fidelity emulator for the AN/SQS-56 Sonar display console and an associated Scenario Generator was undertaken. The Anti-Submarine Warfare (ASW) instructors reluctantly accepted the in-house development of a sonar trainer when they realised the final choice was between that or nothing.

AN/SQS-56 SONAR SIMULATOR

Architecture Adopted

The architecture selected for the sonar simulator was a VME bus based unit for the Sonar Console, with a standard Intel 486DX-66 PC for the Instructor's Scenario Generator. The suitability of PC's for training systems have been pointed out by various authors, including Sweet [2] and Moriarity [3]. The VME bus was selected for the Sonar Console because at the time (late 1991) it was felt that there was a wider selection of modules such as video cards, digital I/O and audio generator cards for the VME bus as opposed to the PC ISA bus. The final design for the Sonar Console consisted of an Acrom 4MB 486DX-50 VME bus processor card, two VGME 34010 Video cards, a dual channel Vigra audio generator with 4MB of on-board RAM and various digital & analogue input/output cards for the interfacing of the various push-buttons and indicator lamps of the console. The interface between the emulated console and the Scenario Generator was a simple RS-232 serial link operating full duplex at 9600 baud.

Even though a number of the major training systems at WATSON were developed in the Australian Defence Department preferred language Ada, the advantages offered by development in C under DOS were felt to be compelling. The selection of C instead of Ada as the development language allowed the use of much more mature and powerful compilers, as well as providing the availability of low cost off-the-shelf libraries for the windowing and graphical applications. In addition to the greater availability of software tools in C, significant cost benefits in comparison to Ada based tools was also obtained.

Figure 1. shows the relatively small amount of hardware, and the compact arrangement of the VME bus card cage and the various associated equipment such as the audio amplifier, lamp dimmer and power supply as fitted to the emulator console. The entire unit consists of the single console, with the only external connections being for power and the RS-232 link to the Scenario Generator.

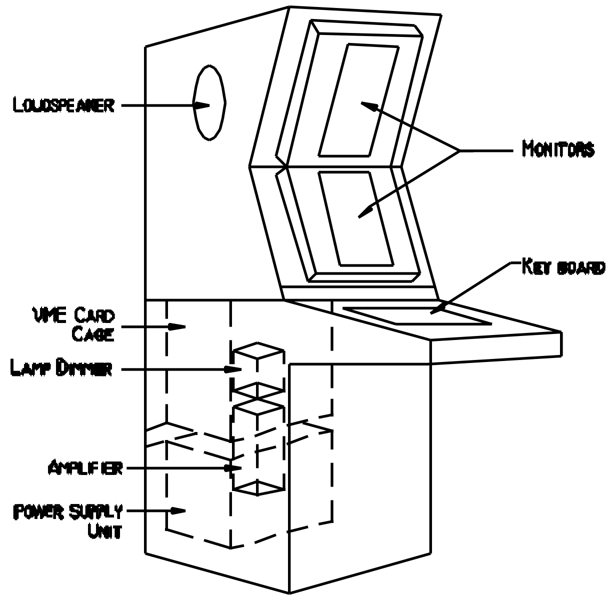

Figure 1.

The AN/SQS-56 Emulator Console

The Scenario Generator

Previous experience with the ship-fit sonar trainer highlighted the importance of scenario generation capability. Hence one of the most important design criteria for the simulator was a powerful but easy to use Scenario Generator for the Sonar Instructor. Due to the constant changeover of instructors at WATSON, it was imperative that the scenario generator provide an intuitive user interface.

The most effective way of meeting this requirement has been identified on numerous occasions as the use of a Graphical User Interface (GUI). Garretson & Dedek [4] provide a particularly good summary of the benefits and advantages of GUI's for the implementation of instructor interfaces.

The graphical windowing package used was the C-Scape libraries produced by the Liant Software Corporation. C-Scape was used with great success in the GPS Simulator project, and the compiler selected was the Borland C/C++, again based on experience gained with the GPS project.

In recognition of the fact that the development engineers were not sonar experts, constant involvement from the ASW instructors was sought and enthusiastically given. In fact the enthusiasm of the instructors was quite surprising, given their earlier attitude to the non-Milspec simulator.

To enable the demonstration of the various alternatives to the instructors, a Rapid Prototyping approach was taken for the software development. The speed and power of the PC based C/C++ compiler was used to great benefit, as suggestions for changes from the instructors could be incorporated in minutes and demonstrated immediately during the review sessions that were held periodically.

The final Scenario Generator developed, enables an instructor to generate a 'game' in minutes. The instructor has full control over the various environmental parameters, such as sea state, ocean depth, thermal layer depth, speed of sound above/below the thermal layer and the nature of the sea bottom. To generate contacts for the sonar operator, the instructor can choose up to sixteen 'vehicles' from the various classes of vehicles that have been pre-defined (the instructor can also add/delete or modify the class definitions). Once the 'game' is started by the instructor, he can manoeuvre any of the 'vehicles' (including own-ship) in the 'game', while the Sonar Console reacts as appropriate to the various contacts. All controls may be achieved by the instructor with a couple of mouse clicks in an intuitive manner.

The instructor may even fire torpedoes either at or from own-ship, and if the weapon is fired from own-ship, the torpedo launch sound (as would be detected by the ship's underwater telephone) is played for the student, followed by the torpedo run-out sound. If the target is hit, the student will hear the underwater explosion as well as implosion sounds from the submarine.

Additionally, the instructor can monitor the control settings being used by the student, and may activate the various fault and alarm indicators on the console.

The Emulator Console

From a system design point of view, the development of the console was the easier part of the project, as the method of operation was defined by the real Sonar Set. The only unknowns were the actual appearance of the various contacts, the effects of environment and the various display settings. Again constant input from the ASW instructors was sought, with Rapid Prototyping again being used to implement comments regarding features such as the amount of bearing spread that should be exhibited by contacts, the amount and appearance of sea clutter etc.

To keep the cost as low as possible, only Commercial Off-the-Shelf (COTS) hardware items were used. In spite of that, the emulated Sonar Console was built with high degree of fidelity. Figure 2. shows a photograph of a student being trained on the simulator. The Console may be seen in foreground, with the Scenario Generator PC visible to the left. The equipment in the background is part of the Milspec MULLOKA Sonar Trainer located in the same room.

Figure 2.

Sonar Operator Training on the Simulator

The fidelity achieved gives a realistic 'look & feel' to the console. Most literature, for example Oldfield, Martin & Parker [5], confirms the desirability of using real audio recordings for high audio fidelity. Thus realism for the various audio effects was achieved by the simple expediency of using 'live' recordings from the RAN's passive sonar sounds library. Sounds for various biologicals (whales, dolphins & snapping shrimp) as well as various surface and submarine propeller sounds were digitised and stored in the 4MB of RAM on the audio generator card. With the various sound files being available without downloading during the game, it is a simple matter for the software to select the appropriate sound file according to operator action. The cursor position used to select the sector for both active and passive audio output to the operator is tracked within 100ms, thus audio selection appears to be instantaneous to the operator. With two channels available, two simultaneous sounds may be activated. One channel is normally used for the background noise, and the other for passive or active sounds detected from contacts.

The construction of the emulated console was handled almost entirely in-house, with only the manufacture of the steel framework being sub-contracted to outside contractors. The entire unit was hand built at WATSON, using the local workshop facilities with all labour being provided by the on-site Systems Engineering contractor.

Development Costs

The size of the development project is indicated by the number of lines of C code developed. The Scenario Generator contains 17,000 lines, while the console emulator consists of 20,000 lines of code. Both counts include only the executable code and excludes headers, definitions and comments. The entire development project was completed with three man-years of engineering/software effort, and a total equipment cost of $65,000. The project took one elapsed year to complete. The three man years include all design, implementation and testing effort. The costs include all materials used in the production of the simulator.

The total cost of the project thus compares very favourably with the six million dollar cost of the previously installed Milspec Sonar Trainer.

While it must be admitted that comparisons like that are a little unfair, in comparing a commercially supplied system with an in-house developed project, there is nevertheless an order of magnitude difference in costs, regardless how one does the comparison.

Training Experience with the Simulator

Since the commencement of training with the simulator, it has been very enthusiastically received by the instructors and students alike. The instructors like the flexibility and variety of training scenarios they can create easily, while the student's interest is maintained by the diverse and extremely realistic situations that the simulator can present. New instructors commencing duties at WATSON have found it easy to familiarise themselves with the simulator, and usually take only half a day to be able to utilise the equipment for instruction.

Furthermore, in the approximately two years since training commenced with the simulator, WATSON has received a number of comments from RAN ships stating that there has been a noticeable increase in the competency of new sonar operators.

Although initially conceived as a training aid for novice operators, the fidelity with which it is possible to create scenarios has meant that the equipment has been used for a number of different training situations. This has included the on-going training of experienced sonar operators, as well as its use, on occasions, to provide sonar capability in the Milspec FFG Operations Room simulator at WATSON.

Cost-Benefit Analysis

While there is a vast amount of anecdotal evidence for the effectiveness of the simulator, quantitative measurements were found to be impossible to obtain. The reason being the structure of the courses, with the students being simply marked as having achieved the required level of proficiency or not. The duration of the course is fixed, regardless of the time taken to reach the specified proficiency.

The cost effectiveness of the simulator was much easier to analyse. Figure 3. tabulates the comparison for the major cost factors between the previously installed Milspec sonar trainer and the simulator. It may be seen that in spite of the significantly lower initial cost, the simulator has in fact proved to be superior in all categories, with the exception of suitability for Maintainer Training. As WATSON does not carry out any Sonar Equipment Maintainer training, this limitation is of no practical significance.

Item	Milspec	Simulator
Initial Cost	$6.0M	$65,000
Maintenance p.a.	$75,000	$5,000
No. Students p.a.	60	60
No. Instructors	2	1
Peak Power kW	110	2.0
Avg. Power kW	15	1.6
MTBF (hours)	770	7,500
MTTR (hours)	2.5	1.5
No. of Targets	1	15
Simulate Torpedo	No	Yes
Passive Audio	No	Yes
Three Φ Power	Yes	No
400Hz Power	Yes	No
Mains Power	Non Std.	Domestic
Maint. Training	Yes	No

Figure 3.

The cost effectiveness of the trainer was so significant, that not long after training commenced, a second unit was requested by the ASW instructors. With the constant reduction in PC hardware costs, the second unit was in fact built for $50,000.

As great as the cost-benefit of the simulator was, even of greater significance was the resultant change in the attitude of the instructors towards simulation. Having observed the benefits from using even very low cost simulators, the requests for other training systems became numerous.

OTHER DEVELOPMENT

Other Training Equipment

Following the success of the AN/SQS-56 project, similar simulators have been designed and built for another sonar set, the AN/SQS-23 as fitted to the DDG's, and an Electronic Warfare (EW) Countermeasures Set, the AN/SLQ-32 fitted to the FFG's. Both of these simulators use the Scenario Generator developed for the SQS-56 project, with minor modifications as appropriate.

A PC based low fidelity radar signal simulator based on a commercial Arbitrary Waveform Generator has also been developed at a fraction of the cost of Milspec equipment available for that function.

In addition to the hardware based training equipment mentioned above, a number of Computer Based Training (CBT) style software packages have also been developed. These packages include software simulators for the Chaff Fire Control Panels fitted to the DDG's and FFG's, a Radar Weapons Exercises package for teaching the identification and classification of radar signals, a Chaff Employment Trainer for PWO's, and a PC based medium fidelity Radar Display Simulator.

PC Radar Display Simulator

In January of 1995, having seen a variety of training systems developed for the PC, the Combat Systems Faculty requested that the possibility of producing a PC based generic radar display simulator be investigated. With the RAN's limited access to jamming equipment, the ability to simulate the effects of various types of jamming was identified as the main priority, with fidelity considerations being of secondary importance. A low priority objective, possibly as part of future enhancements, was the incorporation of a UPA-59 Identify Friend or Foe (IFF) panel simulator.

Although all of the development for PC's up to that time had been for DOS, it was felt that the graphical image manipulations required, in particular the simulation of phosphor decay, would be better handled by Windows, so the development was undertaken for Windows 3.1.

The required image generation and the simulation of phosphor decay, was found to be easy to implement by using Palette Animation techniques. The generation of the images to simulate the various effects required was achieved with surprising ease. With three man-months of development effort, the first prototype was functioning with the ability to simulate:

- Circular Sweep (with variable intensity)
- Range Selection

- Range Rings (with variable intensity)
- Brightness Control for the Display
- Sea Returns (sea states 0-7)
- Cloud Density (low, medium, high)
- Surface & Air Contacts (with movement)
- Various Types of Jamming (fixed bearing)
- Mutual Interference (fixed bearing)
- Coast Lines (without own-ship motion)
- Sector Blanking (inside/outside sector)

The main shortcomings were the relatively high memory requirement of 12MB, and more importantly, the time required to compute the image initially. Following the initial image computation, the use of Palette Animation meant sweep simulation at 12 r.p.m. could be executed with under 10% processor loading.

Executing on a 486DX-66, the initial image computation was taking about 10 seconds, so any movement of own-ship relative to coast lines was out of the question.

Having satisfied the major requirement, investigation of the simulation of the IFF panel was undertaken in the second half of 1995.

The panel to be emulated is a small (6x12 inch) but relatively complex device, consisting of:

- 16 two & three position toggle switches
- 14 push buttons
- 14 single digit mechanical displays
- 5 indicator lamps (with engraving)
- 4 five digit numeric LED display unit
- Complex engravings on the panel

After considering a number of alternative approaches, it was decided the best way to obtain a high fidelity reproduction would be to use a scanned image of the panel. While this approach was selected primarily to reproduce the engravings with high fidelity, it turned out to be an extremely effective approach. The emulation of the panel, complete with animation of the switches/indicators, and functional interaction with the emulated radar display, was completed in a single week.

Despite the overall effectiveness of the approach taken, there was one problem. The original Radar Display Simulator was designed to use a standard SVGA (800x600 resolution) video card with 256 colours. Using the same colour depth for the IFF panel, it was impossible to accommodate both palette requirements simultaneously. Thus we were forced to use video cards with SVGA & 65,000 colour capability. Fortunately, the rapid advances in PC technology meant that by the end of calendar 1995, these cards were available at low cost.

Future Enhancements Planned

With the exponential increase in computational power available on PC's recently, the ability to implement own-ship motion is just about within reach. The most powerful machine available to us up to the present time has been a Pentium-100, which has reduced the initial computation time to around 3 seconds. The imminent availability of 200MHz PC's is expected to reduce this to around 1.0 - 1.5 seconds, and with minor improvements to the software organisation, sub 1.0 second computation time should be achievable. For our applications, that would correspond to 'real-time' operation.

Once real-time image generation has been achieved, the next step being planned is the networking of the Radar Display Simulator with the Scenario Generators for the various part task trainers, and thus be able to complement the sonar and the EW simulation with radar display capability.

EXPERIENCE GAINED

Benefits of Using PC Hardware

The major benefits experienced from using PC based hardware for the development and implementation of training systems can be summarised under three categories.

- Low cost of hardware
- Software development on standard PC's
- Ability to develop & debug in-situ

The low cost of PC based hardware is very obvious to everybody, as is the ever increasing processing power available. There has been a similar exponential increase in the capacity and capability of peripherals available. As an example, a 10ms access time 1.0GB disk can currently be purchased for around $300.

The ability to develop the software on Standard PC's is not so universally appreciated, but our experience at WATSON has demonstrated the benefits to exceed the obvious one of low cost of the development platforms. More importantly, it means that software development using a Rapid Prototyping approach can be commenced on day one of the project, long before any special hardware is available for the incorporation of the software. Towards the end of a project, when the special hardware is available, the ability to develop and debug in-situ means that the Rapid Prototyping benefits are extended to the very end of the project.

Shortcomings of Using PC Hardware

While the benefits to be derived from using PC hardware for training systems were very great, there were also a number of annoying shortcomings that have been experienced.

- Constant evolution of the hardware
- Lack of consistency/standardisation
- Lack of detailed hardware documentation

Although one of the main benefits of the PC is the (almost) total upwards compatibility from the earliest 286 to the latest Pentium, there are nonetheless constant changes at the hardware level. Constant evolution of the display hardware, from EGA to VGA to SVGA and XGA has been the most obvious. Colours available have increased by a factor of a mere million. Keeping up with these constant changes can be quite demanding.

The great cost advantages of PC's derives from the number of different manufacturers all competing for the user's dollar, however WATSON's experience has been, that unfortunately not all PC's are equivalent. While the number of instances of encountering this problem was very low, it can waste a great deal of time in chasing non-existent software problems when it does occur. Surprisingly, we have found this type of compatibility problem exclusively with 'brand name' machines.

However, undoubtedly the major problem we have encountered in developing systems for the PC hardware has been the lack of a single source of detailed documentation. Adequate documentation for the convoluted interrupt structure is particularly difficult to find. This problem was of much more significance in the DOS days, and with the advent of Windows one tends not to have to do the sort of low level software development that can be quite frustrating due to the difficulties with the documentation.

Benefits of Using PC Based Software

The major benefits of using PC based software for the development and implementation of training systems at WATSON were found to be:

- Great variety of low cost tools
- Speed and power of the tools
- Availability of low cost Off-the-Shelf libraries

Experience at WATSON has demonstrated an almost unlimited variety of extremely high performance PC software development tools at very low cost. As an example, the Borland C/C++ Compiler at around $500 per user provides an extremely fast and very powerful compiler/linker/debugger. The complete software suite for the SQS-56 console can be compiled and linked in about three minutes (on a 486DX-50), and more typically partial compilation during the Rapid Prototyping process can be achieved in around 30 seconds.

Similar to the availability of development tools, there is an almost unlimited variety of low cost off-the-shelf libraries, ranging from windowing for DOS, graphics manipulation and ethernet communications, to complex packages implementing entire applications such as the Distributed Interactive Simulation (DIS) protocol.

More recently, there has been the availability of Rapid Application Development (RAD) tools like Visual Basic from Microsoft and Delphi from Borland. These new tools make development of software for Windows even more rapid than was possible for DOS.

Shortcomings of Using PC Based Software

The shortcomings experienced with PC based software development in a DOS environment can be summed up in one word. That is, ONE megabyte. As applications became based around GUI's, with the windowing libraries taking up around 450 KB's, the 1MB limit imposed by DOS becomes intolerable. The only DOS based solution to the problem, namely the use of a DOS Extender is fine until one starts to deal with projects involving the combination of source code and libraries from a number of different sources. In that situation, it is not uncommon to find conflicting requirements to use different compilers and/or extenders.

While Windows overcame a number of development obstacles experienced under DOS, the continued limitation of 64KB segmentation, together with the phenomenal complexity of the Application Programming Interface (API) and the enormous amount of housekeeping overhead required, meant that Windows development was significantly more demanding. The appearance of RAD tools and Windows 95 will hopefully put these limitations behind us.

In fact it was the newly available Delphi from Borland that enabled the implementation of the IFF panel simulation in a week.

Future Direction for In-House Development

In addition to the on-going development of similar training aids as described earlier, for example for the new ANZAC class frigates about to enter service with the RAN, future directions for in-house projects will probably involve the DIS protocol. The Australian Defence Forces (ADF) in general, and the RAN in particular, are just starting to become interested in the DIS protocol, and the networking of simulators that it allows.

With the RAN being conceptually committed to the implementation of DIS on both the ANZAC and DDG/FFG Command Team Training Systems, a number of possible areas of in-house involvement via the DIS interface are being evaluated.

- The possibility of using the PC based Scenario Generator as a low cost asset control station is being investigated. The use of DIS to integrate Scenario Generators with the major trainers should provide significant cost savings without sacrificing functionality.

- The possibility of using PC based DIS Stealth visualisation software to provide visuals for de-briefing sessions following Command Team Training exercises is being investigated. This type of software hopefully will start to become available at low cost for the Pentium. Although these types of applications might have to wait for the general availability of multi-processor NT based machines, with more advanced graphics accelerator boards.

- The possibility of using DIS to connect the in-house developed PC based Radar Display Simulator to provide real time radar image as would be observed from a specified platform from the Command Team Trainer/s is under consideration.

CONCLUSIONS

Lessons Learned

WATSON's experience over the last five years, has demonstrated the benefits to be derived from having even a small team of implementers (in our case five engineers) working in close cooperation with the subject matter experts and the end users. By concentrating on the training requirements instead of the technical requirements, not only was the training objective achieved, but usually with a surprising level of fidelity.

Possibly the most important lesson learned, was the benefits from involving the instructors in the entire project. The involvement of the instructors in the development cycle, creates a sense of ownership by the eventual users, and encourages constant suggestions for improvements.

By involving the instructors in the project, and concentrating on the development of tools for the use of the instructors, we avoided most of the pitfalls encountered by earlier ADF attempts to introduce low cost training equipment.

WATSON's experiences with Rapid Prototyping and the involvement of the 'customer' in the development cycle, mirrors the findings of Sawler & Mielke [6] during their development of a low cost PC based radar simulator.

WATSON has gained considerable experience with the development of low cost, high fidelity, hardware based simulators, as well as with the development of CBT style software simulator training packages. Projects have been developed for DOS, DOS with Extenders and Windows 3.1.

That experience has demonstrated the power, flexibility and cost effectiveness of PC based trainers. PC's have been found to be a powerful platform for software development using C/C++, both in a DOS and a Windows environment.

WATSON's experience has indicated a desirability to stay with the mainstream operating systems, to date DOS and Windows. While other operating systems such as Windows NT have offered some advantages in the past, the non availability of development tools and off-the-shelf libraries has reduced the attractiveness for the relatively minor projects undertaken. The ability to run the software developed on the largest possible number of existing machines also served to limit our interest to DOS and Windows 3.1. This is expected to change shortly with the advent of Windows 95, and the subsequent convergence of Windows and Windows NT.

The instructors and students have come to accept non-Milspec equipment in general, and the PC in particular, as valid training tools, and recognise that with the proper software, PC's are suitable for a wider range of applications than word processors and games.

Thus we have progressed from a situation in 1991 where approval for the original AN/SQS-56 simulator took two years, to where the small on-site development team of five engineers cannot keep up with the demand for training systems.

Summary and Recommendations

In summary, we have found using C/C++ in a PC environment an extremely powerful and cost effective development platform. The PC's have proved to be equally suitable for the implementation of both high and low fidelity simulators. The use of PC's with CBT style software for training has proved to be particularly cost effective.

The important contribution from the subject matter experts (i.e. the instructors) cannot be over emphasised. A major factor in the success we have achieved with the in-house development of training systems has been the evolutionary approach taken to the system design, with constant and ongoing involvement of the instructors.

The final important factor to note, is that all of the training systems described in this paper have been designed as an aid to the instructor, not as a replacement for him/her.

Based on WATSON's experience, we would unreservedly recommend the approaches described in this paper for anyone undertaking development of similar sized training systems.

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