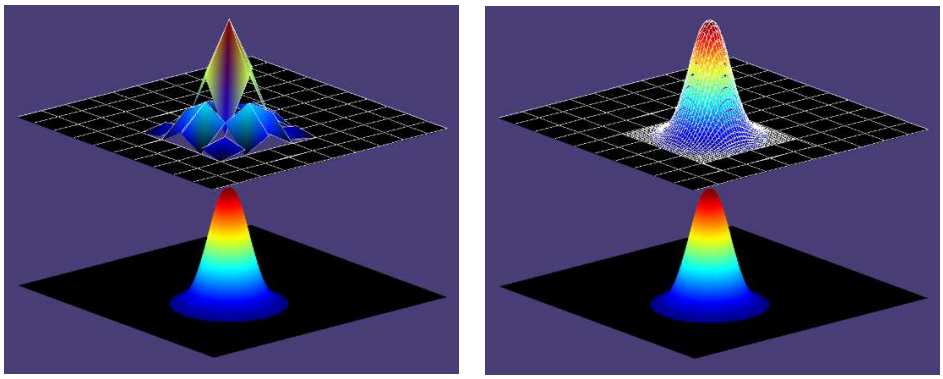
MOOS-IvP Autonomy Tools Users Manual

The uHelmScope, pMarineViewer, uXMS, uTermCommand, pEchoVar, uProcessWatch and uPokeDB Tools



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Abstract

This document describes seven common MOOS-IvP autonomy tools. The uHelmScope application provides a run-time scoping window into the state of an active IvP Helm executing its mission. The pMarineViewer application is a geo-based GUI tool for rendering marine vehicles and certain autonomy properties in their operational area. The uXMS application is a terminal based tool for live scoping on a MOOSDB process. The uTermCommand application is a terminal based tool for poking the MOOSDB with a set of MOOS file pre-defined variable-value pairs selectable with tab-completion of aliases from the command-line. The pEchoVar application provides a way of echoing an observed write to a variable with a new write with the same value to a different variable name. The uProcessWatch application is a way of monitoring the presence or absence of a set of MOOS processes and summarizing the collective status in a single MOOS variable. The uPokeDB application is a way of poking the MOOSDB from the command line with one or more variable-value pairs without any pre-existing configuration of a MOOS file.

This work is the product of a multi-year collaboration between the Center for Advanced System Technologies (CAST), Code 2501, of the Naval Undersea Warfare Center in Newport Rhode Island and the Department of Mechanical Engineering and the Computer Science and Artificial Intelligence Laboratory (CSAIL) at the Massachusetts Institute of Technology in Cambridge Massachusetts.

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Contents

1 Overview

1.1 Purpose and Scope of this Document

The MOOS-IvP autonomy tools described in this document are software applications that are typically running as part of an overall autonomy system running on a marine vehicle. They are each MOOS applications, meaning they are running and communicating with a MOOSDB application as depicted in Figure 1.

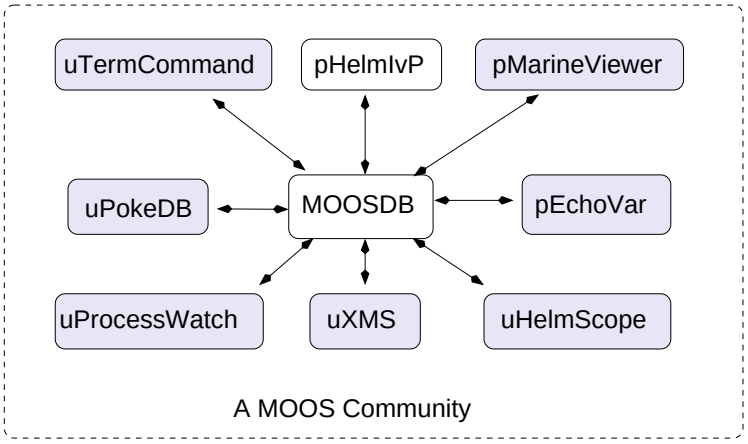

Figure 1: A MOOS community consists of a running MOOSDB application and a number of applications connected and communicating with each other via publish and subscribe interface. The pHelmIvP application provides the autonomy decision-making capapability and the other highlighted applications provide support capabilities for the system.

The scope of this paper is on these seven tools. Important topics outside this scope are (a) MOOS middleware programming, (b) the IvP Helm and autonomy behaviors, and (c) other important MOOS utilities applications not covered here. The intention of this paper is to provide documenation for these common applications for current users of the MOOS-IvP software.

1.2 Brief Background of MOOS-IvP

MOOS was written by Paul Newman in 2001 to support operations with autonomous marine vehicles in the MIT Ocean Engineering and the MIT Sea Grant programs. At the time Newman was a post-doc working with John Leonard and has since joined the faculty of the Mobile Robotics Group at Oxford University. MOOS continues to be developed and maintained by Newman at Oxford and the most current version can be found at his website. The MOOS software available in the MOOS-IvP project includes a snapshot of the MOOS code distributed from Oxford. The IvP Helm was developed in 2004 for autonomous control on unmanned marine surface craft, and later underwater platforms. It was written by Mike Benjamin as a post-doc working with John Leonard, and as a research scientist for the Naval Undersea Warfare Center in Newport Rhode Island. The IvP Helm is a single MOOS process that uses multi-objective optimization to implement behavior coordination.

Acronyms

MOOS stands for "Mission Oriented Operating Suite" and its original use was for the Bluefin Odyssey III vehicle owned by MIT. IvP stands for "Interval Programming" which is a mathematical programming model for multi-objective optimization. In the IvP model each objective function is a piecewise linear construct where each piece is an *interval* in N-Space. The IvP model and algorithms are included in the IvP Helm software as the method for representing and reconciling the output of helm behaviors. The term interval programming was inspired by the mathematical programming models of linear programming (LP) and integer programming (IP). The pseudo-acronym IvP was chosen simply in this spirit and to avoid acronym clashing.

1.3 Sponsors of MOOS-IvP

Original development of MOOS and IvP were more or less infrastructure by-products of other sponsored research in (mostly marine) robotics. Those sponsors were primarily The Office of Naval Research (ONR), as well as the National Oceanic and Atmospheric Administration (NOAA). MOOS and IvP are currently funded by Code 31 at ONR, Dr. Don Wagner and Dr. Behzad Kamgar-Parsi. MOOS is additionally supported in the U.K. by EPSRC. Early development of IvP benefited from the support of the In-house Laboratory Independent Research (ILIR) program at the Naval Undersea Warfare Center in Newport RI. The ILIR program is funded by ONR.

1.4 The Software

The MOOS-IvP autonomy software is available at the following URL:

```
http://www.moos-ivp.org
```

Follow the links to *Software*. Instructions are provided for downloading the software from an SVN server with anonymous read-only access.

1.4.1 Building and Running the Software

After checking out the tree from the SVN server as prescribed at this link, the top level directory should have the following structure:

```
moos-ivp/
   MOOS/
   MOOS-2208/
   README.txt
   README-LINUX.txt
   README-OS-X.txt
   build-moos.sh
   build-ivp.sh
   ivp/
```

Note there is a `MOOS` directory and an `IvP` sub-directory. The `MOOS` directory is a symbolic link to a particular MOOS revision checked out from the Oxford server. In the example above this is Revision 2208 on the Oxford SVN server. This directory is left completely untouched other than

giving it the local name MOOS-2208. The use of a symbolic link is done to greatly simplify the process of bringing in a new snapshot from the Oxford server.

The build instructions are maintained in the README files and are probably more up to date than this document can hope to remain. In short building the software amounts to two steps - building MOOS and building IvP. Building MOOS is done by executing the build-moos.sh script:

```
> cd moos-ivp
> ./build-moos.sh
```

Alternatively one can go directly into the MOOS directory and configure options with ccmake and build with cmake. The script is included to facilitate configuration of options to suit local use. Likewise the IvP directory can be built by executing the build-ivp.sh script. The MOOS tree must be built before building IvP. Once both trees have been built, the user's shell executable path must be augmented to include the two directories containing the new executables:

```
moos-ivp/MOOS/MOOSBin
moos-ivp/ivp/bin
```

At this point the software should be ready to run and a good way to confirm this is to run the example simulated mission in the missions directory:

```
> cd moos-ivp/ivp/missions/alpha/
> pAntler alpha.moos
```

Running the above should bring up a GUI with a simulated vehicle rendered. Clicking the DEPLOY button should start the vehicle on its mission. If this is not the case, some help and email contact links can be found at www.moos-ivp.org/support/.

1.4.2 Operating Systems Supported by MOOS and IvP

The MOOS software distributed by Oxford is well supported on Linux, Windows and Mac OS X. The software distributed by MIT/NUWC includes additional MOOS utilities (seven of which are the topic of this document) and the IvP Helm and related behaviors. These modules are support on Linux and Mac OS X.

1.5 Where to Get Further Information

1.5.1 Websites and Email Lists

There are two websites - the MOOS website maintained by Oxford University, and the MOOS-IvP website maintained by MIT/NUWC. At the time of this writing they are at the following URLs:

```
http://www.robots.ox.ac.uk/~pnewman/TheMOOS/

http://www.moos-ivp.org
```

What is the difference in content between the two websites? As discussed previously, MOOS-IvP, as a set of software, refers to the software maintained and distributed from Oxford *plus* additional MOOS applications including the IvP Helm and library of behaviors. The software bundle released at moos-ivp.org does include the MOOS software from Oxford - usually a particular released version. For the absolute latest in the core MOOS software and documentation on Oxford MOOS modules, the Oxford website is your source. For the latest on the core IvP Helm, behaviors, and MOOS tools written by MIT/NUWC, the moos-ivp.org website is the source.

There are two mailing lists open to the public. The first list is for MOOS users, and the second is for MOOS-IvP users. If the topic is related to one of the MOOS modules distributed from the Oxford website, the proper email list is the "moosusers" mailing list. You can join the "moosusers" mailing list at the following URL:

`https://lists.csail.mit.edu/mailman/listinfo/moosusers,`

For topics related to the IvP Helm or modules distributed on the moos-ivp.org website that are not part of the Oxford MOOS distribution (see the software page on moos-ivp.org for help in drawing the distinction), the "moosivp" mailing list is appropriate. You can join the "moosivp" mailing list at the following URL:

`https://lists.csail.mit.edu/mailman/listinfo/moosivp,`

1.5.2 Documentation

Documentation on MOOS can be found on the Oxford University website:

`http://www.robots.ox.ac.uk/~pnewman/MOOSDocumentation/index.htm`

This includes documentation on the MOOS architecture, programming new MOOS applications as well as documentation on several bread-and-butter applications such as `pAntler`, `pLogger`, `uMS`, `pMOOSBridge`, `iRemote`, `iMatlab`, `pScheduler` and more. Documentation on the IvP Helm, behaviors and autonomy related MOOS applications not from Oxford can be found on the www.moosivp.org website under the Documentation link. Below is a summary of documents:

Documents Released or Pending Approval for Release

- *An Overview of MOOS-IvP and a Brief Users Guide to the IvP Helm Autonomy Software* - This is the primary document describing the IvP Helm regarding how it works, the motivation for its design, how it is used and configured, and example configurations and results from simulation.
- *MOOS-IvP Autonomy Tools Users Manual* - A Users Manual for seven MOOS applications - `uHelmScope`, `pMarineViewer`, `uXMS`, `uTermCommand`, `uPokeDB`, `uProcessWatch`, `pEchoVar`. These applications are common supplementary tools for running an autonomy system in simulation and on the water. See [1].
- *A Tour of MOOS-IvP Autonomy Software Modules* - This document acts as a catalog of existing modules (Both MOOS applications and IvP Behaviors). For each module, it relates (a) where it can be downloaded, (b) what the module does, (c) who it was written by, (d) rough estimate on size and complexity, and (e) what modules it may depend on for its build.

- *Autonomy Behaviors of the IvP Helm Users Guide* - This document is a catalog and users manual for existing IvP Helm behaviors available on the moos-ivp.org website. It provides a detailed description of capabilities and interface specification for each behavior.

Documents In-Progress

- *Extended MOOS-IvP Autonomy Examples from Simulation and In-water Exercises* - This document describes a set of example scenarios and helm configurations and describes their performance in simulation and in field exercises where possible.
- *The IvP Build Toolbox and General Guide for Writing New Behaviors for the IvP Helm* - This document is a users manual for those wishing to write their own IvP Helm behaviors. It describes the IvPBehavior superclass in detail. It also describes the IvPBuild Toolbox containing a number of tools for building IvP Functions which is the primary output of behaviors.
- *The IvP Solver - A Look at Interval Programming as a Mathematical Programming Model* - This document describes both the mathematical structure of IvP functions and problems as well as the algorithms used for solving an IvP problem.
- *MOOS-IvP Extensions - Extending a MOOS-IvP Autonomy System with New MOOS Applications and IvP Behaviors* - This document

2 uHelmScope

2.1 Brief Overview

The uHelmScope application is a console based tool for monitoring output of the IvP helm, i.e., the pHelmIvP process. The helm produces a few key MOOS variables on each iteration that pack in a substantial amount of information about what happened during a particular iteration. The helm scope subscribes for and parses this information, and writes it to standard output in a console window for the user to monitor. The user can dynamically pause or alter the output format to suit one's needs, and multiple scopes can be run simultaneously. The helm scope in no way influences the performance of the helm - it is strictly a passive observer.

2.2 Console Output of uHelmScope

The example console output shown in Listing 1 is used for explaining the uHelmScope fields.

Listing 1 - Example uHelmScope *output.*

```
 1  ==============   uHelmScope Report  ============== ENGAGED  (17)
 2    Helm Iteration: 66      (hz=0.38)(5)  (hz=0.35)(66)  (hz=0.56)(max)
 3    IvP functions:  1
 4    Mode(s):        Surveying
 5    SolveTime:      0.00    (max=0.00)
 6    CreateTime:     0.02    (max=0.02)
 7    LoopTime:       0.02    (max=0.02)
 8    Halted:         false   (0 warnings)
 9  Helm Decision: [speed,0,4,21] [course,0,359,360]
10    speed = 3.00
11    course = 177.00
12  Behaviors Active: ---------- (1)
13    waypt_survey (13.0) (pwt=100.00) (pcs=1227) (cpu=0.01) (upd=0/0)
14  Behaviors Running: --------- (0)
15  Behaviors Idle: ------------ (1)
16    waypt_return (22.8)
17  Behaviors Completed: ------- (0)
18
19  #  MOOSDB-SCOPE ------------------------------------ (Hit '#' to en/disable)
20  #
21  #  VarName           Source       Time     Community  VarValue
22  #  ----------------  -----------  -------  ---------  -----------
23  #  BHV_WARNING        n/a          n/a      n/a       n/a
24  #  AIS_REPORT_LOCAL  pTrans..rAIS 24.32    alpha      "NAME=alpha,TYPE=KAYAK,MOOSDB"+
25  #  DEPLOY*           iRemote      11.25    alpha      "true"
26  #  RETURN*           pHelmIvP     5.21     alpha      "false"
27
28  @  BEHAVIOR-POSTS TO MOOSDB ---------------------- (Hit '@' to en/disable)
29  @
30  @  MOOS Variable     Value
31  @  -------------     -------  (BEHAVIOR=waypt_survey)
32  @  PC_waypt_survey   -- ok --
33  @  WPT_STAT_LOCAL    vname=alpha,index=1,dist=80.47698,eta=26.83870
34  @  WPT_INDEX         1
35  @  VIEW_SEGLIST      label,alpha_waypt_survey : 30,-20:30,-100:90,-100: +
36  @  -------------     -------  (BEHAVIOR=waypt_return)
37  @  PC_waypt_return   RETURN = true
38  @  VIEW_SEGLIST      label,alpha_waypt_return : 0,0
39  @  VIEW_POINT        0,0,0,waypt_return
```

There are three groups of information in the uHelmScope output on each report to the console - the general helm overview (lines 1-17), a MOOSDB scope for a select subset of MOOS variables (lines

19-26), and a report on the MOOS variables published by the helm on the current iteration (lines 28-39). The output of each group is explained in the next three subsections.

2.2.1 The General Helm Overview Section of the `uHelmScope` Output

The first block of output produced by `uHelmScope` provides an overview of the helm. This is lines 1-17 in Listing 1, but the number of lines may vary with the mission and state of mission execution. The integer value at the end of line 1 indicates the number of `uHelmScope` reports written to the console. This can confirm to the user that an action that should result in a new report generation has indeed worked properly. The integer on line 2 is the counter kept by the helm, incremented on each helm iteration. The three sets of numbers that follow indicate the observed time between helm iterations. These numbers are reported by the helm and are not inferred by the scope. The first number is the average over the most recent five iterations. The second is the average over the most recent 58 iterations. The last is the maximum helm-reported interval observed by the scope. The number of iterations used to generate the first two numbers can be set by the user in the `uHelmScope` configuration block. The default is 5 and 100 respectively. The number 58 is shown in the second group simply because 100 iterations hadn't been observed yet. The helm is apparently only on iteration 66 in this example and `uHelmScope` apparently didn't start and connect to the `MOOSDB` until the helm was on iteration 8.

The value on Line 3 represents the the number of IvP functions produced by the active helm behaviors, one per active behavior. The solve-time on line 5 represents the time, in seconds, needed to solve the IvP problem comprised the n IvP functions. The number that follows in parentheses is the maximum solve-time observed by the scope. The create-time on line 6 is the total time needed by all active behaviors to produce their IvP function output. The loop time on line 7 is simply the sum of lines 5 and 6. The Boolean on line 8 is true only if the helm is halted on an emergency or critical error condition. Also on line 8 is the number of warnings generated by the helm. This number is reported by the helm and *not* simply the number of warnings observed by the scope. This number coincides with the number of times the helm writes a new message to the variable `BHV_WARNING`.

The helm decision space (i.e., IvP domain) is displayed on line 9, with the following lines used to display the actual helm decision. Following this is a list of all the active, running, idle and completed behaviors. At any point in time, each instantiated IvP behavior is in one of these four states and each behavior specified in the behavior file should appear in one of these groups. Technically all *active* behaviors are also *running* behaviors but not vice versa. So only the running behaviors that are not active (i.e., the behaviors that could have, but chose not to produce an objective function), are listed in the "`Behaviors Running:`" group. Immediately following each behavior the time, in seconds, that the behavior has been in the current state is shown in parentheses. For the active behaviors (see line 13) this information is followed by the priority weight of the behavior, the number of pieces in the produced IvP function, and the amount of CPU time required to build the function. If the behavior also is accepting dynamic parameter updates the last piece of information on line 13 shows how many successful updates where made against how many attempts. A failed update attempt also generates a helm warning, counted on line 8. The idle and completed behaviors are listed by default one per line. This can be changed to list them on one long line by hitting the 'b' key interactively. Insight into why an idle behavior is not in the running state can be found in the another part of the report (e.g., line 37) described below in Section 2.2.3.

2.2.2 The MOOSDB-Scope Section of the `uHelmScope` Output

Part of understanding what is happening in the helm involves the monitoring of variables in the `MOOSDB` that can either affect the helm or reveal what is being produced by the helm. Although there are other MOOS scope tools available (e.g., uXMS or uMS), this feature does two things the other scopes do not. First, it is simply a convenience for the user to monitor a few key variables in the same screen space. Second, `uHelmScope` automatically registers for the variables that the helm reasons over to determine the behavior activity states. It will register for all variables appearing in behavior conditions, runflags, activeflags, inactiveflags, endflags and idleflags. Variables that are registered for by this criteria are indicated by an asterisk at the end of the variable name. If the output resulting from these automatic registrations becomes unwanted, it can be toggled off by typing 's'.

The lines comprising the MOOSDB-Scope section of the `uHelmScope` output are all preceded by the '#' character. This is to help discern this block from the others, and as a reminder that the whole block can be toggled off and on by typing the '#' character. The columns in Listing 1 are truncated to a set maximum width for readability. The default is to have truncation turned off. The mode can be toggled by the console user with the 't' character, or set in the MOOS configuration block or with a command line switch. A truncated entry in the `VarValue` column has a '+' at the end of the line. Truncated entries in other columns will have ".." embedded in the entry. Line 24 shows an example of both kinds of truncation.

The variables included in the scope list can be specified in the `uHelmScope` configuration block of a MOOS file. In the MOOS file, the lines have the form:

```
VAR = VARIABLE_1, VARIABLE_2, VARIABLE_3, ...
```

An example configuration is given in Listing 4. Variables can also be given on the command line. Duplicates requests, should they occur, are simply ignored. Occasionally a console user may want to suppress the scoping of variables listed in the MOOS file and instead only scope on a couple variables given on the command line. The command line switch `-c` will suppress the variables listed in the MOOS file - unless a variable is also given on the command line. In line 23 of Listing 1, the variable `BHV_WARNING` is a *virgin* variable, i.e., it has yet to be written to by any MOOS process and shows `n/a` in the four output columns. By default, virgin variables are displayed, but their display can be toggled by the console user by typing '-v'.

2.2.3 The Behavior-Posts Section of the `uHelmScope` Output

The Behavior-Posts section is the third group of output in `uHelmScope` lists MOOS variables and values posted by the helm on the current iteration. Each variable was posted by a particular helm behavior and the grouping in the output is accordingly by behavior. Unlike the variables in the MOOSDB-Scope section, entries in this section only appear if they were written to on the current iteration. The lines comprising the Behavior-Posts section of the `uHelmScope` output are all preceded by the '@' character. This is to help discern this block from the others, and as a reminder that the whole block can be toggled off and on by typing the '@' character. As with the output in the MOOSDB-Scope output section, the output may be truncated. A trailing '+' at the end of the line indicates the variable value has been truncated.

There are a few switches for keeping the output in this section concise. A behavior posts a few standard MOOS variables on every iteration that may be essentially clutter for users in most cases.

A behavior FOO for example produces the variables PWT_FOO, STATE_FOO, and UH_FOO which indicate the priority weight, run-state, and tally of successful updates respectively. Since this information is present in other parts of the uHelmScope output, these variables are by default suppressed in the Behavior-Posts output. Two other standard variables are PC_FOO and VIEW_* which indicate the precondition keeping a behavior in an idle state, and standard viewing hints to a rendering engine. Since this information is not present elsewhere in the uHelmScope output, it is not masked out by default. A console user can mask out the PWT, STATE_* and UH_* variables by typing 'm'. The PC_* and VIEW_* variables can be masked out by typing 'M'. All masked variables can be unmasked by typing 'u'.

2.3 Stepping Forward and Backward Through Saved Scope History

The user has the option of pausing and stepping forward or backward through helm iterations to analyse how a set of events may have unfolded. Stepping one event forward or backward can be done with the '[' and ']' keys respectively. Stepping 10 or 100 events can be done with the '{' and '}, and '(' and ')' keys respectively. The current helm iteration being displayed is always shown on the second line of the output. For each helm iteration, the uHelmScope process stores the information published by the helm (Section 2.5), and thus the memory usage of uHelmScope would grow unbounded if left unchecked. Therefore information is kept for a maximum of 2000 helm iterations. This number is *not* a configuration parameter - to preclude a user from inadvertently setting this too high and inducing the system maladies of a single process with runaway memory usage. To change this number, a user must change the source code (in particular the variable m_history_size_max in the file HelmScope.cpp). The uHelmScope history is therefore a moving window of fixed size that continues to shift right as new helm information is received. Stepping forward or backwards therefore is subject to the constraints of this window. Any steps backward or forward will in effect generate a new *requested* helm index for viewing. The requested index, if older than the oldest stored index, will be set exactly to the oldest stored index. Similarly in the other direction. It's quite possible then to hit the '[' key to step left by one index, and have the result be a report that is not one index older, but rather some number of indexes newer. Hitting the space bar or 'r' key always generates a report for the very latest helm information, with the 'r' putting the scope into streaming, i.e., continuous update, mode.

2.4 Console Key Mapping and Command Line Usage Summaries

The uHelmScope has a separate thread to accept user input from the console to adjust the content and format of the console output. It operates in either the *streaming mode*, where new helm summaries are displayed as soon as they are received, or the *paused mode* where no further output is generated until the user requests it. The key mappings can be summarized in the console output by typing the 'h' key, which also sets the mode to *paused*. The key mappings shown to the user are shown in Listing 2.

Listing 2 - Key mapping summary shown after hitting 'h' in a console.

```
 1  KeyStroke  Function
 2  ---------  --------------------------
 3     Spc     Pause and Update latest information once - now
 4     r/R     Resume information refresh
 5     h/H     Show this Help msg - 'r' to resume
```

```
 6     b/B     Toggle Show Idle/Completed Behavior Details
 7     t/T     Toggle truncation of column output
 8     m/M     Toggle display of Hiearchical Mode Declarations
 9      f      Filter PWT_* UH_* STATE_* in Behavior-Posts Report
10      F      Filter PC_* VIEW_* in Behavior-Posts Report
11     s/S     Toggle Behavior State Vars in MOOSDB-Scope Report
12     u/U     Unmask all variables in Behavior-Posts Report
13     v/V     Toggle display of virgins in MOOSDB-Scope output
14     [/]     Display Iteration 1 step prev/forward
15     {/}     Display Iteration 10 steps prev/forward
16     (/)     Display Iteration 100 steps prev/forward
17      #      Toggle Show the MOOSDB-Scope Report
18      @      Toggle Show the Behavior-Posts Report
19
20  Hit 'r' to resume outputs, or SPACEBAR for a single update
```

Several of the same preferences for adjusting the content and format of the uHelmScope output can be expressed on the command line, with a command line switch. The switches available are shown to the user by typing uHelmScope -h. The output shown to the user is shown in Listing 3.

Listing 3 - Command line usage of the uHelmScope *application.*

```
 1  > uHelmScope -h
 2  Usage: uHelmScope moosfile.moos [switches] [MOOSVARS]
 3    -t:  Column truncation is on (off by default)
 4    -c:  Exclude MOOS Vars in MOOS file from MOOSDB-Scope
 5    -x:  Suppress MOOSDB-Scope output block
 6    -p:  Suppress Behavior-Posts output block
 7    -v:  Suppress display of virgins in MOOSDB-Scope block
 8    -r:  Streaming (unpaused) output of helm iterations
 9    MOOSVAR_1 MOOSVAR_2 .... MOOSVAR_N
```

The command line invocation also accepts any number of MOOS variables to be included in the MOOSDB-Scope portion of the uHelmScope output. Any argument on the command line that does not end in .moos, and is not one of the switches listed above, is interpreted to be a requested MOOS variable for inclusion in the scope list. Thus the order of the switches and MOOS variables do not matter. These variables are added to the list of variables that may have been specified in the uHelmScope configuration block of the MOOS file. Scoping on *only* the variables given on the command line can be accomplished using the -c switch. To support the simultaneous running of more than one uHelmScope connected to the same MOOSDB, uHelmScope generates a random number N between 0 and 10,000 and registers with the MOOSDB as uHelmScope_N.

2.5 IvPHelm MOOS Variable Output Supporting uHelmScope Reports

There are six variables published by the pHelmIvP MOOS process, and registered for by the uHelmScope process, that provide critical information for generating uHelmScope reports. They are: IVPHELM_SUMMARY, IVPHELM_POSTINGS, IVPHELM_ENGAGED, IVPHELM_STATEVARS, IVPHELM_DOMAIN, and IVPHELM_MODESET. The first three are produced on each iteration of the helm, and the last three are typically only produced once when the helm is launched.

```
IVPHELM_SUMMARY  = "iter=66,ofnum=1,warnings=0,utc_time=1209755370.74,solve_time=0.00,
     create_time=0.02,loop_time=0.02,var=speed:3.0,var=course:108.0,halted=false,
```

```
      running_bhvs=none,active_bhvs=waypt_survey$6.8$100.00$1236$0.01$0/0,
      idle_bhvs=waypt_return$55.3$n/a,completed_bhvs=none"

  IVPHELM_POSTINGS  = "waypt_return$@!$66$@!$PC_waypt_return=RETURN = true$@!$VIEW_SEGLIST=label,
      alpha_waypt_return : 0,0$@!$VIEW_POINT=0,0,0,waypt_return$@!$PWT_BHV_WAYPT_RETURN=0
      $@!$STATE_BHV_WAYPT_RETURN=0"

  IVPHELM_POSTINGS  = waypt_survey$@!$66$@!$PC_waypt_survey=-- ok --$@!$WPT_STAT_LOCAL=vname=alpha,
      index=1,dist=80.47698,eta=26.83870$@!$WPT_INDEX=1$@!$VIEW_SEGLIST=label,
      alpha_waypt_survey:30,-20:30,-100:90,-100:110,-60:90,-20$@!$PWT_BHV_WAYPT_SURVEY=100$@!$
      STATE_BHV_WAYPT_SURVEY=2

  IVPHELM_DOMAIN = "speed,0,4,21:course,0,359,360"

  IVPHELM_STATEVARS = "RETURN,DEPLOY"

  IVPHELM_MODESET   = "---,ACTIVE#---,INACTIVE#ACTIVE,SURVEYING#ACTIVE,RETURNING"

  IVPHELM_ENGAGED   = "ENGAGED"
```

The IVPHELM_SUMMARY variable contains all the dynamic information included in the general helm overview (top) section of the uHelmScope output. It is a comma-separated list of var=val pairs. The IVP_DOMAIN variable also contributes to this section of output by providing the IvP domain used by the helm. The IVPHELM_POSTINGS variable includes a list of MOOS variables and values posted by the helm for a given behavior. The helm writes to this variable once per iteration *for each behavior*. The IVPHELM_STATEVARS variable affects the MOOSDB-Scope section of the uHelmScope output by identifying which MOOS variables are used by behaviors in conditions, runflags, endflags and idleflags.

2.6 Configuration Parameters for uHelmScope

Configuration for uHelmScope amounts to specifying a set of parameters affecting the terminal output format. An example configuration is shown in Listing 4, with all values set to the defaults. Launching uHelmScope with a MOOS file that does not contain a uHelmScope configuration block is perfectly reasonable.

Listing 4 - An example uHelmScope *configuration block.*

```
 1  //------------------------------------------------------------
 2  // uHelmScope configuration block
 4
 5  ProcessConfig = uHelmScope
 6  {
 7    AppTick    = 1
 8    CommsTick  = 1
 9
10    PAUSED             = true     // All Parameters and Parameter-Values
11    HZ_MEMORY          = 5, 100   // are __NOT__ Case Sensitive
12    DISPLAY_MOOS_SCOPE = true
13    DISPLAY_BHV_POSTS  = true
14    DISPLAY_VIRGINS    = true
15    DISPLAY_STATEVARS  = true
16    TRUNCATED_OUTPUT   = false
```

```
17    BEHAVIORS_CONCISE  = false
18
19    VAR = BHV_WARNING, AIS_REPORT_LOCAL   // MOOS Variable names
20  }                                       // __ARE__ Case Sensitive
```

Each of the parameters, with the exception of HZ_MEMORY can also be set on the command line, or interactively at the console, with one of the switches or keyboard mappings listed in Section 2.6. A parameter setting in the MOOS configuration block will take precedence over a command line switch. The HZ_MEMORY parameter takes two integer values, the second of which must be larger than the first. This is the number of samples used to form the average time between helm intervals, displayed on line 2 of the uHelmScope output.

2.7 Publications and Subscriptions for uHelmScope

Variables published by the uHelmScope application

- NONE

Variables subscribed for by the uHelmScope application

- <USER-DEFINED>: Variables identified for scoping by the user in the uHelmScope will be subscribed for. See Section 2.2.2.
- <HELM-DEFINED>: As described in Section 2.2.2, the variables scoped by uHelmScope include any variables involved in the preconditions, runflags, idleflags, activeflags, inactiveflags, and endflags for any of the behaviors involved in the current helm configuration.
- IVPHELM_SUMMARY: See Section 2.5.
- IVPHELM_POSTINGS: See Section 2.5.
- IVPHELM_STATEVARS: See Section 2.5.
- IVPHELM_IVP_DOMAIN: See Section 2.5.
- IVPHELM_IVP_MODESET: See Section 2.5.
- IVPHELM_IVP_ENGAGED: See Section 2.5.

3 pMarineViewer

3.1 Brief Overview

The `pMarineViewer` application is a MOOS application written with FLTK and OpenGL for rendering vehicles and associated information and history during operation or simulation. The typical layout shown in Figure 2 is that `pMarineViewer` is running in its own dedicated local MOOS community while simulated or real vehicles on the water transmit information in the form of a stream of *AIS reports* to the local community.

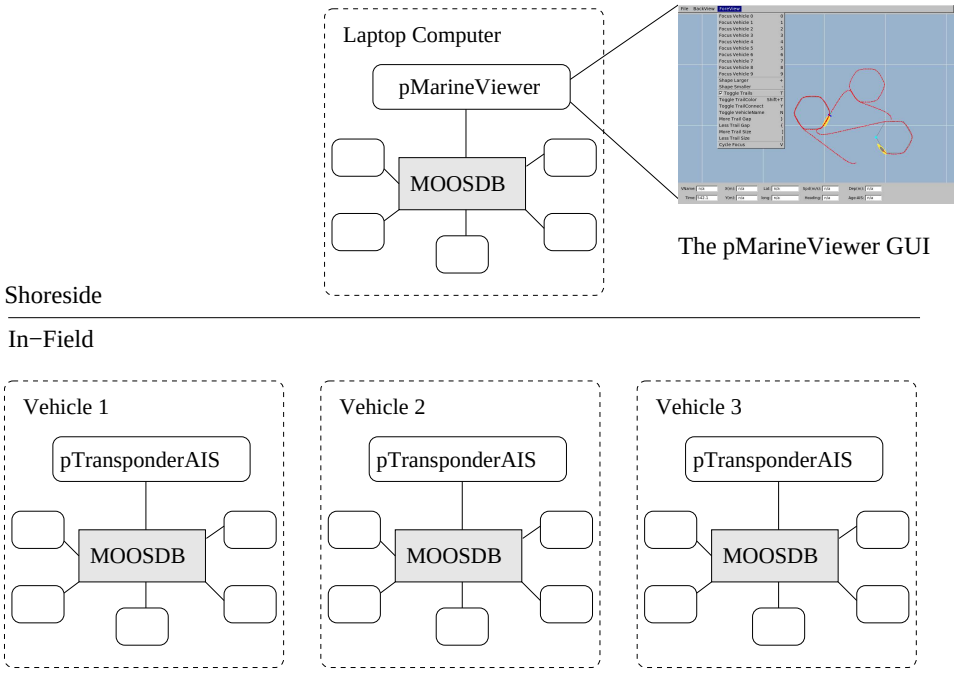

Figure 2: A common usage of the `pMarineViewer` is to have it running in a local `MOOSDB` community while receiving AIS reports on vehicle poise from other MOOS communities running on either real or simulated vehicles. The vehicles can also send messages with certain geometric information such as polygons and points that the view will accept and render.

The user is able manipulate a geo display to see multiple vehicle tracks and monitor key information about individual vehicles. In the primary interface mode the user is a passive observer, only able to manipulate what it sees and not able to initiate communications to the vehicles. However there are hooks available and described later in this section to allow the interface to accept field control commands. The key variable subscribed to by `pMarineViewer` is the variable `AIS_REPORT`, which has the following structure given by an example:

```
AIS_REPORT = "NAME=nyak201,TYPE=kayak,MOOSDB_TIME=53.049,UTC_TIME=1195844687.236,X=37.49,
             Y=-47.36, SPD=2.40,HDG=11.17,DEPTH=0"
```

Reports from different vehicles are sorted by their vehicle name and stored in histories locally in the `pMarineViewer` application. The `AIS_REPORT` is generated by the vehicles based on either sensor information, e.g., GPS or compass, or based on a local vehicle simulator.

3.2 Description of the pMarineViewer GUI Interface

The viewable area of the GUI has two parts - a geo display area where vehicles and perhaps other objects are rendered, and a lower area with certain data fields associated with an *active* vehicle are updated. A typical screen shot is shown in Figure 3 with two vehicles rendered - one AUV and one kayak. Vehicle labels and history are rendered. Properties of the vehicle rendering such as the trail length, size, and color, and vehicle size and color, and pan and zoom can be adjusted dynamically in the GUI. They can also be set in the `pMarineViewer` MOOS configuration block. Both methods of tuning the rendering parameters are described later in this section.

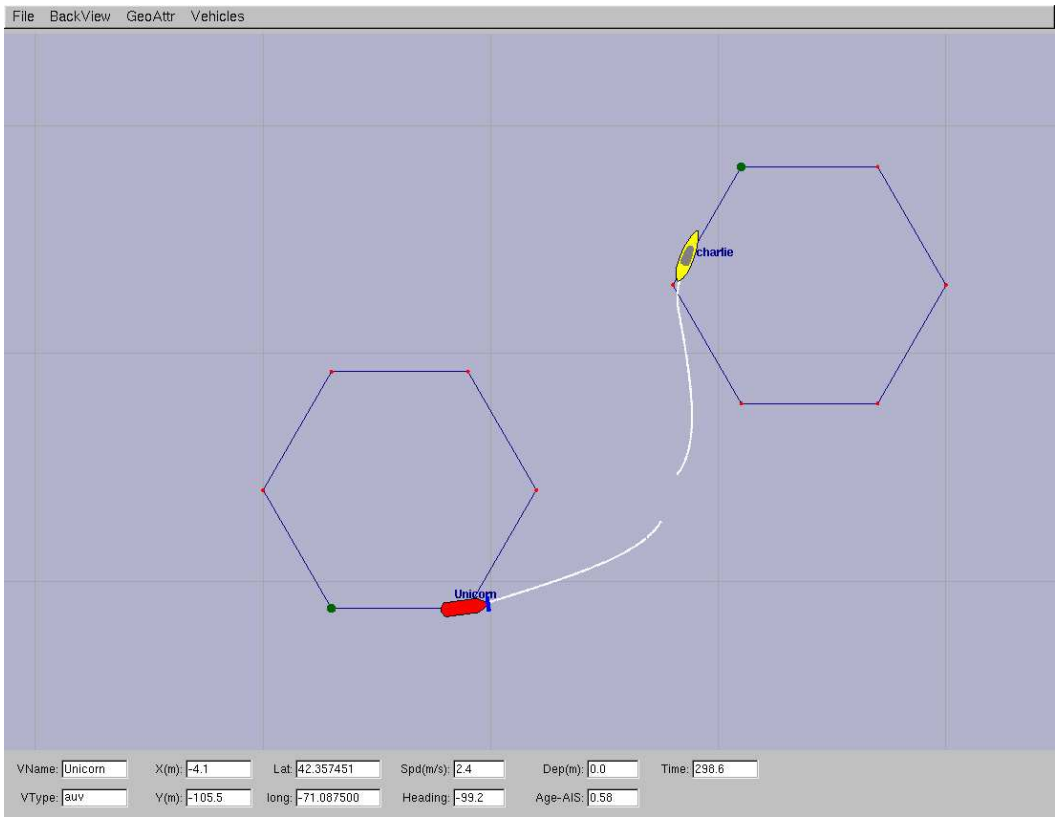

Figure 3: A screen shot of the `pMarineViewer` application running with two vehicles - one kayak platform, and one AUV platform. The unicorn AUV platform is the *active* platform meaning the data fields on the bottom reflect the data for this platform.

The lower part of the display is dedicated to displaying detailed position information on a single *active* vehicle. Changing the designation of which vehicle is active can be accomplished by repeatedly hitting the 'v' key. The active vehicle is always rendered as red, while the non-active vehicles have a default color of yellow. Individual vehicle colors can be given different default values (even red, which could be confusing) by the user. The individual fields are described below in Listing 5.

Listing 5 - Description of the on-screen fields of pMarineViewer.

```
Field    Description
-----    -----------
VName    The name of the active vehicle associated with the data in the other
         GUI data fields. The active vehicle is typically indicated also by
         changing to the color red on the geo display.

VType    The platform type, e.g., AUV, Glider, Kayak, Ship or Unknown.

X(m)     The x (horizontal) position of the active vehicle given in meters in
         the local coordinate system.

Y(m)     The y (vertical) position of the active vehicle given in meters in the
         local coordinate system.

Lat      The latitude (vertical) position of the active vehicle given in
         decimal latitude coordinates.

Lon      The longitude (horizontal) position of the active vehicle given in
         decimal longitude coordinates.

Speed    The speed of the active vehicle given in meters per second.

Heading  The heading of the active vehicle given in degrees ($0-359.9$).

Depth    The depth of the active vehicle given in meters.

Age-AIS  The elapsed time in seconds since the last received AIS report for
         the active vehicle.
Time     Time in seconds since the pMarineViewer process launched.

```

In simulation, the age of the AIS report is likely to remain zero as shown in the figure, but when operating on the water, monitoring the AIS age field can be the first indicator when a vehicle has failed or lost communications. Or it can act as an indicator of comms quality.

3.3 Pull-Down Menu Options

Properties of the geo display rendering can be tuned to better suit a user or circumstance or for situations where screen shots are intended for use in other media such as papers or PowerPoint. There are two pull-down menus - the first deals with background properties, and the second deals with properties of the objects rendered on the foreground. Many of the adjustable properties can be adjusted by two other means besides the pull-down menus - by the hot keys defined for a particular pull-down menu item, or by configuring the parameter in the MOOS file configuration block.

3.3.1 The BackView Pull-Down Menu

Most pull-down menu items have hot keys defined (on the right in the menu). For certain actions like pan and zoom, in practice the typical user quickly adopts the hot-key interface. But the pull-down menu is one way to have a form of hot-key documentation always handy. The zooming

commands affect the viewable area and apparent size of the objects. Zoom in with the 'i' or 'I' key, and zoom out with the 'o' or 'O' key. Return to the original zoom with ctrl+'z'.

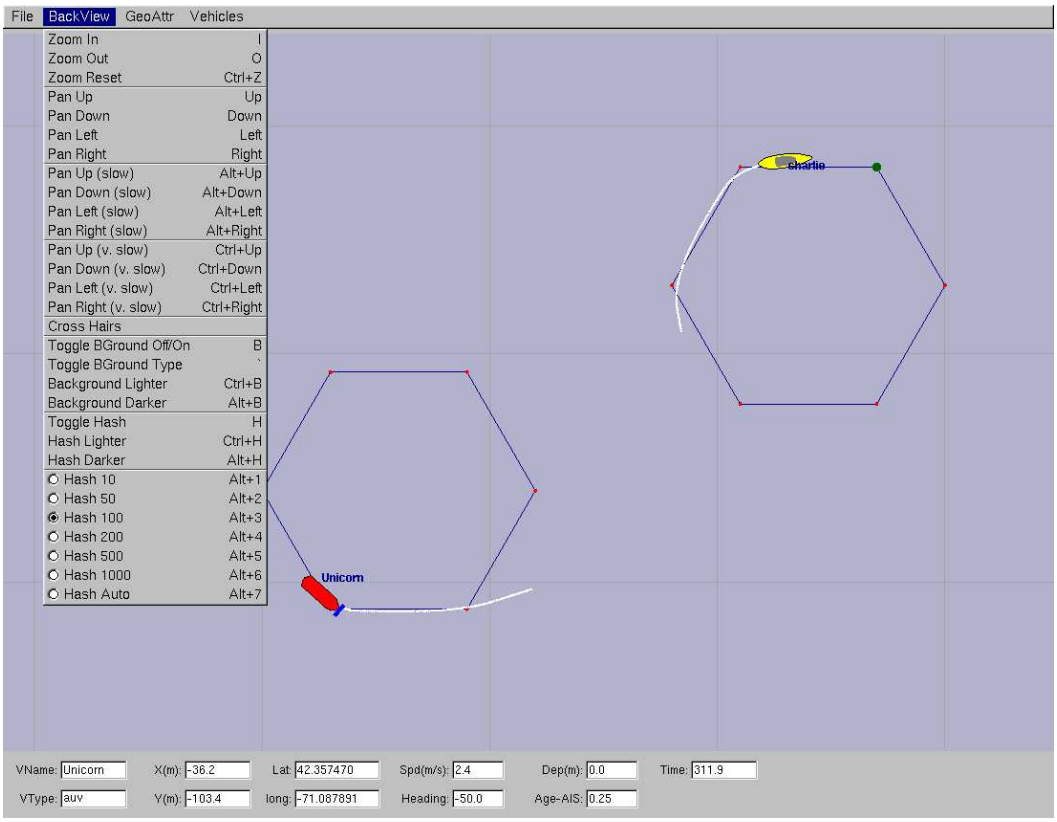

Figure 4: The *BackView* pull-down menu of the `pMarineViewer` lists the options, with hot-keys, for affecting rendering aspects of the geo-display background.

Panning is done with the keyboard arrow keys. Three rates of panning are supported. To pan in 20 meter increments, just use the arrow keys. To pan "slowly" in one meter increments, use the Alt + arrow keys. And to pan "very slowly", in increments of a tenth of a meter, use the Ctrl + arrow keys. The viewer supports two types of "convenience" panning. It will pan put the active vehicle in the center of the screen with the 'C' key, and will pan to put the average of all vehicle positions at the center of the screen with the 'c' key. These are part of the 'Vehicles' pull-down menu discussed in Section 3.3.3.

The background can be in one of two modes; either displaying a gray-scale background, or displaying a geo image read in as a texture into OpenGL from an image file. The default is the geo display mode if provided on start up, or the grey-scale mode if no image is provided. The mode can be toggled by typing the 'b' or 'B' key. The geo-display mode can have two sub-modes if two image files are provided on start-up. More on this in Section 3.7. This is useful if the user has access to a satellite image *and* a map image for the same operation area. The two can be toggled by hitting the back tick key. When in the grey-scale mode, the background can be made lighter by hitting the ctrl+'b' key, and darker by hitting the alt+'b' key.

Hash marks can be overlaid onto the background. By default this mode is off, but can be toggled

with the 'h' or 'H' key. The hash marks are drawn in a grey-scale which can be made lighter by typing the ctrl+'h' key, and darker by typing the alt+'h' key. Certain hash parameters can also be set in the `pMarineViewer` configuration block of the MOOS file. The `hash_view` parameter can be set to either `true` or `false`. The default is `false`. The `hash_delta` parameter can be set to any positive integer not greater than 1000. The default is 100.

3.3.2 The GeoAttributes Pull-Down Menu

The GeoAttributes pull-down menu allows the user to edit the properties of geometric objects capable of being rendered by the `pMarineViewer`. In general the Polygon, SegList, Point, and XYGrid objects are received by the viewer at run time to reflect artifacts generated by the IvP Helm indicating aspects of progress during their mission. The hexagons in Figure 5 for example represents the set of waypoints being used by the vehicles shown.

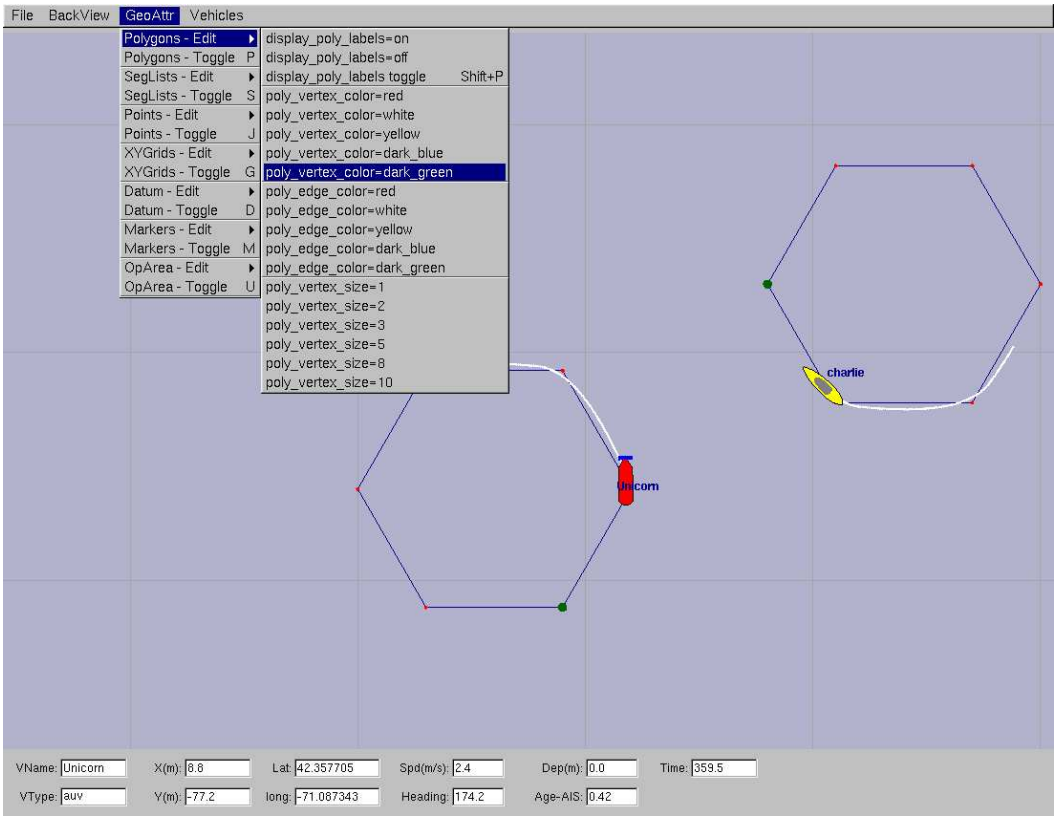

Figure 5: The *GeoAttributes* pull-down menu of the `pMarineViewer` lists the options and hot keys for affecting the rendering of geometric objects

The Datum, Marker and OpArea objects are typically read in once at start-up and reflect persistent info about the operation area. The datum is a single point that represents (0,0) in local coordinates. Marker objects typically represent physical objects in the environment such as a buoy, or a fixed sensor. The OpArea objects are typically a combination of points and lines that reflect a

region of earth where a set of vehicles are being operated. Each category has a hot key that toggles the rendering of all objects of the same type, and a secondary drop-down menu as shown in the figure that allows the adjustment of certain rendering properties of objects. Many of the items in the menu have form `parameter = value`, and these settings can also be achieved by including this line in the `pMarineViewer` configuration block in the MOOS file.

3.3.3 The Vehicles Pull-Down Menu

The *Vehicles* pull-down menu deals with properties of the objects displayed in the geo display foreground. The `Vehicles-Toggle` menu item will toggle the rendering of all vehicles and all trails. The `Cycle_Focus` menu item will set the index of the *active* vehicle, i.e., the vehicle who's attributes are being displayed in the lower output boxes. The assignment of an index to a vehicle depends on the arrival of AIS reports. If an AIS report arrives for a previously unknown vehicle, it is assigned a new index.

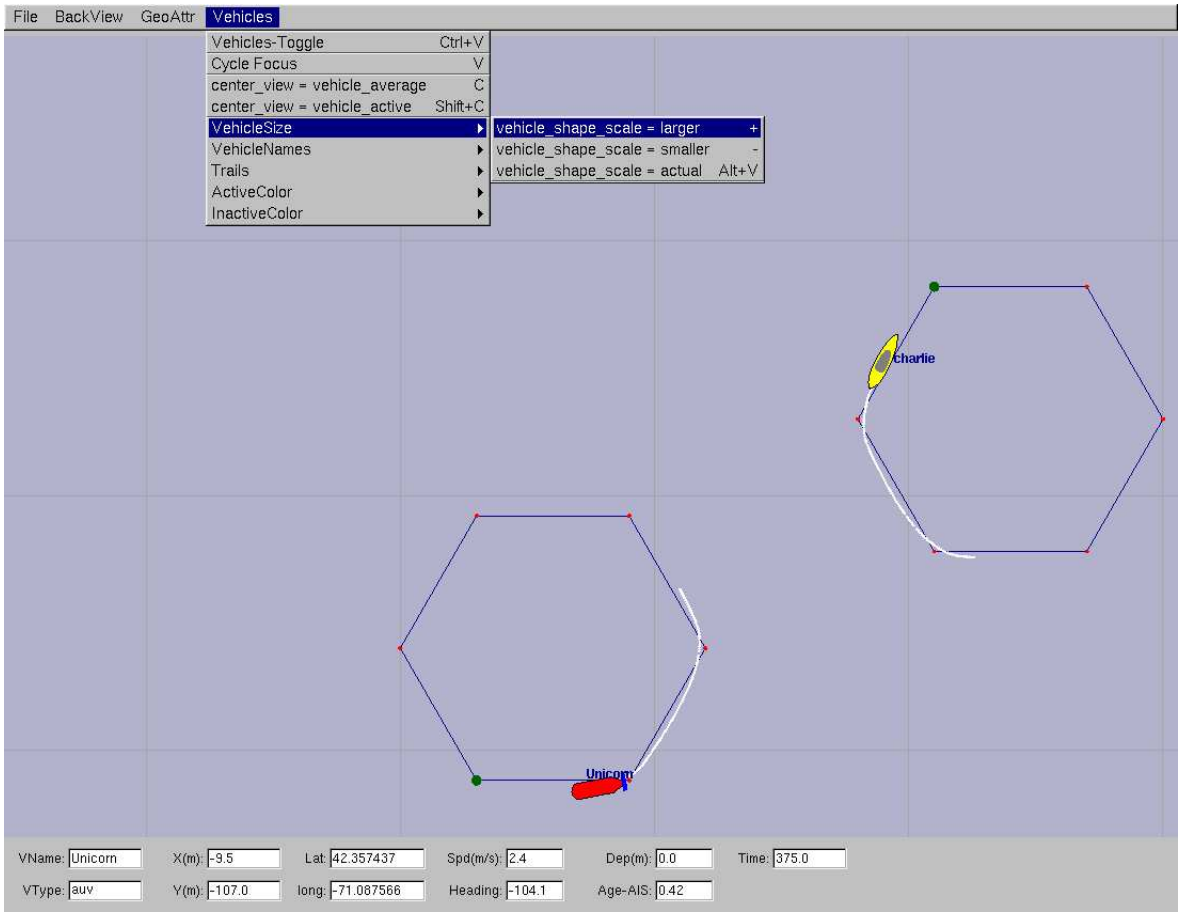

Figure 6: The *ForeView* pull-down menu of the `pMarineViewer` lists the options, with hot-keys, for affecting rendering aspects of the objects on the geo-display foreground, such as vehicles and vehicle track history.

The `center_view` menu items alters the center of the view screen to be panned to either the position of the active vehicle, or the position representing the average of all vehicle positions. Once

the user has selected this, this mode remains *sticky*, that is the viewer will automatically pan as new vehicle information arrives such that the view center remains with the active vehicle or the vehicle average position. As soon as the user pans manually (with the arrow keys), the viewer breaks from trying to update the view position in relation to received vehicle position information. The rendering of the vehicles can made larger with the '+' key, and smaller with the '-' key, as part of the `VehicleSize` pull-down menu as shown. The size change is applied to all vehicles equally as a scalar multiplier. Currently there is no capability to set the vehicle size individually, or to set the size automatically to scale.

Vehicle trail (track history) rendering can be toggled off and on with the 't' or 'T' key. The default is on. A set of predefined trail colors can be toggled through with the CTRL+'t' key. The individual trail points can be rendered with a line connecting each point, or by just showing the points. When the AIS report stream is flowing quickly, typically the user doesn't need or want to connect the points. When the viewer is accepting input from an AUV with perhaps a minute or longer delay in between reports, the connecting of points is helpful. This setting can be toggled with the 'y' or 'Y' key, with the default being off. The size of each individual trail point rendering can be made smaller with the '[' key, and larger with the ']' key.

The color of the active vehicle is by default red and can be altered to a handful of other colors in the ActiveColor sub-menu of the Vehicles pull-down menu. Likewise the inactive color, which is by default yellow, can be altered in the InactiveColor sub-menu. These colors can also be altered by setting the `active_vcolor` and `inactive_vcolor` parameters in the `pMarineViewer` configuration block of the MOOS file. They can be set to any color as described in the Colors Appendix.

3.4 Displayable Vehicle Shapes, Markers and other Geometric Objects

3.4.1 Displayable Vehicle Shapes

The shape rendered for a particular vehicle depends on the *type* of vehicle indicated in the AIS report received in `pMarineViewer`. There are four types that are currently handled, an AUV shape, a glider shape, a kayak shape, and a ship shape, shown in Figure 7.

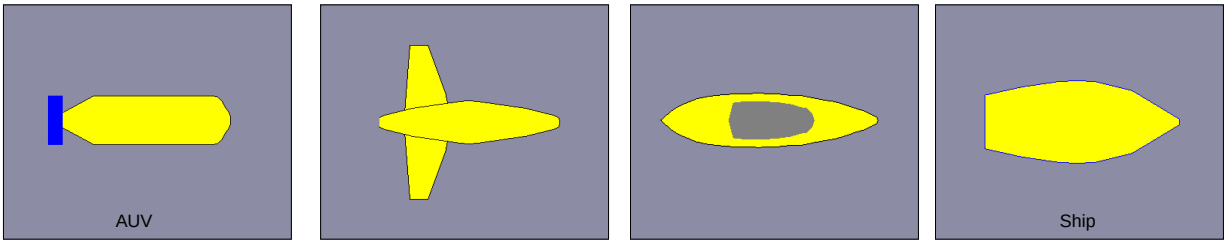

Figure 7: Vehicle types known to the `pMarineViewer`.

The default shape for an unknown vehicle type is currently set to be the shape "ship". The default color for a vehicle is set to be yellow, but can be individually set within the `pMarineViewer` MOOS configuration block with entries like the following:

```
vehicolor = alpha, turquoise
```

```
vehicolor = charlie, navy,
vehicolor = philly, 0.5, 0.9, 1.0
```

The parameter `vehicolor` is case insensitive, as is the color name. The vehicle name however is case sensitive. All colors of the form described in the Colors Appendix are acceptable.

3.4.2 Displayable Marker Shapes

A set of simple static markers can be placed on the geo display for rendering characteristics of an operation area such as buoys, fixed sensors, hazards, or other things meaningful to a user. The five types of markers are shown in Figure 8. They are configured in the `pMarineViewer` configuration block of the MOOS file with the following format:

```
// Example marker entries in a pMarineViewer config block of a .moos file
// Parameters are case insensitive. Parameter values (except type) are
// case sensitive.
marker  = type=efield,x=100,y=20,SCALE=4.3,label=alpha,COLOR=red
marker  = type=square,lat=42.358,lon=-71.0874,scale=2,color=blue
```

Each entry is a string of comma-separated pairs. The order is not significant. The only mandatory fields are for the marker type and position. The position can be given in local x-y coordinates or in earth coordinates. If both are given for some reason, the earth coordinates will take precedent. The *scale* parameter is by default 1 and simply scales linearly the size of the shape. Shapes are roughly 10x10 meters by default. The GUI provides a hook to scale all markers globally with the 'ALT-M' and 'CTRL-M' hot keys and in the GeoAttributes pull-down menu.

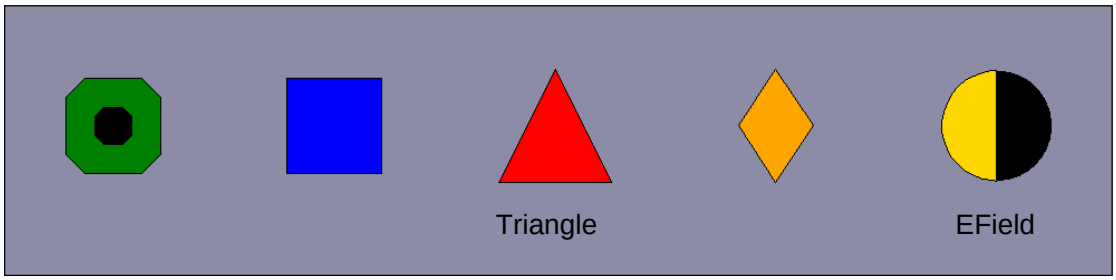

Figure 8: Marker types known to the `pMarineViewer`.

The color parameter is optional and markers have the default colors shown in Figure 8. Any of the colors described in the Colors Appendix are fair game. The black part of the Gateway and Efield markers is immutable. The label field is optional and is by default the empty string. Note that if two markers of the same type have the same non-empty label, only the first marker will be acknowledged and rendered. Two markers of different types can have the same label.

In addition to declaring markers in the `pMarineViewer` configuration block, markers can be received dynamically by `pMarineViewer` through the `VIEW_MARKER` MOOS variable, and thus can originate from any other process connected to the `MOOSDB`. The syntax is exactly the same, thus the above two markers could be dynamically received as:

```
VIEW_MARKER  = "type=efield,x=100,y=20,SCALE=4.3,label=alpha,COLOR=red"
VIEW_MARKER  = "type=square,lat=42.358,lon=-71.0874,scale=2,color=blue"
```

The effect of a "moving" marker, or a marker that changes color, can be achieved by repeatedly publishing to the VIEW_MARKER variable with only the position or color changing while leaving the label and type the same.

3.4.3 Displayable Geometric Objects

Some additional objects can be rendered in the viewer such as convex polygons, points, and a set of line segments. In Figures 3 and 4, each vehicle has traversed to and is proceeding around a hexagon pattern. This is apparent from both the rendered hexagon, and confirmed by the trail points. Displaying certain markers in the display can be invaluable in practice to debugging and confirming the autonomy results of vehicles in operation. The intention is to allow for only a few key additional objects to be drawable to avoid letting the viewer become overly specialized and bloated.

In addition to the AIS_REPORT variable indicating vehicle pose, pMarineViewer registers for the following additional MOOS variables - VIEW_POLYGON, VIEW_SEGLIST, VIEW_POINT. Example values of these variables:

```
VIEW_POLYGON = "label,nyak201-LOITER:85,-9:100,-35:85,-61:55,-61:40,-35:55,-9"
VIEW_POINT   = 10.00,-80.00,5,nyak200
VIEW_SEGLIST = "label,nyak201-WAYPOINT:0,100:50,-35:25,-63"
```

Each variable describes a data structure implemented in the geometry library linked to by pMarineViewer. Instances of these objects are initialized directly by the strings shown above. A key member variable of each geometric object is the *label* since pMarineViewer maintains a (C++, STL) map for each object type, keyed on the label. Thus a newly received polygon replaces an existing polygon with the same label. This allows one source to post its own geometric cues without clashing with another source. By posting empty objects, i.e., a polygon or seglist with zero points, or a point with zero radius, the object is effectively erased from the geo display. The typical intended use is to let a behavior within the helm to post its own cues by setting the label to something unique to the behavior. The VIEW_POLYGON listed above for example was produced by a loiter behavior and describes a hexagon with the six points that follow.

3.5 Support for Command-and-Control Usage

For the most part pMarineViewer is intended to be only a receiver of information from the vehicles and the environment. Adding command and control capability, e.g., widgets to re-deploy or manipulate vehicle missions, can be readily done, but make the tool more specialized, bloated and less relevant to a general set of users. A certain degree of command and control can be accomplished by poking key variables and values into the local MOOSDB, and this section describes three methods supported by pMarineViewer for doing just that.

3.5.1 Poking the MOOSDB with Geo Positions

The graphic interface of pMarineViewer provides an opportunity to poke information to the MOOSDB based on visual feedback of the operation area shown in the geo display. To exploit this, two

command and control hooks were implemented with a small footprint. When the user clicks on the geo display, the location in local coordinates is noted and written out to one of two variables - MVIEWER_LCLICK for left mouse clicks, and MVIEWER_RCLICK for right mouse clicks, with the following syntax:

```
MVIEWER_LCLICK  = "x=958.0,y=113.0,vname=nyak200",
```

and

```
MVIEWER_RCLICK  = "x=740.0,y=-643.0,vname=nyak200".
```

One can then write another specialized process, e.g., pViewerRelay, that subscribes to these two variables and takes whatever command and control actions desired for the user's needs. One such incarnation of pViewerRelay was written (but not distributed or addressed here) that interpreted the left mouse click to have the vehicle station-keep at the clicked location.

3.5.2 Configuring GUI Buttons for Command and Control

The pMarineViewer GUI can be optionally configured to allow for four push-buttons to be enabled and rendered in the lower-right corner. Each button can be associated with a button label, and a list of variable-value pairs that will be poked to the MOOSDB to which the pMarineViewer process is connected. The basic syntax is as follows:

```
BUTTON_ONE   = LABEL # VARIABLE=VALUE # VARIABLE=VALUE  ...
BUTTON_TWO   = LABEL # VARIABLE=VALUE # VARIABLE=VALUE  ...
BUTTON_THREE = LABEL # VARIABLE=VALUE # VARIABLE=VALUE  ...
BUTTON_FOUR  = LABEL # VARIABLE=VALUE # VARIABLE=VALUE  ...
```

The left-hand side contains one of the four button keywords, e.g., BUTTON_ONE. The right-hand side consists of a '#'-separated list. Each component in this list is either a '='-separated variable-value pair, or otherwise it is interpreted as the button's label. The ordering does not matter and the '#'-separated list can be continued over multiple lines as in lines 59-60 in Listing 6 on page 28.

The variable-value pair being poked on a button call will determine the variable type by the following rule of thumb. If the value is non-numerical, e.g., true, one, it is poked as a string. If it is numerical it is poked as a double value. If one really wants to poke a string of a numerical nature, the addition of quotes around the value will suffice to ensure it will be poked as a string. For example:

```
BUTTON_ONE   = Start # Vehicle=Nomar # ID="7"
```

In this case, clicking the button labeled "Start" will result in two pokes, the second of which will have a string value of "7", not a numerical value. As with any poke to the MOOSDB of a given variable-value pair, if the value is of a type inconsistent with the first write to the DB under that variable name, it will simply by ignored.

3.5.3 Configuring Command and Control Actions from the Pull-Down Menu

The `pMarineViewer` GUI can be optionally configured to have a separate `Action` pull-down menu with user-defined pokes to the MOOSDB. These pokes can also be configured in groups to allow several pokes with a single menu selection. The syntax is shown below by example, taken from the configuration in the `alpha.moos` file.

```
ACTION     = MENU_KEY=deploy # DEPLOY=true # RETURN=false
ACTION+    = MENU_KEY=deploy # MOOS_MANUAL_OVERIDE=false
ACTION     = RETURN=true
```

The information to the right of the `ACTION` keyword is a `'#'`-separated list of variable-value pairs. If the pair has the key word `MENU_KEY` on the left, the value on the right is a key associated with all variable-value pairs on the line. When a menu selection is chosen that contains a key, then all variable-value pairs with that key are posted to the `MOOSDB`. If the `ACTION` key word has a trailing `'+'` character as above, the pull-down menu will render a line separator after the menu item. The above configuration should result in a rendering similar to that in Figure 9.

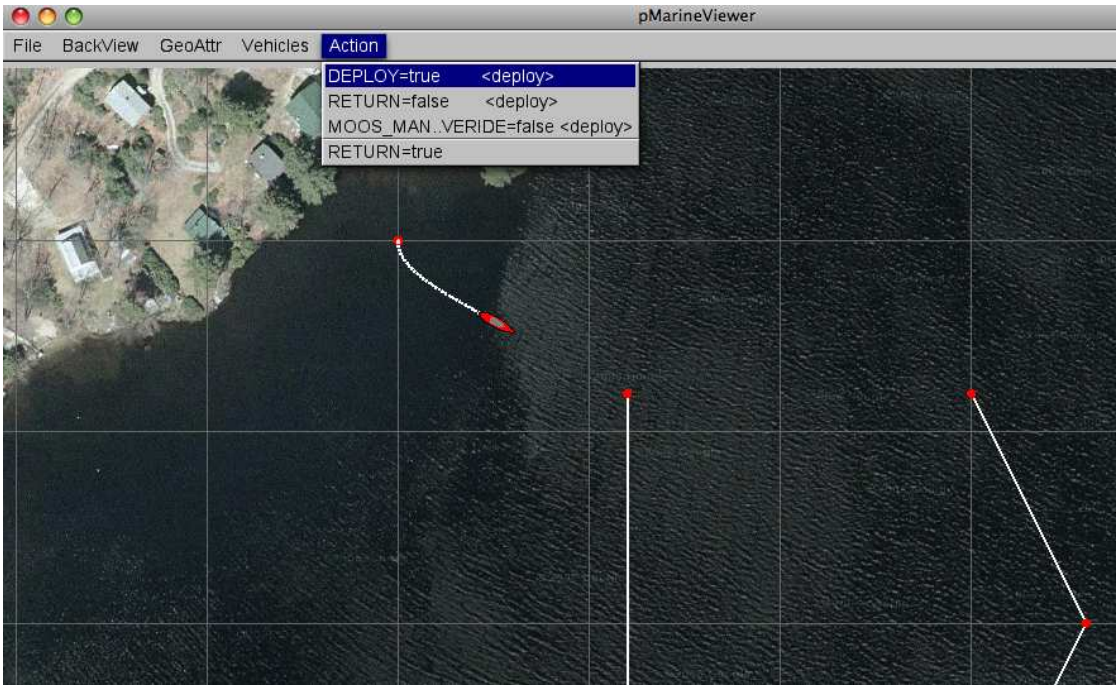

Figure 9: **The `Actions` pull-down menu of the `pMarineViewer`**: The three variable-value pairs above the menu divider will be poked in unison when any of the three are chosen.

The variable-value pair being poked on an action selection will determine the variable type by the following rule of thumb. If the value is non-numerical, e.g., `true`, `one`, it is poked as a string. If it is numerical it is poked as a double value. If one really wants to poke a string of a numerical nature, the addition of quotes around the value will suffice to ensure it will be poked as a string. For example:

```
ACTION   = Vehicle=Nomar # ID="7"
```

3.6 Configuration Parameters for pMarineViewer

Many of the display settings available in the pull-down menus described in Sections 3.3 can also be set in the `pMarineViewer` block of the MOOS configuration file. Mostly this redundancy is for convenience for a user to have the desired settings without further keystrokes after start-up. An example configuration block is shown in Listing 6.

Listing 6 - An example pMarineViewer configuration block.

```
LatOrigin  =   47.7319
LongOrigin = -122.8500

//---------------------------------------------
// pMarineViewer configuration  block

ProcessConfig = pMarineViewer
{
  // Standard MOOS parameters affecting comms and execution
  AppTick    = 4
  CommsTick  = 4

  // Parameters and their default values
  HASH_VIEW     = false
  HASH_DELTA    = 50
  HASH_SHADE    = 0.65
  BACK_SHADE    = 0.70
  TRAIL_VIEW    = true
  TRAIL_SIZE    = 0.1
  TRAIL_GAP     = 1.0
  TIFF_VIEW     = true
  ZOOM          = 1.0
  DISPLAY_VNAME = false
  VERBOSE       = false

  // Setting the vehicle colors - default is yellow
  VEHICOLOR     = nyak200,dark_blue
  VEHICOLOR     = nyak201,0.0,0.0,0.545
  VEHICOLOR     = nyak202,hex:00,00,8b

  // All polygon parameters are optional - defaults are shown
  // They can also be set dynamically in the GUI in the GeoAttrs pull-down menu
  polygon_edge_color   = yellow
  polygon_vertex_color = red
  polygon_label_color  = khaki
  polygon_edge_width   = 1.0
  polygon_vertex_size  = 3.0
  polygon_viewable_all = true;
  polygon_viewable_labels = true;

  // All seglist parameters are optional - defaults are shown
  // They can also be set dynamically in the GUI in the GeoAttrs pull-down menu
  seglist_edge_color   = white
  seglist_vertex_color = dark_blue
  seglist_label_color  = orange
  seglist_edge_width   = 1.0
```

```
47    seglist_vertex_size  = 3.0
48    seglist_viewable_all = true;
49    seglist_viewable_labels = true;
50
51    // All point parameters are optional - defaults are shown
52    // They can also be set dynamically in the GUI in the GeoAttrs pull-down menu
53    point_vertex_size  = 4.0;
54    point_vertex_color = yellow
55    point_viewable_all = true;
56    point_viewable_labels = true;
57
58    // Define two on-screen buttons with poke values
59    BUTTON_ONE = DEPLOY # DEPLOY=true
60    BUTTON_ONE = MOOS_MANUAL_OVERIDE=false # RETURN=false
61    BUTTON_TWO = RETURN # RETURN=true
62
63  }
```

Color references as in lines 27-29 can be made by name or by hexadecimal or decimal notation. (All three colors in lines 27-29 are the same but just specified differently.) See the Colors Appendix for a list of available color names and their hexadecimal equivalent.

The `VERBOSE` parameter on line 24 controls the output to the console. The console output lists the types of mail received on each iteration of `pMarineViewer`. In the non-verbose mode, a single character is output for each received mail message, with a '*' for `AIS_REPORT`, a 'P' for a `VIEW_POLYGON`, a '.' for a `VIEW_POINT`, and a 'S' for a `VIEW_SEGLIST`. In the verbose mode, each received piece of mail is listed on a separate line and the source of the mail is also indicated. An example of both modes is shown in Listing 7.

Listing 7 - An example pMarineViewer console output.

```
 1    // Example pMarineViewer console output NOT in verbose mode
 2
 3    13.56 > ****..
 4    13.82 > **..
 5    14.08 > **..
 6    14.35 > **..
 7    14.61 > ****.P.P
 8    14.88 > **..
 9    15.14 > **..
10
11    // Example pMarineViewer console output in verbose mode
12
13    15.42 >
14       AIS(nyak201)
15       AIS(nyak200)
16       Point(nyak201_wpt)
17       Point(nyak200_wpt)
18
19    15.59 >
20       Point(nyak201)
21       Poly(nyak201-LOITER)
22       AIS(nyak201)
23       AIS(nyak200)
```

```
24        Point(nyak200)
25        Poly(nyak200-LOITER)
```

3.7 More about Geo Display Background Images

The geo display portion of the viewer can operate in one of two modes, a grey-scale background, or an image background. Section 3.3.1 addressed how to switch between modes in the GUI interface. To use an image in the geo display, the input to `pMarineViewer` comes in two files, an image file in TIFF format, and an information text file correlating the image to the local coordinate system. The file names should be identical except for the suffix. For example `dabob_bay.tif` and `dabob_bay.info`. Only the `.tif` file is specified in the `pMarineViewer` configuration block of the MOOS file, and the application then looks for the corresponding `.info` file. The info file contains six lines - an example is given in Listing 8.

Listing 8 - An example .info file for the pMarineViewer

```
1  // Lines may be in any order, blank lines are ok
2  // Comments begin with double slashes
3
4  datum_lat  = 47.731900
5  datum_lon  = -122.85000
6  lat_north  = 47.768868
7  lat_south  = 47.709761
8  lon_west   = -122.882080
9  lon_east   = -122.794189
```

All six parameters are mandatory. The two datum lines indicate where $(0, 0)$ in local coordinates is in earth coordinates. The `lat_north` parameters correlates the upper edge of the image with its latitude position. Likewise for the other three parameters and boundaries. Two image files may be specified in the `pMarineViewer` configuration block. This allows a map-like image and a satellite-like image to be used interchangeably during use. (Recall the ToggleBackGroundType entry in the BackView pull-down menu discussed earlier.) An example of this is shown in Figure 10 with two images of Dabob Bay in Washington State. Both image files where created from resources at www.maps.google.com.

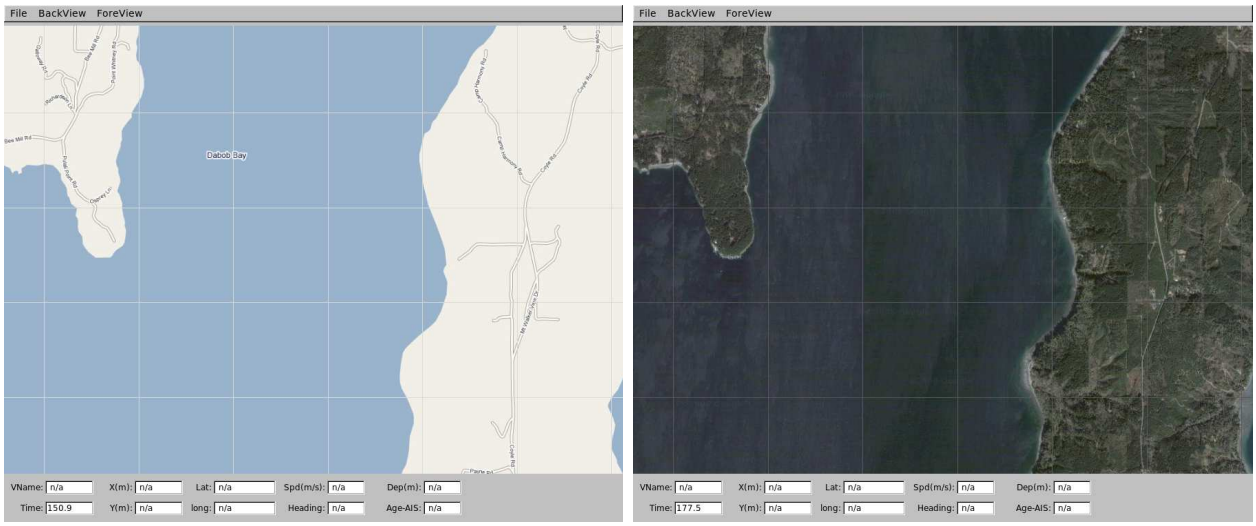

Figure 10: Two images loaded for use in the geo display mode of `pMarineViewer`. The user can toggle between both as desired during operation.

In the configuration block, the images can be specified by:

```
TIFF_FILE   = dabob_bay_map.tif
TIFF_FILE_B = dabob_bay_sat.tif
```

By default `pMarineViewer` will look for the files `Default.tif` and `DefaultB.tif` in the local directory unless alternatives are provided in the configuration block.

Variables published by the pMarineViewer application

- `MVIEWER_LCLICK`: When the user clicks the left mouse button, the position in local coordinates, along with the name of the active vehicle is reported. This can be used as a command and control hook as described in Section 3.5. As an example:

  ```
  MVIEWER_LCLICK = ‘‘x=-56.0,y=-110.0,vname=alpha’’
  ```

- `MVIEWER_RCLICK`: This variable is published when the user clicks with the right mouse button. The same information is published as with the left click.

- `HELM_MAP_CLEAR`: This variable is published once when the viewer connects to the `MOOSDB`. It is used in the `pHelmIvP` application to clear a local buffer used to prevent successive identical publications to its variables.

Variables subscribed for by pMarineViewer application

- `AIS_REPORT`: This is the primary variable consumed by `pMarineViewer` for collecting vehicle position information. An example:

  ```
  AIS_REPORT = "NAME=nyak201,TYPE=kayak,MOOSDB_TIME=53.049,UTC_TIME=1195844687.236,X=37.49,
               Y=-47.36, SPD=2.40,HDG=11.17,DEPTH=0"
  ```

- AIS_REPORT_LOCAL: This serves the same purpose as the above variable. In some simulation cases this variable is used.
- VIEW_POLYGON: A string representation of a polygon.
- VIEW_POINT: A string representation of a point.
- VIEW_SEGLIST: A string representation of a segment list.
- TRAIL_RESET: When the viewer receives this variable it will clear the history of trail points associated with each vehicle. This is used when the viewer is run with a simulator and the vehicle position is reset and the trails become discontinuous.
- GRID_CONFIG: A string representation of a grid. This initializes and registers a new grid with the viewer.
- GRID_DELTA: A string representation of a change in values for a given grid and specific grid cells with new value for each given cell.

4 uXMS

4.1 Brief Overview

The uXMS application is a terminal based tool for live scoping on a MOOSDB process. Since it is not dependent on any graphic libraries it is more likely to run out-of-the-box on machines that may not have proper libraries like FLTK installed. It is easily configured from the command line or a MOOS configuration block to scope on as little as one variable. It can be run in a mode where screen updates only occur at the user's request. For these reasons, it is a good choice when bandwidth is an issue. It is also possible to have multiple versions of uXMS connected to the same MOOSDB. The uXMS tool was meant to be an alternative to the more feature-rich, high-bandwidth, GUI-based uMS process written and distributed on the Oxford MOOS website.

4.2 Configuration Parameters for uXMS

Configuration for uXMS amounts to specifying the *scope list* - those variables uXMS will register with the MOOSDB for updates and display in the console output. The scope list can be augmented in two ways - from the command line, and from the uXMS configuration block of a MOOS file. In the MOOS file, lines have the form:

```
VAR = VARIABLE_1, VARIABLE_2, VARIABLE_3, ...
```

Duplicates, should they occur, are simply ignored. An example configuration is given in Listing 9.

Listing 9 - An example uXMS configuration block.

```
1  //------------------------------------------------------------------
2  // uXMS configuration block
3
4  ProcessConfig = uXMS
5  {
6    AppTick    = 5
7    CommsTick  = 5
8
9    // Navigation information (Or use -nav on the command line)
10   VAR  = NAV_X, NAV_Y, NAV_HEADING, NAV_SPEED, NAV_DEPTH
11
12   // Helm output information (Or use -helm on the command line)
13   VAR  = DESIRED_HEADING, DESIRED_SPEED, DESIRED_DEPTH
14
15   // More helm information (Or use -helm on the command line)
16   VAR  = BHV_WARNING, BHV_ERROR, MOOS_MANUAL_OVERIDE
17   VAR  = HELM_IPF_COUNT, HELM_ACTIVE_BHV, HELM_NONIDLE_BHV
18   VAR  = DEPLOY, RETURN, STATION_KEEP
19
20   // PID output information (or use -pid on the command line)
21   VAR  = DESIRED_RUDDER, DESIRED_THRUST, DESIRED_ELEVATOR
22
23   // uProcessWatch output (or use -proc on the command line)
24   VAR  = PROC_WATCH_SUMMARY, PROC_WATCH_EVENT
25
26   // Display parameters - Values shown are defaults
26   PAUSED               = true    // false if -r on cmd-line
```

```
27    DISPLAY_VIRGINS       = true    // false if -v on cmd-line
28    DISPLAY_EMPTY_STRINGS = true    // false if -e on cmd-line
29    DISPLAY_SOURCE        = false   // true  if -s on cmd-line
30    DISPLAY_TIME          = false   // true  if -t on cmd-line
31    DISPLAY_COMMUNITY     = false   // true  if -c on cmd-line
32  }
```

4.3 Command Line Arguments of uXMS

Many of the parameters available for setting the .moos file configuration block can also be affected from the command line. The command line configurations always trump any configurations in the .moos file. As with the uPokeDB application, the server host and server port information can be specified from the command line too to make it easy to pop open a uXMS window from anywhere within the directory tree without needing to know where the .moos file resides. The basic command line usage for the uXMS application is the following:

```
> uXMS -h
Usage: uXMS [file.moos] [-nav] [-helm] [-pid] [-proc]
       [--clean|-c] [--resumed|-r] [--virgins|-v]
       [--source|-s] [--time|-t] [--all|-a]
       [server_host=value] [server_port=value]
       [MOOS_VARIABLES]

[file.moos] Filename to get configuration parameters
[-nav]      Auto-subscribe for NAV_* variables
[-helm]     Auto-subscribe for IvPHelm variables
[-pid]      Auto-subscribe for PID (DESIRED_*) vars
[-proc]     Auto-subscribe for uProcessWatch vars
[-c]        Ignore scope variables in file.moos
[-r]        Start in data-streaming mode
[-v]        Don't display virgin variables
[-s]        Show the Source field in the data report
[-t]        Show the Time field in the data report
[-a]        Show ALL MOOS variables in the MOOSDB
[server_host=value]  Connect to MOOSDB at IP=value
[server_port=value]  Connect to MOOSDB at port=value
```

The -nav, -pid, -helm, and -proc switches are convenient aliases for common groups of variables. See Listing 9. Using the --clean switch will cause uXMS to ignore the variables specified in the .moos file configuration block and only scope on the variables specified on the command line (otherwise the union of the two sets of variables is used). Typically this is done when a user wants to quickly scope on a couple variables and doesn't want to be distracted with the longer list specified in the .moos file. Arguments on the command line other than the ones described above are treated as variable requests. Thus the following command line entry:

```
>  uXMS foo.moos -proc -clean DB_CLIENTS
```

would result in a scope list of PROC_WATCH_SUMMARY, PROC_WATCH_EVENT and DB_CLIENTS, regardless of what may have been specified in the uXMS configuration block of foo.moos.

The specification of a .moos file on the command line is optional. The only two pieces of information uXMS needs from this file are (a) the server_host IP address, and (b) the server_port

number of the running MOOSDB to scope. These values can instead be provided on the command line:

```
> uXMS DB_CLIENTS server_host=18.38.2.158  server_port=9000
```

If the `server_host` or the `server_port` are not provided on the command line, and a MOOS file is also not provided, the user will be prompted for the two values. Since the most common scenario is when the MOOSDB is running on the local machine ("localhost") with port 9000, these are the default values and the user can simply hit the return key.

```
> uXMS DEPLOY DB_CLIENTS    // The latter two args are MOOS variables to scope
> Enter Server: [localhost]
>    The server is set to "localhost"
> Enter Port: [9000] 9123
>    The port is set to "9123"
```

4.4 Console Interaction with uXMS at Run Time

When uXMS is launched, a separate thread is spawned to accept user input at the console window. When first launched the entire scope list is printed to the console in a five column report. The first column displays the variable name, and the last one displays the variable value as shown in Listing 10. Each time the report is written the counter at the end of line 2 is incremented. The variable *type* is indicated by the presence or lack of quotes around the value output. Quotes indicate a string type as in line 3, and lack of quotes indicate a double. A variable value of `n/a` indicates the variable has yet to be published to the MOOSDB by any process as in lines 8 and 11. Should a variable actually have the value of `n/a` as a string, it would have quotes around it.

Listing 10 - The uXMS console output with -proc, -nav and -pid command line options.

```
 1    VarName               (S)  (T)  (C) VarValue
 2    ----------------      ---  ---  ---  ----------- (1)
 3    PROC_WATCH_SUMMARY                  "All Present"
 4    NAV_X                               10
 5    NAV_Y                               -10
 6    NAV_HEADING                         180
 7    NAV_SPEED                           0
 8    NAV_DEPTH                           n/a
 9    DESIRED_RUDDER                      0
10    DESIRED_THRUST                      0
11    DESIRED_ELEVATOR                    n/a
```

By default at start-up, uXMS is in a paused mode and the three middle columns are unexpanded. Listing 11 shows the console help menu which can be displayed at any time by typing 'h'. Displaying the help menu automatically puts the program into a paused mode if it wasn't already. A common usage pattern to minimize bandwidth is to remain in paused mode and hit the space bar or 'u/U' key to get a single updated report. This action also results in the replacement of the help menu if it is currently displayed, with a new report. A streaming mode is entered by hitting the 'r/R' key, and a report is generated once every iteration of uXMS, the frequency being determined by the MOOS AppTick setting on line 6 in Listing 9. Variables the have never been written to in the MOOSDB ("virgin variables") have a `VarValue` field of "n/a". Virgin variables

can be suppressed by hitting the 'v' key, and by default are displayed. String variable that have an empty string value can also be suppressed by hitting the 'e' key and are also displayed by default.

Listing 11 - The help-menu on the uXMS console.

```
 1   KeyStroke    Function
 2   ---------    --------------------------
 3       s        Suppress Source of variables
 4       S        Display Source of variables
 5       t        Suppress Time of variables
 6       T        Display Time of variables
 7       c        Suppress Community of variables
 8       C        Display Community of variables
 9       v        Suppress virgin variables
10       V        Display virgin variables
11       e        Suppress empty strings
12       E        Display empty strings
13  Space/u/U     Update information once - now
14      p/P       Pause information refresh
15      r/R       resume information refresh
16      h/H       Show this Help msg - 'R' to resume
```

The three middle columns can be expanded as shown in Listing 12. Column 2 can be activated by typing 'S' and deactivated by 's' and shows the variable source, i.e., the latest process connected to the MOOSDB to post a value to that variable. The third column shows the time (since MOOSDB start-up) of the last write to that variable. uXMS subscribes to the variable `DB_UPTIME` and reads this mail first and assigns this time stamp to all other incoming mail in that iteration. Time display is activated with 'T' and deactivated with 't'. The fourth column shows the MOOS community of the last variable posting. Unless an inter-MOOSDB communications process is running such as pMOOSBridge or MOOSBlink, entries in this column will be the local community, set by the parameter of the same name in global section of the MOOS file. Output in this column is activated with 'C' and deactivated with 'c'.

Listing 12 - An example uXMS console output with all fields expanded.

```
 1    VarName               (S)ource      (T)ime      (C)ommunity   VarValue
 2    ----------------      ----------    ----------  ----------     ----------- (4)
 3    PROC_WATCH_SUMMARY     uProcessWatch 364.486     nyak200       "AWOL: pEchoVar"
 4    NAV_X                  pEchoVar      365.512     nyak200       10
 5    NAV_Y                  pEchoVar      365.512     nyak200       -10
 6    NAV_HEADING            pEchoVar      365.512     nyak200       180
 7    NAV_SPEED              pEchoVar      365.512     nyak200       0
 8    DESIRED_RUDDER         pMarinePID    365.512     nyak200       0
 9    DESIRED_THRUST         pMarinePID    365.512     nyak200       0
```

Variables that have yet to be written, as lines 8 and 11 in Listing 10, can be suppressed by the hitting 'v' key, and restored by the 'V' key. In the paused mode, each change in report format has the side-effect of requesting a new report reflecting the desired change in format. The decision was made to use the upper and lower case keys for toggling format features rather simply using the the 's' key for toggling off and on, which was the case on the first version of uXMS. In high latency, low bandwidth use, toggling with one key can be leave the user wondering which state is active.

4.5 Running uXMS Locally or Remotely

The choice of uXMS as a scoping tool was designed in part to support situations where the target MOOSDB is running on a vehicle with low bandwidth communications, such as an AUV sitting on the surface with only a weak RF link back to the ship. There are two distinct ways one can run uXMS in this situation and its worth noting the difference. One way is to run uXMS locally on one's own machine, and connect remotely to the MOOSDB on the vehicle. The other way is to log onto the vehicle through a terminal, run uXMS remotely, but in effect connecting locally to the MOOSDB also running on the vehicle.

The difference is seen when considering that uXMS is running three separate threads. One accepts mail delivered by the MOOSDB, one executes the iterate loop of uXMS where reports are written to the terminal, and one monitors the keyboard for user input. If running uXMS locally, connected remotely, even though the user may be in paused mode with no keyboard interaction or reports written to the terminal, the first thread still may have a communication requirement perhaps larger than the bandwidth will support. If running remotely, connected locally, the first thread is easily supported since the mail is communicated locally. Bandwidth is consumed in the second two threads, but the user controls this by being in paused mode and requesting new reports judiciously.

4.6 Connecting multiple uXMS processes to a single MOOSDB

Multiple versions of uXMS may be connected to a single MOOSDB. This is to simultaneously allow several people a scope onto a vehicle. Although MOOS disallows two processes of the same name to connect to MOOSDB, uXMS generates a random number between 0-999 and adds it as a suffix to the uXMS name when connected. Thus it may show up as something like `uXMS_871` if you scope on the variable `DB_CLIENTS`. In the unlikely event of a name collision, the user can just try again.

4.7 Publications and Subscriptions for uXMS

Variables published by the uXMS application

- `None`

Variables subscribed for by the uXMS application

- `USER-DEFINED`: The variables subscribed for are those on the *scope list* described in Section 4.2.

5 uTermCommand

5.1 Brief Overview

The uTermCommand application is a terminal based tool for poking the MOOS database with pre-defined variable-value pairs. This can be used for command and control for example by setting variables in the MOOSDB that affect the behavior conditions running in the helm. One other way to do this, perhaps known to users of the iRemote process distributed with MOOS, is to use the Custom Keys feature by binding variable-value pairs to the numeric keys [0-9]. The primary drawback is the limitation to ten mappings, but the uTermCommand process also allows more meaningful easy-to-remember cues than the numeric keys.

5.2 Configuration Parameters for uTermCommand

The variable-value mappings are set in the uTermCommand configuration block of the MOOS file. Each mapping requires one line of the form:

```
CMD = cue --> variable --> value
```

The *cue* and *variable* fields are case sensitive, and the *value* field may also be case sensitive depending on how the subscribing MOOS process(es) handle the value. An example configuration is given in Listing 13.

Listing 13 - An example uTermCommand configuration block.

```
 1  //------------------------------------------------------------
 2  // uTermCommand configuration block
 4
 5  ProcessConfig = uTermCommand
 6  {
 7    AppTick    = 2
 8    CommsTick  = 2
 9
10    CMD  = deploy_true   -->  DEPLOY       --> true
11    CMD  = deploy_false  -->  DEPLOY       --> false
12    CMD  = return_true   -->  RETURN       --> true
13    CMD  = return_false  -->  RETURN       --> false
14    CMD  = station_true  -->  STATION_KEEP --> true
15    CMD  = station_false -->  STATION_KEEP --> false
16  }
```

Recall the *type* of a MOOS variable is either a string or double. If a variable has yet to be posted to the MOOSDB, it accepts whatever type is first written, otherwise postings of the wrong type are ignored. In the uTermCommand configuration lines such as 10-15 in Listing 13, the variable type is interpreted to be a string if quotes surround the entry in the value field. If not, the value is inspected as to whether it represents a numerical value. If so, it is posted as a double. Otherwise it is posted as a string. Thus **true** and **"true"** are the same type (no such thing as a Boolean type), **25** is a double and **"25"** is a string.

5.3 Console Interaction with uTermCommand at Run Time

When uTermCommand is launched, a separate thread is spawned to accept user input at the console window. When first launched the entire list of cues and the associated variable-value pairs are listed. Listing 14 shows what the console output would look like given the configuration parameters of Listing 13. Note that even though quotes were not necessary in the configuration file to clarify that **true** was to be posted as a string, the quotes are always placed around string values in the terminal output.

Listing 14 - Console output at start-up.

```
 1    Cue                   VarName                    VarValue
 2    -----------           ---------------            --------------
 3    deploy_true           DEPLOY                     "true"
 4    deploy_false          DEPLOY                     "false"
 5    return_true           RETURN                     "true"
 6    return_false          RETURN                     "false"
 7    station_true          STATION_KEEP               "true"
 8    station_false         STATION_KEEP               "false"
 9
10  >
```

A prompt is shown on the last line where user key strokes will be displayed. As the user types characters, the list of choices is narrowed based on matches to the cue. After typing a single 'r' character, only the `return_true` and `return_false` cues match and the list of choices shown are reduced as shown in Listing 15. At this point, hitting the TAB key will complete the input field out to `return_`, much like tab-completion works at a Linux shell prompt.

Listing 15 - Console output after typing a single character 'r'.

```
 1     Cue                   VarName                    VarValue
 2     -----------           ---------------            --------------
 3     return_true           RETURN                     "true"
 4     return_false          RETURN                     "false"
 5
 6   > r
```

When the user has typed out a valid cue that matches a single entry, only the one line is displayed, with the tag `<-- SELECT` at the end of the line, as shown in Listing 16.

Listing 16 - Console output when a single command is identified.

```
 1     Cue                   VarName                    VarValue
 2     -----------           ---------------            --------------
 3     return_true           RETURN                     "true" <-- SELECT
 4
 5   > return_true
```

At this point hitting the ENTER key will execute the posting of that variable-value pair to the MOOSDB, and the console output will return to its original start-up output. A local history is augmented after each entry is made, and the up- and down-arrow keys can be used to select and re-execute postings on subsequent iterations.

5.4 More on uTermCommand for In-Field Command and Control

The uTermCommand utility can be used in conjunction with a inter-MOOSDB communications utility such as pMOOSBridge or MOOSBlink to effectively control a set of vehicles in the field running the IvP Helm. The user uses uTermCommand to alter a key variable in the local MOOSDB, and this variable gets mapped to one or more vehicles at different IP addresses in the network, sometimes changing variables names in the mapping. The helm is running on the vehicles with one or more behaviors composed with a condition affected by the newly changed variable in its local MOOSDB. The idea is depicted Figure 11.

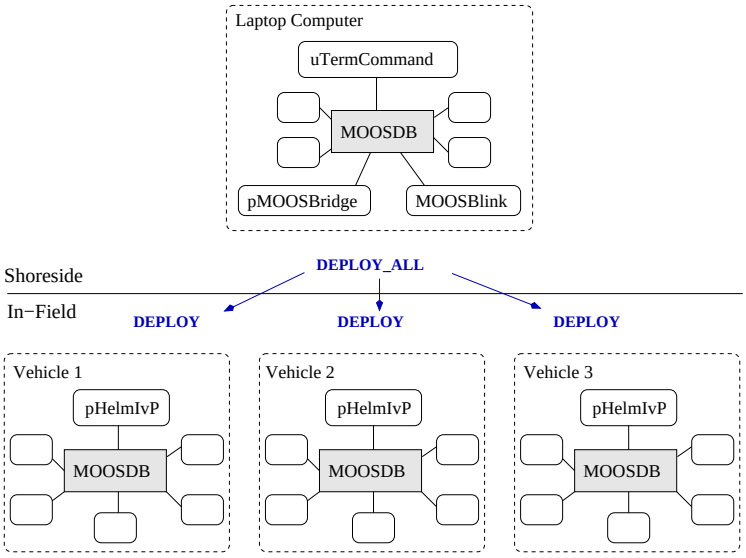

Figure 11: A common usage of the uTermCommand application for command and control.

In the example below in Listing 17, uTermCommand is used to control a pair of vehicles in one of two ways - to deploy a vehicle on a mission, or to recall it to a return point. The configuration block contains three groups. The first group, lines 10-13, are for affecting commands to both vehicles at once, and the second two groups in lines 15-18 and lines 20-23 are for affecting commands to a particular vehicle.

Listing 17 - An example uTermCommand configuration block.

```
 1  //------------------------------------------------------------
 2  // uTermCommand configuration block
 4
 5  ProcessConfig = uTermCommand
 6  {
 7    AppTick    = 2
 8    CommsTick  = 2
 9
10    CMD  = all_deploy_true    -->  DEPLOY_ALL        --> true
11    CMD  = all_deploy_false   -->  DEPLOY_ALL        --> false
12    CMD  = all_return_true    -->  RETURN_ALL        --> true
13    CMD  = all_return_false   -->  RETURN_ALL        --> false
14
15    CMD  = 200_deploy_true    -->  DEPLOY_200        --> true
```

```
16    CMD  = 200_deploy_false   -->  DEPLOY_200        --> false
17    CMD  = 200_return_true    -->  RETURN_200        --> true
18    CMD  = 200_return_false   -->  RETURN_200        --> false
19
20    CMD  = 201_deploy_true    -->  DEPLOY_201        --> true
21    CMD  = 201_deploy_false   -->  DEPLOY_201        --> false
22    CMD  = 201_return_true    -->  RETURN_201        --> true
23    CMD  = 201_return_false   -->  RETURN_201        --> false
24   }
```

The variable-value postings made by uTermCommand are made in the local MOOSDB and need to be communicated out to the vehicles to have a command and control effect. A few tool exist for this depending on the communications environment (wifi-802.11, radio-frequency, acoustic underwater communications, or local network in simulation mode, etc.). The configuration blocks for two tools, pMOOSBridge and MOOSBlink are shown in Listing 18. Note that each has a way of communicating with several vehicles at once with one variable change - lines 8-9 in MOOSBlink and lines 22-25 in pMOOSBridge. In this way the uTermCommand user can deploy or recall all vehicles with one command. Communication with a single vehicle is set up with lines 11-14 and lines 27-30.

Listing 18 - An example MOOSBlink and pMOOSBridge configuration block for implementing simple command and control with two vehicles.

```
 1  //------------------------------------------------------------
 2  // pMOOSBlink config block
 3
 4  ProcessConfig = MOOSBlink
 5  {
 6    BroadcastAddr = 192.168.1.255
 7
 8    Share = global,  DEPLOY_ALL, DEPLOY, 1
 9    Share = global,  RETURN_ALL, RETURN, 1
10
11    Share = nyak200, DEPLOY_200, DEPLOY, 1
12    Share = nyak201, DEPLOY_201, DEPLOY, 1
13    Share = nyak200, RETURN_200, RETURN, 1
14    Share = nyak201, RETURN_201, RETURN, 1
15  }
16
17  //------------------------------------------------------------
18  // pMOOSBridge config block
19
20  ProcessConfig = pMOOSBridge
21  {
22    SHARE = [DEPLOY_ALL]  -> nyak200 @ 192.168.0.200:9000 [DEPLOY]
23    SHARE = [DEPLOY_ALL]  -> nyak201 @ 192.168.0.201:9000 [DEPLOY]
24    SHARE = [RETURN_ALL]  -> nyak200 @ 192.168.0.200:9000 [RETURN]
25    SHARE = [RETURN_ALL]  -> nyak201 @ 192.168.0.201:9000 [RETURN]
26
27    SHARE = [DEPLOY_200]  -> nyak200 @ 192.168.0.200:9000 [DEPLOY]
28    SHARE = [DEPLOY_201]  -> nyak201 @ 192.168.0.201:9000 [DEPLOY]
29    SHARE = [RETURN_200]  -> nyak200 @ 192.168.0.200:9000 [RETURN]
30    SHARE = [RETURN_201]  -> nyak201 @ 192.168.0.201:9000 [RETURN]
31  }
```

The last piece of the command and control process started with uTermCommand is implemented on the vehicle within the autonomy module, pHelmIvP. One may configure the helm behaviors to all have as a precondition `DEPLOY=true` and also have a way-point behavior configured to a convenient return point with the precondition `RETURN=true`.

5.5 Publications and Subscriptions for uTermCommand

Variables published by the uTermCommand application

- `USER-DEFINED`: The only variables published are those that are poked. These variables are specified in the MOOS configuration block as described in Section 5.2.

Variables subscribed for by the uPokeDB application

- `None`

6 pEchoVar

6.1 Brief Overview

The pEchoVar application is a lightweight process that runs without any user interaction for "echoing" the posting of specified variable-value pairs with a follow-on posting having different variable name. For example the posting of `FOO = 5.5` could be echoed such that `BAR = 5.5` immediately follows the first posting. The motivation for developing this tool was to mimic the capability of pNav (see the MOOS website) for passing through sensor values such as `GPS_X` to become `NAV_X`. More on this in Section 6.3.

6.2 Configuration Parameters for pEchoVar

The echo configurations are set in the pEchoVar configuration block of the MOOS file. Each mapping requires one line of the form:

```
Echo = source_variable --> target_variable
```

The *source_variable* and *target_variable* fields are case sensitive since they are MOOS variables. A source variable can be echoed to more than one target variable. If the set of lines forms a cycle, this will be detected and pEchoVar will quit with an error message indicating the cycle detection. An example configuration is given in Listing 19.

Listing 19 - An example pEchoVar configuration block.

```
1  //------------------------------------------------------------
2  // pEchoVar configuration block
3
4  ProcessConfig = pEchoVar
5  {
6    AppTick   = 20
7    CommsTick = 20
8
9    Echo = GPS_X           ->  NAV_X
10   Echo = GPS_Y           ->  NAV_Y
11   Echo = COMPASS_HEADING ->  NAV_HEADING
12   Echo = GPS_SPEED       ->  NAV_SPEED
13 }
```

6.3 Configuring for Vehicle Simulation with pEchoVar

When in simulation mode with iMarineSim, the navigation information is generated by the simulator and not the sensors such as GPS or compass as indicated in lines 9-12 in Listing 19. The simulator instead produces `MARINESIM_*` values which can be echoed as `NAV_*` values as shown in Listing 20.

Listing 20 - An example pEchoVar configuration block during simulation.

```
1  //------------------------------------------------------------
2  // pEchoVar configuration block (for simulation mode)
3
4  ProcessConfig = pEchoVar
```

```
 5  {
 6    AppTick   = 20
 7    CommsTick = 20
 8
 9    Echo = MARINESIM_X       ->  NAV_X
10    Echo = MARINESIM_Y       ->  NAV_Y
13    Echo = MARINESIM_HEADING ->  NAV_HEADING
14    Echo = MARINESIM_SPEED   ->  NAV_SPEED
15  }
```

6.4 Publications and Subscriptions for pEchoVar

Variables published by the pEchoVar application

- `USER-DEFINED`: Each echo mapping described in Section 6.2 has a variable being echoed from, and a variable being echoed to. The variable being echoed *to* is published by `pEchoVar`.

Variables subscribed for by the pEchoVar application

- `USER-DEFINED`: Each echo mapping described in Section 6.2 has a variable being echoed from, and a variable being echoed to. The variable being echoed *from* is subscribed for by `pEchoVar`.

7 uProcessWatch

7.1 Brief Overview

The uProcessWatch application is process for monitoring the presence of other MOOS processes, identified through the uProcessWatch configuration, to be present and connected to the MOOSDB under normal healthy operation. It does output a health report to the terminal, but typically is running without any terminal or GUI being display. The health report is summarized in two MOOS variables - `PROC_WATCH_SUMMARY` and `PROC_WATCH_EVENT`. The former is either set to "All Present" as in line 3 of Listing 10, or is composed of a comma-separated list of missing processes identified as being AWOL (absent without leave), as shown in line 3 of Listing 12. The `PROC_WATCH_EVENT` variable lists the last event affecting the summary, such as the re-emergence of an AWOL process or the disconnection of a process and thus new member on the AWOL list.

7.2 Configuration Parameters for uProcessWatch

Configuration of uProcessWatch is done by declaring a *watch list* in the uProcessWatch configuration block of the MOOS file. Each process to be monitored is identified on a separate line of the form:

```
WATCH = process_name[*]
```

The *process_name* field is case sensitive. The asterisk is optional and affects the strictness in pattern matching the process to the list of known healthy processes. Duplicates, should they be erroneously listed twice, are simply ignored. An example configuration is given in Listing 21.

Listing 21 - An example uProcessWatch configuration block.

```
 1  //------------------------------------------------------------
 2  // uProcessWatch configuration block
 3
 4  ProcessConfig = uProcessWatch
 5  {
 6    AppTick  = 2
 7    CommsTick = 2
 8
 9    // Declare the watch-list below
10    WATCH  = pHelmIvP
11    WATCH  = iMarineSim
12    WATCH  = pEchoVar
13    WATCH  = pLogger
14    WATCH  = pMarinePID
15    WATCH  = pTransponderAIS
16    WATCH  = pMOOSBridge*
17  }
```

Monitoring the state of items on the watch list is done by examining the contents of the variable `DB_CLIENTS` which is a comma separated list of clients connected to the MOOSDB. A strict pattern match is done between an item on the watch list and members of `DB_CLIENTS`. The optional asterisk after the process name indicates that a looser pattern match is performed. This is to accommodate MOOS processes that may have their names chosen at run time, such as uXMS, or may have suffixes

related to their community name such as pMOOSBridge. The `WATCH = pMOOSBridge*` declaration on line 16 in Listing 21 would not report this process as AWOL even if it is connected to the MOOSDB as `pMOOSBridge_alpha`.

7.3 Publications and Subscriptions for uProcessWatch

Variables published by the uProcessWatch application

- `PROC_WATCH_SUMMARY`: A string set either to "All Present" as in line 3 of Listing 10, or composed of a comma-separated list of missing processes identified as being AWOL (absent without leave), as shown in line 3 of Listing 12.
- `PROC_WATCH_EVENT`: A string containing the last event affecting the summary, such as the re-emergence of an AWOL process or the disconnection of a process and thus new member on the AWOL list.

Variables subscribed for by the uProcessWatch application

- `DB_CLIENTS`: Published by the MOOSDB, this variable contains a comma-separated list of processes currently connected to the MOOSDB. This list is what uProcessWatch scans and checks for missing processes.

8 uPokeDB

8.1 Brief Overview

The uPokeDB application is a lightweight process that runs without any user interaction for writing to (poking) a running MOOSDB with one or more variable-value pairs. It is run from a console window with no GUI. It accepts the variable-value pairs from the command line, connects to the MOOSDB, displays the variable values prior to poking, performs the poke, displays the variable values after poking, and then disconnects from the MOOSDB and terminates. It also accepts a .moos file as a command line argument to grab the IP and port information to find the MOOSDB for connecting. Other than that, it does not read a uPokeDB configuration block from the .moos file.

Other Methods for Poking a MOOSDB

There are few other MOOS applications capable of poking a MOOSDB. The uMS (MOOS Scope) is an application for both monitoring and poking a MOOSDB. It is substantially more feature rich than uPokeDB, and depends on the FLTK library. The iRemote application can poke the MOOSDB by using the CustomKey parameter, but is limited to the free unmapped keyboard keys, and is good when used with some planning ahead. The latest versions of uMS and iRemote are maintained on the Oxford MOOS website. The uTermCommand application (Section 5) is a tool primarily for poking the MOOSDB with a pre-defined list of variable-value pairs configured in its .moos file configuration block. Unlike iRemote it associates a variable-value pair with a key *word* rather than a keyboard key. The uMOOSPoke application, written by Matt Grund, is similar in intent to uPokeDB in that it accepts a command line variable-value pair. uPokeDB has a few additional features described below, namely multiple command-line pokes, accepting a .moos file on the command-line, and a MOOSDB summary prior and post-poke.

8.2 Command-line Arguments of uPokeDB

The command-line invocation of uPokeDB accepts two types of arguments - a .moos file, and one or more variable-value pairs. The former is optional, and if left unspecified, will infer that the machine and port number to find a running MOOSDB process is localhost and port 9000. The uPokeDB process does not otherwise look for a uPokeDB configuration block in this file. The variable-value pairs are delimited by the '=' character as in the following example:

```
uPokeDB alpha.moos foo=bar temp=98.6 ‘‘motto=such is life’’ doublestr:=98.6
```

Since white-space characters on a command line delineate arguments, the use of double-quotes must be used if one wants to refer to a string value with white-space as in the third variable-value pair above. The value *type* in the variable-value pair is assumed to be a double if the value is numerical, and assumed to be a string type otherwise. If one really wants to poke with a string type that happens to be numerical, i.e., the string "98.6", then the ":=" separator must be used as in the last argument in the example above. If uPokeDB is invoked with a variable type different than that already associated with a variable in the MOOSDB, the attempted poke simply has no effect.

The specification of a MOOS file on the command line is optional. The only two pieces of information uPokeDB needs from this file are (a) the server_host IP address, and (b) the server_port

number of the running MOOSDB to poke. These values can instead be provided on the command line:

```
> uPokeDB foo=bar server_host=18.38.2.158  server_port=9000
```

If the `server_host` or the `server_port` are not provided on the command line, and a MOOS file is also not provided, the user will be prompted for the two values. Since the most common scenario is when the MOOSDB is running on the local machine ("localhost") with port 9000, these are the default values and the user can simply hit the return key.

```
> uPokeDB foo=bar                       // User launches with no info on server host or port
> Enter Server: [localhost]             // User accepts the default by just hitting Return key
>    The server is set to "localhost"   // Server host is confirmed to be set to "localhost"
> Enter Port: [9000] 9123               // User overrides the default 9000 port with 9123
>    The port is set to "9123"          // Server port is confirmed to be set to "9123"
```

8.3 Session Output from uPokeDB

The output in Listing 22 shows an example shows an example session when a running MOOSDB is poked with the following invocation:

```
uPokeDB alpha.moos DEPLOY=true RETURN=true
```

Lines 1-18 are standard output of a MOOS application that has successfully connected to a running MOOSDB. Lines 20-24 indicate the value of the variables prior to being poked, along with their source, i.e., the MOOS process responsible for publishing the current value to the MOOSDB, and the time at which it was last written. The time is given in seconds elapsed since the MOOSDB was started. Lines 26-30 show the new state of the poked variables in the MOOSDB after `uPokeDB` has done its thing.

Listing 22 - An example uPokeDB session output.

```
 1  ************************************************
 2  *                                              *
 3  *       This is MOOS Client                    *
 4  *       c. P Newman 2001                       *
 5  *                                              *
 6  ************************************************
 7
 8  ---------------MOOS CONNECT-----------------------
 9    contacting MOOSDB localhost:9000 -  try 00001
10    Contact Made
11    Handshaking as "uPokeDB"
12    Handshaking Complete
13    Invoking User OnConnect() callback...ok
14  ------------------------------------------------
15
16  uPokeDB AppTick   @ 5.0 Hz
17  uPokeDB CommsTick @ 5 Hz
18  uPokeDB is Running
19
20  PRIOR to Poking the MOOSDB
21    VarName               (S)ource    (T)ime      VarValue
```

```
22    ----------------      ----------  ----------   -------------
23    DEPLOY                 pHelmIvP    1.87        "false"
24    RETURN                 pHelmIvP    1.87        "false"
25
26  AFTER Poking the MOOSDB
27    VarName               (S)ource    (T)ime      VarValue
28    ----------------      ----------  ----------   -------------
29    DEPLOY                 uPokeDB     8.48        "true"
30    RETURN                 uPokeDB     8.48        "true"
```

8.4 Publications and Subscriptions for uPokeDB

Variables published by the uPokeDB application

- `USER-DEFINED`: The only variables published are those that are poked. These variables are provided on the command line. See Section 8.2.

Variables subscribed for by the uPokeDB application

- `USER-DEFINED`: Since uPokeDB provides two reports as described in the above Section 8.3, it subscribes for the same variables it is asked to poke, so it can generate its before-and-after reports.

9 Appendix - Colors

Below are the colors used by IvP utilities that use colors. Colors are case insensitive. A color may be specified by the string as shown, or with the '_' character as a separator. Or the color may be specified with its hexadecimal or floating point form. For example the following are equivalent: "darkblue", "DarkBlue", "dark_blue", "hex:00,00,8b", and "0,0,0.545".

antiquewhite, (fa,eb,d7)
aqua (00,ff,ff)
aquamarine (7f,ff,d4)
azure (f0,ff,ff)
beige (f5,f5,dc)
bisque (ff,e4,c4)
black (00,00,00)
blanchedalmond(ff,eb,cd)
blue (00,00,ff)
blueviolet (8a,2b,e2)
brown (a5,2a,2a)
burlywood (de,b8,87)
cadetblue (5f,9e,a0)
chartreuse (7f,ff,00)
chocolate (d2,69,1e)
coral (ff,7f,50)
cornsilk (ff,f8,dc)
cornflowerblue(64,95,ed)
crimson (de,14,3c)
cyan (00,ff,ff)
darkblue (00,00,8b)
darkcyan (00,8b,8b)
darkgoldenrod (b8,86,0b)
darkgray (a9,a9,a9)
darkgreen (00,64,00)
darkkhaki (bd,b7,6b)
darkmagenta (8b,00,8b)
darkolivegreen(55,6b,2f)
darkorange (ff,8c,00)
darkorchid (99,32,cc)
darkred (8b,00,00)
darksalmon (e9,96,7a)
darkseagreen (8f,bc,8f)
darkslateblue (48,3d,8b)
darkslategray (2f,4f,4f)
darkturquoise (00,ce,d1)
darkviolet (94,00,d3)
deeppink (ff,14,93)
deepskyblue (00,bf,ff)
dimgray (69,69,69)
dodgerblue (1e,90,ff)
firenrick (b2,22,22)
floralwhite (ff,fa,f0)
forestgreen (22,8b,22)
fuchsia (ff,00,ff)
gainsboro (dc,dc,dc)
ghostwhite (f8,f8,ff)
gold (ff,d7,00)
goldenrod (da,a5,20)
gray (80,80,80)
green (00,80,00)
greenyellow (ad,ff,2f)
honeydew (f0,ff,f0)
hotpink (ff,69,b4)
indianred (cd,5c,5c)
indigo (4b,00,82)
ivory (ff,ff,f0)
khaki (f0,e6,8c)
lavender (e6,e6,fa)
lavenderblush (ff,f0,f5)
lawngreen (7c,fc,00)
lemonchiffon (ff,fa,cd)
lightblue (ad,d8,e6)
lightcoral (f0,80,80)
lightcyan (e0,ff,ff)
lightgoldenrod(fa,fa,d2)
lightgray (d3,d3,d3)
lightgreen (90,ee,90)
lightpink (ff,b6,c1)
lightsalmon (ff,a0,7a)
lightseagreen (20,b2,aa)
lightskyblue (87,ce,fa)
lightslategray(77,88,99)
lightsteelblue(b0,c4,de)

lightyellow (ff,ff,e0)
lime (00,ff,00)
limegreen (32,cd,32)
linen (fa,f0,e6)
magenta (ff,00,ff)
maroon (80,00,00)
mediumblue (00,00,cd)
mediumorchid (ba,55,d3)
mediumseagreen(3c,b3,71)
mediumslateblue(7b,68,ee)
mediumspringgreen(00,fa,9a)
mediumturquoise(48,d1,cc)
mediumvioletred(c7,15,85)
midnightblue (19,19,70)
mintcream (f5,ff,fa)
mistyrose (ff,e4,e1)
moccasin (ff,e4,b5)
navajowhite (ff,de,ad)
navy (00,00,80)
oldlace (fd,f5,e6)
olive (80,80,00)
olivedrab (6b,8e,23)
orange (ff,a5,00)
orangered (ff,45,00)
orchid (da,70,d6)
palegreen (98,fb,98)
paleturquoise (af,ee,ee)
palevioletred (db,70,93)
papayawhip (ff,ef,d5)
peachpuff (ff,da,b9)
pelegoldenrod (ee,e8,aa)
peru (cd,85,3f)
pink (ff,c0,cb)
plum (dd,a0,dd)
powderblue (b0,e0,e6)
purple (80,00,80)
red (ff,00,00)
rosybrown (bc,8f,8f)
royalblue (41,69,e1)
saddlebrowm (8b,45,13)
salmon (fa,80,72)
sandybrown (f4,a4,60)
seagreen (2e,8b,57)
seashell (ff,f5,ee)
sienna (a0,52,2d)
silver (c0,c0,c0)
skyblue (87,ce,eb)
slateblue (6a,5a,cd)
slategray (70,80,90)
snow (ff,fa,fa)
springgreen (00,ff,7f)
steelblue (46,82,b4)
tan (d2,b4,8c)
teal (00,80,80)
thistle (d8,bf,d8)
tomatao (ff,63,47)
turquoise (40,e0,d0)
violet (ee,82,ee)
wheat (f5,de,b3)
white (ff,ff,ff)
whitesmoke (f5,f5,f5)
yellow (ff,ff,00)
yellowgreen (9a,cd,32)

References

[1] Michael R. Benjamin. MOOS-IvP Autonomy Tools Users Manual. Technical Report MIT-CSAIL-TR-2008-065, MIT Computer Science and Artificial Intelligence Lab, November 2008.

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