ACAMS – INTEGRATED SOFTWARE FOR ACCELERATOR ALIGNMENT AND MEASUREMENT[*]

K.J. Tremblay, K.S. Baggett and C. J. Curtis
Thomas Jefferson National Accelerator Facility
12000 Jefferson Avenue
Newport News, Virginia, USA

1. INTRODUCTION

ACAMS (Accelerator Combined Alignment and Measurement System) is a software package that has been developed at Thomas Jefferson National Accelerator Facility (Jefferson Lab). ACAMS was developed to replace four MS-Dos based software programs. These programs operated independently and commonly used theodolite observations as the basis for data collection. The methodology used to collect the data had similarities, but there were inconsistencies and shortcomings in these various processes.

ACAMS integrates all the reductions, adjustment and reporting into one package. Jefferson Lab Alignment Group now relies on ACAMS for most of the field surveys undertaken. Many new features that were lacking in the older packages have been included in the development of ACAMS. This paper will discuss the reasoning behind the development, currently available features, and the future direction that the software will take.

2. JUSTIFYING DEVELOPMENT

2.1 Commercial vs. In-House Development Packages

Prior to the development of ACAMS, the alignment group at Jefferson Lab evaluated two commercially available software packages. Both commercial packages are very complete, with a long list of features available to the end user. However, both packages appeared to be designed towards certain specific applications in the industrial measurement community, rather than fitting the requirements that were desired at our facility. There are distinct advantages for using an off the shelf package but as this software is crucial to the operation of our group, the decision was made to develop a custom package. Some of the main arguments for and against this decision are outlined below.

One of the main issues addressed when evaluating commercial versus in-house software was the control of the database. Both of the evaluated packages were locked into a proprietary database, which limited the ability to manipulate the data during post processing. Items such as text point names have historically been part of our database, and we wished to continue with this capability.

A second issue was the degree of customization. Again, both packages had some level of customization, but the degree of customization which was required was very high and neither

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package addressed customization to the desired level. Our field crews continually contribute valid suggestions which help guide the development direction of the software. Having the ability to control changes and add features was one of the most important factors in the decision to proceed with in-house development.

The cost of development and debugging were a disadvantage to be considered. Overall the first debugged copy, suitable for field work, took approximately six months or a half man year to deliver. There is also the maintenance costs of the software to consider. There are approximately thirty thousand lines of C++ code to maintain, plus several older FORTRAN routines that have been modified and turned into 32 bit windows DLLs.

Theodolites are used for approximately seventy percent of the field alignment tasks at Jefferson Lab. Optical tooling and a portable coordinate measuring machine (CMM) are used for most of the remaining tasks. There is an effort to decrease the use of optical tooling since there is minimal redundancy of observations. With such emphasis on the use of theodolites, our group felt that our software should maximize the effectiveness of our lab-specific tasks. These tasks included stand and magnet alignment, alignment of various spectrometers, fiducialization of components and other tasks typically carried out by intersecting theodolites.

3. SOFTWARE FEATURES AND DETAILS

3.1 Hardware Requirements and Interface

The requirements for the field version of the software are either a laptop or regular desktop computer, with access to a compact flash (CF) reader and an expanded serial card, or 2 PCMCIA cards. Most laptops allow for 2 PCMCIA cards. One of the cards is for a multi-port serial card (National Instruments part NI PCMCIA 232/4, Socket part SL0751-161 or similar). Each instrument to be connected, must have a serial port available on the computer. The second card is for a CF card adaptor. The CF card is automatically read when the program initializes and all files on the laptop are updated. By using this technique, all files on all the various computers are kept up to date. The office version of the software does not check for a CF card, but all initialization files and software version operations are handled from a lab network server.

ACAMS has been tested on various laptops. The standard operating system is Windows 2000, but it has been used with Windows 98, Windows NT 4.0 and Windows XP, with no apparent problems. The slowest processor speed that the software has been tested on is an Intel Celeron 300. The software has not shown any adverse effects utilizing the latest Pentium 4 processors available. The minimum ram that has been used with a Windows 98 system is 64 megabytes.

The lab has also developed a new multiplexer interface box that powers the theodolites, and handles communications between the computer and theodolites. The cost of these multiplexer boxes is significantly less than the units required for the commercial packages.

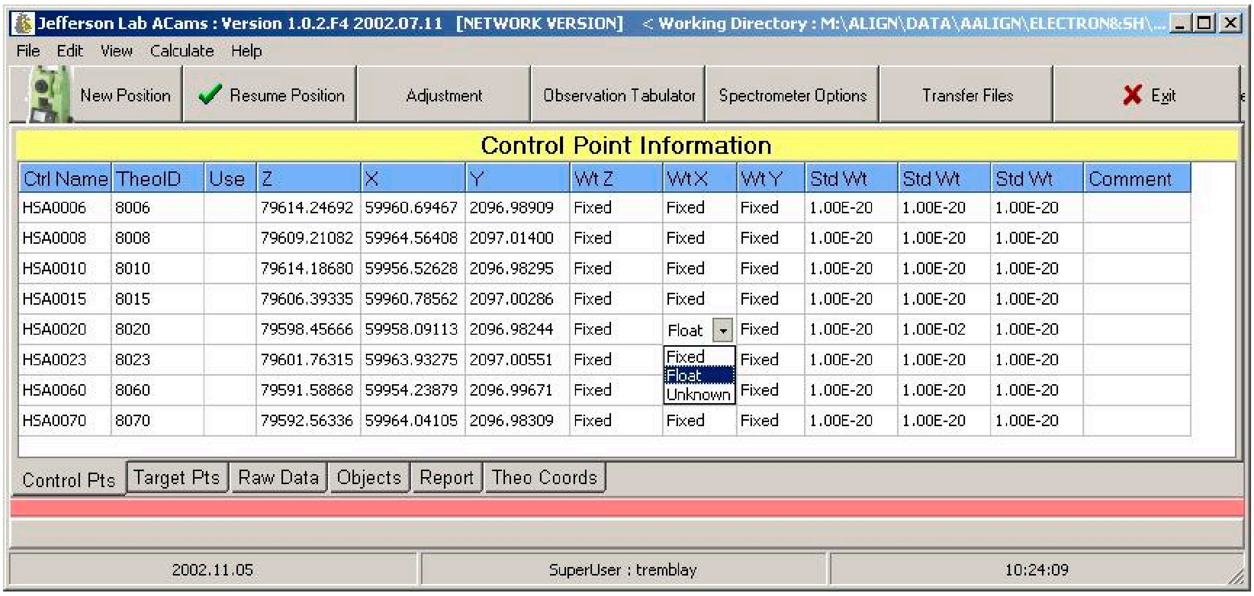
3.2 Survey Selection / Project Details

As stated earlier, ACAMS has been developed to integrate all the various types of theodolite survey packages that existed at Jefferson Lab. After the program initializes, the user is asked to select a method, type of survey, or continue an existing project. The main options are to conduct either stand alignment (rough alignment of stands / bolts etc. Step 1), Step 2 alignment (alignment of machine elements), fiducialization of elements and finally, spectrometer positioning. Other options are available to the user, such as re-starting existing job, copying and using control from an existing job, and resuming the last job.

After the crew has selected the task type the target and control information is generated by following prompts. For example, in the stand alignment option, users are prompted for a nearby control monument. This one monument is used as the basis for a search of nearby stands and other control which are displayed in checklists. Users can chose to either reject or include data in the project. By carrying out these tasks in a specific manner, errors are reduced.

3.3 Common Interface

Upon completion of the job information section, the users are presented with the common interface (Fig. 1). There are a group of commands on the top taskbar that take the user to various options. Two of these options are for moving to the data collection screen. Using the 'New Position' option, allows the users to start a new theodolite position, while 'Resume Position', allows the users to resume theodolite setups (see section 3.5). The upper task bar also contains the Adjustment options (see section 3.4), Observation Tabulator (section 3.5), Spectrometer Options (section 3.6) and the Transfer File option.



Ctrl Name	TheoID	Use	Z	X	Y	Wt Z	Wt X	Wt Y	Std Wt	Std Wt	Std Wt	Comment
HSA0006	8006		79614.24692	59960.69467	2096.98909	Fixed	Fixed	Fixed	1.00E-20	1.00E-20	1.00E-20	
HSA0008	8008		79609.21082	59964.56408	2097.01400	Fixed	Fixed	Fixed	1.00E-20	1.00E-20	1.00E-20	
HSA0010	8010		79614.18680	59956.52628	2096.98295	Fixed	Fixed	Fixed	1.00E-20	1.00E-20	1.00E-20	
HSA0015	8015		79606.39335	59960.78562	2097.00286	Fixed	Fixed	Fixed	1.00E-20	1.00E-20	1.00E-20	
HSA0020	8020		79598.45666	59958.09113	2096.98244	Fixed	Float	Fixed	1.00E-20	1.00E-02	1.00E-20	
HSA0023	8023		79601.76315	59963.93275	2097.00551	Fixed		Fixed	1.00E-20	1.00E-20	1.00E-20	
HSA0060	8060		79591.58868	59954.23879	2096.99671	Fixed		Fixed	1.00E-20	1.00E-20	1.00E-20	
HSA0070	8070		79592.56336	59964.04105	2096.98309	Fixed	Fixed	Fixed	1.00E-20	1.00E-20	1.00E-20	

Fig. 1 Common Interface

The default screen displays the control points. Control point z, x and y coordinates are displayed along with their associated weight. Weights may be adjusted by clicking on the appropriate cell, and are then updated for use in further adjustments.

At the bottom of the common interface screen are tabs which take you to six associated commands. Figure 2, shows an example of the report generated based on a project's results. Figure 3, shows a sample of the raw data that has been captured. There are a second group of tabs in the Raw Data screen which allow the users to page through to the respective theodolite data. Other options available from the lower task bar include screens for the target data and the adjusted theodolite coordinates.

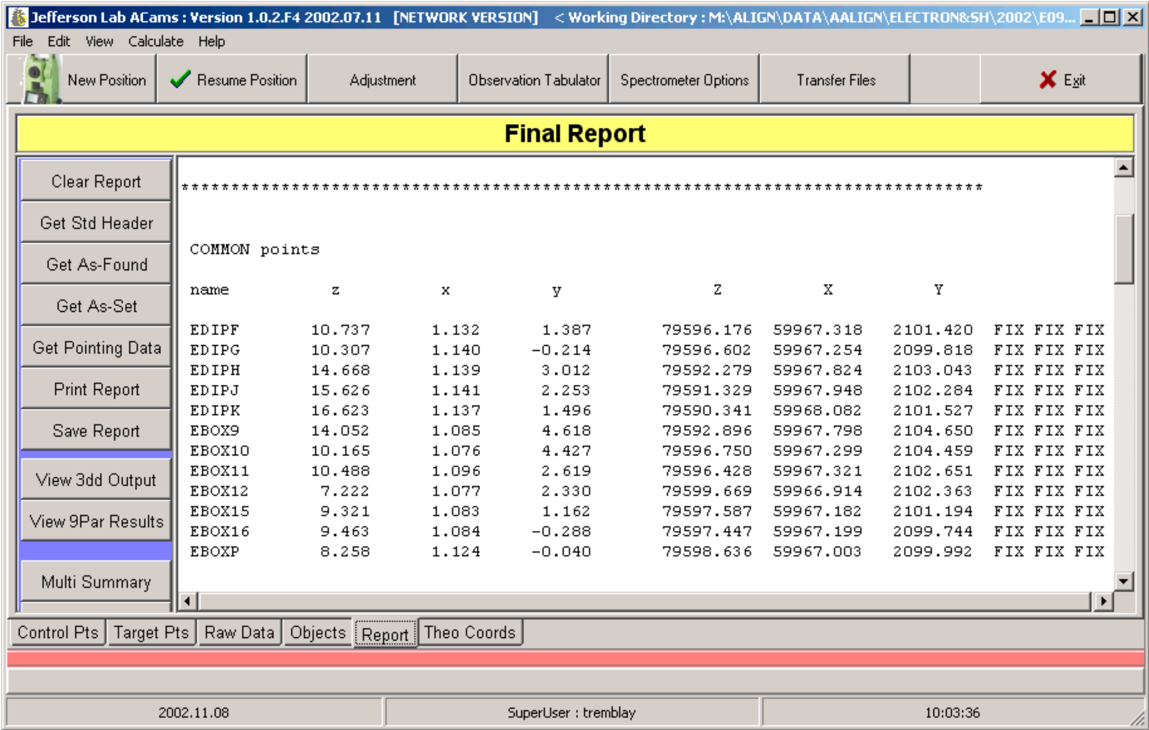


Fig. 2 Report Screen

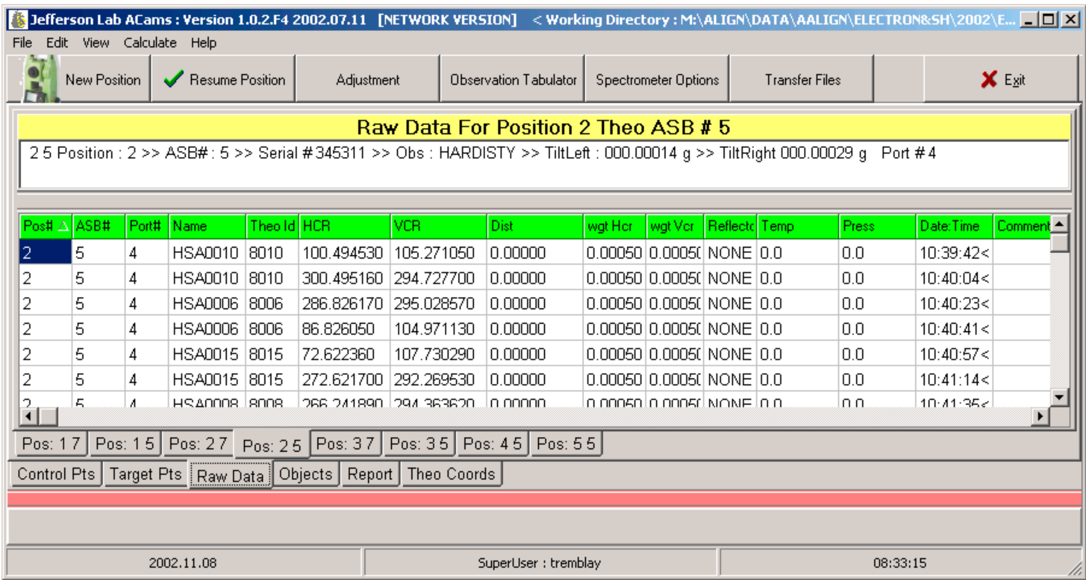


Fig. 3 Raw Data Screen

The main screen also has a traditional Windows menu interface with numerous options available under, 'File', 'Edit', 'View', 'Calculate' and a 'Help' section but are not discussed here.

3.4 Adjustment

The raw data file is processed in 2 steps. The first step uses the program APPROX which creates an input file for the least-squares bundle adjustment 3DCD[1] (originally developed at the Stanford Linear Accelerator). APPROX determines whether the control is local or object oriented. There is no need for orientation of the theodolites, as APPROX will create an iterative solution to arrive at a theodolite position. 3DCD has been modified at the lab and now runs as a background Windows DLL, with the results generated and displayed as shown in figure 4. Other options available through this screen allow you to view the complete adjustment results, weight the observations (figure 5), and control points and allowances for a gravity / non-gravity adjustment.

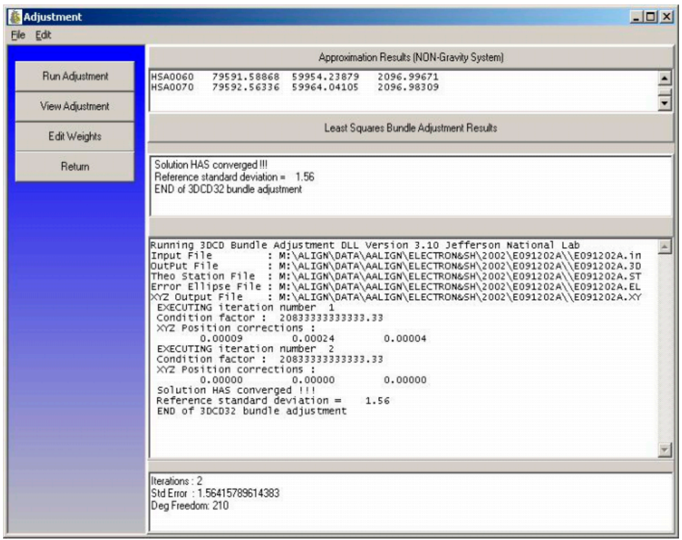


Fig. 4 Adjustment Results Screen

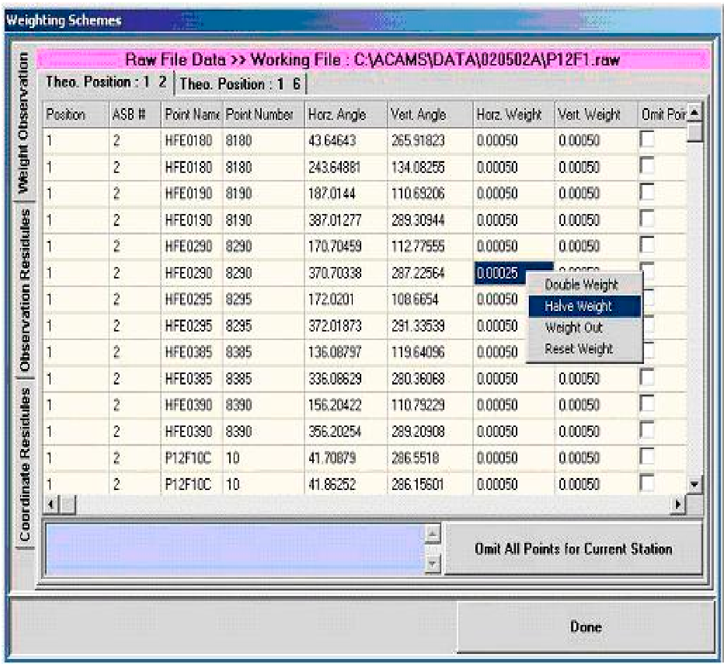


Fig. 5 Weighting Schemes

Fig. 6 Observation Tabulator

3.5 Observation Tabulator

The observation tabulator (fig 6) allows the user to see which targets or control points have been observed at the various theodolite stations. It displays whether a point has been observed with both faces (displays a ✓), single face (½), or not at all (shows a X) for each station. This allows the users to ensure that the proper number of observations have been recorded for each target or control point.

3.6 Data Collection

From the main menu, once ‘New Position’ or ‘Resume Position’ are selected, the program passes into data collection mode. Theodolites, attached via a serial port, are automatically sensed and polled. In theory, up to nine theodolites could be attached at one time, although the maximum tested to date has been five. Figure 7 shows the data capture screen, which displays the target name, plus the theodolite ID number on the left pane; the observations are displayed on the right pane. The theodolite ID number or target ID is defined as the numeric value that the theodolite sends for each observation. Each theodolite operator may observe any point in any sequence. Additionally the operators can shoot forward and reverse face observations in any order. If theodolite positions have been established by shooting the control points first, ‘AutoPoint’ can be invoked to determine which point is being observed without the operator having to enter in any point ID number at the theodolite. Another feature available is that all observations are kept in the data file, but any point can be re-observed, with the latest points being used for calculations. The earlier observed data can also be used in calculations so that it can show a final difference between as-found targets, and as-set targets in the report.

As shown in the capture data screen, points that have both a forward and reverse observation are updated by highlighting the cells displaying the target name in green. If an observation is out of tolerance the cells displaying the angles are highlighted in red. This color coding gives the operators an immediate warning of any problems. If a point ID is sent from the theodolite to the computer, and there is no matching angle or matching ID number, the point is flagged but does not cause the operation to come to a halt. The crews review the data before moving the theodolites to a new position, and determine if the point was erroneous or if it was a new point to be added.

Another feature available from the top tool bar is the ‘Show Movements’ option. This option allows the users to see how far a surveyed object is from its design or ideal location (figure 8).

Also available are standard windows drop down menus that include fitting routines, calculation options, real time positioning (RTP) options and a short cut to the observation tabulator.

Distances can be observed in the data capture routine. There is a facility for selecting particular prisms, as well as recording atmospheric conditions. The data can also be reduced directly from ACAMS and incorporated into the adjustment routine.

TOC

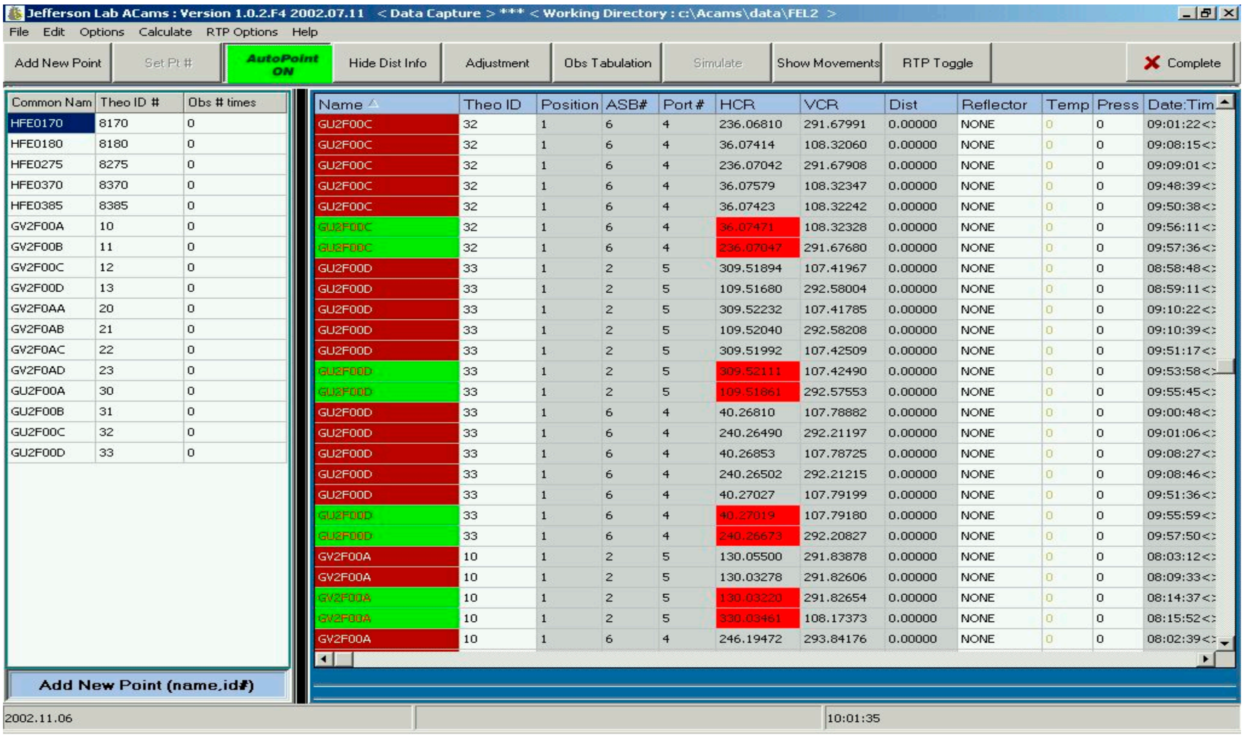


Figure 7 Capture Data Screen

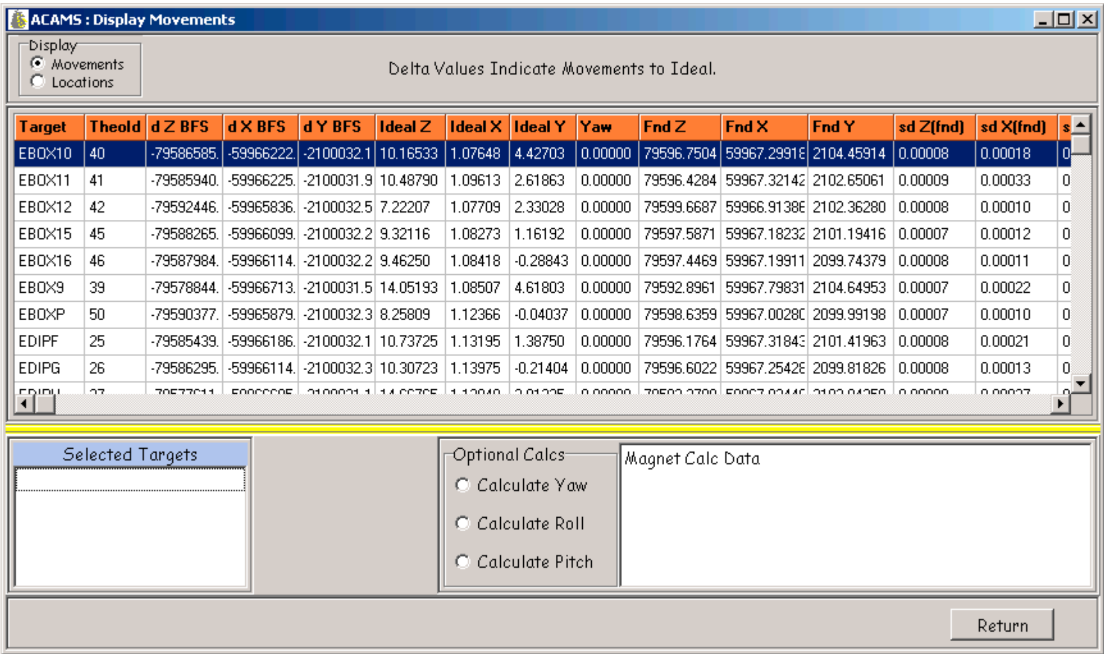


Figure 8 Display Movements Screen

3.7 RTP Routine

One of the main features available in ACAMS is the Real Time Positioning (RTP) routine. This routine is used to position any object into its desired alignment. The procedure requires the crew to observe the control points, the components to be aligned, and obtain an adjustment from 3DCD. They can then use the 'RTP Toggle' option on the main data capture toolbar. This takes the program to a new screen (figure 9) where the theodolites are polled at set time intervals or the instrument operators take manual observations, to align a component to any given set of design coordinates.

As the instrument operators take observations, the coordinates are automatically updated, using a least squares solution. A value, based upon the original forward and reverse observations taken to the targets, is used to correct single face observations taken in RTP. The input file to 3DCD is updated with the corrected angles, and after the adjustment, the differences between design and the presently located target are calculated. The differences are then displayed (fig 9), and the crew can make the necessary adjustments to the object, and iterate to an acceptable position. After adjusting all the required elements by using the RTP routine, the crews will lock-down the elements and conduct a final survey using forward and reverse observations. An additional feature currently being added, is the tie to our fiducial database and calculating the reverse least squares transformation to find the component center.

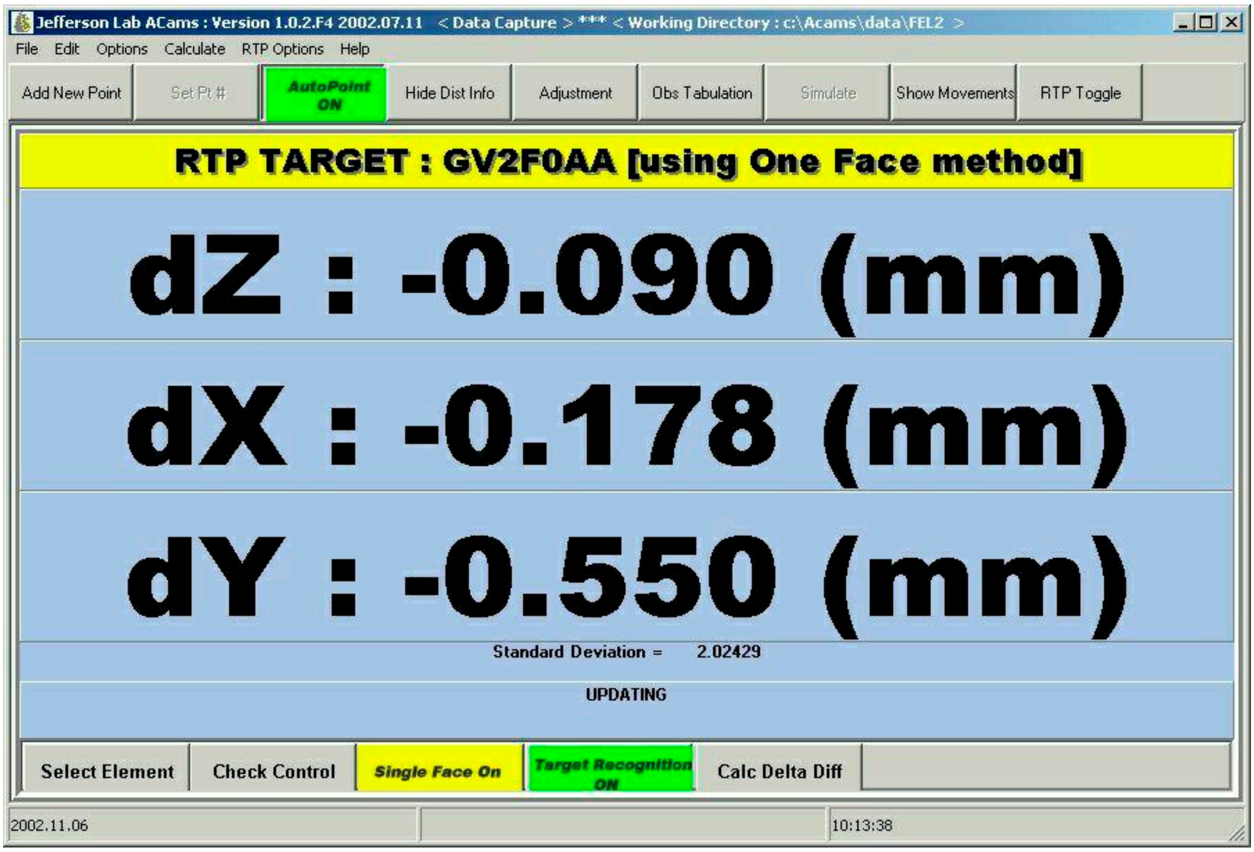


Figure 9 RTP Screen

3.8 Spectrometer Alignment

Jefferson Lab's Hall A contains two high resolution spectrometers and Hall C has a High Momentum (HMS) and a Short Orbit (SOS) spectrometer. All four spectrometers rotate about a central target. The alignment group is frequently called upon to determine the angle between the incoming beam and the centerline of the spectrometers. ACAMS is used to survey the spectrometer with respect to the local monuments. After a satisfactory adjustment with 3DCD, the results are processed using transformation software to determine the central axis of the spectrometers with respect to the beam. ACAMS automates this process resulting in smooth flow of information.

3.9 Reporting

Final reports can be auto-generated based on specific job related tasks or there is a facility for building a custom report. These reports are useful summaries, as well as providing a means for our group to track the history of various projects.

4. FUTURE ENHANCEMENTS

One of the main reasons for developing ACAMS was to allow our group to customize the software as circumstances dictated. To this end, some of the planned enhancements are outlined.

4.1 Enhanced Coordinate System Manipulation and Shape Fitting Routines

Currently ACAMS uses SLAC's geometric fitting routines in WINFIT[2] that were developed in the early 1990's. It is envisioned that, as time allows, our software group will develop our own set of shape fitting routines and at the same time integrate the use of alternate coordinate systems which will allow the field crews greater flexibility while undertaking various surveys.

4.2 Integration with Portable CMM

Traditionally, the target surveys have been performed with theodolites, but as the experiments have become more complex, lines of sight have disappeared, which has necessitated the greater reliance on the portable CMM. The group's portable CMM has successfully been used for target alignment in experimental Halls A and C. Many of these operations have required that local control first be established with the use of theodolites. It is our goal to integrate the portable CMM into ACAMS, and have all the data for the project be collected using one set of data collecting tools. Preliminary work has been undertaken, with communications being worked out and the calculation of coordinates from the portable CMM being successfully achieved. Further work is required to make this addition a smooth operation.

4.3 Wireless Data Updates

Many areas of Jefferson Lab are now equipped to accept wireless network connections. Occasionally, there is a need to update information required for immediate use in the field. This now requires a return trip to the office to receive an updated CF card. Tapping into the capabilities of the wireless network is a possibility which may alleviate this situation.

4.4 Additional Theodolite Integration

ACAMS was designed to be as modular as possible. As updated theodolite equipment becomes available, we will endeavor to integrate it into the software.

4.5 Integration with Laser Tracker

At some stage, it is envisioned that the lab will obtain a laser tracker. It is hoped that prior to our obtaining a tracker, we will be able to obtain a unit temporarily, in order to work out the communication parameters, and integrate it into our data collection routines. As with other labs, the tracker will probably become one of our more heavily used tools, and an evaluation will be undertaken whether to use the supplied software or integrate it into ACAMS.

5. CONCLUSION

With an investment of approximately a half man-year of coding, ACAMS has combined several disjointed field operations and procedures into a tightly integrated operation. Additions have been made to the software, which have provided several new and valuable tools to the users. The crews have commented on the software's ease of use, the ability to rapidly align components, and conduct other essential alignment tasks.

ACAMS was developed in order to integrate Jefferson Lab's existing theodolite based alignment software into one package. ACAMS is now the main tool used by the Alignment Group. The software has given Jefferson Lab a tool that fits it's requirements, and traditional alignment operations while also allowing the group to have the flexibility and control over its development as circumstances dictate.

Future development that includes integration of updated and new equipment, and the ability to customize the software to specific tasks should make ACAMS a tool that will be used at the lab for many years.

6. ACKNOWLEDGMENTS

We would like to thank and recognize the alignment group at the Stanford Linear Accelerator for supplying the original code for the bundling program 3DCD, and a particular thanks to Catherine LeCocq for the use of the WINFIT program. A special thanks also goes out to all the field staff at the lab for their patience, suggestions and verification of all the processes developed for ACAMS.

7. REFERENCES

[1] 3DCD, *Software Authors;* J.M.Gaunt, C.LeCocq, B.Crittenden, Stanford Linear Accelerator Center, 2575 Sand Hill Road, Menlo Park, CA 94025 1991.

[2] WINFIT, *Software Author*; C.LeCocq, Stanford Linear Accelerator Center, 2575 Sand Hill Road, Menlo Park, CA 94025 1991.