

'DIMONS' SOFTWARE FOR AUTOMATIC DATA COLLECTION AND AUTOMATIC DEFORMATION ANALYSIS

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Abstract

The DIMONS (Displacement Monitoring System) software has been developed to support fully automated deformation monitoring schemes with automatic data acquisition. The software allows for a remote control and pre-programming of observations with robotic total stations and other sensors; fully automatic reduction and processing of positioning surveys; automatic identification of unstable reference stations using the Iterative Weighted Similarity Transformation; and automatic determination and graphical presentation of displacements of monitored points with their variance-covariance information. The software has been developed as a part of the Diamond Valley Lake automated monitoring system, a project run by the Metropolitan Water District of Southern California.

1. Introduction

As described in another paper of this symposium [Duffy et al., 2001], the Metropolitan Water District of Southern California has just completed construction of three large earthen dams as a part of the Diamond Valley Lake project, the largest water reservoir in Southern California. The three dams are required to undergo monthly, preferably weekly, monitoring during the filling period. Given the size of this facility, the largest dam construction project in the United States, Metropolitan's labour costs for geodetic monitoring would more than double if it was performed using their conventional techniques. Therefore, alternative methods were considered to perform the data collection activities. The most practical and economical solution proved to be the use of Robotic Total Stations (RTS) in a completely automated measurement scheme. With appropriate control software, the data could be collected, transferred to Metropolitan's offices, and processed automatically, greatly reducing both the labour cost and time needed to collect the measurements. In early 2000, the Engineering and Mining Surveys Research Group at the University of New Brunswick won a contract to develop the control software to run the automated system, and the system was fully implemented by the end of the year. This paper discusses the design and implementation of the DIMONS (Displacement Monitoring System) software for geodetic data collection at Diamond Valley Lake.

2. System Requirements

At the beginning of the software development phase, the general requirements for the displacement monitoring software were already known. The system was to automatically collect RTS and meteorological readings at each of the eight permanently installed measuring stations, according to a user-specified schedule, and transfer it back to the office. The data was then to be

processed, screened for blunders and possible unstable reference points, and coordinates were to be computed for all observed stations.

In addition to these general requirements, a number of specific capabilities and characteristics were identified in Metropolitan's Request for Proposals to develop the system. In meeting the needs of Metropolitan, a system was developed that:

1. Operates under the most recent version of the Microsoft Windows NT operating system.
2. Stores its data in a relational database.
3. Supports operation in fully automatic, semi-automatic, or interactive measurement modes.
4. Is compatible with the Leica TCA1800S robotic total station.
5. Supports flexible, user-definable scheduling of data collection activities.
6. Interfaces with digital temperature and pressure sensors for meteorological data storage and correction of measured distances.
7. Is accessible remotely.
8. Has the ability to transfer observation data between different computers.
9. Performs an automatic restart of measurements following a power loss.
10. Will automatically power down the RTS at the end of a measurement cycle.
11. Performs automatic data processing, including a stability analysis of the reference points observed by each RTS.
12. Has the ability to incorporate data from a roving total station, which would be moved from observing point to observing point.

Items (1) through (12) provide a good overview of the functionality of the system. In addition, DIMONS was designed with a number of other characteristics in mind, which were intended to make the system easier to develop and maintain:

13. Software modules are easily accessible from a variety of programming languages, including scripting languages.
14. It is possible to add RTS and meteorological sensors from a number of different manufacturers without modifying the existing software.
15. It will collect data even if the communications network is not operational.
16. It is possible to combine data from different observing sites without conflicts.

3. DIMONS Software Description

3.1 Software Architecture

The software capabilities outlined in the previous section were realized by utilizing a component-based model for software development. The key functionality of the system is provided by a number of OLE Automation servers, and different client applications are used to provide different levels of interaction with the system. Because the servers themselves contain no graphical interface, they can be used by client applications on a remote machine, thereby allowing remote access to the system. Furthermore, Automation servers can be accessed from a wide variety of programming languages, including scripting languages like VBScript. This allows end users to create their own utilities to perform more specialized tasks.

The components making up DIMONS can be divided into three main layers of functionality: an input/output layer, responsible for accessing external devices, the program database, and the Windows registry; a layer of key utilities, where most of the system functionality is contained; and

a user interface layer, containing client applications that utilize the system to perform various configuration and data manipulation tasks. A schematic overview of the different components of DIMONS is presented in Figure 1.

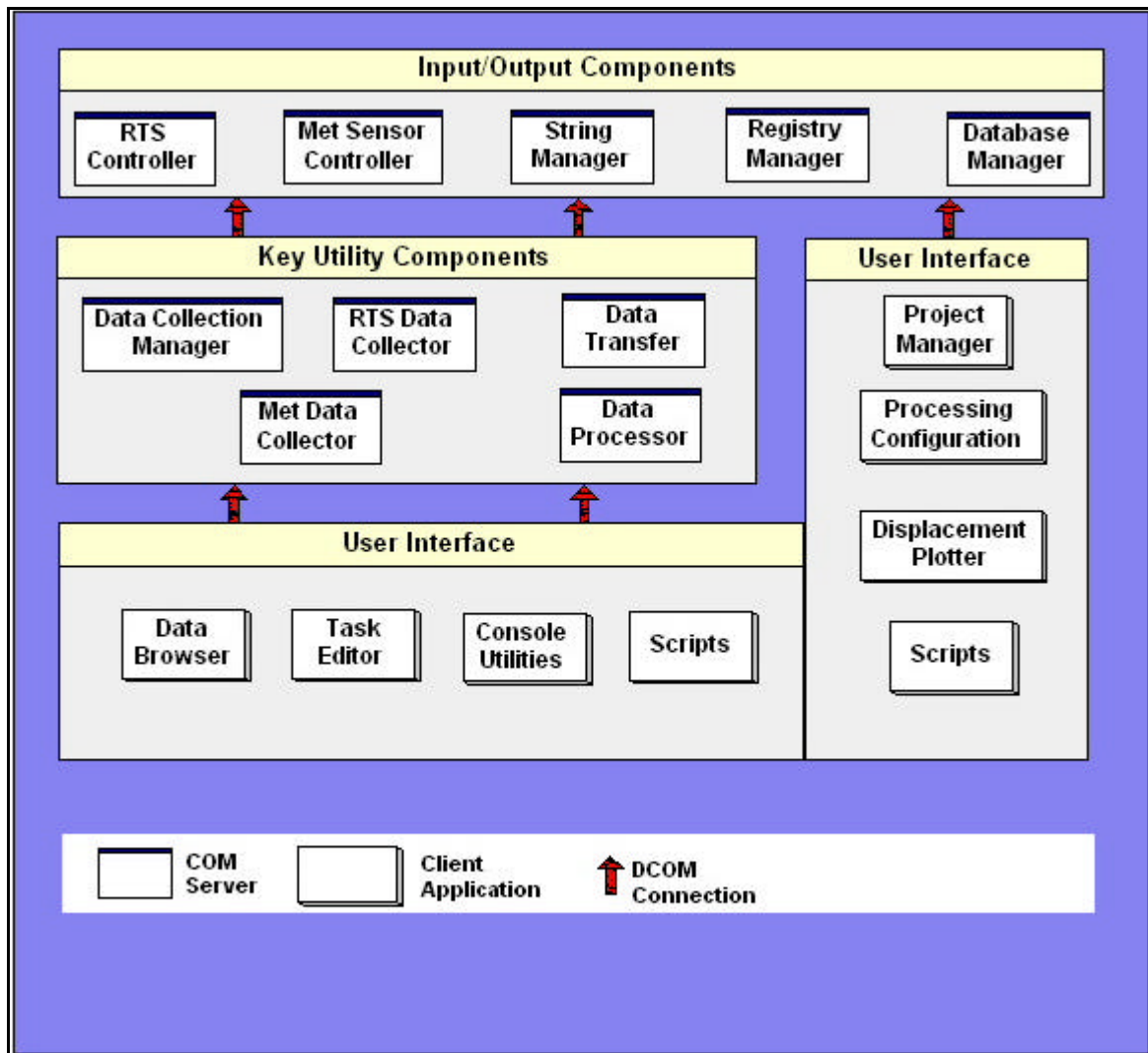


Figure 1. DIMONS software architecture.

Most user interaction with the system is performed using the provided graphical utilities. The Project Manager, shown in Figure 2, is used to define the survey network configuration and to set tolerance parameters for data collection. Other utilities are used to define parameters for data processing; to browse the collected data; and to generate displacement plots. Several console-based applications, which use a command-line interface and can be scheduled using the Windows Scheduler, are supplied to enable unattended execution of data collection, transfer of observation data between different computers, and data processing.

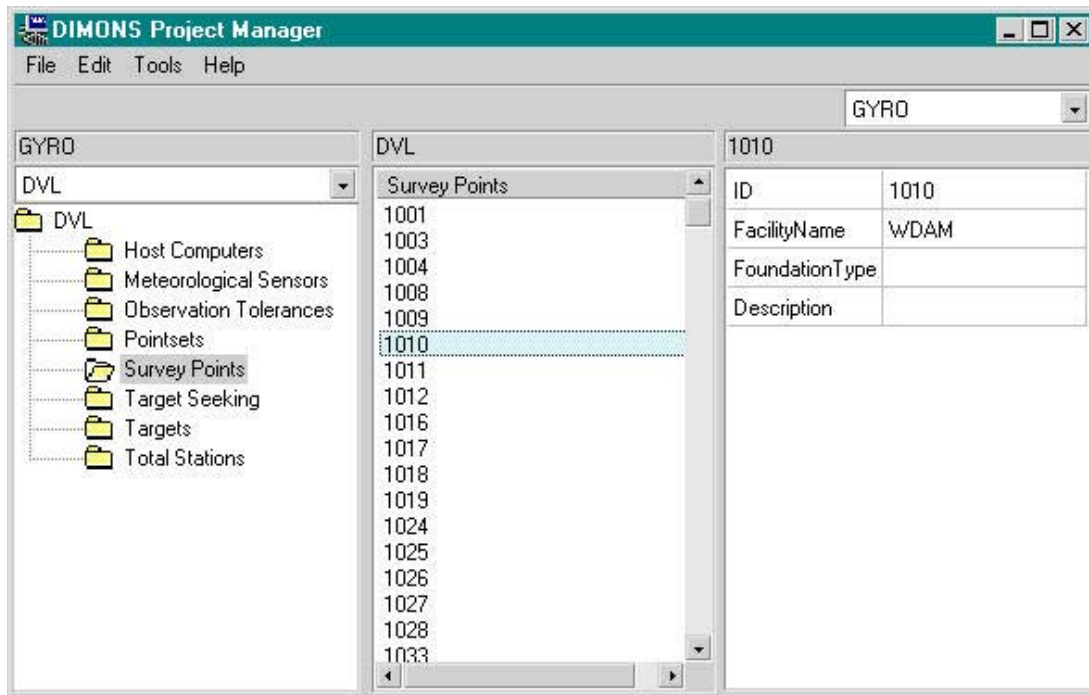


Figure 2. DIMONS Project Manager window.

3.2 Data Storage

DIMONS uses a relational database to store configuration parameters, observation data, and processed point coordinates. In order to provide maximum flexibility to the user, OLE DB drivers are used to access the database; therefore, virtually all Windows database formats are supported, provided the appropriate driver is installed on the system. To provide compatibility with Metropolitan's existing geodetic and geotechnical databases, the Microsoft Jet database driver was used in the Diamond Valley Lake project.

The database tables were designed taking into account the fact that the monitoring configuration may change with time. Maintenance and operation of the system may include replacing instruments or prisms, adding or removing monitoring points, releveling the instrument, or changing the tolerance settings for data collection, among other things. It was important that the history of these configuration parameters be retained, so that later reprocessing of the observation data would use the settings that were in effect *at the time of observation*. Therefore, the DIMONS database retains a history of configuration parameters, and all observations are time-tagged.

3.3 Data Processing

The data collected during each measurement cycle consists of several sets of directions, zenith angles and distances, collected in both telescope faces. Atmospheric temperature, pressure, and humidity are collected at user-defined intervals during the measurements. This raw observation data is subjected to several stages of reduction and processing before final point coordinates are obtained; the processing steps are illustrated graphically in Figure 3.

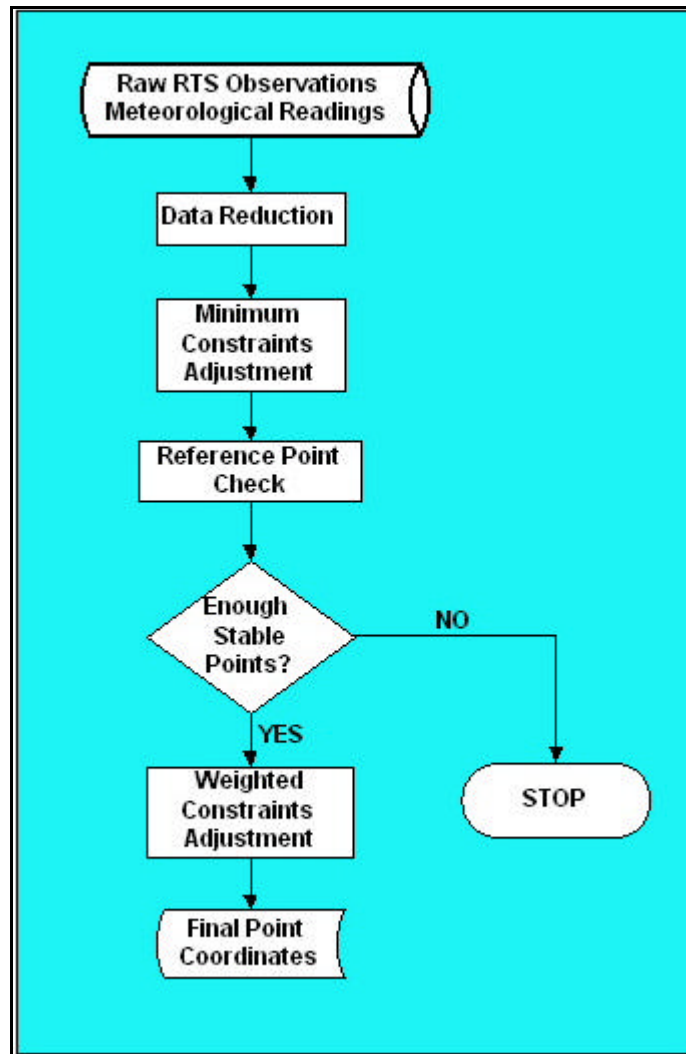


Figure 3. DIMONS data processing stages.

The raw directions, zenith angles, and distances collected by the RTS are corrected for atmospheric conditions and instrument and target offsets, and then the sets are combined using a least squares adjustment. The observation residuals obtained from the adjustment are compared with the user-specified tolerance settings. For each target, the largest zenith angle and distance residual is compared with the tolerance. If it exceeds the tolerance, the observation with the largest residual is discarded (unless only the minimum allowable number of observations are present). For direction measurements, residuals from all targets are considered together, because of the unknown orientation parameter common to all targets in a set.

Preliminary coordinates for all of the observed points are computed using a minimally constrained adjustment; if one of the minimally constrained points is found to have moved, the only effect on the resultant coordinate set will be a rigid-body translation or rotation. The use of multiple fixed points, or weighted stations, at this stage would cause distortions if an unstable reference point were present.

The minimum constraints displacements, derived with respect to a user-defined base cycle, are analyzed using the Iterative Weighted Similarity Transformation (IWST) described in Chen et al. [1990]. The effect of rigid-body translations or rotations are removed from the displacements, and the resultant datum-free displacements for the reference points are assessed in terms of their

significance. If any reference points are found to have moved significantly, they are not used in the final calculation of coordinates. If more than half of the reference points are determined to be unstable, the calculations are terminated.

Finally, the reduced observations are reprocessed using the stable reference points identified by IWST to define the datum. The reference point coordinates from the base cycle are introduced as pseudo-observations with low variances, instead of specifying one fixed point and one azimuth as was done in the minimum constraints adjustment. Because all of the stable reference points contribute in defining the datum, the effect of random pointing errors on the resultant coordinates is minimized.

3.4 Graphical Display of Displacements

The end result of data processing is a series of time-tagged coordinate values that are stored in the DIMONS database. Because the database is in a readily accessible format, the end user can easily extract coordinate values using standard Structured Query Language (SQL) queries.

To aid in analysis of displacement trends, the DIMONS displacement plotting application is used. This program allows the user to choose the points to plot and the two epochs for which to compute displacements. The displacements are then generated using Microstation. Because each user may have different requirements for the reporting format, the DIMONS plot contains only displacement vectors and their confidence regions. The Microstation seed file used to generate the plot can then be configured to contain links to other layers of information, such as the dam outline and point names as shown in Figure 4 below.

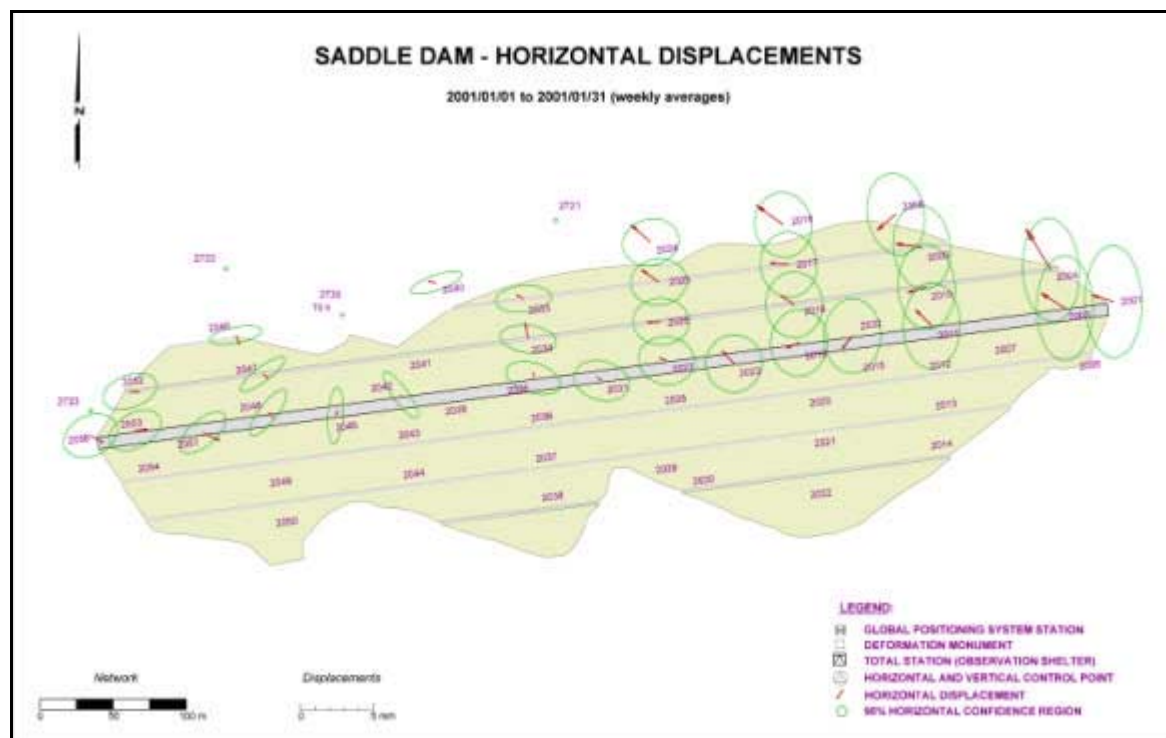


Figure 4. DIMONS horizontal displacement plot

The horizontal displacement plot is useful when the user wishes to examine displacement trends among groups of points. It can also be helpful to examine the time series for a given point, to see the day-to-day repeatability of coordinate solutions and to determine if there is a systematic trend in the position differences. The storage of coordinate solutions in a relational database makes it very easy to selectively examine subsets of the data, as shown in Figure 5 below. This figure shows the variation in coordinate solutions from point 2018, considering only the solutions that were collected at 12 noon. SQL allows the user to specify virtually any criterion in order to choose the particular solutions desired.

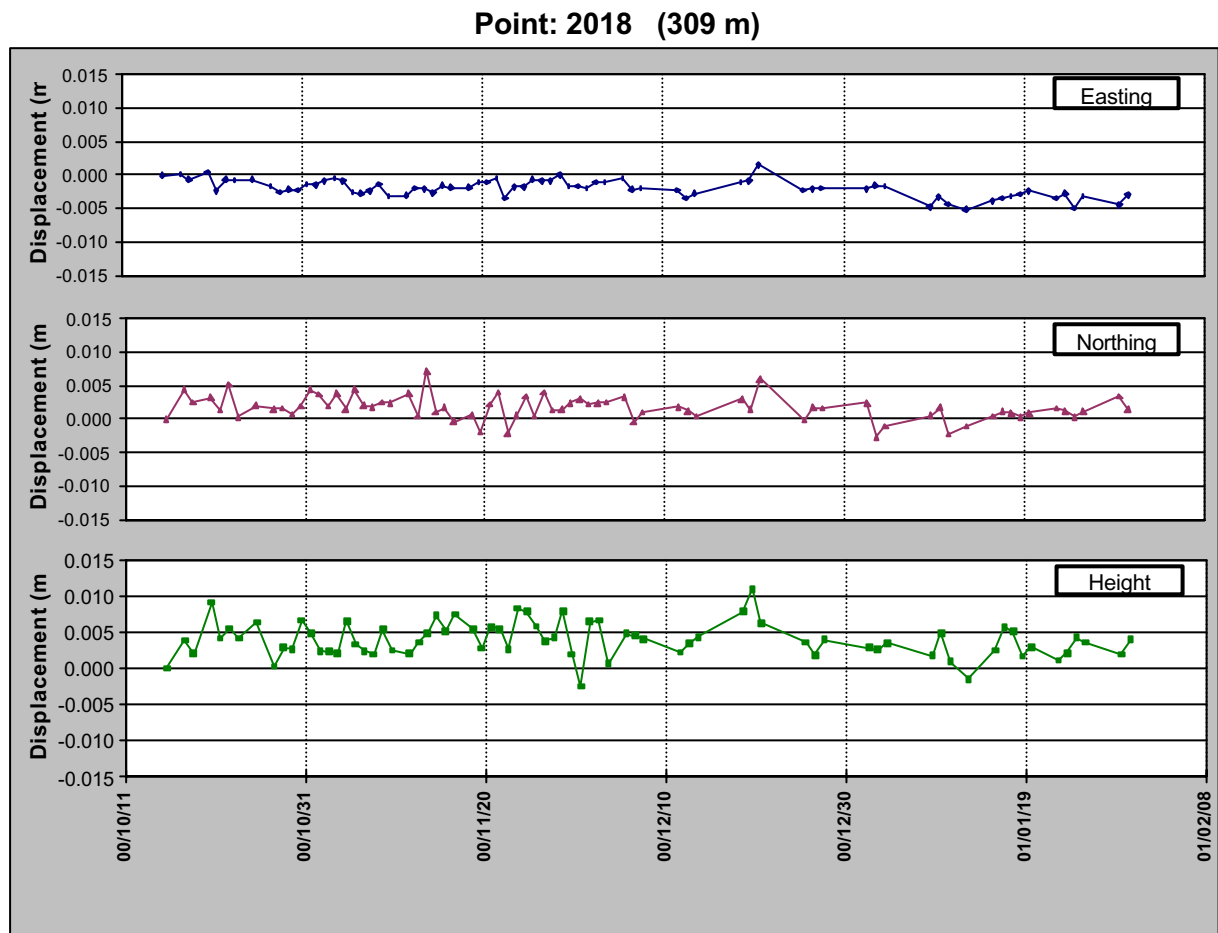


Figure 5. Variation in coordinate solutions from noontime measurements, point 2018

4. DIMONS Configuration at DVL

The Diamond Valley Lake facilities have eight permanently installed observing stations; four on the East Dam, three on the West Dam, and one on the Saddle Dam. Each observing station is equipped with an RTS and meteorological sensor, solar power, a computer, and a wireless Ethernet connection. One of the DVL observing stations is shown in Figure 6. Because these stations are connected via wireless Ethernet, they could not be integrated directly into the Metropolitan enterprise network, as this would pose a security risk. Instead, a local IP addressing scheme is used for the total station computers. A server computer, located in the Radial Gate structure close to the West Dam, is part of both the local wireless network and the Metropolitan enterprise network. This computer acts as a gateway to allow Metropolitan survey personnel to remotely access the RTS computers. Many functions of DIMONS can be executed remotely

using this scheme; certain items, including scheduling, must be performed locally, so the pcAnywhere remote access software is used as well. Figure 7 shows the configuration of DIMONS hosts at DVL.



Figure 6. Observing station TS4, on the West Dam

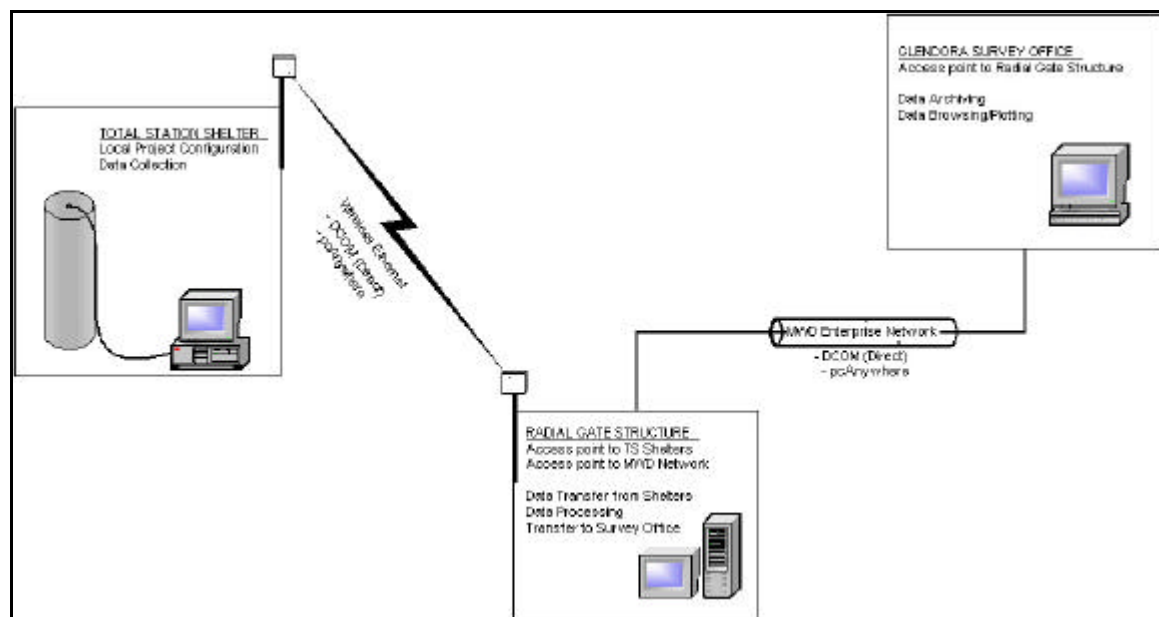


Figure 7. Relationships among DIMONS hosts at DVL

Each of the observing stations collects data on a set schedule. Ten measurement cycles are collected per week: at 4 am, 12 noon, and 8 pm on Monday, Tuesday and Wednesday, and again at 4 am on Thursday. This allows Metropolitan survey personnel to examine the data and prepare weekly reports for submittal on Fridays.

Twice daily, the Radial Gate computer collects the new readings from the observing stations and stores them in its local database. Once all the data has been collected, it is reduced and new point positions are calculated. The database is backed up to the Glendora survey office, where the new

coordinate values are examined by the system operator. All of the data collection, transfer, and processing activities are scheduled to take place automatically; once the system is configured, the role of the operator is reduced to maintenance and quality control.

5. Conclusions

A software package has been developed that supports fully automated deformation monitoring schemes. DIMONS interfaces with RTS and meteorological sensors to collect geodetic survey data according to a customizable schedule. The data is subjected to rigorous processing techniques to arrive at a final set of coordinates for an observing session. The final coordinates are stored in the project database, easily accessible for generation of displacement plots or further analysis. DIMONS has been in operation at Diamond Valley Lake since October 2000. Data is being collected and processed from eight RTS stations with no operator presence required on site.

References

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- Duffy, M., C. Hill, C. Whittaker, A. Chrzanowski, J. Lutes, and G. Bastin (2001) "An automated and integrated monitoring scheme for Diamond Valley Lake in California." *Proceedings (CDRom)*, 10th FIG Symposium on Deformation Measurements (Metropolitan Water District of S. California), Orange, CA, March 19-23.