Base Program Interim Phase Test Procedure - Coherent Laser Vision System (CLVS)

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ABSTRACT

The purpose of the CLVS research project is to develop a prototype fiber-optic based Coherent Laser Vision System suitable for DOE's EM Robotics program. The system provides three-dimensional (3D) vision for monitoring situations in which it is necessary to update geometrics on the order of once per second.

The CLVS project plan required implementation in two phases of the contract, a Base Contract and a continuance option. This is the Test Procedure and test/demonstration results presenting a proof-of-concept for a system providing three-dimensional (3D) vision with the performance capability required to update geometrics on the order of once per second.

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1.0 INTRODUCTION

The test plan is to demonstrate CLVS system performance and proof-of-concept. The test procedure will confirm, by demonstration and analysis, the functional and technical performance requirements.

The objective of the test is to determine the accuracy of three dimensional measurements performed by the CLVS system. This will be done by measuring the range accuracy and the angular (azimuth and elevation) pixel beam pointing stability and beam pointing speed of the CLVS.

The test verifies compliance with system requirements and specifications and demonstrates proof-of-concept of the CLVS system. The CLVS tests satisfy the following system test requirements:

- real-time CLVS functional performance
- range accuracy as a function of range and immunity of range measurements to lighting and surface shading.
- establish maximum acceptable tolerances on the standard deviation of measurement errors throughout the CLVS range. These tolerances specified on angular (azimuth and elevation) and radial measure.
- establish a specification of what constitutes "total immunity to 3-D position estimates to ambient lighting, color and surface shading".

These tests shall demonstrate to DOE the proof-of-concept.

2.0 SYSTEM PERFORMANCE

2.1 Functional Requirements

System functional performance shall be confirmed by a witnessed demonstration. Functional performance requirements are summarized in Table 2-1.

Table 2-1. Functional Performance Requirements

Frame Size	128 x 128 pixels
Frame Rate	one frame per second
Depth of Range	1.5-meters
Lighting/Shading/Color Immunity¹	Total immunity to lighting/shading/color

2.2 Technical Requirements

System technical performance shall be confirmed by tests and analysis. Technical performance requirements are summarized in Table 2-2. Technical performance tests results and analysis shall be documented in the CLVS Final Report.

Table 2-2. Technical Performance Requirements

Range Standard Deviation	1-mm
Range Repeatability	1-mm
Angle Standard Deviation	± 0.5 pixel
Angle Repeatability	± 0.5 pixel

¹ Immunity to lighting, shading and color is defined to mean no significant difference in functional and technical performance for any target lighting, shading, or color condition as defined in Figure 1.

2.3 Technical Characterization

System technical characterization shall be performed by tests and analysis. System technical characterization is summarized in Table 2-3.

Table 2-3. System Characterization

Range Linearity	System linearized via calibration
Pointing Angle Linearity	System linearized via calibration
Pixel Resolution	Overlap of lenslet array beams
Field of View	SNR falls off at edges of Bragg cells

3.0 TEST EQUIPMENT

The tests will be performed with the CLVS scanner mounted on an optical bench. Test equipment required consists of:

- a linear track and translator
- Tek544 Oscilloscope
- Multicolored reflective target
- Beam Profiler

4.0 TEST CONDITIONS

The tests will be performed in the CRC Laser laboratory at room temperatures and nominal range of 0.75 meters as defined in Figure 4-1.

The RF drive power to each Bragg cell shall be limited to 3W to ensure that the cells are not damaged. Since 3W is well below the maximum which, although unknown, is expected to be greater than 6W and since Bragg cell efficiency is proportional to drive power, SNR during the tests is expected to be at least 12dB below the maximum safe operating point.

Figure 4-1. Test Conditions

5.0 TEST PROCEDURES

The CLVS system being tested consists of: transmitter, optical receiver, scanner, digital receiver, and video monitor. System diagrams are provided in Appendix C. Functional requirements (section 2.1) will be demonstrated in the lab. Tests of Technical Requirements (section 2.2) and System Characterization (section 2.3) will be conducted prior to the demonstration and documented in Appendix A of this report. Test results will be available during the demonstration. Technical performance tests and system characterization shall be conducted following a 12 hour period with the system turned off and again after the system has been operating for 12 hours, in order to detect system drift.

5.1 Real-Time Functional Performance

Functional requirements listed in Table 1 will be demonstrated in the CRC laboratory by displaying several images. Frame size and frame rate will be demonstrated by observing the display. Frame rate will also be demonstrated by measuring the pixel time using an oscilloscope attached to the A/D card pixel clock test point and computing the frame rate. Depth of range will be demonstrated by placing the target at several locations within the 1.5 meter depth of range. Insensitivity to lighting conditions will be demonstrated by operating the system under all lighting conditions specified in Figure 4-1. Insensitivity to color and shading will be demonstrated by using a multi-colored target.

5.2 Range Accuracy

This test demonstrates range accuracy as a function of range and immunity of range measurements to lighting, surface, and shading.

Range values of targets at calibrated ranges will be collected by positioning a reflective target at five different calibrated ranges on a bench and recording the CLVS measured range.

Immunity of range measurements to lighting and shading conditions will be demonstrated by repeating the test with different lighting and shading conditions. The reflective target to be used for all tests will be multicolor to demonstrate immunity to color.

5.2.1 Range Accuracy Test Procedure

These tests will be performed with normal ambient room lighting (lighting condition L1). Reference Figure 4-1. Position the flat reflective target at distance d1 on the bench. The actual range is determined by calibrated positions on the bench. The rms value of measurement errors of selected pixels from 20 frames shall be used for range accuracy analysis. Repeat this test for each of the distances d2 through d5. Record the CLVS measured range for distance d1. Repeat this test for each of the distances d2 through d5.

Repeat the above tests for lighting conditions L2 and L3. Compute and record RMS range error. A range accuracy (mean error) of 1mm or less is the goal.

5.2.2 Range Repeatability

Range repeatability as a function of actual range is determined by computing the rms value of the CLVS range errors. A range accuracy (RMS error) of 1 mm or less is the goal. The standard deviation of measurement errors of selected pixels from 20 frames shall be used for range repeatability analysis.

5.2.3 Lighting & Shading Immunity

Range accuracy immunity to lighting , shading, and color conditions is determined by repeating the range accuracy and repeatability test for each lighting condition.

5.2.4 Hot and Cold Test

Range accuracy will be tested with the system having been warmed up for at least twelve hours and with the system having been turned off for at least twelve hours.

5.3 Angular Beam Pointing Stability and Pointing Resolution

Critical requirements on the scanner are that the beam does not wander with time when pointing at a fixed pixel and that the beam consistently returns to the same point during scanning. Pointing stability will be tested by pointing the beam at a beam profile sensor and monitoring the position of the peak of the beam, both in azimuth and elevation, over a long period of time. Return repeatability will be tested using the same configuration but commanding the beam to step away to another pixel and then return. The scatter of the measured beam peaks is evidence of the quality of pointing repeatability.

The quality of the beam will be measured by measuring beam profiles along two orthogonal slices through the beam after it goes through the Bragg cells. This will be done at several representative pixels. Beam profile will be compared with the nominal Gaussian shape of the ideal beam pattern.

6.0 CHARACTERIZATION

Characterization tests are performed to characterize CLVS system performance parameters which are not part of the system acceptance criteria.

6.1 Range Linearity

This test demonstrates range linearity as a function of actual range.

Range values of targets at calibrated ranges will be collected by positioning a reflective target at calibrated 5cm intervals over the 1.5 meter depth of range on an optical bench and recording the CLVS measured range for a single pixel.

These tests will be performed with normal ambient room lighting (lighting condition L1). Position the reflective target at distance D1 on the optical bench. The actual range is determined by calibrated positions on the optical bench. Record the actual range and CLVS measured range for each target position.

Range linearity is determined by computing the deviation from the linear regression line.

Note: Repeatable deviation from linearity can be corrected by calibration.

6.2 Angular linearity

This test determines angular linearity as a function of pixel.

Note: Repeatable angular deviation can be corrected by calibration.

The beam profiler is used to profile adjacent pixels along the zero elevation horizontal scan and the zero azimuth vertical scan.

6.3 SNR

This test characterizes the CLVS system field of view and SNR performance as a function of pixel.

Staring at a uniform target, plot received signal strength vs. pixels across the entire 128x128 frame. This quantifies the actual field of view achieved by the system.

7.0 TEST AND CHARACTERIZATION RESULTS

7.1 Functionality

Tests showed that functional requirements are satisfied (see Table 7-1).

Table 7-1. Functional Performance

	Spec	Test Result	Test Method
Frame Size (M x N)	128 x 128	128 x 128	inspection
Depth of Range	1.5m	1.5m	measure
Pixel Period (P)	61 msec	62.5 μ sec	measure
Frame Rate (R)	1 frame/sec	0.9766 frame/sec	calculate

7.2 Range linearity

The test procedure was to point the laser beam at a fixed strongly reflecting (i.e. scotchlight) target and record 16,384 (i.e. 128 by 128) range measurements. This data acquisition was repeated at 50 mm intervals from 0 to 1500 mm. The plan was to determine the linear regression coefficients and report the calibrated results. Initial data analysis indicated that two sets of calibration coefficients were needed, one set for measurements made on the laser waveform up-sweep and the second set for down-sweep measurements. Table 7-2 shows the regression coefficients. Table 7-3 shows the calibrated data.

Table 7-2. Calibration Coefficients

$$\text{Range (mm)} = a * \text{bin_number} + b$$

Sweep	a	b
Up-sweep	3.719622	-144.77836
Down-sweep	3.700087	-140.84165

During testing, it was determined that measurements made with the up sweep at ranges past the midpoint of the depth of range must be corrected by subtracting 1.5 from the estimated FFT bin value. The system software has not been corrected. The measurements have been corrected during analysis.

Two hardware problems were noticed. First, the hardware occasionally reports FFT bin numbers incorrectly. The problem seems to be in the VME interface although it has not been tracked down or fixed. Majority voting software was installed which corrects the problem as long as at least

Table 7-3. Range Linearity Test Data

Actual Range (mm)	Measured Range (mm)	Mean Error (mm)	Standard Deviation of Error (mm)
0	0.44	0.4360	0.1332
50	50.43	0.4344	0.0606
100	100.37	0.3674	0.0656
150	150.24	0.2442	0.0629
200	199.53	-0.4668	0.1922
250	249.92	-0.0759	0.0979
300	300.65	0.6479	0.1633
350	350.03	0.0296	0.1340
400	399.55	-0.4454	0.3644
450	449.85	-0.1472	0.2156
500	499.44	-0.5572	0.1873
550	550.12	0.1193	0.3311
600	599.47	-0.5317	0.2287
650	649.48	-0.5216	1.1888
700	699.74	-0.2628	0.4051
750	749.37	-0.6343	2.1743
800	801.13	1.1299	2.4600
850	849.03	-0.9664	3.0426
900	900.13	0.1259	1.5983
950	949.12	-0.8815	2.2491
1000	1001.30	1.2950	2.2305
1050	1050.18	0.1848	0.5795
1100	1099.71	-0.2856	1.5411
1150	1150.38	0.3786	1.2297
1200	1199.91	-0.0863	0.9089
1250	1249.95	-0.0546	2.2807
1300	1300.17	0.1700	0.6455
1350	1349.69	-0.3112	1.5236
1400	1400.28	-0.2786	2.0837
1450	1449.89	-0.1140	1.8347
1500	1500.50	0.5006	2.9855

three of the five reported bins are correct. However, at times, more than two errors are made and the majority voting software cannot produce the correct estimate in these cases. The second problem is that Catalina's software that selects the peak FFT bin and the two neighbors on either side does not work properly when the range is at either the near or far extreme, i.e. the peak of the FFT is near bin 0 or bin 511. Both of these problems should be resolved in the continuation phase of the contract. They do not have major effect on the Base Program results.

Figure 7-1 shows the standard deviation of the measurements when up-sweep and down-sweep data were separated. Both sets show larger variation in the farther half of the depth of range. We feel that some of the variation is due to the problem with reporting bin number. The problem is associated with incorrect low order bits, which would have a stronger effect on small bin numbers than on large bin numbers, and the longer range measurements correspond to small bin numbers. However, the very large variance of the up sweep measurements relative to the down sweep has not been explained.

Figure 7-1. Standard Deviation of Up and Down Sweep

Figures 7-2 and 7-3 show the mean and standard deviation of the linear regression error after applying corrections and calibrations discussed above.

Figure 7-2. Mean Regression Error vs. Range

Figure 7-3. Standard Deviation of Regression Error vs. Range

7.3 Signal strength

Signal strength was measured as a function of range and as a function of pixel location. Signal strength vs range, Figure 7-4, was obtained from the range linearity data. Much of the variation in signal strength from measurement to measurement is probably due to speckle as the beam was fixed on a single point of the scotchlight target during the measurements. There does seem to be roughly 10 dB reduction in signal strength as range varies from 0 to 1.5 meters.

Figure 7-4. Received Peak Power vs. Range

Signal strength vs pixel was obtained by scanning a flat target at mid range twenty times and smoothing the reported FFT magnitude peaks. Figure 7-5 shows vertical and horizontal slices through the center of the image. The 0 dB reference is the maximum returned signal. The maximum does not occur at the center of the image but off in one quadrant. The 15 or so dB variation in measured signal strength agrees with test results reported by Colorado University. Figure 7-6 shows a contour plot of the received power.

Figure 7-5. Orthogonal Slices through the Center of the Frame

Figure 7-6. Contour Plot of Received Power

Figure 7-7 shows a single frame obtained from a flat surface. The image quality is good over regions where Figure 7-6 shows signal strength to be high and poor where signal strength is low. The row of noisy pixels at the top right of the image may be due to a software problem.

Figure 7-7. Single Frame obtained from a Flat Surface

7.4 Range Accuracy

Range accuracy testing was done using a square piece of highly reflective scotchlight as the target. The target was placed at each of five locations within the 1.5 m depth of range under each of the three lighting conditions listed in Figure 4-1. A set of 20 frames was recorded for each data set.

Measurements of range were corrected using the calibration procedure discussed in Section 7.2. Noise spikes were removed by processing each frame using a two dimensional median filter. The 20 frames were then combined by computing the average and standard deviation of the range of each pixel. A subimage of approximately 15 by 15 pixels corresponding to the scotchlight target was extracted for further processing. The subimage was selected to minimize the variation in range with beam pointing angle. The mean of all ranges in the subimage was reported as the CLVS Range. The root-mean-square (RMS) of the computed standard deviations was reported as Sigma.

Tables 7-4 through 7-6 show the results for three lighting conditions when the system had been on for at least 12 hours. The last column in these tables shows the linear regression error after correcting the range. Analysis of the data showed that the calibration constants computed as described in Section 7.2 did not remove all of the systematic error. The range accuracy data were corrected a second time as shown:

$$R = 1.00255 * R - 0.369 \quad R \leq 750 \text{ mm}$$

$$R = 1.00255 * (R - 1.855) - 0.369 \quad R > 750 \text{ mm}$$

Table 7-4. Test1 Results, L1, (system on for 12-hours prior)

Range	Baseline Range (mm)	CLVS Range Mean (mm)	CLVS Range Sigma (mm)	Corrected Range* Error (mm)
d1	0	0.2411	0.25	-0.13
d2	375	374.5667	0.16	0.15
d3	750	748.414	0.36	-0.05
d4	1125	1124.636	0.26	0.28
d5	1500	1498.679	0.66	0.27

Table 7-5. Test1 Results, L2, (system on for 12-hours prior)

Range	Baseline Range (mm)	CLVS Range Mean (mm)	CLVS Range Sigma (mm)	Corrected Range* Error (mm)
d1	0	0.3274	0.25	-0.04
d2	375	374.6116	0.16	0.20
d3	750	748.267	0.26	-0.19
d4	1125	1124.396	0.28	0.03
d5	1500	1498.688	0.63	0.28

Table 7-6. Test1 Results, L3, (system on for 12-hours prior)

Range	Baseline Range (mm)	CLVS Range Mean (mm)	CLVS Range Sigma (mm)	Corrected Range* Error (mm)
d1	0	0.3325	0.27	-0.04
d2	375	374.5813	0.17	0.17
d3	750	748.255	0.27	-0.21
d4	1125	1124.146	0.32	-0.22
d5	1500	1497.835	0.39	-0.57

* Correction:

1. Subtract 1.855mm from ranges > 750mm
2. $R = 1.00255 * R - 0.369$

With this additional calibration, the range errors in Tables 7-4 through 7-6 were computed.

The CLVS Range Sigma column is the standard deviation of range measurements over the subimage measured during 20 scans of the target. Since the data acquisition procedure was manual, one frame being recorded at a time, the 20 frames span a time interval of several minutes. CLVS Range Sigma is a measure of measurement repeatability. The largest standard deviation is 0.66 mm, well within the 1.0 mm goal.

The Corrected Range Error column is a measure of measurement accuracy. The largest error is .57 mm, well within the 1.0 mm goal.

The largest range of range measurements across lighting conditions is 0.85 mm, at 1500 mm nominal range. This is within the 1 mm goal. Indeed, the measurements at 1500 mm exhibit the largest variance of the entire set indicating that the system is operating at maximum range. Discounting the longest range measurement, the next largest error is 0.49 mm, well within the goal.

Table 7-7 shows similar results under normal lighting conditions when the system had been turned off for at least 12 hours, i.e. a cold test. Two observations are clear from the test results. First, the variance of the measurements at mid range is an order of magnitude larger than variances of measurements at other ranges. This is attributed to a bug in the system software. Second, computing the regression line using the four measurements with small sigmas shows that the data do not have to be corrected as required by the warm test. This is attributed to uncompensated system thermal drift. The other CLR systems developed by CRC incorporate a reference arm specifically to compensate for this drift. The reference arm was not included in the demonstration CLVS to minimize cost with the understanding that a fully developed CLVS would require a reference arm.

Table 7-7. Test2 Results, L1, (system off for 12-hours prior)

Range	Baseline Range (mm)	CLVS Range Mean (mm)	CLVS Range Sigma (mm)	Corrected Range* Error (mm)
d1	0	.1058	.28	.09
d2	375	375.0093	.07	-.05
d3	750	754.0212	2.2	3.92
d4	1125	1126.7874	.49	-.22
d5	1500	1502.222	.65	.17

* Correction

1. Subtract 1.855mm from ranges > 750mm

With the exceptions noted, differences between cold and warm operation are typified by the single test under normal lighting conditions. Nothing was to be gained by taking cold data under other lighting conditions.

7.5 Angular Pointing Stability

In order to measure the angular pointing stability of the acousto-optic scanner, a laser beam profile measurement instrument was positioned 60 cm in front of the scanner. This profiler is able to measure both the shape and the position of the laser beam in both the azimuth and elevation directions. With the scanner set such that the beam was in the center of the scan (pixel #64 for both at the azimuth and the elevation), the profiler was programmed to take a sample every five minutes for a period of 16 hours over the course of a night. Figure 7-8 contains plots of the of the beam drift in both the elevation (position 1) and the azimuth (position 2) direction. As can be seen, the total drift over this period of time was 77 μm in elevation and 63 μm in azimuth. At the range that the data was taken, the spacing between adjacent pixels is about 550 μm , thus the total observed drift is less than 15% of the pixel spacing.

Figure 7-8. Plots of the Beam Drift

7.6 Angular Pointing Linearity

Angular pointing linearity was measured by measuring the angular spacing between adjacent pixels. This was accomplished by mounting the beam profiler to an X-Y positioner stage at a range of 60 cm from the scanner and measuring the lateral distance between beam positions. Since measuring this distance in both directions for all 128x128 pixel positions is impractical, only a representative sample of points was measured. The beam was set to the center elevation position (pixel #64) and the beam spacing was measured for the first and last ten and the middle 20 azimuthal pixels. These measurements were then repeated for the elevation pixels for the center azimuth position. As can be seen by the plot in Figure 7-9, the spacing between all the measured points falls in the range .052 to .056 degrees. The small amount of spread in the spacing values ($\pm .002$ degrees) denotes the linearity of the scanner pointing. Much of the residual scatter in the data can be attributed to the variation in the beam shape as a function of beam position as discussed in the next section.

The average of the angular spacings is .0536 degrees for the elevation direction and .0543 for the azimuth direction. In order to double check these values, the spacing between two widely separated pixels was measured for both directions and these values were used to calculate the per pixel angular spacing. They are .0545 degrees for the elevation direction and .0555 degrees for the azimuth direction. Using these values, the total angular scanning field-of-view for this scanner geometry is 7.053 degrees by 6.925 degrees (azimuth by elevation) for the 128x128 frame.

7.7 System Losses

As originally designed, the AO scanner geometry consists of a collimating lens, two AO crystals, a Fourier transform lens, a 2-D lenslet array and a scan lens. The greatest impact to system performance is the optical losses associated with the crystals. The efficiency of the crystals is well characterized by the University of Colorado's final report. Their results were confirmed by measurements taken at CRC. For example, for a drive frequency of 75 MHz to each crystal at a power level of 3 Watts, the optical transmission through the elevation deflector and the azimuth deflector was 15% (-8.2 dB) and 13.5% (-8.7 dB) respectively. Thus the combined total two-way loss is 33.8 dB.

In addition to this transmission loss, the interaction of the beam with the crystals caused a distortion of the shape of the output beam. It is suspected that this distortion is caused by problems with the transducers on the crystals since they are associated with the position of the beam with respect to the transducer. The main effect of this distortion is to increase the size of the focussed spot at the lenslet array. Beam profile measurements taken both without the crystals in the optical train and with them in the train show that the focussed spot size at the array increases from a near-diffraction-limited value of 90 μm to 150 μm . Since the lenslet size is 125 μm this effect reduces the amount of usable power in each pixel as well as increases the cross-talk in adjacent pixels. In order to determine the amount of signal loss associated with this effect, signal strength measurements were made on a target positioned at the focus in place of the lenslet array and at a comparable distance in front of the 50 mm scan lens with the array. After correcting for the scan lens

Figure 7-9. Angular Spacing Between Pixels

transmission loss and for the scan lens aperture gain, the loss due to overfilling the lenslet aperture was measured as 10 dB.

Another source of loss is the 50 mm scan lens itself. Due to budgetary constraints, it was decided to use an off the shelf lens with conventional coatings for visible light. Since the laser light is infrared, the transmission through this lens was 23% (-6.4 dB). Thus the two way loss is 12.8 dB. Therefore, the total two way optical loss through the scanner optics was 56.6 dB for the center pixel position.

7.8 Increased Drive Power

The system was tested and demonstrated with 3W of RF drive power to each Bragg cell to ensure that the cells were not damaged. The cells should be able to be driven at 6W or more, which would increase processed SNR at least 12 dB.

During the performance demonstration on 13 November 1996, the drive power was raised to 6W. Image quality improved significantly as expected. The following day we attempted to obtain test data at the higher drive power but one of the cells was damaged.

Appendix A

CLVS System Requirements and Specifications

The following is a summary of the CLVS system requirements. The table provides a summary of CLVS specifications.

Requirements

- Development of a 128 X 128 pixel switched fiber-optic 3D vision scanner.
- Development of a fiber-optic CLR transmitter providing linear frequency modulation at the pixel repetition rate. The transmitter was to be based on CRC's existing designs augmented by a fiber optic amplifier to compensate for insertion losses of the scanner.
- Development of a digital receiver to detect range for each pixel at a 128 X 128 pixel frame, one frame per second over a distance of 1.5-meters.
- System implementation using PC or VME based computer hardware (or both). Integrate all CLVS subsystems to achieve performance of the system functional capabilities to acquire and download range image data under direct operator and remote computer control.
- Perform a proof-of-concept baseline system test to demonstrate range accuracy as a function of range and immunity of range measurements to lighting and surface shading.

CLVS Requirements and Specifications

Frame Size (M x N)	128 x 128	Requirement
Frame Rate	one frame per second	Requirement
Depth of Range	1.5-meters	Requirement
Range Accuracy	1mm, rms	Requirement
Pixel rate/sec	16,384	Derived Requirement
Pixel Period	61msec	Derived Specification
Scanner Response Time	11 msec	Scanner Specification
Dwell/chirp time	50 msec	Derived Specification
Laser chirp Df	25 GHz	Derived Specification
Frequency shift/range	3.3 MHz/m	Derived Specification
Signal bandwidth	16.7 MHz	Derived Specification
Sample rate (A/D)	10 MHz	Derived Specification
Samples/dwell	512	Derived Specification
Power spectrum resolution	19.5 kHz	Derived Specification
Focus	fixed	Requirement
Range Resolution (without interpolation)	5.9 mm	Derived Specification

Signal BW = Depth of Range * Frequency Shift/range

Power Spectrum Resolution = Sample Rate / (Samples/dwell)

Range Resolution = Power Spectrum Resolution / (Frequency Shift/range)

Depth of Range = (Samples per dwell / 2) * Range Resolution

Appendix B

CLVS System Drawings

CLVS System Block Diagram

Digital Receiver Diagram

Optical Transceiver and Scanner Block Diagram

Wi

th Lenslet Array

Without Lenslet Array

Scanner Schematic

CLVS PC Hardware Configuration

VS System Software Diagram

CL

CLVS Signal Processing Flow

APPENDIX C

List of Acronyms and Abbreviations

Abbreviations**Acronyms**

A/D	Analog/Digital
AO	Acousto-optic
AZ	Azimuth
CLR	Coherent Laser Radar
CLVS	Coherent Laser Vision System
CRC	Coleman Research Corp
CPU	Central Processing Unit
dB	Decibel
DFB	Distributed feedback
DSP	Digital signal processing
EL	Elevation
FM	Frequency modulated
Ghz	Gigahertz
GUI	Graphical user interface
I&Q	In-phase & quadrature
IR	Infrared
LO	Local oscillator
MHz	Megahertz
OS/2	IBM Operating System 2
PC	Personal computer
PCI/VME	PCI (Peripheral Computer Interface) bus to VMEbus Interface
pinFET	positive intrinsic negative Field-Effect-Transistor
RF	Radio frequency
RS-170	Video signal standard
TBD	To be determined
TBR	To be reviewed
TBS	To be supplied
TeO ₂	Tellurium di-oxide
UTP	Uniphase Telecommunications Products
VME	Computer bus standard
2D	Two-dimensional
3D	Three-dimensional