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ADVANCED MEASUREMENT TECHNIQUES FOR U.S. SHIPBUILDING

TASK REPORT:
LITERATURE SEARCH
AND
MARKET PLACE SURVEY

Prepared by

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16. Abstract

The purpose of this report was to discover as many viable types of industrial measurement systems as possible and to classify those that could be used in shipbuilding. The second part of the project is to obtain demonstrations of the identified measurement systems and analyze them in the shipbuilding environment. This part is to be done at the National Steel and Shipbuilding Company (NASSCO). The measurement systems or instruments surveyed and included were: 1) photogrammetry, including convergent, stereo, digital image processing, and automated anaylsis methods; 2) theodolites, including standard manual optical instruments, computer assisted systems, and motorized laser guided systems; 3) digitizers, including sonic and infrared systems; 4) coordinate measuring machines; and 5) lasers, including theodolites and scanners. Analyses of these systems are detailed in individual appendices attached to the summary report. Robots, satellite position indicators, ultrasonic digitizers, and infrared scanners were not considered appropriate for shipbuilding or industrial measurement and were not included.

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Advanced Measurement Techniques for U.S. Shipbuilding

TASK REPORT

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TASK REPORT

I INTRODUCTION

A. Project Description

This report is part of the larger National Shipbuilding and Research Program (NSRP) project "Advanced Measurement Techniques for U.S. Shipbuilding," MARAD Contract DTMA91-84-C-41043, with the National Steel and Shipbuilding Company (NASSCO) as the primary contractor. The purpose of this part of the research is to discover and classify as many viable types of industrial measurement systems as possible. The NASSCO researcher will use this information as a basis from which to obtain demonstrations of the identified measurement systems, in the shipbuilding environment if possible, and will present a final report to the Design and Integration Panel (SP-4) of the Society of Naval Architects and Marine Engineers (SNAME) Ship Production Committee.

This study was conducted at the University of Michigan Transportation Research Institute (UMTRI) by Mr. Albert W. Horsmon, Jr., Senior Engineering Research Associate, Marine Systems Division, as the principal investigator, and Professor Howard Bunch as project director.

The following measurement systems or instruments were surveyed:

1. photogrammetry, including convergent, stereo, digital image processing, and automated analysis methods;
2. theodolites, including standard manual optical instruments, computer assisted systems, and motorized laser guided systems;
3. digitizers, with sonic and infrared systems;
4. coordinate measuring machines;
5. lasers, including theodolites and scanners;
6. robots, satellite, ultrasonic, infrared scanners.

Analyses of the first five groups of systems are the focus of this report and are detailed in the appendix. Detailed analyses were not made on the last group of instruments.

B. Summary of Interim Progress Reports

A series of interim progress reports were made to the NASSCO researcher, Charles J. Lupica, in the form of weekly telephone conversations. During these weekly talks, the NASSCO and UMTRI researchers adjusted the emphasis of the project to concentrate more on emerging measurement technologies, such as laser scanners, as opposed to those which were already well developed, such as standard terrestrial surveying equipment.

Other subjects discussed included:

1. the format of the measurement system report forms (adjusted to expand the technology description);
2. that theodolites have a limited capability in the shipbuilding environment; and
3. that 1/32" accuracy is the minimum accepted.

Preliminary copies of the convergent photogrammetry and sonic digitizer measurement system analyses were sent to NASSCO on August 4, 1989. The NASSCO researcher desired the technology description area be expanded as much as possible. An outline of the final report and a listing of all the measurement systems surveyed, including names to contact for demonstrations, were sent to NASSCO on September 21, 1989.

C. Literature Searches

Two major computerized literature searches were conducted. One was through the University of Michigan's Engineering Library. The other was of DIALOG databases including the National Technical Information Service (NTIS), Engineering Index,Thomas New Industrial Product List, and Japan Technology Index. These searches produced limited results; their main benefit was to direct the investigator to manufacturers of specific equipment. Therefore, the best literature source was to query the vendors.

The most significant source of information was the manufacturer, or his representative. After analysis, this material was filed according to the related technology description and forwarded to the sponsor for further reference.

II. INDIVIDUAL SYSTEM DESCRIPTIONS

The individual systems are described in detailed individual appendices, in a format approved by NASSCO early in the project. Most of the descriptions are generalized to a typical system. Most systems can be customized, either in hardware or software. An analysis of the costs and merits of all the possible custom versions of all the systems is beyond the scope of this phase of the research.

The photogrammetric measurement systems are all based on photographic processes, but the two methods by which the photos are taken, and the various methods by which they are analyzed, are significantly different. The four photogrammetric systems are convergent, stereo, digital image processing, and automated analysis, and are detailed in Appendices A through D, respectively.

The sonic and infrared digitizers surveyed are similar in operation. A signal emitted at the the point being measured is received at a sensing device which determines the position. The sonic device measures and triangulates the time delay from emission to detection. The infrared device locates the point source of emitted light with sensing cameras that can determine the source location in space. The sonic digitizer is detailed in Appendix E. The infrared device is detailed in Appendix F.

Theodolite industrial measurement systems are logical adaptations of standard land surveying instruments. These instruments measure horizontal and vertical angles and are usually operated in pairs. When a line of sight from two instruments intersects on a point on the object being measured, the point is fixed in space. The theodolites analyzed in Appendices G through I include standard manual optical instruments, computer assisted systems, and motorized laser guided systems.

Coordinate measuring machines are physical contact devices which accurately measure the position in space of the contact point relative to a known zero point. The best of these machines is far more accurate than necessary for shipbuilding, but simplified versions are available which may be appropriate for part and sub-assembly measurement. They are detailed in Appendix J.

A laser scanner bombards a targeted object with laser light that is received by digitizing cameras to record the positions of the various targets. A completed system has just been developed, and is described in Appendix K. A laser system from Finland called ACMETER was identified, and from limited information was included in the analysis in Figure 1., but adequate information was not available at the writing of this report to give a complete analysis. It will be forwarded when received.

Four systems surveyed were not included in this report for the reasons set forth below. Robot arms are calibrated, and in some instances controlled by sonic and infrared digitizers and by laser scanners. Therefore, robots were not considered viable measurement tools.

RATING BY STAGE OF CONSTRUCTION

MEASUREMENT SYSTEM		FABRICATION	SUB-ASSEMBLY	ASSEMBLY	OUTFIT	ERECTION
PHOTGRAMMETRY	CONVERGENT	C	C	B	A	A
	STEREO	C	C	B	A	A
	DIGITAL IMAGERY	C	B	A	A	A
	AUTOMATED ANALYSIS	C	C	B	A	A
SONIC DIGITIZER		A	A	A	C	C
THEODOLITES	STANDARD MANUAL	C	C	B	B	B
	AUTOMATED ANALYSIS	C	C	B	A	A
	MOTORIZED, LASER TARGETED	C	C	C	A	A
LASER	ACMETER	C	C	B	A	A
	SCANNERS	C	C	A	C	C
COORDINATE MEASURE MACHINE		A	B	C	C	NA
INFRARED		A	A	A	C	C

RATING SCHEME:

A = VERY GOOD - This measurement system is very well suited to this stage of construction and has been proven or has well defined potential.

B = GOOD - This measurement system will be adequate for measuring the particular stage of construction but is not the best considering the alternatives.

C = NOT VERY GOOD - This system may work, but will not provide adequate accuracy, or will be too cumbersome.

NA = NOT APPLICABLE - Not reasonably adaptable to measure at this stage of construction.

FIGURE 1.

Satellites have not been downsized from their global navigation tasks and are not expected to be adapted to industrial measurement. The concept of creating miniature receiving attennae and a localized positioning satellite was considered unreasonable by one global navigation engineer.

The only ultrasonic system discovered was a crude version of a sonic digitizer. This system was interesting in that it was developed with minimal funding by one graduate student.

Finally, the infrared scanner surveyed was not accurate enough for this study, nor was development for industrial measurement planned. However, the principal development engineer for this infrared scanner stated that with the proper funding, this system could be made into a viable industrial measurement tool.

All of the systems surveyed were either designed to be used with a computer or, with the most recent versions, were available with direct computer links. The minimum output of a computer aided system was an x,y,z coordinate. Most software is capable of converting this data to another reference coordinate system. Some software can perform error analysis. Most of the software is available on the open commercial market or can be developed by a knowledgeable programmer and has not been elaborated on in this report.

III. RATING BY STAGE OF CONSTRUCTION

The "Rating By Stage of Construction" chart in Figure 1 was produced to give a generalized projection of which measurement systems are best suited for given stages of construction. The ratings are subjective and should not be taken as limiting a particular measurement system from being used in another stage of construction. The ratings are likely to change after the various systems are physically tested.

The rating chart was developed to analyze capability evident from literature, without regard to cost. The final analysis of the systems will depend not only on acquisition cost, but on practical capability, operator skill and training requirements, and turn-around time for measurements. These attributes will be evaluated at NASSCO.

The most apparent aspect of the chart is that none of the measurement systems surveyed has the capability to conveniently and accurately measure both fabrication parts and large blocks. It seems that a complete measurement capability at a particular shipyard would use two or three complete types of systems, possibly with multiples of some of the less costly systems for measuring parts on an assembly line.

IV. COST COMPARISON

The "Cost Comparison" in Table 1 is designed to present a rough idea of initial system cost. Costs vary significantly because of configurations available in the various instruments. Operator requirements were purposely omitted from this comparison because all the systems surveyed could conceivably be operated by a single skilled person. However, the most efficient number of operators and assistants could range from 2 to 6, depending on the system and turn-around time desired.

Table 1.

COST COMPARISON

	$ (000)
Photogrammetry, Convergent	100-300
Photogrammetry, Stereo	100-300
Photogrammetry, Digital Imagery	130-200
Photogrammetry, Automated Analysis	225-275
Sonic Digitizer	10-25
Theodolites, Standard Manual	5-50
Theodolites, Automated Analysis	40-100
Theodolites, Motorized, Laser Targeted	350
Laser Scanners	135
Coordinate Measuring Machines	5-300
Infrared Digitizer	60

V. FUTURE TRENDS

All of the systems surveyed were in some sort of development stage. Some of the development is evolutionary, as in fine tuning instruments, or making computer software more flexible. Some of the future developments are revolutionary and are under active trial phase development. Developments for each of the systems are described within the individual system descriptions.

VI. SUMMARY

This "discovery" phase of the research produced some interesting results. Measurement systems such as photogrammetry, previously thought by some to be completely developed and of little interest to this project, are in various stages and forms of further development. Theodolites are becoming more automated. Lasers are being used for targeting, range-finding, and as traditional alignment tools.

The UMTRI researchers used information from literature searches and many sources in industry, from manufacturers to sales organizations to end users, to discover as many types of measurement systems as possible. This does not rule out the possibility that some viable systems were excluded. This concept, along with the knowledge that all the surveyed systems are under some stage of development, indicates that the "discovery" phase of the advanced measurement project should never be considered 100 percent complete.

Advanced Measurement Techniques for U.S. Shipbuilding

PHOTOGRAMMETRY - CONVERGENT METHOD

1. TECHNOLOGY DESCRIPTION

The convergent method is one of two (the other is stereo) methods of photogrammetric measurement. Camera stations are arranged such that camera axes are inclined relative to a normal view of the object and converge toward one another. Discrete points on the object must be easily identified in the photos or physically targeted, usually the latter. Point positions are determined by a complex triangulation network.

Known camera positions are required to perform the photogrammetric measurements. Some operators pre-survey camera locations relative to the measured object with theodolites. Sophisticated programming of the triangulation schemes with a few premeasured control points on the object allows determination of camera locations from analysis of the photos in the monocomparator.

Relatively simple but complete manual digitizing of the points of interest on the photographic plates is performed on a photogrammetric monocomparater. This machine accurately records the two dimensional position of all visible points of interest in one photo at a time. Control points are used to determine scale in each photograph. The two dimensional positions from the various photos are combined to fix the points in three dimensional space. A key element is rigorous analytical formulation of the mathematics involved and subsequent programming of the same to develop the analytical software. Processing by a computer can produce a variety of accurately scaled products such as tables of offsets, one-line diagrams, and drawings.

A. Required Planning

Discrete points of interest must be manually targeted, usually with an adhesively attached bullseye. Camera placement should be carefully planned, possibly with the use of models to eliminate delays at the sight or rework for lack of coverage. The effect of surroundings on locations and lines of sight should also be evaluated. There is no need to pre-survey locations of the camera station XYZ coordinates, or control points on or near the object. The only required externally measured data are a few distances between pairs of points on or near the object to establish scale. These measurements are frequently taken with theodolites.

B. Data Processing

Analysis of photographs is done on an photogrammetric monocomparater, a machine for manually viewing and digitizing the photographs into numeric information for synthesis by computer. Each point of interest must be targeted individually by the operator for entry into the computer file.

C. Results Turn Around

One to three days after photography occurs, depending on complexity of structure, proficiency of analytical machine operator, sophistication of the software analysis package, and the capability of the computer.

D. Equipment Description

Terrestrial camera, large flash units, portable photo development lab, point transfer device, analytic monocomparater, computer with customized software.

E. Equipment Cost

System cost is about $250,000 to $300,000 including two cameras (up to $25K each), plate processing equipment, analytical compiler.

F. Potential for Computer Integration

Current systems use computers to synthesize digitized information. A good software package will put this information into a form readily usable by another system or will produce offset tables in the measured object's coordinate system.

G. Site Preparation Requirements

Camera stations should be located 15 - 30 feet from the item to be measured. Distance can be reduced by use of special cameras. Targeting of control points and otherwise difficult to identify points, such as flat surfaces, is required. Adequate lighting must be provided.

H. System Reliability

Excellent. Minimal periodic maintenance and cleaning on the cameras and compiler is required.

I. Imposition Upon Regular Shipyard Operations

Targeting can be done as other work progresses. On-going work, either directly in the field of view or directly attached to the item being photographed (to prevent movement), must be suspended, but only for the relatively short amount of time (one-two hours) needed to photograph most subjects. Photographic analysis is done off site in an office environment.

2. DEGREE OF ACCURACY

Accuracy of 1:50,000 at one sigma probability is easily achieved. The convergent method is normally about 2 - 3 times as accurate as the stereo method of photogrammetry.

3. SET UP TIME

About 1/2 day may be needed to set up control points and cameras and to shoot photos. Situations such as poor lighting, a large number of control or target points, or a large complicated object would increase this time unless a larger team were available.

4. MANNING REQUIREMENTS

A typical shipyard team has six full time workers, also responsible for other optical measurement systems and accuracy control at the same time. It is possible to perform the measurements with only one (obviously well-trained) person if necessary.

5. FUTURE TRENDS

The leading concepts for the future are integrated measuring systems, automation of repetitive measurement tasks, and creation of "as-built" data bases. More user friendly computer software is being developed to ease the analysis tasks.

6. MARKETING INFORMATION

JFK, Inc., Box 3556, Indialantic, FL 32903, (305) 725-2715

Wild Leitz USA, Inc., 24 Link Drive, Rockleigh, NJ 07647 (201) 767-1100

Helava Associates Inc., 21421 Hilltop St., Southfield, MI 48034 (313) 352-2640

Geodetic Services, Inc., 1511 South Riverview Drive, Melbourne, FL 32901 (305) 724-6831

American Society for Photogrammetry and Remote Sensing, 210 Little Falls St., Falls Church, VA. 22046-4398. (703) 534-6617.

Pentax Instruments, 35 Inverness Drive East, Englewood, CO., 80112 (303) 700-8000

7. KNOWN LOCATIONS OF USE

Newport News Shipyard; McDonnell Douglas, Northrop, and Rockwell Aircraft companies have in-house photogrammetric capabilities. JFK and Geodetic services have performed numerous photogrammetric surveys.

8. SUMMARY OF POTENTIAL APPLICATIONS

Checking erection butts, mapping as-built units, digitizing information from models into full scale offsets, checking dimensions of complicated geometry vendor supplied equipment (such as castings, diesel generator sets, etc.), checking circularity of submarine hulls, preplanning and preproduction of repair or modification units for existing vessels from photogrammetric information, using basic information to prepare bids, measurement of complicated 3-D structures, checking fit for erection stages of shipbuilding.

9. SOURCES OF INFORMATION.

1. "Transfer of Photogrammetry Technology to the U.S. Shipbuilding," by John F. Kenefick, JFK, Inc. P. O. Box 35567, Indialantic, FL 32903, Presented to U.S Naval Shipyards Group Superintendents, November, 1987.

2. "Industrial Photogrammetry, Second Edition," undated document, John F. Kenefick, Photogrammetric Consultants, Inc.

3. "Industrial Photogrammetry," M. J. Gunn and Ronald S. Hicks. Presented at Hampton Roads Section Meeting of SNAME, October, 1987.

4. "Photogrammetry and Computed-Aided Piping Design," Chemical Engineering February 28, 1985.

5. "Photogrammetry and Shipbuilding; Measuring a Complex Casting;" National Shipbuilding Research Program, February 1989.

6. "Joining Ships Built In Halves Using Close-Range Photogrammetry," by D. Douglas Peel, Southwest Marine, Inc., San Diego, CA, undated document.

7. "Excerpts from Descriptions of JFK Photogrammetric Surveys," December, 1987, John F. Kenefick, Photogrammetric Consultant, Inc., Indialantic, FL.

8. "Photogrammetry for the Present and Future," Helava Associates, Southfield, MI.

9. "Application of Zone Logic and Outfit Planning Concepts to Overhaul, Modernization and Repair of U.S. Navy Ships," by Dennis Moen, Journal of Ship Production, Vol. 1, No. 4, NOV 1985.

Advanced Measurement Techniques for U.S. Shipbuilding

PHOTOGRAMMETRY - STEREO METHOD

1. TECHNOLOGY DESCRIPTION

The stereo method is one of two (the other is convergent) methods of photogrammetric measurement. Usually, two cameras are used with roughly (+ or - 10^{o}) parallel axes to take two overlapping photographs called a stereo pair. Camera stations are arranged to completely cover the subject with overlapping photographs. Relatively simple but complete manual digitizing of photographs is performed by a special photogrammetric analytic stereocompiler, then processed by a computer to produce a variety of accurately scaled products such as tables of offsets, one-line diagrams, and drawings.

The key difference between the convergent and stereo methods of photogrammetry is that the stereo photos are taken at nearly right angles to the object whereas the convergent photos are at various angles. Subjects of stereo photogrammetry need not be targeted. This feature is desireable when large areas must be surveyed and targeting would consume a large part of on site time.

The angle at which photos can physically be taken, dependent on access to the subject or other obstructions, is another factor to consider in selecting stereo or convergent methods. The accuracy of stereo photogrammetry is less than half that of the convergent method.

A. Required Planning

Discrete points of interest must be targeted, but not as many as in the convergent method. The operator must plan placement of cameras and evaluate effect of surroundings on locations and lines of sight. Camera stations need not be pre-surveyed but control points must be.

B. Data Processing

Analysis of photographs is done through an "Analytical Compiler", also called a "stereocompiler," which is a machine for viewing the photographs in pairs and digitizing numeric information for synthesis by computer. Older analytic compilers use mechanical linkages to translate photogrammetric information into a computer, whereas newer compilers are electronically linked to the computer.

C. Results Turn Around

Approximately three full days may be needed to set up control points, cameras, shoot and process photos, and analyze results for a reasonable size job. Overnight results would be possible with a well coordinated, experienced team and a rush requirement. Job time is also dependent on the complexity of the structure, proficiency of analytical machine operator, proficiency of software analysis package,.and capability of computer.

D. Equipment Description

Terrestrial camera(s), point transfer device, analytic compiler, computer, adequate software.

E. Equipment Cost

System cost is about $200,000 to $300,000 including 2 cameras (up to $25K each), plate processing equipment, analytical compiler. The variation in cost is from options on types of cameras, compilers, and software packages.

F. Potential for Computer Integration

System uses computer to synthesize digitized information. Good software will put this information into a form usable by another system.

G. Site Preparation Requirements

Camera stations should be located 15 - 30 feet from the object being measured. Distance can be reduced by use of special cameras. Targeting of control points is required. Lighting may be required for poor light situations. Photographic analysis is done off site in an office environment.

H. System Reliability

Excellent. The weak link would be calibrating and repair of an older analog compiler, otherwise a modern system would be as reliable as the computer system used for analysis.

I. Imposition upon Regular Shipyard Operations

On-going work, either directly in the field of view or directly attached to the item being photographed (to prevent movement), is suspended. Targeting can be done as other work progresses, but workers and staging must be removed to take photographs.

2. DEGREE OF ACCURACY

Accuracy of 1:20,000 at one sigma probability is easily achieved. Plus or minus .02" to 1/32" is often specified and obtainable.

3. SET UP TIME

About 1/2 day may be needed to set up control points and cameras and shoot photos. Situations such as poor lighting, a large number of control points, or a large complicated object would increase this time unless a larger team were available.

4. MANNING REQUIREMENTS

A typical shipyard team has six full time workers, also responsible for other optical measurement systems and accuracy control at the same time.

5. FUTURE TRENDS

The leading concepts for the future are integrated measuring systems, automation of repetitive measurement tasks, and creation of "as-built" data bases. Automated analysis methods are described in Appendices C and D.

6. MARKETING INFORMATION

The major US consulting group is JFK, Inc., Box 3556, Indialantic, FL 32903. Equipment is supplied by Wild Heerbrugg Ltd., Heerbrugg Switzerland through the US distributor in Rockleigh, NJ. Most photogrammetric services are geared to terrestrial surveys and may not be equipped to perform industrial work.

JFK, Inc., Box 3556, Indialantic, FL 32903, (305) 725-2715

Wild Leitz USA, Inc., 24 Link Drive, Rockleigh, NJ 07647 (201) 767-1100

Helava Associates Inc., 21421 Hilltop St., Southfield, MI 48034 (313) 352-2640

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American Society for Photogrammetry and Remote Sensing, 210 Little Falls St., Falls Church, VA. 22046-4398. (703) 534-6617.

7. KNOWN LOCATIONS OF USE

Prearrangement of weapons module fit on CV-61 at Puget Sound Naval Shipyard.

8. SUMMARY OF POTENTIAL APPLICATIONS

Preplanning and preproduction of repair or modification units of existing vessels from photogrammetric information, checking erection butts, mapping as-built units, digitizing information from models into full scale offsets, using basic information to prepare bids, measurement of complicated 3-D structures, checking fit for erection stages of shipbuilding.

9. SOURCES OF INFORMATION

1. "Transfer of Photogrammetry Technology to the U.S. Shipbuilding," by John F. Kenefick, JFK, Inc. P. O. Box 35567, Indialantic, FL 32903, Presented to U.S Naval Shipyards Group Superintendents, November, 1987.

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7. "Excerpts from Descriptions of JFK Photogrammetric Surveys," December, 1987, John F. Kenefick, Photogrammetric Consultant, Inc., Indialantic, FL.

8. "Photogrammetry for the Present and Future," Helava Associates, Southfield, MI.

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PHOTOGRAMMETRY - DIGITAL IMAGERY

1. TECHNOLOGY DESCRIPTION

Digital imagery is a refinement in the method of photogrammetric analysis. Photographic methods and triangulation techniques are the same as other forms of photogrammetry. Discrete points are located by the photo analyzer operator, then the computer creates a digital file for that point on that photo. The same points on related photos are similarly located, but measured automatically using digital correlation techniques and stored as digital image patches. These patches have smaller digital image files to keep computer storage space requirements low, but still include enough of the image for subsequent correlation.

The core of the system is the Digital Comparator Correlator System (DCCS) which performs the automatic point correlation analysis on about 80% of the points. This reduces operator involvement and fatigue significantly. In addition, the DCCS has a post-process operation, called least squares correlation, which redigests all the correlation information to refine the final measurement.

However, the existing system, which uses convergent photos, has not been tried on a purely industrial application. The new system under development uses similar digital imaging but is designed to use stereo photos on a special analysis system and stereo pair viewing screen. This system should be ready for use in the spring of 1990.

A. Required Planning

Planning is similar to the other photogrammetric processes for camera setup and light except that the photographs should overlap by 60% and not be too convergent so as to hide or significantly change the shading on subject from photo to photo.

B Data Processing

The photos are processed on the proprietary Helava DCCS. The operator identifies control points and other points of interest on the master photo; i.e., the first photo on which that point appears. These points are processed into a digital image patch by a precise monocomparator equipped with a solid-state area sensor used to digitize patches.

The points on the master photo are identified by the operator on subsequent photos, then automatically correlated to the master photos stereoscopically, by the digital image processing software, to perform the triangulation required for precise measurement. Once the integrated software performs the triangulation work, each point measured is identified as a set of x,y,z object coordinates.

C. Results Turn Around

Apart from taking the photographs, this analysis system consumes about one-quarter the time of other photogrammetric analysis systems due to the digital correlation performing 80 percent of the measurements and to reduce operator fatigue.

D. Equipment Description

In addition to the photogrammetric cameras, tripods, flashes, and film processing devices, this specialized, integrated system consists of a specially developed servo controlled precision x-y stage, a MicroVAX-II with a 71 Mbyte hard disk and a 95 Mbyte tape storage device, solid state video sensors, and video monitors.

E. Equipment Cost

About $150,000 for cameras, computer and the complete analysis package. The VAX is required and configured specifically for this system but can be shared for other limited operations.

F. Potential for Computer Integration

The system uses a computer for the analysis. Conversion of this computer output to a form directly usable by the builder should be relatively straightforward.

G. Site Preparation Requirements

Same as for other photogrammetric processes. (Henceforth "Same" for other items)

H. System Reliability

This system should be very reliable. Components are designed for a minimum of maintenance and reduced operator involvement, so it should be somewhat more reliable than the other photogrammetric processes.

I. Imposition upon Regular Shipyard Operations

Impositions are the same as for other photogrammetric processes.

2. DEGREE OF ACCURACY

The accuracy is based on the size of the stage and the size of item in the photograph. Defined accuracy is 0.002mm on a 254mm x 254mm stage. If the photo on the stage is a 10m x 10m area of a large assembly, the accuracy on measuring the assembly would be roughly 0.08mm.

3. SET UP TIME

Set up time should be somewhat less than for other processes because camera location need not be precisely controlled, just generally parallel.

4. MANNING REQUIREMENTS

One person could easily manage the full job from picture taking through analysis. Such a person would be well qualified in photography, digital image analysis, and shipbuilding quality control, thus a two person team would be more reasonable to span the the range of expertise necessary to constitute a viable operation.

5. FUTURE TRENDS

The use of digital cameras to feed digital images directly to the DCCS system is being investigated. This step would eliminate the need to expose, develop and manipulate photographs - all information would be stored electronically. This step could produce near real time results. A considerably different system is under development which uses stereo photos and analysis with digital correlation.

6. MARKETING INFORMATION

The Digital Comparator Correlator System was developed and is updated by Helava Associates, Inc., 21421 Hilltop St, Southfield MI. 48034. (313) 352-2640.

7. KNOWN LOCATIONS OF USE

Presently the system is used only in aerial mapping. Helava is a subsidiary of General Dynamics where classified but more advanced applications are being developed with the U.S. Army.

8. SUMMARY OF POTENTIAL APPLICATIONS

The system could be used in shipbuilding with some adaptations. It may not be able to distinguish between many similar features of repetitive steel surfaces or shapes, so the percentage of automatically correlated points would likely be reduced. The new system should be much better at industrial photogrammetry.

9. SOURCES OF INFORMATION

The same references as for the other photogrammetric methods apply in part in addition to literature from Helava Associates, Inc., 21421 Hilltop St, Southfield MI. 48034. (313) 352-2640, Richard Seymour and Dr. Uki Helava at General Dynamics (619) 592-5056

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for U.S. Shipbuilding

PHOTOGRAMMETRY - AUTOMATED ANALYSIS

1. TECHNOLOGY DESCRIPTION

The only system in this category is the STARS (Simultaneous Triangulation and Resection System) developed by Geodetic Services, Inc (GSI) of Melbourne, Florida. The method of photography is very similar to the standard convergent photogrammetry. Therefore, this description will dwell mainly on the specialties of STARS.

The key to STARS is the use of retroreflective targets, a powerful strobe flash on the camera to illuminate them, and automatic sighting and analysis of these bright targets on the resulting photos. GSI's AUTOSET -1 video - scanning automatic monocomparator scans each photo, determines the centroid of each target, and automatically measures the point.

A. Required Planning

Discrete points of interest must be manually targeted with the special retroreflective targets.

B. Data Processing

Described in the technology description.

C. Results Turn Around

Results are available in 2-3 hours for minor projects. A major project involving 1500 points, such as measuring the whole side of a ship, could be completed in about 12-14 hours as opposed to possibly two weeks for a manual monocomparator.

D. Equipment Description

Special CRC-1 close range photogrammetric camera with strobe flash, portable photo development lab, AUTOSET-1 monocomparator, IBM AT computer or equivalent, and GSI STARS software.

E. Equipment Cost

System cost is about $225,000 to $275,000 for a "turnkey" system.

F. Potential for Computer Integration

Current system uses computer to synthesize digitized information. The software package will put this information into a form readily usable by another system or produce offset tables in the measured object's coordinate system.

G. Site Preparation Requirements

Preparation is the same as for other convergent photogrammetry methods with the exception of using the special retroreflective targets.

H. System Reliability

Reliability appears to be excellent. Minimal periodic maintenance and cleaning on the cameras and compiler is required.

I. Imposition Upon Regular Shipyard Operations

Impositions are no different than for other convergent photogrammetry systems.

2. DEGREE OF ACCURACY

Accuracy of 1:200,000 is easily achieved.

3. SET UP TIME

About 1/2 day may be needed to set up control points and cameras and to shoot photos. Situations such as poor lighting, a large number of control or target points, or a large complicated object would increase this time unless a larger team were available.

4. MANNING REQUIREMENTS

A typical operation would use two persons, but the system is operable by one person. Many people may be needed to target a large object in a reasonable period of time.

5. FUTURE TRENDS

GSI is working to continuously update its software towards user friendliness.

6. MARKETING INFORMATION

Geodetic Services, Inc., 1511 South Riverview Drive, Melbourne, FL 32901 (305) 724-6831

7. KNOWN LOCATIONS OF USE

NASA antenna surveys, DC-8 engine nacelle cone, AVCO Aerostructures to measure a wing forming fixture.

8. SUMMARY OF POTENTIAL APPLICATIONS

The potential is generally the same as for other convergent photogrammetry methods. However, STARS may make a given project, previously thought of as too time consuming for photogrammetry, a viable photogrammetric measurement project.

9. SOURCES OF INFORMATION.

"Industrial Photogrammetry: New Developments and Recent Applications", GSI Technical Report 85-004, Clive S. Fraser and Duane C. Brown, (contains large related bibliography).

"A Large Format , Microprocessor Controlled Film Camera Optimized for Industrial Photogrammetry", Duane C. Brown, XV Congress of the International Society for Photogrammetry, Rio de Janeiro, 1984.

GSI Technical Bulletin on STARS Demonstration in April, 1987.

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SONIC DIGITIZING

1. TECHNOLOGY DESCRIPTION

Sonic Digitizing is a method of 3-D position indicating that works on the principal of analyzing the differences in time from a sound generated at the point of measurement to a grid of calibrated microphones. A spark emitting probe is manually positioned at the point of the object to be digitized. A spark is generated at the end of the probe. A precisely placed system of microphones mounted on a plane senses the sound of the spark and determines its position in 3-D space by comparing the differences in time for the signal to reach the microphones. The timed signal is processed to a digitized electrical signal and recorded in a file on the host computer. Post-processing of the raw signal establishes a data file of coordinates based on the measured object's coordinate system.

A 2-D system is available for digitizing drawings or similar flat plane items, and may be appropriate for flat parts cut from large panels.

A. Required Planning

The volume of search is presently device limited to 12 x 12 x 12 FT. The item to be digitized must be accessible to the operator to point the entire surface with the emitter probe. Up to 16 probes can be accommodated by one device, but for an industrial measurement project not involving dynamics, too many probes would be overkill. Each point on the measured item must be in a clear line of sight of at least three of the microphones. Areas larger than the present 12 FT cube limit could be done piecewise by moving the microphone array to overlapping locations.

B. Data Processing

The multiplexer unit converts the sound data to ASCII format for processing by computer. The basic software included with the system catalogues output and performs simple spatial calculations to give an xyz data file.

C. Results Turn Around

Results are available as soon as they are digitized. The full scale object measuring time depends more upon the skill of the operator(s) than the limitations of the instrument in a shipbuilding measurement project. The only time computer or software may be the source of delays would be in the case of real time measurement of moving objects with multiple emitters - not a likely situation in a shipyard.

D. Equipment Description

Sparking probes, receiver grid (4 speakers for 3-D, 2 speakers for 2-D), control unit, multiplexer, user provided computer

E. Equipment Cost

A full system, including customized computer software, is about $25,000. The hardware alone with basic start up software is $10,000.

F. Potential for Computer Integration

Excellent, already part of the system.

G. Site Preparation Requirements

The measurement site must be free from vibration to achieve reasonable accuracy. Welding in the immediate vicinity is likely to interfere with the system. Access to all points to be measured must be provided for the operator.

H. System Reliability

Appears to be excellent. Sparking sound emitters are simple, sturdy devices, inexpensive and simple to replace.

I. Imposition upon Regular Shipyard Operations

The main limitation is on welding. Arc strikes from welding emit similar sounds which interfere with the microphones. Development of variable frequency probes and microphones could probably avoid this problem. The system can not be used in an explosive environment.

2. <u>DEGREE OF ACCURACY</u>

+ or - .01 cm.

3. <u>SET UP TIME</u>

Depends on the size of the project. 5-10 minutes for a subassembly within the 12 FT cube range, longer to mount receivers on a scaffold or other portable device and calibrate the system.

4. <u>MANNING REQUIREMENTS</u>

1-3 persons could reasonably operate this system. System has the capability to receive up to 16 sparkers at one time, mainly for analyzing motion, but this would be too many for a shipyard, stationary measuring job.

5. <u>FUTURE TRENDS</u>

Development of the range beyond a 12 - 15 FT cube is technically feasible but not presently available.

6. <u>MARKETING INFORMATION</u>

Same as sources of information.

7. <u>KNOWN LOCATIONS OF USE</u>

3-D position modeling at Ford Motor, multiple emitter 3-D motion analysis at UMTRI Biosciences, independent control for robotics positioning, medical imaging.

8. <u>SUMMARY OF POTENTIAL APPLICATIONS</u>

Would be an inexpensive, quick, and accurate method to verify subassembly accuracy within the present 12 -15 FT cube volume range. Developments in range, possibly to 25 FT cube would make sonic digitizing more useful.

9. SOURCES OF INFORMATION .

1. Science Accessories Corp, 970 Kings Highway West, Southport, CT 06490

2. Science Accessories' GP-8-3D Operator's Manual.

3. Advanced Computer Consultants, Richard Hill, 3650 Larkwood Ct, Bloomfield Hills, MI 48013.

4. James Foulk and Hong-Wei Hsiao at University of Michigan Industrial and Operations Engineering Lab, Beal Ave, Ann Arbor, MI.

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INFRARED DIGITIZER

1. TECHNOLOGY DESCRIPTION

The infrared digitizer is similar in principal to the sonic digitizer in that a signal generated at the point to be measured is received by a device, set in a predetermined reference frame, to determine the position of the object. This Appendix describes the only system surveyed named OPTOTRAK, developed in Canada by Northern Digital.

The OPTOTRAK measurement system consists of up to 256 light emitting diodes as markers either attached to or made to contact the object at points to be measured. As the marker is activated it is sensed by at least two but up to 24 dual axis infrared position sensors, or cameras, which determine a line of sight to the marker. Sets of two dimensional coordinates are analyzed to give a three dimensional position for each of the markers. The system was developed primarily for motion analysis but should be adaptable to industrial measurement. It is presently limited to a 16 foot radius from the camera to the marker, but should be adaptable to larger scale projects without motion.

A. Required Planning

The system requires 120V power and must be isolated from other infrared light sources. Maximum cabling distances have the controller unit 100 feet from the cameras and the host computer 150 feet from the controller. The object must either be pretargeted with emitters or accessible to a technician to direct a probe to the object for contact measurement.

B. Data Processing

The systems are directly linked to a computer where data reduction is part of the package.

C. Results Turn Around

Results should be available nearly instantly for each point being measured. Overall results would depend on the method of targeting or the size of a project. Repeated measurements could be done instantaneously with sequenced activation of pretargeted emitters.

D. Equipment Description

The system consists of up to 256 light emitting diodes as markers, at least two but up to 24 dual axis infrared position sensors, or cameras, a system controller, each of which can control 6 cameras, and a host computer of the IBM PC type.

E. Equipment Cost

OPTOTRAK costs around $58,000 for a two camera system.

F. Potential for Computer Integration

Computer integration is an integral part of the system.

G. Site Preparation Requirements

Set up may be a bit cumbersome because of the leads to a targeted object. 120V power must be supplied to the host computer and the controller.

H. System Reliability

Reliability is unknown and seems to be controlled by the various wires to emitters, controllers and computer.

I. Imposition upon Regular Shipyard Operations

Interference on regular work is unknown.

2. DEGREE OF ACCURACY

Accuracy has been quoted as 0.025" at 16 feet..

3. SET UP TIME

Set up time is dependent on the need for pretargeting and system calibration. Discounting targeting time, set up should take around 15 minutes.

4. MANNING REQUIREMENTS

The OPTOTRAK system should be easily operated by one person after the cameras and markers are physically set.

5. FUTURE TRENDS

The system has just been developed so evolutionary trends are expected in increasing range and in developing unwired, remote activation emitters.

6. MARKETING INFORMATION

Northern Digital, Inc., 403 Albert St., Waterloo, Ontario, Canada, N2L 3V2.

7. KNOWN LOCATIONS OF USE

Most described uses have been in bio-engineering analyses. No known industrial measurement projects were identified.

8. SUMMARY OF POTENTIAL APPLICATIONS

The OPTOTRAK, with its currently limited range, may be appropriate for use in parts and small assembly measurement.

9. SOURCES OF INFORMATION

Informational literature provided by Northern Digital, Inc., 403 Albert St., Waterloo, Ontario, Canada, N2L 3V2 (800) 265-2741 Jerry Krist was the company representative with which the OPTOTRAK possibilities were discussed.

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THEODOLITES

1. TECHNOLOGY DESCRIPTION

Theodolites have been adapted from the field of surveying to be used as industrial measuring tools. The theodolite is a rugged but (at a minimum) accurate instrument for measuring horizontal and vertical angles (transits measure only horizontal angles). They are usually set up in pairs and referenced one to the other. Aimed simultaneously at a single target, the position of the target is determined by means of triangulation. The best modern systems for industrial measurement employ electronic theodolites tied into a computer with software to quickly compute the positions the instant both "guns" are set on the target. These systems are described in Appendices H and I.

A. Required Planning

The operator(s) must have reasonable visual access to the target along most of the surface being measured. Theodolites can be moved and reset to cover different parts of a difficult to cover target, but such a procedure increases measurement time. Items are usually targeted so that both theodolites are positively aimed at the same point. Movement of heavy machinery near the measurement site can upset theodolite calibration and should be minimized.

B. Data Processing

The difficulty of processing data can range from tedious and time consuming to very simple, depending on how advanced the system is. At a minimum, raw data should be reduced via computer using readily available software that includes error analysis of the theodolites being used. Good software can usually arrange the output in a form directly useable by a shipyard's main computer. The biggest problem with a manual system is visually reading the theodolite scale and verbally calling the readings to a third person who records them in writing then enters them into the computer, a tedious and error prone system. Electronic reading theodolites and good software can make this process a lot smoother.

C. Results Turn Around

The results availability from a theodolite system are totally dependent on the type of raw data processing used. Manual sighting of optical guns, hand recording of data, and manual reduction of data to coordinates (including error analysis) could take two full days for a medium (50 points) project. Reduction of data with computer linked electronic theodolites is instantaneous - the limiting time factor is the speed at which data is collected. A totally manual system is dependant on the skill of the operators and may take up to half a day for the same medium project.

D Equipment Description

Theodolites are instruments which measure horizontal and vertical angles to define a line of sight from the instrument through a magnifying telescope. They are usually mounted on a tripod and a tribrach for leveling. Simple machines have external micrometer type scales and, even if of high quality, are limited in their accuracy. Better instruments have lighted, enclosed and magnified optical scales which can be more accurate, the best of which virtually eliminate human error in reading the scales. The best and most accurate machines have electronic digital readouts which make reading much easier.

E. Equipment Cost

A relatively simple theodolite can be had for around $2,000, but accuracy is limited to about 20 seconds of arc. A good 1 second or better instrument can be about $6,000 and the best 0.5 arc second electronic reading theodolites run about $15,000.

F. Potential for Computer Integration

Manual systems are not directly computer integrated unless the various angular readings are read in by the operator and processed by purpose designed software. The more advanced systems described in Appendices H and I are fully computer integrated.

G. Site Preparation Requirements

The site should be isolated from heavy machinery movements. The object is usually targeted for easier point recognition. Lighting may be needed if the measurements are taken at night to avoid other work or normal passage of heavy machinery.

H. System Reliability

Reliability should be very good considering that theodolites are primarily designed for rugged surveying tasks.

I. Imposition upon Regular Shipyard Operations

Light work around a theodolite measuring operation can proceed but heavy work that may move the object or require the use of heavy machinery in the vicinity must be stopped or planned around.

2. DEGREE OF ACCURACY

The best 0.5 arc second theodolites could produce an accuracy on the object of about 0.001" at 40 FT. With most theodolites at the 1 second accuracy level, targeting, heat distortion, and manual sighting, an accuracy of around 0.005" is a better expectation and within requirements of the shipbuilding industry.

3. SET UP TIME

Set up may take two to three hours depending on the number of targets, lighting, and calibration of the theodolites to the object.

4. MANNING REQUIREMENTS

An efficient team for a theodolite measurement operation consists of two sighter/readers and one recorder. One person could conduct a measurement with a great deal more time.

5. FUTURE TRENDS

The future trends with manual systems are for more accurate instruments. The advanced systems in the following appendices are the future for these type systems.

6. MARKETING INFORMATION

Wild Leitz USA, Inc., 40 Technology Parkway South, Norcross, GA, 30092 (800) 367-9453.

K+E Electro Optical Products, Cubic Precision, 750 Huyler St., Teterboro, NJ., 07608 (201) 288-6000.

Pentax Instruments, 35 Inverness Drive East, Englewood, CO 80112. (303) 799-8000.

7. KNOWN LOCATIONS OF USE

No users of manual theodolite systems for industrial measurements were identified.

8. SUMMARY OF POTENTIAL APPLICATIONS

Potential shipyard uses of a manual theodolite system would be for checking dimensions of large assemblies and blocks, butts at the erection sight, layout of the building berth, setting of fixtures and jigs, and alignment and calibration of weapons systems.

9. SOURCES OF INFORMATION

Manufacturer's literature.

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THEODOLITES, COMPUTER LINKED, LASER ASSISTED

1. TECHNOLOGY DESCRIPTION

Theodolites have been adapted from the field of surveying to be used as industrial measuring tools. The basic theodolite systems are described in Appendix G. This Appendix describes the advantages offered by advanced theodolite systems which are directly linked to computers with full software packages designed specifically for industrial measurement. Only differences and advantages offered by the advanced systems over the standard systems will be described.

The systems surveyed for this Appendix are:

1. AIMS II (Analytical Industrial Measuring System) from the K+E Electro-Optical Products Division of Cubic Precision,

2. CAT 2000 (Coordinate Analyzing Theodolite) system from Wild Leitz, and

3. ECDS 2 (Electronic Coordinate Determination System) form Kern Swiss which is now part of the Wild Leitz group. This system is not actively marketed in the U.S. and is not covered in this report.

The key differences between the basic and the advanced theodolite systems is the direct linked to computers. This necessitates the use of at least two electronic reading theodolites which have both horizontal and vertical angles instantly read to the host computer when the desired point is sighted. Thus the possible human errors in optical scale reading and in data recording of a manual system are avoided. This also means that the data are fed directly to a system designed specifically for the industrial measuring task so that results can be instantaneous once the system is established in the object's coordinate system.

The systems are available with laser beam generators for targeting. This arrangement insures that both instruments are focused on the same object and eliminates the need to manually target the object.

Computer software designed specifically for the systems speeds the process of setting up the instruments, corrects measurements for instrument misalignment, have special routines to protect against power loss and incorrect readings, and many other advantages of a purpose built system.

A. Required Planning

Planning different from manual systems is that a power source must be provided to the computer. The theodolites alone can be run on batteries but the standard host computer needs power. An adaptation of the system, although limiting on site data information capacity, is to use a portable computer.

B. Data Processing

The systems are directly linked to a computer where data reduction is part of the package.

C. Results Turn Around

Results availability is purely a function of optical reading time and the number of points to be measured. It is conceivable that experienced operators could take a point every thirty seconds.

D. Equipment Description

The systems come complete with two electronic reading theodolites, a microcomputer interface, the computer, a printer, and the associated software. A laser eyepiece for targeting is available. An advanced version of the CAT system, MANCAT, will support up to eight simultaneously reading theodolites at one time an will be on the open market in the near future.

E. Equipment Cost

The current AIMS II costs $77,000 complete, with the most accurate 0.5 arc second theodolites. A similar CAT 2000 costs about $75,000. Both can be ordered with laser eyepieces for targeting, less accurate theodolites, or electronic distance meters.

F. Potential for Computer Integration

Computer integration is part of the system. Both systems have advanced software packages for performing a number of measuring tasks, setting up the theodolites, determination of geometric shapes from a few points, etc.

G. Site Preparation Requirements

Set up is no different than for a standard theodolite system except that 120V power must be supplied to the host computer. The system can be used with a portable computer to collect data then transfer it to the host computer for analysis.

H. System Reliability

Reliability should be as good or better than a standard theodolite system because there is less time spent on site so there is less exposure to potential damage.

I. Imposition upon Regular Shipyard Operations

Interference on regular work is less than for a standard theodolite system because of less on site time.

2. DEGREE OF ACCURACY

Accuracy is no different than for a standard theodolite system except that the reliability of the measurements should be better because there is less opportunity for operator error. Accuracy varies depending on distance from the target, accuracy of the instruments, and care of the operators. The AIMS system is available with less accurate theodolites for a related reduction in cost.

3. SET UP TIME

Set up time is less than for a standard theodolite system because of the direct computer tie and the software specifically designed for quick set up.

4. MANNING REQUIREMENTS

The CAT or AIMS systems could be operated by one person sighting both instruments and entering computer commands. Three persons are the optimal team.

5. FUTURE TRENDS

The evolutionary trends for these systems are for more accurate theodolites, more user friendly software, and software for special measurement tasks. The revolutionary trends are described in Appendix I where laser targeted motorized theodolites are described.

6. MARKETING INFORMATION

Wild Leitz USA, Inc., 40 Technology Parkway South, Norcross, GA, 30092 (800) 367-9453.

K+E Electro Optical Products, Cubic Precision, 750 Huyler St., Teterboro, NJ., 07608 (201) 288-6000.

7. KNOWN LOCATIONS OF USE

NASSCO has a Kern ECDS-2 system. Newport News also has a computer linked system. Similar systems are used by aircraft, auto, and telecommunications manufacturers for such exacting measurement tasks as fixture alignment, missile manufacturing, and robot calibration.

8. SUMMARY OF POTENTIAL APPLICATIONS

Potential shipyard uses of a computer linked theodolite system would be for checking dimensions of large assemblies and blocks, butts at the erection sight, layout of the building berth, and alignment and calibration of weapons systems.

9. SOURCES OF INFORMATION

Sources of information for the AIMS and CAT systems are from the vendor's literature which are attached to this report.

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THEODOLITES, MOTORIZED, LASER TARGETED

1. TECHNOLOGY DESCRIPTION

Theodolites have been adapted from the field of surveying to be used as industrial measuring tools. The basic theodolite systems are described in Appendix F. The advanced system of an electronic theodolite directly linked to a computer for instant analysis is described in Appendix G. This Appendix describes the most advanced theodolite system discovered, most likely to be named AUTOCAT. It has recently been developed as a joint effort between Wild Leitz, Norcross, Georgia and General Dynamics, Fort Worth, Texas. Another system developed by Kern Swiss called SPACE is in operation at General Motors but is not expected to be marketed in the U.S. now that Kern is part of Wild.

The AUTOCAT measurement system consists of at least two digital cameras mounted in electronic, motorized theodolites and directly linked to the host computer. A third electronic, motorized theodolite is a laser beam generator used for targeting and providing a third reference line. The system can be computer driven based on the table of offsets from the object, or operated by a joystick.

In either mode, the laser is directed at the point to be measured. The two digital cameras are also directed to the general position of the laser spot and a digital image of the laser spot is analyzed for its position relative to the true axis of the reading theodolites. The position of the point is now fixed in space.

The laser theodolite can be used as a third reference line but tends to make the system less accurate. The laser spot is actually a revolving circle of light seen at a right angle to a surface. At any other angle it appears as a revolving ellipse. The analysis of the image from the digital cameras can compute the centroid of the ellipse and give a better line of position than the pointing of the laser alone.

A. Required Planning

Planning different from manual or computer linked systems is that a power source must be provided to the computer. The theodolites alone can be run on batteries but the standard host computer needs power. Adaptation of the AUTOCAT system to use a portable computer is unlikely in the near future because of the number of processes controlled by the computer.

B. Data Processing

The systems are directly linked to a computer where data reduction is part of the package. The system can be driven from the objects table of offsets or from a previous measurement project of the same part.

C. Results Turn Around

Results should be available nearly instantly for each point being measured. Although no measuring time was given, it is conceivable that the AUTOCAT could take a point every five seconds driven by computer, and maintain this rate for a long period, without operator fatigue.

D. Equipment Description

The systems come complete with at least two motorized, electronic digital camera theodolites, one motorized, electronic laser theodolite, a mini-computer interface, the computer, a printer, and the associated software.

E. Equipment Cost

AUTOCAT is expected to cost around $330,000 when it comes on the market sometime in 1990.

F. Potential for Computer Integration

Computer integration is an integral part of the system.

G. Site Preparation Requirements

Set up is no different than for a standard theodolite system except that 120V power must be supplied to the host computer and the laser.

H. System Reliability

Reliability is an unknown quantity, but considering the quality of Wild's other instruments, should be very good.

I. Imposition upon Regular Shipyard Operations

Interference on regular work is less than for a standard theodolite system because of less on site time and no need for targeting.

2. DEGREE OF ACCURACY

Accuracy has been quoted as 0.001" with a variance of 0.0025"at 10 meters.

3. SET UP TIME

Set up time is less than for a standard or a computer linked theodolite system because of the direct computer tie, the software specifically designed for quick set up, and no need for targeting.

4. MANNING REQUIREMENTS

The AUTOCAT system should be easily operated by one person after the instruments are physically set.

5. FUTURE TRENDS

The system has just been developed with the best equipment available, so evolutionary trends in more accurate theodolites, more user friendly software, and software for special measurement tasks should be expected.

6. MARKETING INFORMATION

Wild Leitz USA, Inc., 40 Technology Parkway South, Norcross, GA, 30092 (800) 367-9453.

7. KNOWN LOCATIONS OF USE

General Dynamics, Fort Worth,Texas.

8. SUMMARY OF POTENTIAL APPLICATIONS

The AUTOCAT has the same potential as the AIMS or CAT systems where the need for repeated measurements of high quality without the need for targeting can justify the cost.

9. SOURCES OF INFORMATION

Sources of information for the AUTOCAT have been limited to conversations with Mr. Donald L. Michael, General Manager, Wild Industrial Measuring Systems contacted at the address above.

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COORDINATE MEASURING MACHINES

1. TECHNOLOGY DESCRIPTION

Coordinate Measuring Machines (CMM) are mechanical contact devices with mechanically actuated x,y,z axes for accurately measuring 3-D items. They are usually used for precise measurements of machined surfaces of relatively small parts. The largest machine surveyed could measure a part 6FT x 33FT x 10FT (x,y,z). The best machines are relatively slow but extremely accurate and sensitive. As such, they are not ideally suited to the shipyard environment of dust and vibration. Some manufacturers will "downgrade customize" their machines to the desired accuracy and the environmental conditions encountered.

A. Required Planning

CMMs should be set up at the end of an assembly area in a dedicated space. Moving and recalibrating large CMMs for measurements would limit productivity. Parts to be measured must be moved under the machine. Smaller CMMs may be appropriate for measuring small parts and could be moved to different stations for measuring.

B. Data Processing

Data processing depends on the sophistication of the machine. Older machines have direct reading mechanical position indicators, either in the form of dial indicators or vernier scales, while the newest machines have electronic readouts most of which are directly tied to a computer which can reduce raw data referenced to the desired coordinate system.

C. Results Turn Around

Data reduction times can be up to a day for a lot of points on a manual system or instantaneous on an automated, computerized system. A system large enough for steel structural parts, or any new systems, would likely be automated producing quick data.

D. Equipment Description

Only bridge type machines would have the size capacity for steel structural parts. A bridge machine has two long parallel column supported tracks as one horizontal axis which carries a cradle of one or two more horizontal tracks as the other horizontal axis. The vertical axis rides in the carriage on the second horizontal axis. Measurements are either read directly, fed to a digital readout or to a computer off scales attached to each axis.

E. Equipment Cost

Machine costs can vary from $5,000 to $300,000 depending on size, degree of automation, amount of computer control, and specialized sensing heads.

F. Potential for Computer Integration

A CMM of any practical use would have at least a digital x,y,z continuous readout, zeroed at any chosen point, and probably set to record selected coordinates which could be later be entered into a separate computer system. The best systems have coordinates directly read electronically into a computer for evaluation and further use.

G. Site Preparation Requirements

Site selection is relatively permanent for large CMMs and should be chosen to intersect process flow lanes where measurements are most needed. The site should be isolated from vibration, dust, dirt and sunlight and have a sturdy, stable foundation. Smaller machines are somewhat portable but no less in need of a relatively clean site.

H. System Reliability

Because of the large, heavy and mechanical nature of CMMs, reliability is highly dependent on the quality of the machine. The best machines can conduct numerous full range (end to end, top to bottom of their scale) measurements without degraded accuracy. They ride on air bearings and are much more accurate than necessary for shipbuilding.

I. Imposition upon Regular Shipyard Operations

An item must be moved under larger machines to be measured. Space must be dedicated for the machine, protection of the machine and for moving parts in and out of it must be provided. Smaller portable machines require the same care but not the dedicated space.

2. DEGREE OF ACCURACY

Measuring accuracy can be as little as 0.0001", depending on the size of the machine and the axis length. The Poli company could build a custom machine to meet the accuracy requirements set for this study of about 1/32", but this would be unreasonable to investigate considering other systems capable of doing the same job for less cost.

3. SET UP TIME

1 to 2 days may be required to set up a large CMM for the first measurement, a matter of minutes for subsequent measurements. Smaller portable CMMs could be set up in a few minutes with experience.

4. MANNING REQUIREMENTS

A part from personnel to move parts around, one technician can easily operate a machine.

5. FUTURE TRENDS

Larger, custom machines are possible at an increasingly (with size) related reduction in accuracy. The advances in the industry seem to be in the area of a slow but steady increase in accuracy with big strides in connecting the machines electronically into the manufacturing process.

6. MARKETING INFORMATION

Poli S.P.A., Oberdan, 5, 13019 Varallo Sesia, Vercelli, Italy represented in the U.S. by Bobier Tool Supply, Inc., G-4163 Corunna Road, Flint, MI 48532.

Mitutoyo Manufacturing Co., LTD., 33-7, Shiba 5-chome, Minato-ku, Tokyo, Japan with U.S. offices in Paramus, NJ., Detroit, MI., Chicago, IL., Dallas, TX., and Los Angeles, CA.

7. KNOWN LOCATIONS OF USE

No shipyard use locations were identified.

8. SUMMARY OF POTENTIAL APPLICATIONS

Checking sub-assemblies or assemblies, especially useful for checking dimensions where visual or direct line of sight systems can not be used, such as inside a rudder stock or a fabricated machinery foundation.

9. SOURCES OF INFORMATION

1. Bobier Tool Supply, Inc., G-4163 Corunna Road, Flint, MI 48532 (313) 732-4030

2. MTI Corp., 18 Essex Road, Paramus, NJ 07652 (210) 368-0525

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LASER SCANNER

1. TECHNOLOGY DESCRIPTION

The laser tracking system surveyed was the Kern Swiss (now with Wild Leitz) LTS-310. Little information was available aside from the two page description attached to this report, brief description produced from this literature and brief discussions with engineers is included in this Appendix. Further information should soon be available from Wild Leitz.

The LTS-310 was developed as a very accurate device for measuring moving objects. A special laser reflector is attached to the object at the point to be measured, then the system casts a scattered laser beam in the general direction of the reflector and detects the reflection to determine its position in space. The system was not developed for still industrial measurement, but should be adaptable.

A. Required Planning

System planning requirements seem to be as simple as targeting the object and fixing the position of the LTS-310 relative to the object before starting.

B. Data Processing

The system is directly linked to a computer where data reduction is part of the package.

C. Results Turn Around

Results should be available nearly instantly for each point being measured. The measuring time given is 500 samples per second for a single (presumed to be moving) target.

D. Equipment Description

The system is basically described as an angular encoder, a laser interferometer, a computer interface, the computer, and the associated software.

E. Equipment Cost

The price quoted was $135,000.

F. Potential for Computer Integration

Computer integration is an integral part of the system.

G. Site Preparation Requirements

Set up is no different than for a standard theodolite system except that 120V power must be supplied to the host computer and the laser.

H. System Reliability

Reliability is an unknown quantity, but considering the quality of Wild's other instruments, should be very good.

I. Imposition upon Regular Shipyard Operations

Interference with regular operations will depend on adaptation of the system for the measurement of many discrete stationary points. Limitations of the system are unknown.

2. DEGREE OF ACCURACY

Accuracy for stationary industrial measurement is unknown but should be acceptable.

3. SET UP TIME

Unknown.

4. MANNING REQUIREMENTS

The LTS-310 is easily operated by one person after the instrument is physically set.

5. FUTURE TRENDS

Unknown.

6. MARKETING INFORMATION

Wild Leitz USA, Inc., 40 Technology Parkway South, Norcross, GA, 30092 (800) 367-9453.

7. KNOWN LOCATIONS OF USE

Unknown.

8. SUMMARY OF POTENTIAL APPLICATIONS

This system's potential depends mainly on its adaptability to the measurement of many discrete stationary points.

9. SOURCES OF INFORMATION

Sources of information for the LTS-310 have been limited to conversations with Mr. Donald L. Michael, General Manager, Wild Industrial Measuring Systems contacted at the address in 6. above and the announcement attached.

Related Reference: "Range Imaging Sensors," General Motors Research Laboratories report GMR-6090, Paul J. Besl, March 8, 1988. Contains extensive bibliography.