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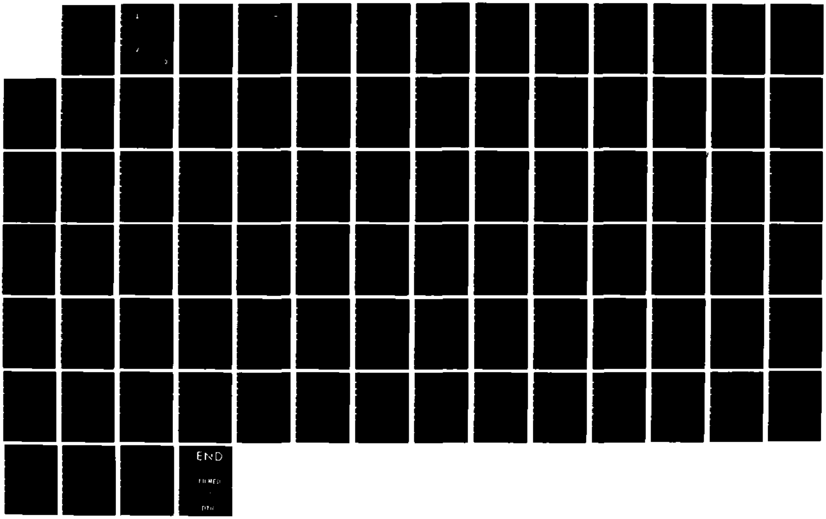

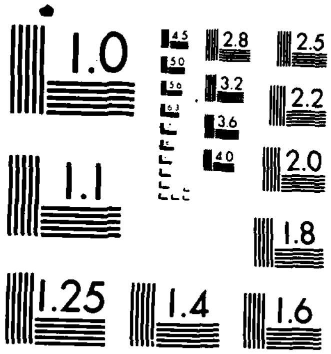

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TECHNICAL REPORT RL-CR-84-1

CONCEPTUAL DESIGN OF A ROBOTIC LOADER SYSTEM FOR REMOTE MISSILE LAUNCHERS

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report deals with the conceptual design of a robotic missile reloading system. This system will be the supply center for several unmanned, remotely controlled missile launchers. The supply center will contain robot equipment sufficient to handle the task of reloading the missile. The motivation for this is to accomplish the reloading in a minimum of time with a minimum of manpower. A review of the major robot configurations is given followed by several ideas for grippers and sensing procedures. A final conceptual design is presented after each of the systems components have been scrutinized. An extensive survey of

20. the state of technology in robotics and application of robotic equipment was conducted. The survey included technical literature as well as product literature obtained from robotics manufacturers.

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I. INTRODUCTION

This work is part of the design of a missile weapons system utilizing automation, robotic and computer control. The system involves a number of unmanned remotely controlled missile launcher vehicles. The missile launchers will be designed as anti-tank weapons that are fired from a remote control station. Also included in the system is a missile supply center. This report is concerned with the conceptual design of that center. It will provide the unmanned missile launchers and robotic system with missiles so that reloading can be accomplished with minimum time and manpower.

The missiles in question range in size from 40-90 inches long and from 4-7 inches in diameter. The weight of a single missile is 30-150 lbs, depending on which missile is chosen. Choosing a particular size missile should be software selectable with no hardware modification required to change sizes.

This design study also includes a robotic state-of-the-art survey to determine the applicability of existing equipment to the task. A literature search was conducted in two parts. First, an extensive search into the technical literature on robots and applications of robots was conducted. The search also included information on sensors and sensing for use in our application.

This search was conducted in the University of Alabama libraries. Additionally, there were two computer aided literature searches. The first was conducted through the University libraries, searching such data bases as NTIS and COMPENDEX. The second computer aided search was done through the U. S. Army information services at Redstone Arsenal.

Secondly, robot manufacturers were contacted for information on the equipment that they manufacture. Information was solicited on the individual systems, including capacities and specifications. This will be referred to as the product literature search.

This report is broken down into several parts. Design constraints for the problem are reviewed followed by the characteristics of several of the component pieces of equipment. Once these have been discussed in detail, a composite design is suggested. Then, results of the literature searches are given, with the report ending on conclusions and references.

II. DESIGN CONCEPT

The first step in any design study is to define the problem in as much detail as possible along with a list of constraints. With recent advances in computer control in mind, we now have the ability to utilize machines in the performance of dangerous and time consuming combat support duties. Specifically in this case, automating the process of reloading missiles into missile launchers is the primary goal.

A. Design Constraints

There are several design constraints that must be met for the concept to work properly. The two major areas are discussed here.

1. Manipulator Constraints

The reloading itself will be performed by a robotic manipulator which is mounted on a truck or a tracked vehicle. The manipulator should have the capability to reach approximately 4-6 feet beyond the edge of the truck. It must also be able to lift 200-250 pounds, including the end effector or gripper. An end effector is a device which in this case fits on the end of the manipulator, grasps the missile, and inserts it into the launch tube.

2. Vehicle Constraints

The next question is on what type of vehicle to mount the manipulator. The price of a single missile being what it is suggests that keeping a large stockpile on one vehicle is tantamount to "putting all your eggs in one basket." Therefore, the supply center itself must be resupplied frequently. The logical answer to this is to have one vehicle devoted to the task of shuttling missiles from a well protected, behind-the-lines stockpile to the battlefield supply center. A second vehicle would have the robotic manipulator and robotic support equipment mounted on the back. With the weight of standard equipment being in the range of 4 to 5 thousand pounds, a heavy duty vehicle will be required.

Lastly, manpower should be reduced as much as possible, if not eliminated completely. This would hopefully speed up the process and would surely reduce the risk to operators.

B. Equipment Characteristics

We will now discuss the characteristics of the individual pieces of equipment. Discussed will be the manipulator, vehicle, end effectors (grippers), and several different sensing methods.

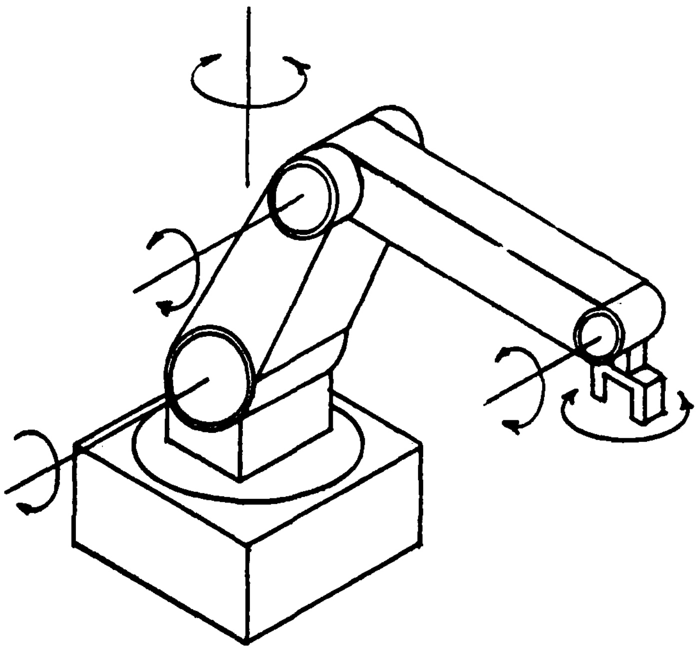


Figure 1. Revolute robot.

1. Manipulator Characteristics

Several types of commercial robot configurations are available today. The three most common fall into the following categories: revolute (articulating) robots, Cartesian coordinate robots, and spherical coordinate robots. Sketches of these three types of robots are shown in Figures 1, 2, and 3, respectively. The revolute robot is one which simulates the human arm and its motion. Cartesian coordinate robots operate in three dimensional (X,Y,Z) where spherical coordinate robots work in the three dimensional space measured in spherical coordinates. Each of the three has several advantages and disadvantages.

The articulating robot is sometimes referred to as a revolute robot because all motion is caused by rotation in each of the joints. This type is the most maneuverable in general, but it tends to have the most errors in repeatability. Some of the largest models have lifting capacities of 200-250 pounds with acceptable repeatability. These are available with either hydraulic or electrical power drives.

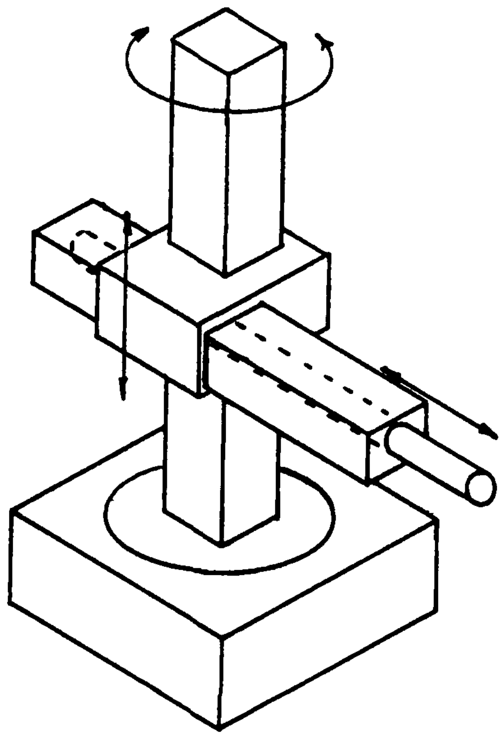


Figure 2. Cylindrical coordinate robot.

The next type to be discussed is the Cartesian coordinate robot. A close "cousin" to it is the cylindrical coordinate robot. These two are very similar and will be reviewed together. They are maneuverable enough to handle most tasks, but they are somewhat bulky by nature. Lifting capacities of these are basically unlimited, but in our case, the size of the robot is a definite restriction. They do, however, have much better repeatability, which is a plus. These are also available in hydraulic or electrical models.

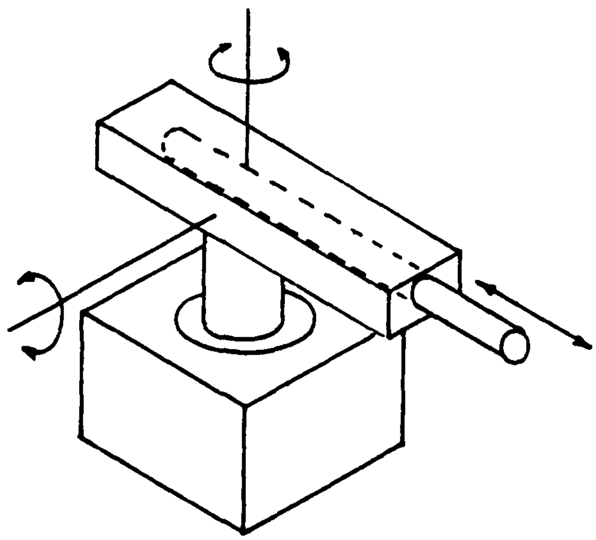


Figure 3. Spherical coordinate robot.

Lastly, the spherical coordinate robots are also good candidates for this task. Their maneuverability is similar to the cylindrical coordinate models, but they are more compact. Their low profile design makes them more acceptable for mobile applications. Since they do have rotating axes that must carry heavy loads, they are restricted to lifting capacities of 300-400 pounds. This is still quite adequate for out needs. Even at these loads, the repeatability is very good. Most models are hydraulically powered.

2. Vehicle Characteristics

There is a good deal of motivation to use standard military vehicles in this application. Going on the assumption that the loading vehicle will be "dug in," high off road mobility will not be treated as a primary constraint. Since this is the principal advantage of tracked vehicles, we will now devote our attention to some form of truck or "Jeep." The primary "workhorse" of the Army for many years has been the "deuce and a half", a 2½ ton truck.[1] They are readily available and have the capacity to handle the robotic equipment. They are also mobile enough to be able to traverse reasonable terrains.

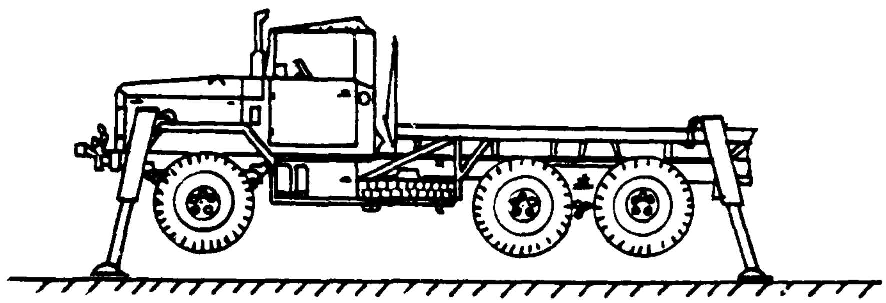


Figure 4. Loading truck with stabilizers.

The shuttle vehicle need not be as large as the loading vehicle which has to carry the heavy manipulator. If the number of missiles is limited to around 20, the shuttle should be able to handle between 1000 and 2000 pounds. The new HMMWV vehicle, now in production from AM General, is perfect for the job. Of course this is only an example.[2]

When loads of around 250 pounds are extended out 8-10 feet, there is a good deal of leverage. This would tend to tip the truck to one side or another causing numerous problems. In order to place the missiles in the launch tubes, the truck should be on as rigid a platform as possible. One simple solution would be to place "legs" on the vehicle similar to the ones in Figure 4. These would function like the supports on the back of a backhoe or a power company truck that has an elevated bucket attached. Four legs would provide the necessary stability.

3. End Effectors

An end effector, or gripper, is a device which, in this case, will hold the missile and insert it into the launch tubes.[3] Gripping the missile is no problem, there have been commercial grippers available for a long time for grasping cylinders. The difficult job is inserting the missile into the tube. Also, the end effector must be adaptable to a range of different sized missiles, and should be as gentle as possible on the missile.

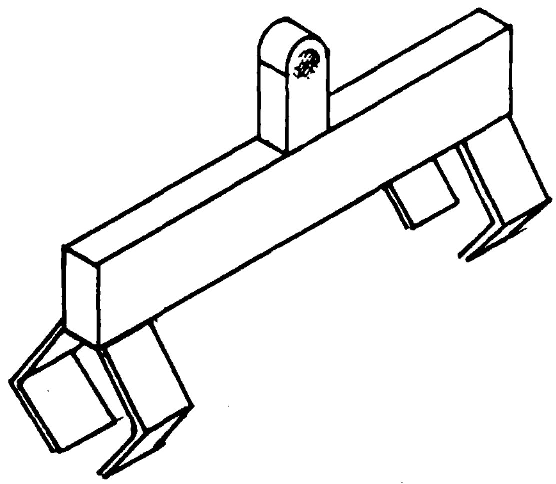


Figure 5. End effector with hard "hands".

Some hydraulic rams are available that could perform the task, but they are somewhat crude and heavy. Since a heavy end effector would reduce the maximum missile load, these are eliminated from futher consideration. Of the designs that can grasp cylinders, two of the more promising will now be discussed.

The first is a design that consists of two or three sets of "hands" evenly spaced on a rigid member about one-third the length of an average missile. Having the member about one-third the length of the missile should provide the necessary stability in transporting the missile from the supply truck to the missile launcher. Each "hand" is a set of opposing V-shaped sections. For speed and a sure grip, pneumatic power is used to open and close the gripper.[3] The loading process is begun by grasping the missile in a central location on the missile to prevent any eccentricity in the load. Once the missile has been aligned with the missile launching tube, the front end of the missile is inserted into the tube. The grippers then close again, and the missile is inserted further into the tube. This process is repeated until only a stub is left outside the tube. The effector now releases completely and is withdrawn. Using the rubber butt plate on the front of the effector, the missile is pressed flush with the edge of the launch tube, thus completing the reloading process.

The second configuration is similar to the first in overall design. Instead of using hard "hands" which could damage the missile if it were not centered in the gripper, the second design uses a clever device which provides soft support for the missile. It consists of polyurethane

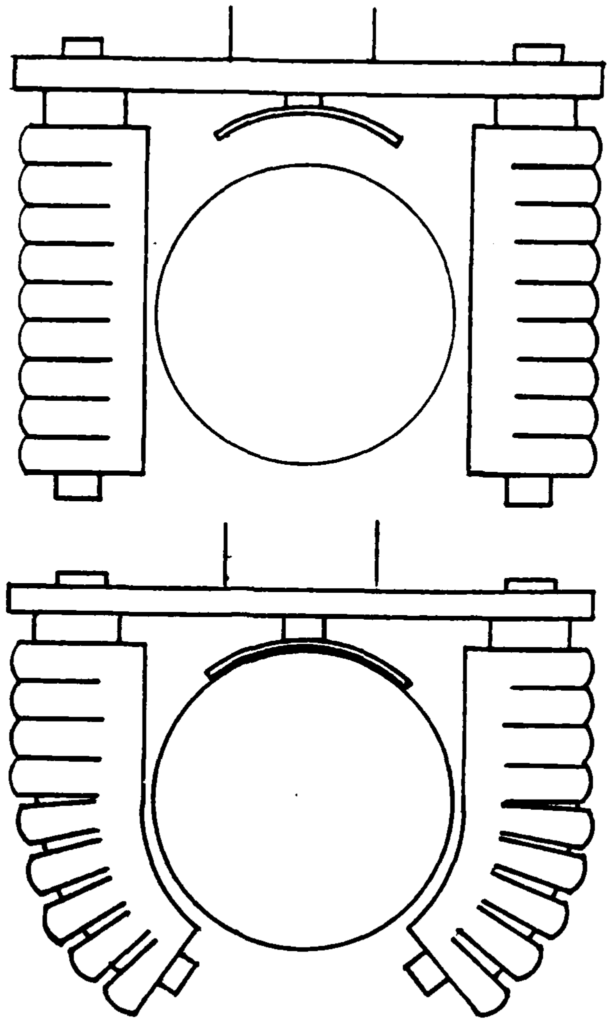


Figure 6a. Pneumatic fingers.

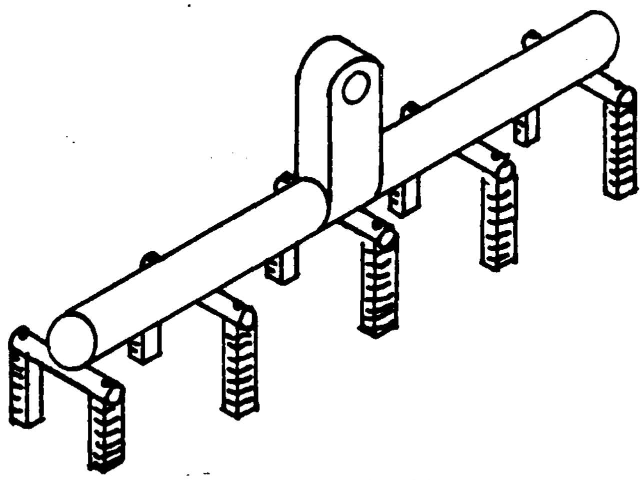


Figure 6b. End effector with pneumatic fingers.

bellows which, when inflated, bend toward the missile grasping it firmly. Each gripper can hold about 20 pounds, when the bellows are inflated to around 80 psi[4]. If there was an arrangement of five or six bellows along a member, this would support most of the missiles that we are concentrating on. Sketches of the bellows and the effector using these are shown in figures 6a. and 6b.

This design would be adaptable to all of the size missiles in question. It would also have the advantage of not damaging the missile should misalignment occur.

The loading process would be almost identical to the process for the hard "hands." The one difference would be that the step size would be reduced for maximum effectiveness.

4. Missile Dispensing

Missiles are now packaged individually in cardboard cartons to protect them in shipping. The packaging presents a problem for the automatic loading process. Current manipulators usually have one end effector which is designed for a special task. The end effectors discussed earlier are no exception. They are simply not capable of removing the missile from the carton. One solution to this is to have the missiles placed in a protective missile dispenser mounted on the back of the shuttling supply truck. The missiles would be removed from the cartons at the behind-the-lines supply center and placed in the dispenser.

Another advantage to the dispenser is reloading speed. The missiles could be presented to the manipulator at the appropriate time. The size of the carousel would depend on the number of missiles to be shuttled at one time. Ten to twenty missiles could easily be carried at one time. This would, however, be the upper limit for the HMMWV's weight carrying abilities. Two types of dispensers will now be introduced, a missile carousel and a missile conveyor.

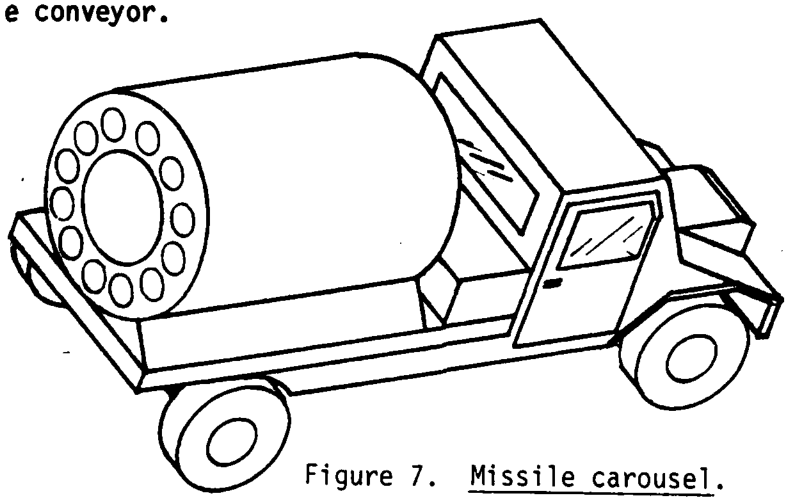


Figure 7. Missile carousel.

a. Missile Carousel

One type of dispenser would be a rotating missile carousel, similar to the one shown in Figure 7. A missile would be held in the carousel until the manipulator was ready for it. Then the carousel would be indexed to a position so that the missile in question would be close to the robot.

The carousel could be mounted vertically or horizontally with similar performance. Considering the choices we have made concerning the manipulator and end effector, the most likely choice is the horizontal mounting. The missiles could be removed from the top or the side. If they are removed from the side, the manipulator would not have to reach as far, thus reducing error.

The missiles would be held in place by spring loaded brackets that should be able to hold the range of missiles described above. The tension in the spring would be sufficient to hold the missile in transport. When the missile is grasped and pulled, the springs will release it. Another safety feature in transport will be a protective shroud around the carousel, preventing the missiles from falling out. An opening in the side of the carousel will allow access to the missiles. The missiles themselves will be indexed to the side position when the manipulator is ready for a new one. The indexing can be accomplished by having an electric motor drive the carousel.

b. Missile Conveyor

With the high price of a single missile in mind, it is unthinkable to keep a large number of missiles in one location. If we limit the number of missiles to a maximum of 10 or 12, another very good dispenser comes to mind. This is a type of rubber conveyor belt with separate, distinct slots for holding missiles. A sketch of this conveyor is shown in Figure 8a. with a sketch of the shuttle truck shown in Figure 8b.

The missiles would be held into the slots by a spring loaded rail. This rail would be locked down in transport to prevent the missiles from bouncing around. The rail is also Teflon coated to minimize friction. When the manipultor is ready for a missile, an electric motor causes the belt to move. As the belt moves, a missile is released into a tray on the end of the truck. The manipulator can now remove the missile from the tray.

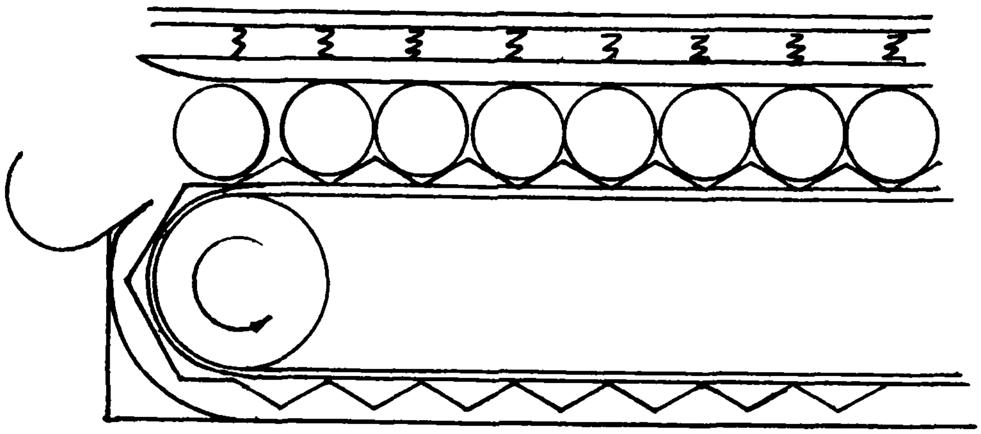


Figure 8a. Conveyor dispenser.

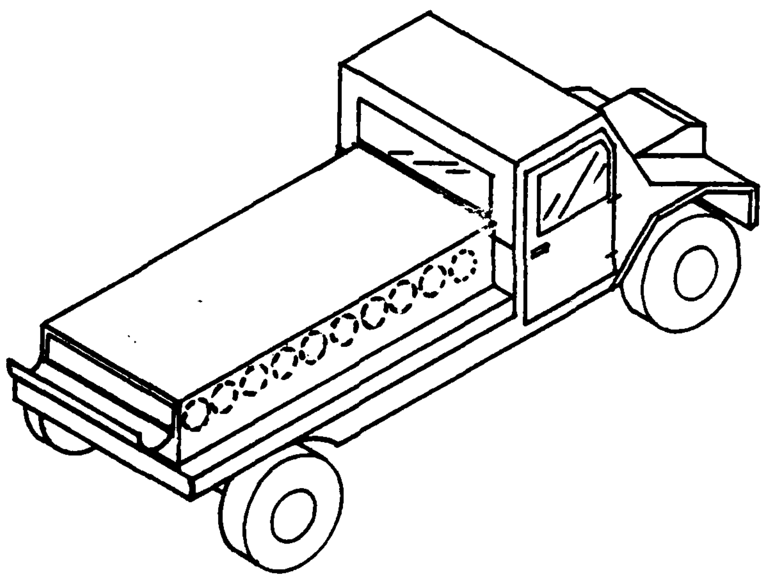


Figure 8b. Missile dispenser (conveyor).

5. Positioning

In real life situation, we cannot assume the trucks and launchers will be placed in well defined locations. This would reduce the flexibility of the system, making it undesirable. In order to get around this problem, a good method of measuring the position of the component vehicles is necessary. This task will be broken up into two parts. First, a general approximation within a couple of inches will be made, then pinpoint the exact location of the launching tubes.

a. General Proximity Sensing

There are several methods for determining the general proximity of the supply truck and the launcher. The most promising is the method of triangulation.[5] If three points on either of the target vehicles can be located, then its location and orientation in space is known. A sketch of this can be seen in Figure 9. Electro-magnetic radiators will be used as beacons at these three points. Using sensitive directional antennas, the location of the beacons is found by triangulation. For this process to work, two antennas are required to be mounted on the loading truck. They should be separated as much as possible for maximum sensitivity.[5] The current technology in directional antennas is improving, but it is still not perfected. A point in space can be located within an inch or two, but this is not good enough as far as robots is concerned. A substantial risk to the missile is taken if it is inserted at a skewed angle. For this reason, this technique is very good for locating the vehicles with a couple of inches, but not for inserting missiles. Another technique for inserting the missiles will be discussed in the next section. With the flexibility in the gripping system, the missiles can, however, be removed from the dispenser without damage under this method. This will save valuable time in locating the missiles.

In discussing the triangulation technique, reference to figure 10 will be made.

Triangulation

- In addition to the absolute coordinate system, a local coordinate system will be placed at each of the directional antennas. The location of each of the local coordinate systems is known in terms of the absolute coordinates.

- The beacon is turned on.

- A direction vector from each of the antennas is calculated. These are denoted as R_1 and R_2.

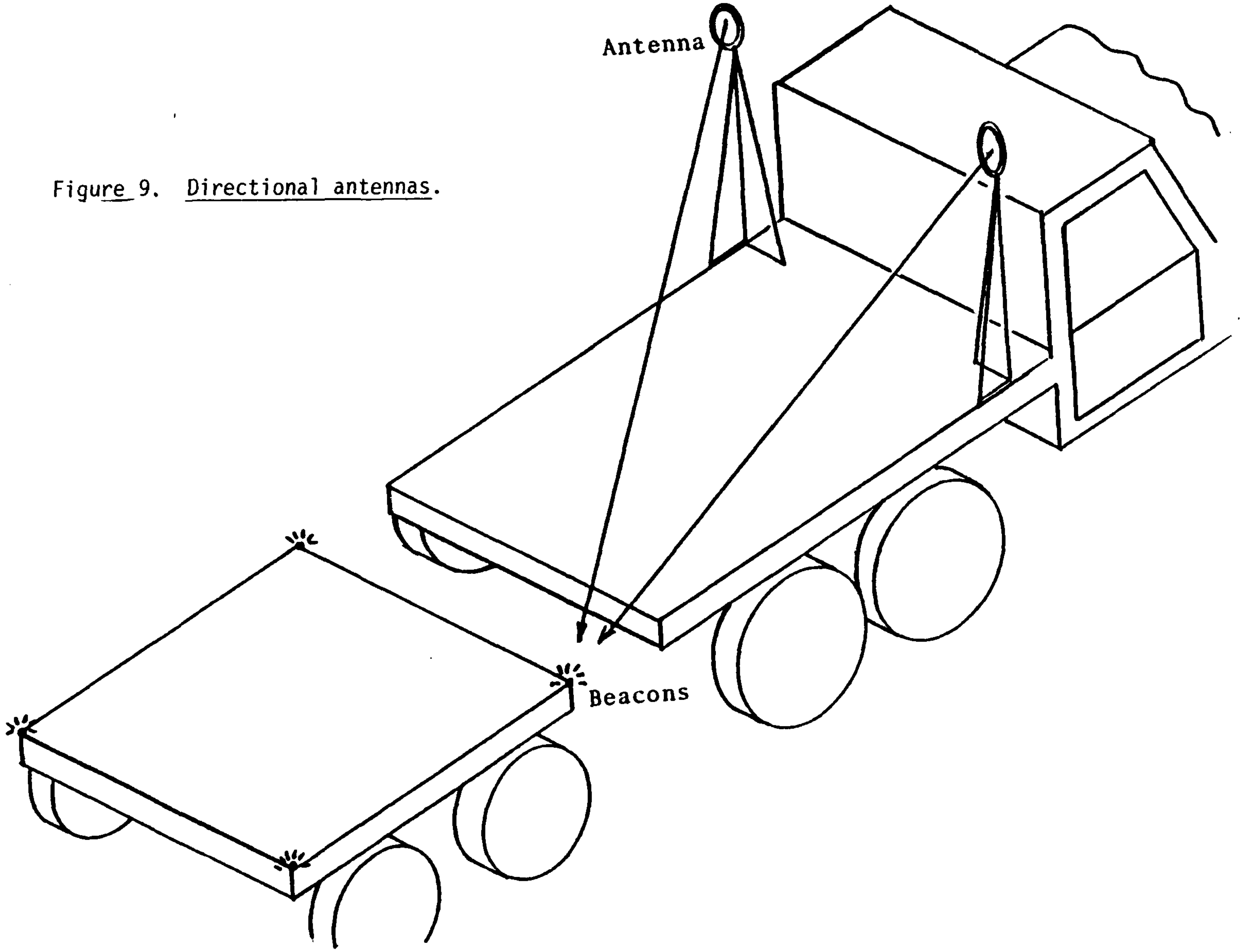


Figure 9. Directional antennas.

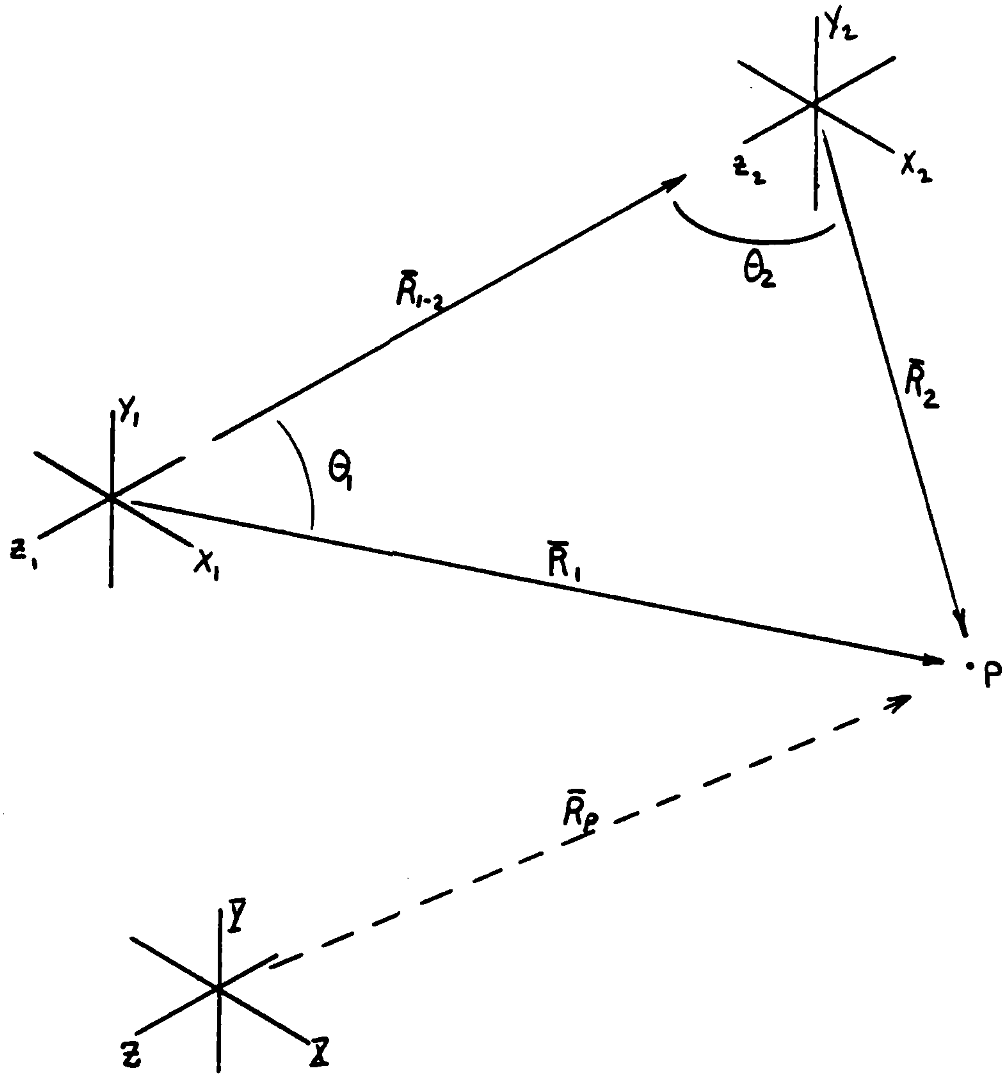


Figure 10. Triangulation.

- Take the dot product of the direction of R_{1-2} and R_2 to obtain the cosine of (180-   ) degrees. Take the dot product of R_{1-2} and R_1 to find the cosine of

  .

- Once these angles are known, we can find the length of vectors 1 and 2 by simple trigonometry.

- The position vector for the point P is now known, (i.e. the position in space).

- Repeat the process for the other two beacons to locate the orientation and location of the target vehicles in space.

- Since the location of the launching tubers is known relative to the beacons, the manipulator knows where the tubes are located.

b. Fine Positioning

Several elaborate methods for sensing three dimensional shapes have arisen in the past few years. The three major types are laser scanning, ultrasonic scanning, and vision systems.[6] Laser scanning is performed by dividing the laser beam into an array of separate beams. The beams illuminate the surface in question and the image is transmitted back to a receiver. This is also referred to as structured light. The pattern returned is very useful in determining the edge of the object. If the edges are detected, a well defined pattern can be produced. This pattern is compared to a reference shape to determine if it is what it should be. The only drawback to this system is the fragile nature of lasers. This will be the preferred method with the introduction of rugged lasers.

Ultrasonics work very well in a dense medium (e.g. water). Ultrasonic signals are severely attenuated in air with 1 db/m being readily observed.[6] This makes application in the field very susceptable to error. Ultrasonics are used with success in naval applications as well as internal medicine. Both of these are in dense media though. The application used here is over several feet, effectively eliminating ultrasonics as a possible candidate system.

The last system is a "passive" vision system. Passive means that the vision system used ambient light to illuminate the target. Digital cameras use a rectangular array of light sensitive diodes to form an image. The light passes through a system of lenses identical to standard film cameras, then impinges on the diode array. In the first digital cameras, the diodes were either on or off, depending on the intensity of light. Later models have the ability to assign a "gray scale" to each diode. Gray scale is just a range of light intensities that the intensity of the element falls into. This produces very good "black and white" images. Knowledgable people in this field believe that color sensitive diodes are just around the corner.

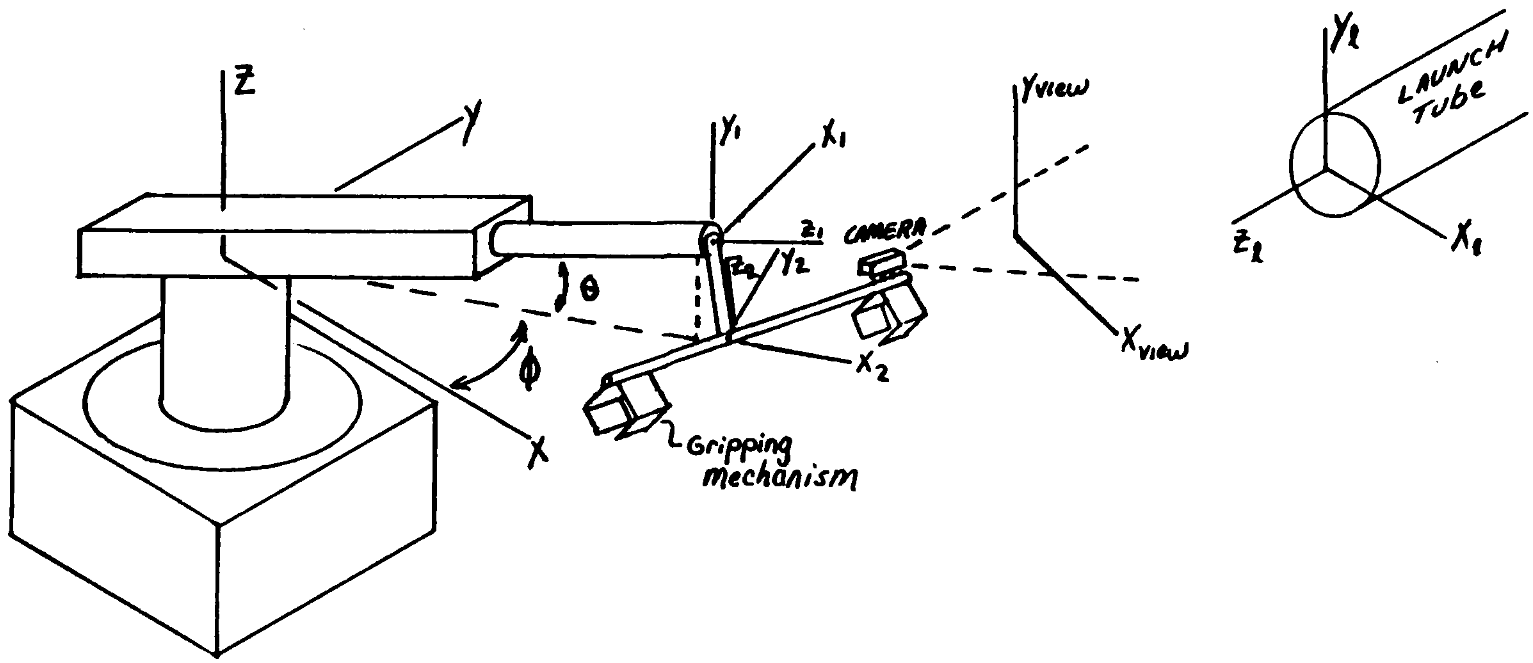


Figure 11. Fine positioning.

The system that is proposed in this report is a form of passive vision systems. Today several manufacturers make very rugged solid-state digital cameras.[7] The camera will be mounted on the end effector, above the end closest to the launcher. A sketch of the proposed system is shown in Figure 11 with the relative coordinate systems for each joint included in the sketch. The triangulation techniques can position the end effector approximately 2 feet away from the launcher with an error of only 1 to 2 inches. The field of view of the camera is restricted to an area that is slightly larger than the launch tube opening.

If the camera were aligned with the tube axis, it would see a circle of radius R. At a reference distance away from the opening X_0, the circle would appear to have a radius R_0, the circle would appear to have a radius R_0. We can use this relationship to determine the distance away from the tube opening that the camera is located. The distance X away from the tube opening can be found by knowing the image size, then using similar triangles which yields the relation:

$$X=(R_0X_0)/R$$

Now comes the problem of misalignment. Viewing the circle from a skewed angle makes the circle appear to be an ellipse. It can show that the cosine of the skewing angle is equal to the ratio of the minor axis to the major axis. One snag in this is the fact that the cosine of a positive angle is the same as the cosine of the negative of the same angle. This problem will be tackled later in the report.

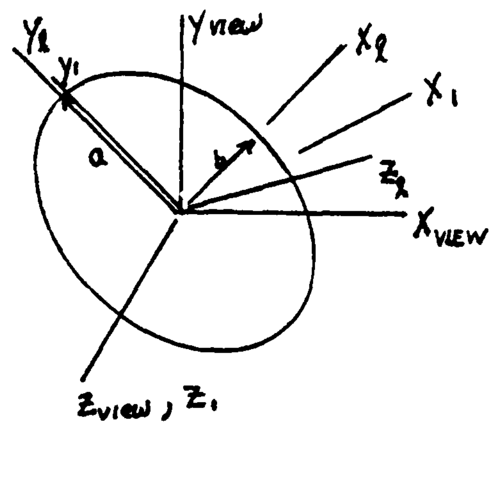


Figure 12. Skewed circle.

If the camera is positioned below and to one side of the opening, an ellipse will still be seen, but it will appear to be tilted to one side similar to the image in figure 12. The image is actually a projection of the circle onto the X-Y viewing plane of the camera. This plane and its orientation in the absolute coordinate system are also shown in figure 10. Using these images, the end effector can be positioned very accurately. This will be referred to as ellipse positioning in this report.

When the image of the circle is projected on the viewing plane, the ellipse will be seen. The first step now is to locate the centroid of the image. There are many computer routines for doing this efficiently. Then the point on the image that is the farthest away from the centroid will be found. This direction is the direction of the major axis, and this distance will be referred to as distance A. The distance A is also equal to the radius of the circular image that is sought. From the relation:

$$X=(A_0 X_0)/A$$

that distance X from the camera to the tube opening is known.

The next step is to center the image in the viewing plane. To do this, the end effector must be aimed at the tube opening. This is accomplished by rotating the wrist joints. The angle that is needed in rotating the end effector toward the opening can be found by knowing the distance from the center of the viewing surface to the centroid of the image, and the distance X.

An ellipse is still seen, but it is centered in the viewing surface which makes computations easier. Viewing transformations from one coordinate system to another involve matrix algebra. Using Figure 11 to illustrate the ideas suggested, the transformations will now be given.

First, it is necessary to go from the viewing coordinate system to the X_1, Y_1, and Z_1 coordinate system. This is performed by a rotation about the Z_1 axis. In matrix form:

$$\begin{bmatrix} x_1 \\ y_1 \\ z_1 \end{bmatrix} = \begin{bmatrix} \cos\phi_2 & \sin\phi_2 & 0 \\ -\sin\phi_2 & \cos\phi_2 & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x_V \\ y_V \\ z_V \end{bmatrix}$$

Next, a transformation from this coordinate system to the launcher coordinate system is required. This is performed by a rotation about the Y_1 axis. In matrix form:

$$\begin{bmatrix} x_\ell \\ y_\ell \\ z_\ell \end{bmatrix} = \begin{bmatrix} \cos\theta & 0 & -\sin\theta \\ 0 & 1 & 0 \\ \sin\theta & 0 & \cos\theta \end{bmatrix} \begin{bmatrix} x_1 \\ y_1 \\ z_1 \end{bmatrix}$$

Now that the coordinates in the launcher coordinate system are know, the next move can be planned. Referring back to Figure 10, repositioning from the present position to the position in launcher coordinates given by (0,0,R), where R is the desired distance away from the tube opening. The position of the launch tube in absolute coordinates can be obtained by making coordinate transformations from the launcher coordinates to the viewing coordinates, then to the first, then second joint coordinate system, then finally back to the robot base. Once it is known where the positions are and it is known where to go in absolute coordinates, then the moves can be made.

The only remaining problem is the ambiguity in the sign of the angles. To solve this problem a trail move, must be made. If the ellipse becomes more of an ellipse, the move was in the wrong direction. Then it must be simply moved back. If the ellipse tends to become a circle, the move will be continued until the circle is obtained. Since the camera is mounted above the missile axis, an ellipse should be seen with a small vertical eccentricity which can be calibrated for a given system.

C. Composite Design

A composite design is exactly what the names implies, a composite of the separate designs. The sketch in Figure 13 shows the final design.

A two vehicle approach is chosen so that frequent resupply of the loading center can take place. This eliminates the need to have a large stockpile of missiles in a hostile environment. The loading vehicle chosen would be a 2 1/2 ton truck. This size is necessary due to the heavy loads of robotic equipment. The shuttle or supply vehicle on the other hand can be smaller.

A good candidate for the shuttle vehicle is the new HMMWV (or Hummer) manufactured by AM General. The HMMWV has sufficient load carrying capabilities to handle the missile dispenser.[1] This is a high mobility vehicle and should have no trouble shuttling missiles.

Of the three major robot configurations, the spherical coordinate robot is chosen because of its low profile design.

The pneumatic "fingers" are selected for the gripping task. They provide the soft touch necessary when handling sophisticated missiles. When grouped together, the fingers have the required strength.

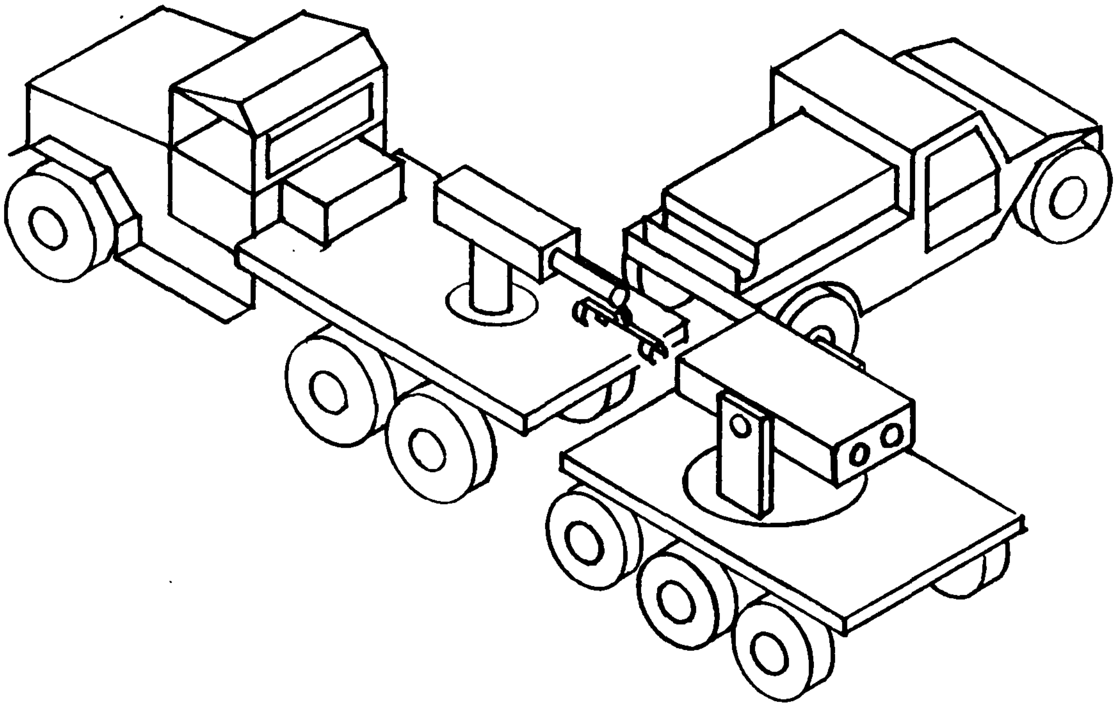
The slotted rubber conveyor dispenser has several advantages over the carousel. It is simpler in design with much less "dead space". It also has a low profile which makes the shuttle touch more stable. For these reasons, it is chosen to be the missile dispenser for the system.

Proximity sensing will be conducted in two stages. A rough estimate of the position of the target vehicles is determined from a triangulation technique. Using electromagnetic radiators as beacons on the target vehicle, its position can be determined from information generated by the directional antenna. The second stage, fine positioning, is accomplished with a digital camera using ellipse positioning.

The fine positioning must be performed for each missile loaded in order to have a "sure fit" each time. Efficient computer algorithms are available that can handle the fine positioning in a minimum of time. This makes repositioning feasible after each reload.

Although the crew can be reduced to one man, it is not feasible to have an unmanned loading center due to the complexity of arming guided missiles.

Figure 13. Composite design.



III. LITERATURE SEARCH

The Literature search was conducted in two phases, including technical and product literature. Technical literature was sought using library facilities, while product literature was obtained from the manufacturing companies themselves. In the sections below, each of the two phases is described in detail.

A. Technical Literature Search

The search conducted attempted to uncover information on several areas of robotic application. It began with an examination of literature written on automatic missile reloading and related topics. As expected, the articles written on this subject were few and far between. Then literature on all types of projectile loading was explored. Once it was seen that these areas were not going to be very productive, attention was turned to robots and application of robotic equipment.

There has been much literature published on this subject. It was broken down into six main categories; applications, robot and manipulator arms, grippers and end effectors, sensors, tactile sensors, and vision sensors. The articles found are located in appendices (A.1-A.6), corresponding to the six major topics.

The search was conducted in The University of Alabama engineering and science libraries along with two outside computer-aided searches. The first computer-aided search was conducted from The University of Alabama through DIALOG Information Services, a subsidiary of the Lockheed Corporation. The first DIALOG data base explored was NTIS (National Technical Information Services, U.S. Dept. of Commerce), which contains over 833,500 citations on government sponsored research, development, and engineering. The second DIALOG data base searched was COMPENDEX (Engineering Index, Inc), which contains over 935,700 citations from approximately 3,500 journals, conference proceedings, and publications of the engineering societies.

A second computer-aided literature search was conducted through the Defense Technical Information Services (DTIC) at Redstone Arsenal, Alabama. The results of this search and the two DIALOG searches have been classified into one of the six categories. These are found in Appendix A.

B. Product Literature Search

Approximately 98 companies were contacted concerning robotic equipment that they manufacture. About one-third of these only manufacture parts and accessories and were eliminated from further consideration. About one-half of the remaining were systems integrators and manufacture no equipment of their own. Several of the companies manufacture welding robots that could be altered to perform material handling tasks.

Of the companies that responded to our request for information, a list has been compiled of the ones that manufacture equipment that could be used without modification. These have been tabulated in Appendix B.1 according to company name, address, robot name, and specifications for each robot.

Also, a list of company names and addresses is given in Appendix B.2 of companies that do not quite meet the specifications outlined, but that are respected robotic manufacturers. Companies are constantly upgrading their equipment, so these companies could introduce heavier equipment at a later date.

Lastly, a list of the systems integrators is given in Appendix B.3. These companies have engineering staffs that can design turnkey systems for most needs. Although they do not produce their own equipment, they are very skilled in putting the pieces of robotic puzzles together.

For the reasons of load carrying ability, compactness, and repeatability, the two configurations that show the most promise are the spherical coordinate robots and and revolute robots. Two of the more respected companies in this area are the Unimation Corporation and Cincinnati Milacron, Incorporated. They each have been in this field a ling time and have proven to be leaders in spherical and revolute robots, respectively.

IV. CONCLUSIONS

One of the major problems in the military is the shortage of trained personnel to handle sophisticiated systems. There are two solutions: Train more personnel or reduce the number of soldiers necessary to operate certain equipment. This report has attempted to offer ideas for reducing crews on missile reloading tasks.

Robotic reloaders are not only possible, they would be very practical. Manpower could be held to a minimum, while at the same time, minimizing reloading time. If manpower and reloading time can be reduced at the time, then more efficient use of the resources is utilized. Also, these resources can be diverted to some other task.

A brief review of the conceptual design summarizes the dual vehicle system chosen.

One vehicle, referred to as the loading vehicle, contains the robot and the robot support equipment. The triangulation equipment is also located on this truck. The second vehicle, referred to as the supply or shuttle vehicle, carries the missiles to the loading truck from the warehouse. A missile dispenser will be mounted on the shuttle vehicle to speed up the reloading process.

Of the three major types of robots, the spherical coordinate robot is chosen on the basis of its low profile and its load carrying abilities.

Proximity sensing is broken up into two stages. The first stage is a rough approximation using triangulation. The second stage is fine positioning using the ellipse technique. Using this two-stage method, the exact location of the missile launching tubes can be pinpointed.

After each missile is loaded, fine positioning must be repeated if flawless insertion of the missiles is to occur. This is because of shifting weights.

It is desirable to reduce manpower as much as possible. Due to the complexity of arming guided missiles, one operator will still be needed to perform these duties.

In closing, robotic reloading of missile can speed up the process as well as reduce valuable manpower. Since this is a new area of robotic application, it is difficult to say just how well it will work. Further research in this area, with attention given to detail, will yield more specific information.

REFERENCES

1. Janes's Military Vehicles and Ground Support Equipment 1982, Third Edition.

2. Managing Modernization Green Book 1982-83, Vol. 2, No. 10, Published by the Association of the U. S. Army, October, 1982.

3. Wayne L. Podell, Terminal Devices for Missile Reloading by Manipulators, NASA Report No. RL-TN-69-5, November, 1969.

4. Air Technical Industries product literature, 1983.

5. Larry M. Leiner, "An Analysis and Comparison of Energy Direction Finding Systems," IEEE Transactions on Aerospace and Electronic Systems, Vol. AES-15, No. 6, November 1979.

6. GEO-Centers, Inc., A Review of Three-Dimensional Vision for Robotics, Sponsored by Defensed Advanced Researc Projects Agency (DoD), May 1982.

7. J. G. van den Hanenberg and J. Vredenbregt, "An Experimental Assembly Robot," Philips Technical Review, Vol. 40, No. 2/3, 1982.

APPENDIX A

TECHNICAL LITERATURE

A. Robotic Applications

1. Industrial Robots Present State of Development, August 1982. This Held at OMNI International Hotel, Norfolk, Virginia on 24-26 August 1982. Volume I", AD-A124 400.

   In the past ten years the Directorate for Ammunition Equipment (D/AE) has been beneficial in either increasing the productivity or safety of a particular process.

2. Material Flow Characteristics in Aerospace Production. Volume V. Kelly, K. L.; Hendry, R., Research Triangle Inst., Research Triangle Park, N.C., Intrim Technical rept. No. 5, 1 Sep-30 Nov 1979, December 1979.

   This report covers the work performed in the second quarter of Phase II of the MFC project. A description and status report are provided for the work being conducted on a survey of state-of-the-art hardware and software in material handling and storage systems.

3. ICAM Robotics Application Guide (RAG). Toepperwein, Lindon L.; Blackson, Mark T.; Fukui, Ron; Park, William T.; Pollard, Brian, General Dynamics Corp., Fort Worth, TX, Fort Worth Div., Final rept. Sep 1978-March 1980, April 1980.

   The Robotics Application Guide provides an introduction to the basic concepts and techniques pertaining to the use of robotics technology for manufacturing and industrial application.

4. R&D Plan for Army Applications of AI/Robotics. Brown, David R.; Fowler Darrell V.; Introne, Joan C., SRI Intrnational, Menlo Park, Calif., May 1982.

   One hundred applications of artificial-intelligence technology and robotics in Army combat and combat support that may be possible and worthwhile are identified.

5. Bomb Rack Conceptual Study and Proposal. Bollinger, William; Mawhinney, William, Naval Air Development Center, Warminster, PA, Air Vehicle Technology Dept., June 1974.

   This report presents a program and cost estimates for the development of a new suspension and release mechanism.

6. A Feasibildity Study for Remote Manipulators. Petty, Jon; Lunger, Robert G., Picatinny Arsenal, Dover, N.J., June 1970.

A study has been conducted by the U.S. Army Explosive Ordnance Disposal (EOD) Center to determine the feasibility of using remote arms (manipulators) to perform limited operations on small munitions from behind a blast/fragmentation shield.

7. Concept Development and Feasibility Study of an Automatic Loader-Rammer for an Armored Self-Propelled 155mm Howitzer. Weithoff, Roger H., FMC Corp., Minneapolis, Minn., Northern Ordnance Div., December 1966.

The design is described of an automatic loader-rammer for a self-propelled 155mm howitzer. The main assembly, which contains three projectiles, is mounted on the left side of the gun and is pivoted about an extension of the gun cradle trunnion.

8. Commercial Handling Equipment Survey for Equipment With Possible Application to Missile System Launcher. Dunstone, D. E., Army Missile Command, Redstone Arsenal, Ala., Ground Support Equipment Lab., August 1969.

The report summarizes the information received from manufacturers during an investigation of commercial materials handling equipment having possible application to rapid reloaders for army missile system launchers.

9. Teleoperators and Human Augmentation. Corliss, William R.,; Johnson, Edwin G., An AEC-NASA Technology Survey, December 1967.

10. Missile Reloading By Manipulators. Podell, Wayne L., Army Missile Command, Redstone Arsenal, Ala., Ground Support Equipment Lab., Apr 1969.

This report is a study of the reloading of missiles by sophisticated manipulators. Three concepts for a large hypothetical missile and two for a smalller missile are presented.

11. Space Applications of Automation, Robotics and Machine Intelligence Systems (ARAMIS). Volume 1: Executive Summary, Final Report. Miller, Rene H.; Minsky, Marvin L.; Smith, David B. S., N82-34127*# Massachusetts Inst. of Tech., Cambridge, Space Systems Lab, NASA-CR-162079, August 1982.

Potential applications of automation, robotics, and machine intelligence system (ARAMIS) to space activities, and to their related ground support functions are explored. The specific tasks which will be required by future space projects are identified. ARAMIS options which are candidates for those space project tasks and the relative merits of these options are defined and evaluated.

12. Space Applications of Automation, Robotics and Machine Intelligence Systems (ARAMIS). Volume 3: ARAMIS Overview. Miller, Rene H.; Minsky, Marvin L.; Smith, David B. S., N82-34128*# Massachusetts Inst. of Tech., Cambridge, Space Systems Lab., August 1982.

An overview of automation robotics, and machine intelligence systems (ARAMIS) is provided. Man machine interfaces, classifications, and capabilities are considered.

13. Evaluation of Automated Decisionmaking Methodologies and Development of an Integrated Robotic System Simulation. Volume 1: Study Results. Lowrie, James W.; Fermelia, Alfred J.; Haley, Dennis C.; Gremban, Keith D.; VanBallen, Jeff; Walsh, Richard, W., N82-34129*# Martin Marietta Aerospace, Denver, Colo, September, 1982.

A variety of artifical intelligence techniques which could be used with regard to NASA space applications and robotics were evaluated. The techniques studied were decision free manipulators, problem solvers, rule based systems, logic programming languages, representation languages, and expert systems.

14. Evaluation of Automated Decisionmaking Methodologies and Development of an Integrated Robotic System Simulation, Volume 2, Part 1. Appendix A: Software Documentation. Lowrie, James W.; Fermelia, Alfred J.; Haley, Dennis C.; Gramban, Keith D.; VanBallen, Jeff; Walsh, Richard W., N82-34130*# Martin Marietta Aerospace, Denver, Colo., September 1982.

Documentation of the preliminary software developed as a framework for a generalized integrated robotic system simulation is presented. The program structure is composed of three major functions controlled by a program executive. The three major functions are: System definition, analysis tools, and post processing.

15. Evaluation of Automated Decisionmaking Methodologies and Development of an Integrated Robotic System Simulation. Volume 2, Appendixes B, C, D and E. Lowrie, James W.; Fermelia, Alfred J.; Haley, Dennis C.; Gremban, Keith D.; VanBallen, Jeff; Walsh, Richard W., N82-34131*# Martin Marietta Aerospace, Denver, Colo., September 1982.

The derivation of the equations is presented, the rate control algorithm described, and simulation methodologies summarized. A set of dynamics equations that can be used recursively to calculate forces and torques acting at the joints of an n link manipulator given the manipulator joint rates are derived.

16. Survey of the State-of-the-Art in Robotics and Artificial Intelligence. Volume 1: Executive Summary. Berger, Gerard; Havas, Robert; Prajoux, Roland, Paris ESA, August 1981, Prepared in cooperation with Laas, Toulouse, 3 Vol., N82-33974# Engins Matra, Velizy (France).

Trends and techniques in robotics and artificial intelligence were surveyed in order to assess their space applicability and to identify areas which can be developed/adapted to European space programs. Increases in mission which these techniques produce are discussed.

17. Survey of the State-of-the-Art in Robotics and Artificial Intelligence. Volume 2: Technical Report. Berger, Gerard; Havas, Robert; Prajoux, Roland, Paris ESA, August 1981, Prepared in cooperation with Laas, Toulouse, Vol., N82-33075# Engins Matra, Velizy (France).

Trends and techniques in robotics and artifcial intelligence were surveyed in order to assess their space applicability and to identify areas which can be developed/adapted to European space programs. Increases in mission efficency which these techniques produce are discussed.

18. Survey of the State-of-the-Art in Robotics and Artificial Intelligence. Volume 3: Appendices and Bibliography. Berger, Gerard; Havas, Robert; Prajoux, Roland, Paris ESA, August 1981, Prepared in cooperation with Laas, Toulouse, 3 Vol., N82-33076# Engins Matra, Velizy (France).

A subject index, annotated bibliography (over 300 items), and glossary for ESA report 'Survey of the state of the art in robotics and artificial intelligence' are presented.

19. An Investigation of Speed and Accuracy in Positioning Missile Handling Vehicles. Randall, R. Bradley; Spier, Wayne L., Human Engineering Labs., Aberdeen Proving Grounds, Md., Septemer 1968.

The purpose of this study was to determine how fast and accurately a simulated misssile-reloading vehicle could be parked next to a simulated launcher. Both track-laying vehicle and trucks were tested at night and by daylight on four types of terrain.

B. Robot and Manipulator Arms

20. The Kinematics of Manipulators Under Computer Contro. Peiper, Donald Lee, Standford Univ., Calif., Dept. of Computer Science, October 1968.

The kinematics of manipulators is studied. A model is presented which allows for the systematic description of new and existing manipulators. Six degree-of-freedom manipulators are studied.

21. Automatic Planning of Manipulator Transfer Movements. Lozano-Perez, Tomas, Massachusetts Inst. of Tech., Cambridge. Artificial Intelligence Lab., December 1980.

22. Experimental Assembly Robot. van den Hanenberg, J. G.; Vredenbrest, J., Philips Res. Lab., Eindhoven, Neth., Philips Tech. Rev. v 40 n 2/3, 1982.

This robot, called EPAAS (for 'Experimental Programmable Adaptive Assembly System') has meanwhile developed into a second-generation robot and further additions will be made to turn it into a robot of the third generation. The arm mechanism possesses five degrees of freedom, and in its kinematic design it resembles a human arm. The fingers of the gripper are equipped with force sensors; to avoid collisions, the arm is fitted with proximity detectors; the gripper possesses 'vision' in the form of a semiconductor camera that moves with the arm.

23. Adaptive Control of a Robotic Manipulator. Lewis, Richard A., JPL, Pasadena, Calif., Proc. IEEE Conf. Decis. Control Incl. Symp. Adapt. Processes, 16th, and a Spec Symp. on Fuzzy Set Theory and Appl, New Orleans, LA, December 1977. Published by IEEE (77Ch1269-OCS), New York, NY 1977.

24. Kinematic Design of Articulated Robot Arm. Murata, H. Memoirs, Faculty Engineering, Kobe University, March 1976.

The arm can handle a light payload with considerable dexterity. Arm lengths are determined through optimization of the area of the region to be covered by the robot hand, and mechanizal dexterity can be represented by service angles.

25. Advance of the New MA23 Force Reflecting Manipulator System. Vertur, J. and others. Paper No. 11, RoManSy 76 Conf., Warsaw, Poland, 14-17 September 1976.

Brief description of the different arms developed for nuclear remote manipulation, undersea work, second generation industrial robots and manipulators for handicapped persons, ranging from 5 kg to 20 kg mass capacity are given as well as some performance data.

26. An Assembly Experiment Using Programmable Robot Arms. Dunne, M.J. (Unimation Inc., USA) (In, Proc. 7th International Symp. Industrial Robots, Tokyo, Japan, 19-21 October 1977, organized by Japan Industrial Robot Association.

Describes the design and operation of the Unimate 6000. The arm is of revolute design, emulating the human arm in having pivotal waist, shoulder, and elbow joints, while the forearm can twist, bend and swivel.

27. RMS Massless Arm Dynamics Capability in the SVDS. Flanders, H.A., Houston, Lockheed Electronics Co. Systems and services Division, June 1977.

Describes the computerized simulation of equations of motion for manipulator arms for use in remote handling in space. Particular applications include space shuttle orbiters.

28. Algorithms for Kinematic Control of Articulated Robot Arm. Muratta, H. Memoirs, Faculty Engineering, Kobe University, March 1977.

Developed for realtime control of the robot arm fitted with redundant degrees of freedom of motion, the algorithm utilized a consideration of kinematics rather than dynamics thus simplifying the resultant equation.

29. The prototype Wrist Joint Assembly TACPAW (Triple Axis Common Pivot Arm Wrist) Phase 2. Kersten, L., Nebraska University, Lincoln College of Engineering & Tech. November 1978.

Describes in detail the manipulator system and its associated servomechanisms. The overall picture of man-machine systems, pivots, remote handling and robots is also discussed.

30. Motional Behavior and Automatic Control of Elastic Robot Structures. Truckenbrodt, A. (TU Munich, West Germany). (In Proc. 8th International Symp. Industrial Robots, Stuttgart 30 May-1 June 1978, 2 Vols.) Bedford, UK, IFS (Publications) Ltd., 1978.

One of the major problems involved in the design of industrial robots is that a high accuracy of the robot motions is render difficult by the deformation of the robot arms. An increased rate of motion produces vibrations in the arms.

31. Industrial Robots With Step-Motors. Morecki, A. and others (Technical Univ. Warsaw & Polish Acad. Sci.). (in, Proc. 8th International Symp. Industrial Robots, Stuttgart, 30 May-1 June, 1978, 2 Vols.). Bedford, UK, IFS (Publications) Ltd., 1978.

Describes a model of an industrial robot with 6 degrees of freedom. It is demonstrated that low-power step motors can be satisfactorily used in driving a robot operating under small loading conditions.

32. Algorithm for Computing the Working Area of the Planar Articulated Robot Arm. Murata, H. and Hashimoto, M. Mem Fac. Engineering, Kobe University, March 1979.

Presents the microcomputer-oriented algorithm which computes the working area of the planar articulated robot arm when its initial position, arm lengths and paths of the joints are given.

33. APAS: Solving the Batch Assembly Problems. Potts, D., Machine Product Engineering, 7 November 1979.

The APAS incorporates seven manipulator arms in all. These had to be specially developed for the system as a state-of-the-art review identified a lack of highspeed, low cost arms with high repeatability.

34. A New Concept in Robot Wrist Flexibility. Stockhouse, T. (Cincinnati Milacron, Inc., USA). (In, Proc. 9th International Symp. Industrial Robots, Washington, DC, March 1979, sponsored by Society of Manufacturing Engineers and Robot Institute of America). Dearborn, Mich., Society Manufacturing Engineers, 1979.

Describes a 3-degree of freedom wrist design in a compact package which is very small for its payload. Applications include the aerospace industry, arc welding and paint spraying.

35. The Remote Axis Admittance--A Key to Robot Assembly. Watson, P. C. (Assembly Associates, USA), SME Paper No. MS79-798, Dearborn, Society Manufacturing Engineers, 1979.

The Remote Axis Admittance (RAA) is a new device to perform the fine motion of parts mating. It can be mounted on the end of robot arm, and will perform the final phases of assembly when the parts are in close proximity and when they are in contact.

36. Dynamic Design Parameters for Robot Arms: Experimental Results. Burchkhardt, C. W. and Gerelle, E. G. R. (Ecole Polytech. Federale de Lausanne, Switzerland). (In, Proc. 10th International Symp. Industrial Robots/5th International Conf. Industrial Robot Technology, 5-7 March, 1980, Milan, Italy, organized by IFS (Conferences) Ltd., Bedford, UK, IFS (Publications) Ltd., 1980.

Presents a theory of gross and fine motion figures of merit or quality factors which are related to the torque density and stiffness density of the arm articulations and can be used in creating a robot to required specifications.

37. A Three Roll Wrist Robot. Frank, M. (Cincinnati Milacron Inc., USA) SME Paper No. MS 80-699 (1980). Dearborn, Society Manufacturing Engineers, 1980.

This wrist has 3 degrees of freedom, all coincident at one point, and is relatively small for its payload. A new robot arm employs this wrist, and as a result, the robot has among other merits, an extremely large working volume, even when significant reorientation of the tool or part is required.

38. Selective Compliance Assembly Robot Arm. Makino, H. and Furuya, N. (Yamanashi University, Japan). (In, Proc. 1st International Conference Assembly Automation, Brighton, UK, 25-27 March 1980 sponsored by IFS (Conferences) Ltd., Bedford, UK, IFS (Publications Ltd., 1980.

A new type assembly robot called 'SCARA' (Selective Compliance Assembly Robot Arm) has been developed and is described. The robot has two jointed link arms swinging about the parallel vertical axes and a tool at the front of the second link.

C. Grippers and End Effectors

39. Terminal Devices for Missile Reloading by Manipulator. Podell, Wayne., Army Missile Command, Redstone Arsenal, Ala., Ground Support Equipment Lab., November 1969.

A terminal device, which may also be called an end effector or 'hand,' is the physical boundary between the manipulator and its task. This is a study of existing terminal devices and how they are used.

40. Adaptive Control of Robot Hand Equipped with Pneumatic Proximity Sensors. Hanafusa, H.; Asada, H., (Kyoto Univ., Japan). (Proc. of Conf. on Industrial Robot Technology, 3rd, and International Symp. on Ind. Robots, 6th) University of Nottingham, England, March 1976. Published by Int. Fluid Serv. Ltd., Kempston, Bedford, Engl. Pap. D4.

41. Industrial Robot Grippers. Lundstrom, G. (Fluid Tech Lab, FFA, Sweden), Industrial Robot, December 1973.

Sketches and photographs are presented of the following robot grippers: (a) grippers with stiff fingers; (b) grippers with springy of flexible fingers; (c) vacuum grippers; (d) magnetic grippers; (e) grippers with sensors and (f) tool carrying, oscillating and moulded grippers.

42. Adaptive Grasping Operation of an Industrial Robot. Ueda, M. and Iwata K. (Nagoya University, Japan). Proc 3rd International Symposium on Industrial Robots, Zurich, Switzerland, 29-31 May 1973.

Describes a method of how to detect the grasping force and how to design the fingers capable of controlling the grasping force. Details are also given on the open loop control system for holding up and transferring an object with a necessary minimum force.

43. Jaw-Type Gripper Mechanisms. Konstantinov, M. S. (Central Lab. for Robots & Manipulator, Bulgaria). Proceeding 5th International Symposium Industrial Robots sponsored by SME, IITRI & RIA, 22-24 September 1975, Dearborn, Society Manufacturing Engineers, 1975.

A lot of peripheral equipment, including gripper mechanisms, must be changed when the shape of the workpiece classification and industrial robot grippers classification will enable the robot designer to establish a firm basis for optimal adaptation of jawtype grippers to parts and to groups of similar workpieces.

44. Approach and Plan: Most Suitable Control of Grasping in Industrial Robot. Sakai, I.; Kumatzawa, T.; Veda, M. (Nagoya University, Japan) and Shingu, H. (Aichi Institute of Technology, Japan). Proc. 5th International Symposium Industrial Robots sponsored by SME, IITRI &

RIA, (22-24 September 1975). Dearborn, Society Manufacturing Engineers, 1975.

Non-linearity between the necessary grasping force and the weight has been found. So the grasping force must be decided not proportionally to the weight by surface condition. The system was developed to get the optimum grasping force.

45. Designing a Multiple Prehension Manipulator. Skinner, F. (Innomation Inc., USA) Mechanical Engineering September 1975.

Fingers which rotate into positions for the various gripping modes and which simplify the design of the mechanical hands for robots and remotely controlled manipulator are described by the author.

46. Multiple Prehension Hands For Assembly Robots. Skinner F. (Innomation Inc., USA) Proc. 5th ISIR, sponsored by SME, IITRI & RIA (22-24 September 1974). Dearborn, Society Manufacturing Engineers, 1975.

An industrial robot can only be as versatile as its gripping mechanisms. When robots are used for programmable automatic assembly, the hand must be able to grip and relocate many different objects. Either quick changing fixed prehension hands or multiple prehension hands are necessary.

47. A New Method of Designing Grippers. Lundstrom, G. (Aeronautical Research Institute of Sweden, Sweden). Proc. 3rd Conference Industrial Robot Technology/6th International Symposium Industrial Robots, Paper F3, Nottingham University (March 1976). Bedford, UK, IFS (Publications) Ltd., 1976.

To design a universal gripper that can grasp and handle more than a limited number of components and also suit available industrial robots and work places poses a very difficult problem. One possible solution is to utilize well planned moulding techniques in combination with polymer materials to produce functional grippers which can be made for a variety of entirely different components.

48. Construction and Design Parameters of a Mechanical Gripper for Automatic Industrial Manipulators. Przegl, Mech., May 1977.

An analysis is made of the parameters of mechanical grippers, with seven V-class kinematic couples. The dependence of the function resistance of the gripper position is determined. An estimate is made of the gripping force as a function of the weight of the manipulated object and the friction coefficient.

49. Description and Control of the State of a Robot. Gerelle, E. G. R. (Inst. Microtech. de I'Ecole Polytechn. Federale, Lausanne, Switzeraland). (In Proc. 7th International Symp. Industsrial Robots,

Tokyo, Japan, 19-21 October 1977, organized by Japan Industrial Robot Association). Tokyo, JIRA, 1977.

There are two essentially different descriptions of the state of a robot, an external one which represents the various articulations of the arm. To each internal state there corresponds a unique external one.

50. Stable Prehension by a Robot Hand With Elastic Figures. Hanafusa, H. and Asada, H. (Kyoto Univ., Japan). (In, Proc. 7th International Symp. Industrial Robots, Tokyo, Japan, 19-21 October 1977, organized by Japan Industrial Robot Association. Tokyo, JIRA, 1977.

To evaluate the prehension state, the concept of stable prehension is introduced and the stability condition is provided by introducing a potential function of the prehension system. A computational algorithm to determine the hand location to grip two-dimensional objects is then proposed.

51. Forced Controlled Assembler. Hill, J. W. (SRI International, USA) Soc. Manufacturing Engineers, Paper No. MS77-749, November 1977.

A powered accomodation device is described that provides controlled forces between the end-effector of a Unimate 2000B manipulator and external objects being handled. Many assembly processes require that parts be pushed into place by the manipulator similar to the way human workers assemble them.

52. Development of Soft Gripper for the Versatile Robot Hand. Hirose, S. and Umetani, Y. (Tokyo Inst. Technology, Japan). (In, Proc. 7th International Symp. Industrial Robots, Tokyo, Japan, 19-21 October 1977, organized by Japan Industrial Robot Association). Tokyo, JIRA, 1977.

The paper deals with a singular type of a multi-purpose gripping mechanism which as a relatively simple control system and can softly and gently conform to objects of any shape and hold them with uniform pressure.

53. Industrial Robots--Gripper Review. Lundstrom, G., Glennie, B. and Rooks, B. W., Bedford, IFS (Publications) (Ltd., November 1977.

Summarizes 4 years cooperative research and development work carried out by six Swedish robot manufacturers to analyze robot gripper requirements.

54. On a Versatile Finger System. Okada, T. and Tsuchiya, S. (MITI & Drive System Co., Japan). (In, Proc. 7th International Symp. Industrial Robots, Tokyo, Japan, 19-21 October, 1977, organized by Japan Industrial Robot Association). Tokyo, JIRA, 1977.

Describes a newly developed flexible mechanical hand which is able to execute man's handwork, equipped with a finger sub-system has a structure similar to human hands and is characterized by the possibility of adductive and abductive motions.

55. On Specific Problems of Design of Multi-Purpose Mechanical Hands in Industrial Robots. Rovetta, A. (Inst. Mechanics of Machines, Milan Poly., Italy). (in, Proc. 7th Internatioanl Symp. Industrial Robots, Tokyo, Japan, 19-21 October 1977, organized by Japan Industrial Robot Association). Tokyo, JIRA, 1977.

Describes the design and operation of two newly developed types of multi-purpose mechanical hands for industrial robots. The first type are grippers with linkages, the second type is a mechanical hand with phalanges and return springs.

56. Model of 'Flexible Manufacturing Cell' For Rotational Parts. Spur, G.; Weisser, W. (Berlin Tech. Univ., W. Germany). (In, Proc. 7th International Symp. Industrial Robots, Tokyo, Japan, 19-21 October 1977, organized by Japan Industrial Robot Association). Tokyo, JIRA 1977.

Examines the various handling operations in a flexible manufacturing cell and describes the suggested gripper system, its performance, jaw changing device and control system.

57. Development of Soft Gripper for the Versatile Robot Hand. Hirose, S. and Umetani, T., Mechanics Mach. Theory, 1978, 13, 3.

Deals with a new type of soft gripper which can softly and gently conform to ojects of any shape and hold them with uniform pressure. This function is realized by means of a mechanism consisting of links and pulleys which can be simply actuated by a pair of wires.

58. Material Handling Device for Irregularly Shaped Heavy Works. Mori, K. and Sugiyama, K. (Hitachi, Japan). (In, Proc. 8th International Symp. Industrial Robots, Stuttgart, 30 May - 1 June 1978, 2 Vols). Bedford, UK, IFS (Publications) Ltd., 1978, 2.

Aims to develop a turnover mechanism without using wire ropes and considers four functions to achieve the objective: transport, grasping, turn-over and attitude control. The gripper developed had four pairs of fingers to achieve a stable grasp of an irregular shaped workpiece.

59. On the Prehension of a Robot Mechanical Hand: Theoretical Analysis and Experimental Tests. Rovetta, A. and Casarico, G. (Polytech. Milan, Italy). (In, Proc. 8th International Symp. Industrial Robots, Stuttgart, 30 May-1 June 1978, 2 Vols). Bedford, UK, IFS (Publications) Ltd., 1978, 1.

Describes the prehension process in a robot mechanical hand constructed at the laboratory of the Institute of Mechanics, Polytechnic of Milan, Italy. The prehension system is composed of two linked, finger-shaped elements located in reciprocal opposition on the same plane.

60. Design of a Three Fingered Robot Gripper. Van der Loos, H. F. M. Industrial Robot, 5 (4), December 1978.

A computerized optimization technique for determining applicability of straight-line-producing four-bar linkages is explained. A multiple-prehension, three-fingered gripper is proposed that, while being relatively robust, allows reliable gripping of many forms commonly found in light assembly operations.

61. Properties of Rotational Hands With Versatility. Arai, T. and Asada, M. J., Fac. Engng. Univ. Tokyo. Series B, 35 (2), September 1979.

The grippers have 1 degree of freedom and are investigated in relation to geometry and statics. Three types of hands are compared, including V-shaped notch ones and a finger without a notch.

62. Grippers and Clamping Elements--Modular Elements for the Automation of Production Technology. Frohlich, W. (Carl Freundenberg Simrit, Germany) Industrial Robot, 6, 4, December 1979.

Briefly describes with illustrations various pieces of equipment available from the author's company including: fingers, internal and external grippers, suction pad and vacuum grippers.

63. Object Handling System for Manual Industry. Okada, T., IEE Trans., Syst. Man. Cybernetics. SMC-9, 2, February 1979.

Describes a compact system which performs multiple prehension and flexible motion. The system has three fingers which have structures similar to those of a human, composed of three, four and five joints, respectively, and can perform bending and extending and also such lateral flexing motions as adduction and abduction.

64. A Method of Non-Positioning Workpieces Taking (Gripping). Witwicki, A. T. (Warsaw Tech. Univ., Poland). (In, Proc. 9th International Symp. Industrial Robots, Washington, DC, 13-15 March, 1979, sponsored by Society of Manufacturing Engineers and Robot Institute of America). Dearborn, Michigan, Soc. Manufacturing Engineers, 1979.

Describes with some detail and illustrations a manipulator gripper fitted with proximity sensors and a non-visual location system suitable for gripping randomly placed workpieces on a production line.

65. Feeding, Orienting, and Hold Insertion System for Bidimensional Parts. Belforte, G. and Quagliotti, F. (Politecnico di Torino, Italy). (In Proc. 1st Conf. Assembly Automation, Brighton, UK, 25-27 March 1980, sponsored by IFS (Conferences) Ltd). Bedford, UK, IFS (Publications) Ltd., 1980.

Describes the theory behind precision orienting of small work pieces during assembly allowing small adjustments while gripping and inserting.

66. Some Problems in Assembling with Industrial Robot. Martensson, N. and Johansson, C. (Linkoping Institute of Technology, Sweden). (In Proc. 1st Conf. Assembly Automation, Brighton, UK, 25-27 March 1980, sponsored by IFS Conferences Ltd). Bedford, UK, IFS (Publications) Ltd., 1980.

To gain experience of robotized assembly, the sub-assembling of a gearshaft to a passenger car gearbox has been studied. Gripper design is very important and a multifunction gripper has proved superior in this case.

67. Sub-Assembly of a Gear-Shift by Industrial Robot. Martensson, N. and Johansson, C. (Linkoping Institute of Technology, Sweden). (In, Proc. 10th International Symp. Industrial Robots/5th International Conf. Industrial Robot Technology, 5-7 March 1980, Milan, Italy, organized by IFS (Conferences) Ltd). Bedford, UK, IFS (Publications) Ltd., 1980.

Essentially concerned with the necessary requirements for a gripper to be used in gearbox shafts including adaptivity and economy.

68. Study and Experimentation of a Multi-Finger Gripper. Nerozzi, A. and Vassura, G. (Bologna Univ., Italy). (In, Proc. 10th International Symp. Industrial Robots/5th International Conf. Industrial Robot Technology, 5-7 March 1980, Milan, Italy, organized by IFS (Conferences) Ltd). Bedford, UK, IFS Publications) Ltd., 1980.

Describes an attempt to design a gripper which is able to catch objects of any shape without damaging them even if they are fragile or soft. A prototype call MIP2 is presented.

69. On a General Prehension Multi-Purpose System. Rovetta, A.; Franchetti, I. and Vincentini, P. (Milan Polytech. & Alfa Romeo.

S.P.A., Italy. (In, Proc. 10th International Symp. Industrial Robots/5th International Conf. Industrial Robot Technology, 5-7 March 1980, Milan, Italy, organized by IFS (Conferences) Ltd). Bedford, UK, IFS (Publications) Ltd., 1980.

Describes the operating properties of the mechanical hand and the mechanical activating system. The theory of the functional design is also presented and basically is characterized by 4 degrees of freedom.

70. A Contour Adapting Vacuum Gripper. Tella, R.; Kelley, R. B. and Birk J. (Rhode Island Univ., USA). (In, Proc. 10th International Symp. Industrial Robots/5th International Conf. Industrial Robot Technology, 5-7 March 1980, Milan, Italy, organized by IFS (Conferences) Ltd). Bedford, UK, IFS (Publications) Ltd., 1980.

Illustrated paper on the basic design and control system for the gripper which offers lift, lock and indirect grip sensing, point contour sensing and active steering for acquisition.

D. Sensors (General)

71. Automatic Inspection Devides for Artillery Projectiles in Modernized Plants. Balk, Herbert J.; Fuller, Kenneth E., DTIC Code: AD-B061 38 1L 19/1 13/8 14/2, Army Armament Research and Development Command Dover, NJ, Product Assurance Directorate, November 1981.

Totally automated production lines for manufacturing artillery shells from the basic raw materials to the finished product without human intervention are coming closer to reality. Hand-in-hand with this concept is the requirement that inspection of the product also be automated from start to finish.

72. Development and Testing of the mk 3 Mod 0 EOD Probe. Shock, Gerald D., DTIC Code: AD-B038 698L 19/1 13/12, Naval Explosive Ordnance Disposal Facility Indian Head, MD, December 1978.

Current tools and procedures are inadequate in providing a capability for the handling of hazardous devices without the necessity of direct hand contact. The concept of using an arm with various manipulating accessories was investigated as a means of providing remote manipulation capability suitable for explosive ordnance disposal (EOD) applications.

73. An Analysis and Comparison of Energy Direction Finding Systems. Leiner, Larry M., IEEE Transactions on Aerospace and Electronic Systems, Vol. AES-15, No. 6, October 1979.

Direction finding systems that use knowledge of only the approximate center frequency and bandwidth of the arriving signal and perform the azimuth estimate using the signal energy azimuthal distribution are of widespread interest. In this paper, a variety of such systems are considered.

74. Use of Optical Reflectance Sensors in Robotics Applications. Catros, J. Y.; Espiau, B., IEEE Trans Syst. Man. Cybernetics, v SMC-10 n 12, September 1980.

A new kind of proximity sensor with fiber optics and its use in some problems of robotics is considered. After modeling and simulation the sensors have been integrated into a gripper and used in some applications that are described. In the first part of this work three data handling problems are presented. First, the problem of detection of targets is considered and various algorithms are compared; then, range estimation is performed using nonlinear filtering; and a third application is a simple problem of pattern recognition, solved using a two-sensor configuration.

75. Computer Controlled Robot with Ultrasonic Sensor. Affinitio, F.J.; Wang, S. S.; Yee, Y. S., IBM Technical Disclosure Bulletin, v 18 n 8, January 1976.

The addition of a narrow beam ultrasonic proximity sensor to the final movable element of a mechanical manipulator provides more definitive range and azimuth inputs along with noncontact sensing, to provide improved control over the movements of the manipulator so that it can be operated in a closed-loop mode as a shape detector.

76. Method of Non-Positioned Workpieces Taking. Witwicki, Andrzej T., International Symposium on Industrial Robots, 9th, Washington, DC, 13-15 March 1979, Published by SME, Dearborn, Mich., 1979.

77. Automatic Acknowledgement of Pieces Position by Pneumatic Systems. Belforte, G.; Quagliotti, F., (Turin Polytech, Italy). Industrial Robot, v 3 n 2, June 1976.

78. Sensory Devices for Industrial Manipulators and Tools. Parks, J. R. (National Physical Laboratory). Paper presented at Symposium on Theory and Practice of Robots and Manipulators, Udine, Italy, 5-8 September 1973.

With the gradually increasing application of industrial manipulators and robots the need is emerging for sensory devices capable of providing these devices with a considerable degree of contact with their environments.

79. Sensors and System Necessary for Industrial Robots in the Near Future. Ueda, M. and Shimitzu, T. (Nagoya University, Japan), (In, Proceedings 4th International Symp. Industrial Robots, Tokyo, Japan, organized by JIRA and SOBIM, 19-21 November, 1974). Tokyo, Japan Industrial Robot Association, 1974.

Some examples of weight sensing systems using strain gauges are described, together with a dimension sensing system using a pulse generator fitted to a finger motor.

80. Preception Problems of Industrial Robots. Krisztinicz, P. (Hungarian Academy of Sciences, Hungary). Industrial Robot, 2(3), September 1975.

The dynamic behavior of pneumatic position sensing elements is analyzed to draw the attention of designers to the problem of switching point displacement which if excess displacement is neglected can cause hazardous phenomena, signal runaways and disturbance.

81. Sensors and Systems of an Industrial Robot. Ueda, M. and others. Mem. Fac. Engng. Nagoya Univ., 27, 2, November 1975.

Extensive review of the design and operatin of simple types of industral robots controlled by pin-board, dial-counters or electronic preset counter. Tactile sensors are described, as well as systems for controlling gripping-force and dimension sensing devices using finger motors.

82. Pedestal and Wrist Force Sensors for Automatic Assembly. Watson, P. C. and Drake, S. H. (The Charles Stark Draper Lab. Inc., USA) Proc. 5th International Symposium Industrial Robots, sponsored by Society of Manufacturing Engineers & Robot Institute of America, 22-24 September 1975. Dearborn, Society Manufacturing Engineers, 1975.

The paper describes a novel 6 degree-of-freedom force sensor system using data reduciton to decouple the desire forces. A pedestal force sensor and a wrist force sensor for assembly systems and manipulator arms are described.

83. Automatic Acknowledgement of Piece Position By Pneumatic Systems. Belforte, G. and Quagliotti, F. (Turin Polytechnic). Industrial Robot, 3(2), June 1976.

The system actuates a clamping device in accordance with the piece position with proximity fluidic sensors controlling the actuating cylinders and detecting the surface.

84. Trends Towards Sensory Control of Industrial Robots. Heginbotham, W. B. (University of Nottingham, UK) Robots and Automation in Manufacturing Industries , No. 5, July 1976, Published by Ing. C. Olivetti, Italy.

Recent developments in sensory control of industrial robots are described by the author by way of examples of different research projects and actually developed hardware. Future development and requirements are also discussed.

85. Tactile Sensors, Sonar Sensors and Parallax Sensors for Robot Applications. Larcombe, M. H. E. (University of Warwick, UK). Proc. 3rd Conference Industrial Robot Technology/6th International Symposium Industrial Robots, Paper C3, Nottingham University, March 1976. Bedford, IFS (Publications) Ltd., 1976.

The tactile Robot Project has produced as a byproduct a number of useful sensing devices which can readily be applied to modern computer controlled industrial robots. The sensors are designed to reduce computer loading by mixed hardware and software techniques.

86. Slip Sensor of Industrial Robot and Its Application. Masuda, R. and others. Electrical Engineering (Japan), 96, 5, September/ Octobr 1976.

Provides a grasping force compensation system to prevent the object being held from being damaged or dropped without providing an excessive force.

87. Use of Sensors in Programmable Automation. Rosen, C. A. and Nitzan, D. National Science Foundation Report, April 1976 (PB80-123142).

Reviews research and prototypical applications of sensors to automated material-handling, inspection, and assembly operations in batch-produced discrete part manufacuring. Sensors are needed for visual inspecton, and orientation of unindexed workpieces, and for adaptive control of manipulator movements.

88. Workpiece Transportation By Robots Using Vision. Kelley R. B. and Birk, J. (Univ. Rhode Island, USA). Paper No. MS77-746, November 1977. Dearborn, Society Manufacturing Engineers, 1977.

Practical methods to avoid obstacles without requiring the complexity of geometric modelling are presented. An algorithm has been developed which computes the arm joint valves needed to compensate for this misalignment.

89. Digitally Implemented Sensing and Control Functions for a Standard Industrial Robot. Niemi, A.; Malinen, P. and Koskinen, K. (Acad. Finaland & Helsinki Univ. Technol, Finland), Proc. 7th International Symposium Industrial Robots, sponsored by Soc. Biomechanics and Japan Industrial Robot Assoc., 19-21 October 1977. Tokyo, JIRA, 1977.

Describes a system of central data processing devices which are digital and because conversions would imply a greater complexity and overall digital information acquisition, processing and transmission system is preferable and used in this case. The system operates on a standard ASEA 6 kg industrial robot.

90. Prospects for Sensory Arrays and Microprocessing Computers to Manufacturing Industry. Pugh, A. and Waddon, K. Radio Electron Engineering 47, 8/9, August/September 1977.

Progress in industrial robots is related to the three generations in level intelligence. 'Generation 2' robots are defined as being automatically programmable mini-robots or lightweight factory manipulator with mini-computer or multiprocessor control, multiple arms and hands, and interactive sensors. A 'Genration 2' robot developed for the inspection of small pieceparts is described incorporating a line-scan camera and a mini-computer.

91. An Approach to the Integrated Intelligent Robot With Multiple Sensory Feedback: (1) Construction and Control Functions (2) Visual Recogntion Techniques. Takeyasu, K. and other (Hitachi Ltd., Japan). (In, Proc. 7th Intrnational Symp. Industrial Robots, Tokyo, Japan, 19-21 October 1977, organized by Japan Industrial Robot Association. Tokyo, JIRA, 1977.

Examines the construction and control of a robot which carries out assembly by integrated visual and tactile sensors, followed by consideration of the recogntion algorithms and visual feedback. The techniques necessary for the robot's smooth and dynamic motion are also described.

92. Automatic Grasping Using Infrared Sensors. Catros, J. Y. and others (IRISA). (In, Proc, 8th International Symp. on Industrial Robots, Stuttgart, 30 May-1 June, 1978, 2 Vols). Bedford, UK, IFS (Publications) Ltd., 1978, 1.

This paper presents a new type of infrared LED sensor and related computer algorithms that have been designed for automatic grasping.

93. Industrial Robots: Looking Forward to the Third Generation. Ferretti, M. Le Nouvel, Automatisme (2), November 1978.

Briefly survey intelligent industrial robots provided with senses, such as sight and touch, controlled by microcomputers. Applications include control of assembly machine-tools.

94. Information Systems of Industrial Robots. Kobrinsky, A. Y. and Govsievich, R. E. Machines and Tooling (USSR), 49, 8, 1978.

A sensor integrated robot is equipped with special system for receiving information about the properties and conditon of the environment and uses this information when performing the prescribed motions program and a block diagram of a sensor integrated robot is given.

95. 'I See', Said the Robot. Thompson, T. Assembly Engng., 21, 4, April 1978.

Robots equipped with accurate, low-cost sensory devices, are now bringing flexible automation economy to precision assembly operations. Smaller sophisticated robots are beginning to invade the workplace with cost-effective results.

96. Sensing System in Supersigma Robot. Cassinis, R. (Polytechnic of Milan, Italy). (In, Proc. 9th International Symp. Industrial Robots, Washington, DC, 13-15 March 1979, sponsored by Society of

Manufacturing Engineers and Robot Inst. America). Dearborn, Mich., Soc. Manufacturing Engineers, 1979.

The paper describes how the great computing power of the Supersigma robot enables inexpensive sensors to be used for a wide range of sophisticiated tasks. The interface of more complex sensors, e.g. to give vision, is also described.

97. Systematic Method of Hybrid Position/Force Control of a Manipulator. Craig, J. J. and Raibert, M. H. IEEE Proc. Computing Society 3rd Int. Computer Software Applications Conf., Chicago, Ill, 6-8 November, New York IEEE, 1979.

Describes fitting of manipulator hand sensors that provide interactions with the environment. A method is presented for controlling both the position of a manipulator and the contact forces generated at the hand.

98. Recognition and Handling of Overlapping Parts. Dessimoz, J. D.; Kunt, M,; Zurchee, J. M. (Federal Institute of Technology, Switzerland). (In, Proc. 9th International Symp. Industrial Robots, Washington, DC, 13-15 March 1979, sponsored by Society of Manufacturing Engineers and Robot Inst. America). Dearborn, Mich., Soc. Manufacturing Engineers, 1979.

The paper is concerned with the problem of picking a single part from the top of a heap of parts. In the method described a curvature function along partly seen contours leads to a good ability to recognize objects and their position.

99. 'Seeing' Robots with 'Feeling' for the Job. Hollingum, J. Engineer, 248, 6431, 18 June 1979.

Automated assembly will need robots to handle many manufacturing variations. The use of visual and tactile sensing with robot arms for assembly is being developed by a number of US organizations. Their development is discussed and the views of some of these companies' leading personalities are presented.

100. Programming and Data Structures for Sensor Controlled Robots. Paul, R. IEEE Electron '79 Conference Record, New York, 24-26 April 1979. Electron, El Sequendo, Calif. 1979 (paper No. 33.4).

Defines the characteristics of a sensor controlled robot and suitable date structures and transformations to represent position, orientation, force, and torque.

101. Robots, Models and Automation. Paul, R. Computer, 12, 7, July 1979.

Examines current trends in developments in industrial robot technology and the impact of the robot on manufacturing. Sensor controlled robots and homogeneous transformations are examined in particular.

102. Smart Sensors for Robot Arms. IEEE Spectrum, 16, May 1976.

103. A Simple Distance Sensor and a New Mini-Computer System. Keda, M.; Matsuda, F. and Matsuyama, S. (Nagoya Univ., Japan). (In, Proc. 9th International Symp. Industrial Robots, Washington, DC, 13-15 March, 1979, sponsored by Society of Manufacturing Engineers and Robot Inst. America). Dearborn, Mich., Soc. Manufacturing Engineers, 1979.

Development of Ueda's simple sensing system described at the 6th International Symposium on Industrial Robots. The new system can be used with objects made of black metal or polished metal.

104. Robot Vision and Sensory Controls. Proceedings of the 1st International Conference, 1-3 April 1981, Stratford upon Avon, UK. Bedford IFS (Publications), 1981.

Includes 34 pages covering the latest developments on vision and control for robots and manipulators, including both theoretical analyses and applications.

105. Assessment of Robotic Sensors. Nitzan, D. (SRI International, Calif.). (In, Proc. 1st International Conference on Robot Vision and Sensory Controls, 1-3 April 1981, Stratford upon Avon, UK, organized by IFS (Conferences) Ltd). Bedford, IFS (Publication) Ltd., 1981.

Review of the various types of robot sensors with a useful bibliography covering image processing, tactile sensors and computer vision.

D. Tactile Sensing

106. Tactile Sensing of Manipulators. Gurfinkel, V. S. and others. Engng.. Cybrnetics, 12, 6, November/December 1974.

Advantages and disadvantages of different types of manipulators are discussed. The block diagram of a tactile recognition system has been developed, based on a study of human fingers feeling objects.

107. The Edinburgh Arm-Eye System. Popplestone, R. J. and others (Univ, of Edinburgh, UK). (In, Proc. Les Robots Industriels, 8-9 October 1974), organized by Ecole Polytechnique Federale de Lausanne.

Describes the robot developed for assembly work. How the hand uses its senses of touch to assist it in assembling the components is also considered.

108. Study of Artificial Tactile Sensors for Shape Recognition. . .Algorithm for Tactile Data Input. Takeda, S. (University of Tokyo, Japan). (In, Proceedings 4th International Symp. Industrial Robots, 19-21 November 1974). Tokyo, Japan, organized by JIRA and SOBIM. Tokyo, Japan Industrial Robot Association, 1974.

The author deals with tactile sensors for three dimensional object recognition. A hardware and software of the artificial tactile senses are developed for this purpose and the research also treats the expriments on putting into a computer, the shape data of an object through the tactile sensors.

109. Artificial Softness Sensing--An Automatic Apparatus for Measuring Viscoelasticity. Kato, I.; Kudo, Y. (Waseda Univ., Japan). Proceedings 2nd Conf. on Remotely manned systems--technology and applications, 9-11 June 1975.

To realize artificially recognizing function of softness similar to human hands, it is not sufficient to recognize the object to be elastic. But we should recognize it to be visoelastic. From this point of view was developed an automatic measuring apparatus for recognizing the viscoelastic characters.

110. Novel Techniques for Tactile Sensing in a Three-Dimensional Environment. Page, C. J.; Pugh, A. and Heginbotham, W. B. (University of Nottingham, UK). (In, Proc. 3rd Conference Industrial Robot Technology/6th International Symposium Industrial Robots, Nottingham Univ., March 1976). Paper C4. Bedford, IFS (Publications) Ltd., 1976.

A simple, parallel-mode tactile transducer for extracting three-dimensional digital representations of complex engineering components is proposed. In addition, algorithms for computer processing of the tactile information to produce a compact structural description of the scrutinized object are evolved.

111. Object Recognition by Grasping. Okade, T. and Tsuchiya, Y., Pattern Recognition, 9, 3, October 1977.

Describes a method for recognizing both the 3-D pattern and the size of objects by grasping them with jointed fingers fitted with tactile sensors.

112. Novel Techniques for Tactile Sensing in a Three-Dimensional Environment. Pugh, A. and Heginbotham, W. B. (University of Nottingham) and Page, C. J. (Instem Ltd., UK). Industrial Robot, 4, 1, March 1977.

A simple, parallel-mode tactile transducer for extracting three-dimensional digital representations of complex engineering components is proposed.

113. A Method for Three-Dimensional Part Identification by Tactile Transducer. Sato, N.; Heginbotham, W. B. and Pugh, A. (Nottingham University, UK). (In, Proc. 7th International Symp. Industrial Robots, Tokyo, Japan, 19-21 Octobor 1977), organized by Japan Industrial Robot Association, Tokyo, JIRA, 1977.

Explains through mathematical analysis the principles behind the tactile head and the design problems and the algorithms needed to produce the tactile data. A graphical representation of contours is also presented.

114. Assembly Robot with a Sense of 'Touch'. Astrop, A., Machinery and Production Engineering, 19-26 December 1979.

Describes the principles of the Remote Centre Compliance (RCC) developed by Charles Stark Draper Laboratories in the USA for overcoming the 'peg in the hole' part assembly problem.

115. The Utilization of an 'Artificial Skin' Sensor for the Identification of Solid Objects. Briot, M. (Laboratoire d'Automatiaue, France). (In, Proc. 9th International Symp. Industrial Robots, Washington, DC, 13-15 March 1979, sponsored by Society of Manufacturing Engineers and Robot Institute of America). Dearborn, Michigan, Soc. Manufacturing Engineers, 1979.

In the first application the position identification of a mechanical part with multiple planar equilibrium faces is studied. The second application concerns the use of this type of sensor on the two parallel fingers of a gripper.

116. Research on Tactile Sensors for an Intelligent Naval Robot. Dixon, J. K.; Salazar, S. and Slagle, J. R. (Naval Research Lab., (In, Proc. 9th International Symp. Industrial Robots, Washington, DC, 13-15 March 1979, sponsored by Society of Manufacturing Engineers and Robot Institute of America). Dearborn, Michigan, Soc. Manufacturing Engineers, 1979.

Design outlines for an object recognition system for an underwater robot using tactile sensors. The system is complex as the robot has identify anything it finds, rather than a small number of known parts, in a remote, possibly hostile environment.

117. Use of Sensory Information for Improved Robot Learning. Seltzer, D. S. (Charles Stark Draper Laboratory, Inc. USA) SME Paper No. MS 79-799 (1979). Dearborn, Society Manufacturing Engineers, 1979.

Robots 'learn' or acquire knowledge by three different methods. Currently, the most popular method is through being 'taught' by an operator during an on-line preparation phase. A second method is the use of off-line geometric data bases and software aids. A third, and as of now rarely used, method is learning from on-line experience.

118. Control Algorithm for Precision Insert Operation Robots. Goto, T. and Others. IEEE Trans. System Man. Cybernetics, SMC, 10(1), January 1980.

Describes a tactile control robot which carries out precision operations with a clearance of a few microns. The robot is fitted with a new insertion control unit which integrates positioning ability, sensitivity, and flexibility. Its most important feature is effective utilization of a flexible mechanism and force sensors.

F. Vision Sensors

119. A Review of Three-Dimensional Vision for Robotics. Geo-Centers, Inc., Inc., Newton Upper Falls, MA, May 1982.

The technologies appropriate to the collection and interpretation of three-dimensional data for robotics applications are reviewed. Included are optical stereoscopy, proximity sensing, laser scanning and structured light. Specifications for current systems are presented and areas of poter*'.l improvement are identified.

120. Coherent Optical Methods for Applications in Robot Visual Sensing. Taboada, J., Pub. in SPIE, v283-3D Machine Perception, 1981.

121. Methods for Interpreting Perspetive Images. Barnard, Stephen T., This article is from Image Undarstanding: Proceedings of a Workshop held at Palo Alto, CA, 15-16 September 1982, AD-A120 072.

122. MIT Progress in Understanding Images. Brady, Michael, This ariticle is from Image Understanding: Proceedings of a workshop held at Palo, CA 15-16 September 1982, AD-A120 072.

123. Computer Recognition of Partrial Views of Three-Dimentsional Curved Objects. McKee, J. W.; Aggarwal, J. K., Texas Univ. At Austin Electronics Research Center, May 1975.

124. An Optical Sensor for Locating Objects Without Marks or Contact. Muhlenfeld, E. (Institute fur Informationsverarbeitung in Technik und Biologie de Fraunhofer-Gesellschaft e.V., German Federal Republic). Paper presented at Symposium on Theory and Practice of Robots and Manipultors, Udine, Italy, 5-8 September 1973.

Robots require optical sensors to recognize and locate objects under various conditioners. The principle operations and performance of a correlation sensor are described, which performs the cognitive computations by processing the light rays emerging from the object to be handled.

125. A Minicomputer Controlled Industrial Robot with Optical Sensor in Gripper. Tsuboi, Y. and others. (Mutsubishi Electric Corp., Japan). (In, Proc. 3rd International Symposium on Industrial Robots, Zurich, Switzerland, 29-31 May 1973).

The development work of a minicomputer controlled robot described started in 1971. The robot is equipped with a television camera in the gripper. Making use of a unique hand-eye coordinator, a first system was realized by using two television camera and a minicomputer.

126. An Opto-Pneumatic Manipulating Arm. Drazan, P. J. and Kennett, R. (University of Surrey, UK). (In, Proc. 4th International Symp. Industrial Robots, Tokyo, Japan, 19-21 November 1974), organized by JIRA and SOBIM. Tokyo, Japan Industrial Robot Association, 1974.

The possibilities of simple vision in the form of a four segment photodiode for locating and tracking objects are investigated. Logic algorithms set in a micro-processor are used to control the arm via simple on-off pneumatic drivers. The design of the type of arm used is also discussed.

127. On the Simple Eyes of Industrial Robot Applying the Correlation Technique. Matsushima, K.; Furuichi, C. and Osogoe, T. (Tokyo Inst. Tech., Japan), (In, Proc. 4th International Symp. Industrial Robots, Tokyo, Japan, 19-21 November 1974). Organized by JIRA and SOBIM. Tokyo, Japan Industrial Robot Association, 1974.

A study was carried out in order to develop a simple artificial eye in order to perceive an object in front of the robot or unmanned car and to lighten the burden of the electronic computer for recognizing the object.

128. Robot Vision as a Factor in the Control of Motion. Young, J. F. (University of Aston, Department of Electrical Engineering, Birmingham, England), (In, Proc. 1st CISM-IFToMM Symposium on Theory & practice of Robots and Manipulators, Udine, Italy), Vol, 2, Springer-Vrlag, Wein-New York, 1974.

Robots for general-purpose use require a method of position-sensing feedback and some low-cost form of visual sensing would be ideal, particularly if it could be combined with means for visual object-recognition.

129. Some Problems of Organization of the Stereovision of a Robot. Boldynev, A. I. and others. Engineering Cybernetics, 13, 3, May-June 1975.

The sterovision system consists of two identical optical channels which form a pair of plane representations of the scene and an optical-electric transducer, usually a television transmitting tube.

130. Video Target Locator. Bowerman, E. R. and Kearns, R. F. (GTE Labs, Inc., USA). Proc. 5th International Symposium Industrial Robots, sponsored by Society of Manufacturing Engineers & Robot Institute of America, September 1975. Dearborn, Society Manufacturing Engineers, 1975.

A close circuit TV camera with a fixed focus lens is used to measure the vertical displacement from and distance along its optical axis to a checker-row target, i.e. a row of alternate black and white squares. The target is recognized by a burst of pulses in the video output during horizontal scan.

131. An Opto-Pneumatic Manipulating Arm. Drazan, P. J. and Kennett, R. (University of Surrey). Industrial Robot 2(1), 7-10 March, 1975.

The possibilities of simple vision in the form of a four segment photodiode for locating and tracking objects are investigated.

132. A Contour-Recogniton Method for Identifying Parts/Parts-Orientations in Automatic Assembly. Driscoll, L. C. (Cyberfacts Inc., USA) and J. Levine (Brandeis Univ., USA). (In, Proc. 5th International Symposium Industrial Robots, sponsored by Society of Manufacturing Engineers & Robot Institute of America, 22-24 September 1975). Dearborn, Society Manufacturing Engineers, 1975.

A contour-recognition method is developed for processing inputs for an infrared/optical, surface-distance measuring system. The objective is to identify parts and parts-orientations in automatic assembly tanks.

133. A Practical Visually Interactive Robot Handling System. Heginbotham, W. B.; Page, C. J. and Pugh, A. (Nottingham University, UK), Industrial Robot 2(2), June 1975.

Describes the experiments carried out on the SIRCH rig paying particular attention to applications of the rig to situations where the parts presented to the machine have not been threatened nor the corresponding parameters retained in the computer memory.

134. A New Integrated Robot-Eye for Colour Discrimination. Kato, I. and others. (Nagoya Municipal Ind. Res. Inst., Japan). (In, Proceedings 5th International Symposium Industrial Robots, 22-24 September 1975, sponsored by Society of Manufacturing Engineers & Robot Institute of America). Dearborn, Society Manufacturing Engineers, 1975.

A new integrated semi-conductor transducer suitable for an industrial robot-eye is proposed. This device consists of an SnO_2-Si hetero junction covered with a colour filter which is highly photosensitive and has a fast response.

135. Visual Robot Instruction. Series, D. A.; Kelley, R. B. and Birk, J. (Univ. Rhode Island, USA). (In, Proceedings 5th International Symposium Industrial Robots, 22-24 September 1975, sponsored by Society of Manufacturing Engineers & Robot Institute of America). Dearborn, Society Manufacturing Engineers, 1975.

Authors advocate the use of a Visual Programming Device (VPD). A VPD is a wand with an array of lights at one end. Is used with a TV camera which is interfaced to a computer that controls a robot.

136. Interactive Handling of TV and Range Data for Remotely Controlled Systems. Yakimovsky, Y. (Jet Propulsion Lab., USA). (In, Proc. 2nd Conf. on Remotely manned systems--technology and applications, 9-11 June 1975).

The sensory subsystem of the JPL robotics project has two types of inputs. The second is a laser range finder, which can be aimed in a requested direction and measure distances to a surface point that reflects the beam back. Both instruments are controlled by and are interfaced to a computer.

137. Machine Vision in an Industrial Environment. Baker, H. (Edinburgh University, UK). (In, Proc. 3rd Conference Industrial Robot Technology/ 6th International Symposium Industrial Robots, Paper C2, Nottingham University, March 1976). Bedford, IFS (Publications) Ltd., 1976.

After a survey of the devices and techniques common to vision research, a scheme is outlined which provides a general and extensible mechanism for vision without the limiting of domain-specified object knowledge.

138. Feature Extraction of 3-D Objects and Visual Processing in a Hand-Eye System Using Laser Tracker. Ishii, M. and Nagata, T. Pattern Recognition, 8, 4, October 1976.

The robot's eye can acquire three-dimensional coordinates of a laser spot on an object based on triangulation and the extract features of the object corresponding to the purpose of the robot.

139. Robot Assembly System Using TV Camera. Tsuboi, Y. and Inoue, T. (Mitsubishi Electric Co.) Industrial Robot, 3(2), June 1976.

Describes system compounds, control algorithms and experimental results with emphasis on the parts locating algorithm for a robot with a TV camera on its gripper incorporated in a computer controlled assembly system.

140. One Trial to Use a Simple Visual Sensing System for and Industrial Robot. Ueda, M.; Sakai, I. and Kumatzawa, T. (Nagoya Univ., Japan). (In, Proc. 3rd Conference Industrial Robot Technology/6th International Symposium Industrial Robots, Paper B1, Nottingham University, March 1976). Bedford, IFS (Publications) Ltd., 1976.

To avoid the complexity of elimination of disturbance of the surrounding light noise we used a laser beam, which has great power density in a very narrow beam. One of the simplest methods to detect distance up the the object surface using a laser beam generator, rotating mirror and a high frequency pulse series has been examined and verified to be useful for an industrial robot.

141. High Precision Manipulator with Visual Sense. Abe, Y.; Tani, K. and Ono, T. (Mech. Engng. Lab. MITA, Japan). (In, Proc. 7th Intrnational Symp. Industrial Robots, Tokyo, Japan, 19-21 October 1977, organized by Japan Industrial Robot Association). Tokyo, JIRA, 1977.

Research was carried out in which a manipulator with positioning accuracy of 0.01 mm was controlled using visual sense composed of fibrescopes and TV cameras. The concept of perspective projection with two vanishing points was introduced as the basis of the positioning control.

142. Servoing With Visual Feedback. Agin, G. J. (Stanford Research Inst., USA). (In, Proc. 7th International Symp. Industrial Robots, Tokyo, Japan, 19-21 October 1977, organized by Japan Industrial Robot Association). Tokyo, JIRA, 1977.

A solid-state TV camera was mounted in the hand of an industrial manipulator, thus enabling the manipulator to automatically position itself coarsely above a workpiece so that a bolt may be inserted in a hole using compliance mountings for fine control.

143. A Simple Real Time Universal System for an Industrial Robot. Anuashuili, A. N. and Zolov. V. D. (Inst. Control Services, USSR). (In, Proc. 7th International Symp. Industrial Robots, Tokyo, Japan, 19-21 October 1977, organized by Japan Industrial Robot Association). Tokyo, JIRA, 1977.

The problems of constructing a visual system of industrial robots for a certain class of applications are discussed. The basic element of the proposed visual system is a semi-conductor image transformer (SIT) with a radial-circular scanning. The problems involved in the implementation of the SIT-based visual systems for a limited class of industrial applications are considered.

144. General Methods to Enable Robots With Vision to Acquire, Orient, and Transport Workpieces. Birk, J. and others. Kingston, Rhode Island Univ., August 1977. PB-272720/4GA.

The methods are intended to assist in increasing the range of industrial applications of robots. The review discusses limitations in the use of human operatives and mechanical feeders for loading machines with oriented workpieces.

145. On Visual Signal Processing for Industrial Robots. Hasegawa, Y.; Masuda, R. (Tokyo Inst. Tech., Japan). (In, Proc. 7th International Symp. Industrial Robots, Tokyok, Japan, 19-21 October 1977, organized by Japan Industrial Robot Association). Tokyo, JIRA, 1977.

As a result of the author's recent studies on visual processsing for industrial robots, some visual signal processing methods, namely, for spatial paramether measurement, feature extraction, and object identification have been developed.

146. Algorithms to Visually Acquire Workpieces. Kelley, R. B.; Birk, J. and Wilson, L. (Rhode Island Univ., USA). (In, Proc. 7th International Symp. Industrial Robots, Tokyo, Japan, 19-21 October 1977, organized by Japan Industrial Robot Association). Tokyo, JIRA, 1977.

The inability of current industrial robots to acquire workpieces from an unoriented supply is one to their most serious limitations. To overcome this drawback, a procedure for acquiring transportable workpieces has been developed which consists of two phases: instruction and execution.

147. V/I--A Visual Institution Software System for Programming Industrial Robots. Kelley, R. B. and Sivestro, K. C. (Rhode Island Univ., USA). Industrial Robot, 4(2), June 1977.

The system allows the robot's task to be described through visual means. Television cameras and hand-held arrays of small lights cut time on programming for robot and position and orientation specification.

148. Digitally Implemented Sensing and Control Functions for a Standard Industrial Robot. Niemi, A.; Malinen, P. and Koskinen, K. (Academy of Finland and Helsinki Univ. of Tech., Finland). (In, Proc, 7th International Symp. Industrial Robots, Tokyo, Japan, 19-21 October 1977, organized by Japan Industrial Robot Association). Tokyo, JIRA, 1977.

149. Application of Industrial Robots That Can See. Potter, R. D. SAE Preprint No. 770438, New York Society of Automotive Engineers, 1977.

Describes Auto-Place Inc. limited sequence robots which have been linked to both laser and video camera techniques to produce robots with visual capacity. They are able to perform inspection, gauging, sorting, assembly and positioning tasks.

150. Applications of Industrial Robots with Visual Feeback. Potter, R. D. (Auto-Place Inc., USA). Society Manufacturing Engineers, Paper No. MS77-748, November 1977.

The Industrial robot is emerging from its 'blind' state being provided with a sense of vision in carrying out industrial jobs. Applications of its increased adaptive abilities through visual feedback are described.

151. Positioning Method for a Robot With TV Camera in 3-Dimensional Space. Tsuboi, Y. and Inoue, T., Syst. Comut. Controls, 8 (4), July-August 1977.

A method of extracting three-dimensional information from an object by freely moving a TV camera in three-dimensional space is discussed. After describing a movable visual system consisting of a robot with visual grab (a manipulator with a TV camera at the top of the hand), the control algorithms of the proposed system are presented.

152. General Methods to Enable Robots with Vision to Acquire, Orient, and Transport Workpieces. Progress Report No. 4, 15 August 1977-15 July 1978. Birk, J. and others, Kingston, Rhode Island Univ., 15 July 1978, (NSF/RA 780260; PB 287 199) (See also PB 272720).

Alternative aproaches to the problem of feeding machines with work pieces supplied unoriented in containers are described. A major subdivision exists between using some mechanical means to force workpieces into a stream versus having a robot acquire pieces directly from the container in which the parts are stored or transported.

153. Robot's Electro-Optic Eyes Put to the Test on Conveyor Belt Job. Butler, P., Engineer, 246, 6362, March 1978.

A system which can show a robot if components on a conveyor belt are the right way up is being given a trial on the shop floor. The sensing system developed by Brown Boveri in Switzerland is described in this article.

154. Visual Identification and Location in a Multi-Object Environment by Contour Tracking and Curvature Description. Dessimoz, J. D. (Ecole Polytech., Federale de Lausanne, Switzerland). (In, Proc. 8th International Symp. Industrial Robots, Stuttgart, 30 May-1 June 1978), 2 Vols. Bedford, UK, IFS (Publications) Ltd., 1978, 2.

Method allows the identification and the location of objects in a TV camera field. The tasking procedure that partitions the image is followed by a quantization noise filter and a regularly spaced resampling.

155. A TV Sensor and Its Link-Up With an Industrial Robot. Geisselman, H. (Institut fur Informationsverabeitung in Technik und Bilogie (IITB), Karlsruhe, W. Germany). (In, Proc. 8th International Symp. Industrial Robots, Stuttgart, 30 May - 1 June 1978), 2 Vols. Bedford, UK, IFS (Publications) Ltd., 1978, 1.

Describes a recently developed TV sensor which can be easily programmed for the handling of different work pieces and which can identify work pieces lying openly on a plane by their forms and position coordinates.

156. Consight-1: A Vision-Controlled Robot System For Transferring Parts From Belt Conveyors. Holland S. W. and others. General Motors Corporation Research Laboratory Research Publication GMR-2790, August 1978.

System picks up parts randomly placed on a moving conveyor belt. The vision subsystem, operating in a visually noisy environment typical of manufacturing plants, determines the position and orientation of parts on the belt.

157. Object Recognition and Handling In An Industrial Robot System With Vision. Kostkinen, K. and Niemi, A. (Helsinki Univ. Technology, Finland). (In, Proc. 8th International Symp. Industrial Robots, Stuttgart, 30 May-1 June 1978), 2 Vols. Bedford, UK, IFS (Publications) Ltd., 1978, 2.

Discusses the implementation of pattern recognition schemes in the visually sensing robot system developed in the author's laboratory. A variety of objects is recognized after observations by means of a relatively rough visual raster which, on the other hand, implies low computer time requirements.

158. Digital Technology Enables Robots To 'See'. Shapiro, S. Computing Design, 17, 1, January 1978.

Robots covering an extremely wide range of sophistication have existed for many years. One key capability has generally not been available: vision. Over the past few years, many research facilities have been attempting to develop practical techniques for providing vision to robots, to enable them to search for and recognize specific parts, and then do something with those parts. Some laboratory success has been indicated; yet practical systems have been rare.

159. Opto-Electronic Identification of the Position of Work Pieces Having Few Different Features. Stratemeier, V. (Robert Bosch GmbH, West Germany) (In, Proc. 8th International Symposium Industrial Robots, Stuttgart, West Germany, 30 May-1 June 1978, 2 Vols). Bedford, IFS (Publications) Ltd., 1978, 2.

Describes a simple and cheap electo-optical device that is able to identify the orientation of round axi-symmetric parts 1 mm-50 mm diameter. Different shapes to the ends, bevels, cones or eccentric recesses serve as a critera for differentation. The differences in features can be within the range of one tenth of a millimeter.

160. Experiment in Flexible Automation. Sarada, P. and Weavr, J. A, Pilips Technical Revew, 1978-79, 38(11/12).

Describes Philips research into the possibilities of flexible automation for small production runs. A visually controlled pick-and-place machine has been built which can recognize objects lying randomly on a table, pick them up and put them down at a specified point in a specified position.

161. Proximity-Vision System For Prototype Manipular Arm. Albus, J. S.,

National Engineering Lab. (NBS) Center for Mech. Engineering & Process Tech., January 1979, (NBSIR-78-15 76; PB 291335/8GA).

The system consists of two separate but complementary subsystems (a) a solid-state TV camera with 128 x 128 resolution elements mounted on a manipulator wrist. Coordinated with this camera is high intensity strobe flash system with optics which project a thin fan-shaped plane of light into the region viewed by the cameras, (b) a pair of close-range infrared proximity sensors mounted in the gripper ends.

162. A Very Fast Vision System for Recognizing Parts and Their Location and Orientation. Armbruster, K. and others. (Informatik III, Univ. Karlsruhe, W. Germany). Washington, DC, 13-15 March 1979, sponsored by Society of Manufacturing Engineers and Robot Institute of America). Dearborn, Michigan, Society Manufacturing Engineers, 1979.

The system consists of a solid state matrix camera, special bipolar processors for image preprocessing and a controlling micro-computer. During a teach-in phase the micro-computer extracts bipolar coded features of a planar object, and in a measuring-phase the stored reference data are compared with the corresponding features of the randomly oriented parts.

163. General Methods To Enable Robots With vision To Acquire, Orient, and Transport Workpieces. Birk, J. and others, Kingston, Rhode Island Univ., Dept. Electrical Engineering, Ref. No. NSF/RA-790230, August 1979. (PB80-106388).

Assesses the problem of giving robots the ability to work with unoriented objects and looks at the applications not only in automating isolated machines, but also in automated batch manufacturing systems, particularly those in which unoriented parts in containers are transported between machines and storage.

164. Visually Estimating Workpiece Pose in a Robot Hand Using the Feature Points Method. Birk, J. and others. (In, Proc. IEEE 17th Conference on Decision Control Incl. Symposium on Adaptive Processes, San Diego, Cal., 10-12 January, 1979). New York, IEEE 1868; Catalogue No. 78. Ch 1392-OCS.

Estimating workpiece pose is necessary if robots are to accomplish many industrial tasks. Method is not subject to the constraint that the workpiece have one of a finite number of states in the robot hand. Workpiece pose is estimated using the three dimensional location of workpiece feature points.

165. Man-Machine Communication in Computer-Aided Remote Manipulation. Crooks, W. H. and others. Perceptronics, Inc., Woodland Hills, California, Technical Report 2/2/78-1/2/79, March 1979. Report No. PATH-1034-79-3 (AD A074566/1).

Describes an analytical and experimental study to investigate the effectiveness of command language structure and the methods for providing feedback information through the use of sensors and displays in automated remote manipulation.

166. A Robot Task Using Visual Tracking. Geschke, C. C., University of Illinois at Urbana-Champaign, USA, Society of Manufacturing Engineers, Paper No. MS79-800, 1979. Dearborn, Society of Manufacturing Engineers, 1979.

Describes the use of RSS, A Robot Servo System for performing a visual tracking task. The task consists of inserting a bolt into a hole using dynamic visual feedback. The location of both the hole in the work area and the bolt in the robot gripper are determined visually in three dimensions, and the position of the bolt is updated an average of ten times per second as the robot moves.

167. A Modular Vision System For Sensor-Controlled Manipulation and Inspection. Gleason, C. J.; Agin, G.J. (SRI Internajtional, USA) (In, Proc. 9th International Symposium Industrial Robots, Washington, DC, 13-15 March 1979, sponsored by Society of Manufacturing Engineers and Robot Institute of America). Dearborn, Society Manufacturing Engineers, 1979.

Describes a prototype hardware/software system for industrial computer vision applicatons. The hardware consists of a solid-state camera, a preprocessor interface and an LSI-11 microcomputer. The software consists of routines for analyzing binary images including connectivity analysis extraction of shape descriptors, automatic recognition, training by showing, and determination of position and orientation. The system has computer controlled dual thresholds which are useful in generating brightness histograms.

168. Real Time Control of a Robot With a Mobile Camera. Hill, J. W. and Park, W. T. (SRI International, USA) (In, Proc. 9th International Symposium Industrial Robots, Washington, DC, 13-15 March 1979, sponsored by Society of Manufacturing Engineers and Robot Institute of America). Dearborn, Society Manufacturing Engineers 1979.

A control system for a Unimate robot that derives its control information from a small, solid-state TV camera attached to its end-effector is described and analyzed. Visual input may be in either of two modes: using conventional lighting or using projected patterns of light to give distance by triangulation.

169. Experimental Results With a Versatile Optoelectronic Sensor in Industrial Applications. Karg, R. and Lanz, O. E. Brown Boveri Research Centre, Switzerland). (In, Proc. 9th International Symposium Industrial Robots, Washington, DC, USA, 13-15 March, 1979).

The sensor may be used in performing tasks such as unloading palettes on which working pieces are only roughly positioned and reading coded labels which are positioned arbitrarily in a wide range with reference to the optical reading head.

170. A Robot System Which Feeds Workpieces Directly From Bins Into Machines. Kelley, R. and others. University of Rhode Island, USA, (In, Proc. 9th Internajtional Symp. Industrial Robots, Washington, DC, 13-15 March 1979, sponsored by Society of Manufacturing Engineers and Robot Institute of America). Dearborn, Michigan, Society Manufacturing Engineers, 1979.

Because workpieces must be pre-oriented, it has not been possible for industrial robots to service many workstations. An experimental robot system employing vision has been developed which feeds workpieces directly from supply bins into machines. The system can be re-programmed to service different workpieces.

171. Recognition and Orientation of Component Profiles Through the Medium of Teletext Graphics. Loughlin, C. (Nottiingham Univ., UK) and Pugh, A. (Hull Univ., UK). (In, Proc., 9th International Symp. Industrial Robots, Washington, DC, 13-15 March 1979, sponsored by Society of Manufacturing Engineers and Robot Institute of America). Dearborn, Michigan, Society Manufacturing Engineers, 1979.

Introduces the idea of Teletext encoded displays into robot handling where visual identification is used.

172. Recognition and Orientation of Component Profiles Within the Low Resolution of Teletext Graphics. Loughlin, C. (Nottingham Univ., UK) and Pugh, A. (Hull Univ., UK). Industrial Robot, 6(4), December 1979.

Teletext as a communication and information medium has aroused considerable interest in the UL and the system has been under test for 3 years by the national television broadcasting authorities. The graphics resolution of the service is adequate for many industrial applications including orientation and inspection problems prior to robot handling.

173. Reduction of Visual Data by a Program Controlled Interface for Computerized Manipulation. Malinen, P. and Niemi, A. (Helsinki University of Technology, Finland). (In, Proc. 9th International Symp. Industrial Robots, Washington, DC, 13-15 March 1979, sponsored by Society of Manufacturing Engineers and Robot Institute of America). Dearborn, Michigan, Society Manufacturing Engineers, 1979.

A system is described consisting of an industrial robot, a computer and a high resolution camera. The camera has an electronic window which operates under computer control. A rough scan raster is used for detection and approximate location of an object. A fine raster and a set of seven threshold levels for brightness are applied in a limited window just around each object.

174. Recognition of Angular Orientation of Objects With the Help of Optical Sensors. Martin, P. S. and Nehr. G. (Inst. of Informatik, Karlsruhe Univ., W. Germany). Industrial Robot, 6, 2, June 1979.

Examines currently known methods of determining angular orientation, briefly explains polar coding, and then presents a determination of angular displacement by polar coding with the help of a circular scanning method.

175. Vision Expands Robotic Skills for Industrial Applications. Shapiro, S. F., Comp. Des., 18, 9, September 1979.

Industrial robots have progressed dramatically in recent years, mainly because of the development of micor-processors. Limited vision capability is still a serious constraint on robot performance. International robot research is briefly described with specific attention devoted to NSF-funded activities at the University of Rhode Island.

176. There's a New Breed of Robot in Sight. Machinery, July 1979.

General Motors in the USA is well advanced with a robot that can 'see' and search for items scattered about on a moving conveyor. The article includes a description of GM's CONSIGHT system which consists of a Cincinnati Milacron robot, lighting system, camera, conveyor motion sensor and supervisory computer.

177. A Vision System For Real Time Control of Robots. Vander-Brug, C. J.; Albus, J. S. and Barkmeyer, E. (Nat. Bureau Standards, USA). (In, Proc. 9th International Symp. Industrial Robots, Washington, DC, 13-15 March 1979, sponsored by Society of Manufacturing Engineers and Robot Institute of America). Dearborn, Michigan, Society Manufacturing Engineers, 1979.

Describes a robot vision system consisting of a solid-state camera, a stobographic light force and a 8-bit micro-processor. The camera is mounted obligingly on the robot wrist so that its field of view covers the region extending from inside the finger tips at a distance of one metre.

178. Vision Systems for Manufacturing (Final Report). Vander-Brug, C. J. and Nagel, R. N. (Nat. Bureau Standards, Washington, DC). (Inc, Proc. Joint Automatic Control Conf. Denver, 17-21 June 1979). (PB-80-134919).

In robot systems, vision is needed to allow the robot to acquire, manipulate, and inspect parts without the need for elaborate fixturing or complex part delivery systems. Paper begins with a brief historical perspective on image processing and pattern recognition, followed by a series of state-of-the-art examples of visual inspection systems and finally robot vision systems are presented.

179. Consight--A Practical Vision-Based Robot Guidance System. Ward, M. R.; Rossol, L. and Holland, S. W. (General Motors, USA). (In, Proc. 9th International Symp. Industrial Robots, Washington, DC, 13-15 March 1979, sponsored by Society of Manufacturing Engineers and Robot Institute of America). Dearborn, Michigan, Society Manufacturing Engineers, 1979.

A vision-based robot system capable of picking up parts randomly placed on a moving conveyor belt is described. The vision subsystem, operating in a visually noisy environment typical of manufacturing plants, determines the position and orientation of parts on the belt.

180. Hardware Computaton of Image Features Based on Local Gradient Direction Histograms. Duncan, D.; Birk, J. and Kelley, R. B. (Rhode Island Univ., USA). (In, Proc. 10th International Symp. Industrial Robots/5th International Conf. Industrial Robot Technology, 5-7 March 1980, Milan, Italy), organized by IFS (Conferences) Ltd. Bedford, UK, IFS (Publications) Ltd., 1980.

Describes the design and construction of special electronic hardware for extracting higher level features, such as corners and holes from a grey single image. An algorithm based on local gradient direction histograms is developed to be implemented in the hardware.

181. Vision Controlled Robot For Part Transfer. Holland. S. W. and others. SAE, Preprint, No. 800378. Meeting 25-29 February 1980. New York, Society Automotive Engineers, 1980.

Describes a vision based robot system capable of picking up parts randomly placed on a moving conveyor belt. The robot tracts the parts and transfers them to a pre-set location. This system can be easily retrained for a wide class of complex curved parts and demonstrates that future systems have a high potential for production plant use.

182. Visual Localization of Automobile Parts Without Significant Outline. Lux, A. (Laboratoire IMAG, France). (In, Proc. 10th International Symp. Industrial Robot Technology, 5-7 March 1980, Milan, Italy), organized by IFS (Conferences) Ltd. Bedford, UK, IFS (Publications) Ltd., 1980.

The application concerns car body parts of a fairly large size lying in the x-y plane, which have to be localized with great accuracy in less than 1 second in order to be picked up by a press robot. Several techniques using a camera and automatic digital image analysis, taking into account three-dimensional information, have been studied, the proposed solution being the simplest of these.

183. Real-Time Teaching and Recognition System For Robot Vision. Taylor, W. K. and Ero, G. (University College, London). Industrial Robot,

7, 2, June 1980.

High speed low cost hardware is trained without computer programming to recognize moving or stationary components. Recognition is indicated by generation of a keyed code number and orientation of the gripper is controlled by teaching the hardware to recognize the component at a number of angles.

184. Robot Vision. Thomas, A. F. and Stout, K. J. (Leicester Polytechnic, UK). Engineering, 200(5), May 1980.

Defines the problem of robot vision and describes some recent developments mainly in the USA, in adding visual perception to robots. US institutions such as SRI International, General Motors Research Labs., National Bureau of Standards are included. The vision system offered by Brown Boveri is also described.

185. Kawasaki Vision System--Model 79A. Toda, H. and Masaki, I. (Kawasaki Heavy Industries Ltd., Japan). (In, Proc. 10th International Symp. Industrial Robots/5th International Conf. Industrial Robot Technology, 5-7 March 1980, Milan, Italy), organized by IFS (Conferences) Ltd. Bedford, UK, IFS (Publications) Ltd., 1980.

Kawasaki Vision System (Model 79A) has been developed during the efforts to produce practically intelligent robots. This system will be applied mainly to path correction for arc welding. It consists of a laser projection unit, and image detection unit, and image processing unit, etc.

186. Manufacturing Industries Take Up New Moves in Optoelectronic Inspection. Walker, J., Engineer, 250, 6484, 13 March 1980.

Describes in some detail two applications of micro-processor controlled photo diode array sensors. The arrays are the products of Integrated Photomatrix Ltd. (IPL). The first application is a Corn Cob Scanner developed for an American Company. The second is a hot bar diameter and straightness gauge developed jointly by IPL and the British Steel Corporation. Another joint development to measure the cross section of hot bar is briefly described.

187. Color Sensing System for an Industrial Robot. Heda, M.; Matsuda, F. and Sake, S. (Nagoya Univ., Japan). (In, Proc. 10th International Symp. Industrial Robots/5th International Conf. Industrial Robot Technology, 5-7 March 1980, Milan, Italy), organized by IFS (Conferences) Ltd. Bedford, UK, IFS (Publications) Ltd., 1980.

System consists of three photo-diodes with a colour filter, a mini-computer and A/D, D/A converter. It can identify three colour components of an object surface and instruct the robot using the programming language.

188. 3-D Vision For Robotic Systems. Luh, J. Y. S. and Yam, E. S. (Purdue Univ., West Lafayette Ind.). (In, Proc., 1st International Conference on Robot Vision and Sensory Controls, 1-3 April 1981), Stratford-upon-Avon, UK, organized by IFS (Publications) Ltd., 1981.

Includes a useful literative review covering the period 1968 to 1980, and using a syntactic approach, a systematic method is developed for identifying a 3-D polyhedral object from a 2-D camera image.

189. Computer Vision Data-Base for the 'Industrial Bin of Parts' Problem. Baird, M. L., General Motors Corporation Laboratory, Research Publications. GMR-2502, August, 1977.

Provides a data-base of digitized images of parts in a bin, which may be used to develop, test and compare computer techniques for determining the position of these parts for robot pick-up.

190. Approach To Programmable Computer Vision For Robotics. Holland, S. W., General Motors Corporation, Research Laboratory Publication GMR-2519, August 1977.

The system determines the position and orientation for industrial parts relying on spatial or positional relationships and is tolerant of poor data or noise. The objective is an automated assembly line where the visual part location could provide feedback to a robot manipulator.

191. Computerized Inspection Using Advanced Optical Systems. Searle, R. H. (Jones & Lamson, USA) Society of Manufacturing Engineers Paper No. AD77-731, November 1977.

Presents the evolution of the optical comparator from the tool room manual, general purpose measuring system into an automatic electro-optical image analyzing system. The various steps in adding electronic digital display combined with variable speed power drives, numerical control of positioning, computer digestion of data, automatic photo-sensitive device reading of image edge position and the replacement of the human factors in the decision process are discussed.

192. Programming a Parallel Computer For Robot Vision. Armstrong, J. L., Computer, 21, 3, August 1978.

Work at the University of Edinburgh has moved towards the automatic recognition and inspection of objects in an industrial environment using a television camera. A need for such systems arises in the context of numerically controlled machine tools.

193. Vision Controlled Subassembly Station. McGhie, D. and Hill, J. W. (SRI International, USA) Society of Manufacturing Engineers Paper No. MS78-685, 1978. Dearborn, Society Manufacturing Engineers, 1978.

An assembly station which uses computer vision and other sensors to minimize the use of jigs and fixtures is described. The assembly station which includes a robot arm with a special force controlled gripper, an x-y table, and a computer vision system, is used to place and fasten the cover of an air compressor.

194. Computer-Controlled Object Identification Using Visual Sensors. Spur, G.; Kraft, H. R. and Sinning, H. (Technical University of Berlin, Germany). (In, Proc. 8th International Symposium Industrial Robots/4th Conference Industrial Robot Technology, Stuttgart, 30 May-1 June 1978, 2 Vols). Bedford IFS (Publications) Ltd., 1978, 2.

Relatively inexpensive image sensors based photoelectronics are available at the present time. These semiconductor sensors have been used in a computer controlled image processing system. Tests have been carried out to process information from digitized grey light levels using a digital computer.

195. Robots and Their Advantage in Inspection. Kirsch, J., SPIE Seminar Proc. 179, Option in Quality Assurance 2, Los Angeles, Calif., 22-23 January 1979, Bellingham, Washington, SPIE, 1979.

Non-contact optical sensors coupled with computer technology used with continuous path robots allow for inspection and for decisions to be made which exceed the capabilities and reliabilty of humans. The robot's arm can position the camera to many inspection points on an assembly and performs video gauging function at each pre-programmed position.

196. Programmable Part Presenter Based On Computer Vision and Controlled Tumbling. Hill, J. W. and Sword, A. J. (SRI International Symp. Industrial Robots/5th International Conf. Industrial Robot Technology, 5-7 March 1980, Milan, Italy), organized by IFS (Conferences) Ltd. Bedford, UK, IFS (Publications) Ltd., 1980.

Mechanism described can take randomly oriented parts up to 150mm long and place them in a required orientation. This is a general purpose concept requiring no special tooling or fixtures. The sensor is a computer vison system that determines stable state, location and orientation.

197. How Robots Are Improving Their Eyesight. Product Engineering, 59(3), March 1980.

Examines recent developments in robotic vision for metal working shop-floor applications and describes the complex problems involved in getting the industrial robots to 'see'. The majority of today's robots are programmable memory controlled machines that are also open loop and contain several degrees of freedom.

198. Robotic Drilling and Riveting Using Computer Vision. Movich, R. C. (Lockheed-California Co., USA). Society of Manufactuirn Engineers, Paper No. MS80-712 (1980). Dearborn, Society Manufacturing Engineers, 1980.

An experimental program using computer vision as a sensory feedback method for automated fastening of aircraft structures is described. Computer vision was investigated for training, calibration, recognition, determination of position and orientation, fine positioning, verification, and inspection.

APPENDIX B

PRODUCT LITERATURE

A. Applicable Equipment List

Air Technical Industries

7501 Clover Ave.
Mentor, Ohio 44060
(216) 951-5191
(800) 321-9680

Equipment: Material handling robots

1) Robo-Arm, spherical coordinate robot, hydraulically operated, 250 lb. capacity, and 126 in. maximum reach.

Asea

Industrial Robot Division
1176 East Big Beaver Rd.
Troy, Michigan 48084
(313) 528-3630

Equipment: Material handling robots

1) IRB 60/2, revolute robot, electrically operated, 132 lb. capacity, 90 in. maximum reach.

Bendix

Robotics Division
21238 Bridge Street
Southfield, Michigan 48034
(313) 352-7700

Equipment: Material handling robots

1) ML-360 CNC, revolute robot, electrically operated, 150 lb. capacity, and 98 in, maximum reach.

Cincinnati Milacron

Industrial Robot Division
Mason-Morrow Rd.
South Lebanon, Ohio 45036
(513) 32-4400
(800) 243-8160

Equipment: Material handling robots

1) T^3-566 Robot, revolute robot, hydraulically operated, 225 lb. capacity, and 102 in. maximum reach.

Cybotech

P. O. Box 88514
Indianapolis, Indiana 46208
(317) 298-5890

Equipment: Material handling robots

1) H80, cylindrical coordinate robot, hydraulically operated, 175 lb. capacity, 79 in. maximum reach.

GMF

56000 New King St.
Troy, Michigan 48098

Equipment: Material handling robots

1) M-2, cylindrical coordinate robot, electrically operated, 176 lb. capacity, 47 in. reach.

2) S-3, revolute robot, electrically operated, 132 lb. capacity, 118 in. maximum reach.

Prab

5944 E. Kilgore Road
Kalamazoo, Michigan 49003
(616) 329-0835

Equipment: Material handling robots

1) 4200 HD, spherical coordinate robot, hydraulically operated, 125 lb. capacity, 82 in. maximum reach.

2) Model FA, cylindrical coordinate robot, hydraulically operated, 250 lb. capacity, 78 in. maximum reach.

Unimation

Shelter Rock Lane
Danbury, Connecticut 06810
(203) 744-1800

Equipment: Material handling systems

1) 2100 B, 2100 C, spherical coordinate robot, hydraulically operated, 300 lb. capacity, and 115 in. maximum reach.

Westinghouse

Industry Automation
400 High Tower Office Building
400 Media Dr.
Pittsburgh, Pennsylvania 15205
(412) 778-4374

Equipment: Material handling robots.

1) Series 6000, cortesian coordinate robots, electrically operated, 100 lb. capacity, 48" X 108" work space.

B. Companies Not Meeting Specifications

Acco-Babcock

Material Handling Group
Industrial Lifters Division
Route 37 North, Box 298
Salem, Illinois 62881
(618) 548-0275

Equipment: Vacuum systems

Advanced Robotics Corp.

Bldg. 8, Newark Ohio Industrial Park
Hebron, Ohio 43025
(614) 929-1065

Equipment: Welding robots

American Robot

354 Hookstown Rd.
Clinton, Pennsylvania 25026
(412) 262-2085

Automation Designs

400 Franklin Street
Briston, Rhode Island 02809
(401) 253-2064

Equipment: Automatic feeders

Automatix

217 Middlesex Tpke.
Burlington, Massachusetts 01803
(617) 667-7900

Equipment: Welding robots and vision systems

Bird-Johnson

110 Norfolk St.
Walpole, Massachusetts 02081
(617) 668-9610

Equipment: Parts and accessories

Currie Manufacturing

1150 Walsh Ave.
P. O. Box 192
Santa Clara, California 95052
(408) 727-0422

Equipment: Machines for stacking boxes

Everett/Charles

700 E. Harrison Ave.
Pomona, California 91767
(714) 625-5571

Equipment: Light assembly robot, vision systems

Excel

Material Handling Systems
1103 Cooper Ave
Fenton, Michigan 48430
(313) 629-1591

Equipment: Automatic conveyor systems

General Numeric Corp.

390-T Kent St.
Elk Grove Village, Illionis 60007
(321) 640-1595

Equipment: Controls

IBM Corp.

P. O. Box 3025
Boca Raton, Florida 33243
(800) 327-0166
(305) 998-2000

Equipment: Precision light assembly robots

International Robomation/Intelligence

2281 Las Palmas Dr.
Carlsbad, California 92008
(714) 438-4424

Equipment: Light material handling and vision systems

Kentronics, Inc. (Pendar)

1821 University Ave.
St. Paul, Minnesota 55104
(612) 645-7717

Equipment: Light material handling

Mobot Corp.

980 Buenos Ave.
San Diego, California 92110
(619) 275-4300

Equipment: Large manufacturing systems

PickOmatic Systems

P.O. Box 820
Sterling Heights, Michigan 48077
(313) 939-9320

Equipment: Feeders

Planet Corp.

1820 Sunset Ave.
Lansing, Michigan 48917
(517) 372-5350

Equipment: Large material handling systems

Positech Corp.

Rush Lake Road
Laurens, Iowa 50554
(712) 845-4548

Equipment: Material handling systems

Reis Machines

1150 Davis Rd.
Elgin, Illinois 60120
(312) 741-9500

Equipment: Light material handling and machining

Rotomation

525 Carswell Ave., Unit M
Daytona Beach, Florida 32017
(904) 255-1101

Equipment: Parts

Schrader Bellows Div.

Schovill, Inc.
202 W. Exchange St.
Akron, Ohio 44309
(216) 375-5202

Equipment: Parts and light assembly

Seiko Instruments

2990 West Lomita Blvd
Torrance, California 90505
(213) 530-3400

Equipment: Light, high precision assembly

Sterling-Detroit Company

261 East Goldengate
Detroit, Michigan 48203
(313) 366-3500

Equipment: Die casting equipment

United States Robots

650 Park Ave.
King of Prussia, Pennsylvania 19406
(215) 768-9210

Equipment: Light assembly robot

The folowing companies manufacture educational robots:

A-B Tool, Engrd. Automation

Automated Process, Inc.

Dynamco

Taumel Assembly Systems

Swanson Erie Corp.

The following companies did not respond to our request for information:

Auto-Place, Inc.

Eaton/Kenway

GCA, Ind. Systems Group

General Electric

Hitachi America

MTS Systems Corp.

Machine Intelligence

Thermwood Corp.

Towa Corp.

Wes-Tech Inc.

C. Systems Designing Companies

Ameco Corp.
P. O. Box 385
Menomonee Falls, Wisconsin 53051

Auto-Robotics, Inc.
P. O. Box 324-T
South Orange, New Jersey 07079

Com Tal Information Systems
1239 Wolters Blvd., Dept. T.
St. Paul, Minnesota 55110

ISI Manufacturing Inc.
31915 Grosebeck Hwy.
Fraser, Michigan 48026

Design Technology Corp.
53 Second Ave.
Burlington, Massachusetts 01803

Midway Machine & Eng.
2324 University Ave.
St. Paul, Minnesota 55114

Munden Corp.
3421 E. La Palma
Anaheim, California 92806

Rob-Con
12001-T Globe Rd.
Livonia, Michigan 48150

Toshiba Seiki Robots
Fleximation Systems Corp.
Automation/Robotics Dept.
53T Second Ave.
Burlington, Massachusetts 01803

Turchan Enterprises, Inc.
128 - 25 T Fond Rd.
Dearborn, Michigan 48126

VSI Automation, Inc.
165-A Park St.
Troy, Michigan 48084

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