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MARS UMBILICAL TECHNOLOGY DEMONSTRATOR

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ABSTRACT

The objective of this project is to develop a autonomous umbilical mating for the mars umbilical technology demonstrator. The Mars Umbilical Technology Demonstrator (MUTD) shall provide electrical power and fiber optic data cable connections between two simulated mars vehicles . The Omnibot is used to provide the mobile base for the system. The mate to umbilical plate is mounted on a three axis Cartesian table, which is installed on the Omnibot mobile base. The Omnibot is controlled in a teleoperated mode. The operator using the vision system will guide the Omnibot to get close to the mate to plate. The information received from four ultrasonic sensors is used to identify the position of mate to plate and mate the umbilical plates autonomously. A successful experimentation verifies the approach.

1. INTRODUCTION

The goal of this project is to design and implement a smart umbilical with a connect and re-connect capability with remote interface verification. The ability to quickly and reliably mate and de-mate umbilical connections under automated control is needed in flights to mars [1]. After review of mars reference mission [1], three umbilicals (i) electrical power/fiber optic data cable umbilical; (ii) mars rover cryogenic servicing umbilical; and (iii) contingency in-situ propellant production water supply umbilical were identified. The electrical power/fiber optic data umbilical is mission critical since it must provide immediate power to the hab/crew vehicle and was chosen for a technology demonstration project.

The Mars Umbilical Technology Demonstrator (MUTD) shall provide electrical power and fiber optic data cable connections between two simulated mars vehicles (cargo vehicle and hab/lab vehicle) spaced 100 meters apart. The MUTD shall deploy 100 meters of electrical and fiber optic cables from the simulated hab/lab to the simulated cargo vehicle. The MUTD shall align the surface and the vehicle umbilical plates and parallel mate the connectors in an accurate manner.

The Omnibot mobile base system [12] at automated ground support system laboratory at Kennedy Space Center will provide the mobile base for the MUTD. The Omnibot is controlled in a teleoperated mode. The umbilical plate is mounted on a three axis Cartesian table on the Omnibot. The table is used to mount the two umbilical plates.

The problem of automated umbilical mating can be divided into two subproblems, global and local positioning. The global positioning is defined as when the two umbilical plates do not have any vertical common projection on each other, and the problem is to bring them close enough such as they do. If two plates have any common vertical projection on each other, the problem to mate them from now on is refereed to as the local positioning.

For global positioning, a teleoperated mode of control is used to move the Omnibot such that the umbilical plates are in local positioning zone. The operator uses vision feedback to command the Omnibot during global positioning and bring the mate in plate to about 14 inches from mate to plate. The work explained in this report will concentrate on the local positioning problem.

The umbilical mating is performed autonomously during local positioning. During local positioning , the position and orientation of mate to plate needs to be determined. Ultrasonic sensors are used to find the position of mate to umbilical plate. At current stage, the project requirement is to have a system functional at Kennedy Space Center. Therefore, the mars environment is not considered.

To identify the position of the plate to mate to, four ultrasonic sensors are installed in the four corner of mate in plate as shown in figure 1. The sensors are numbered clockwise.

Ultrasonics sensors are used extensively in mobile robots [2-7] applications. Sonar sensing, is cost effective, relatively quick in response, processing is not time consuming, and can cover wider distance range. The edge 1 (E1) is defined across sensors 1 and 2 as shown in figure 1. The following steps outline the procedure for local positioning of autonomous umbilical mating:

1. Obtain raw distance data d_1 ,d_2 ,d_3, and d_4 from the four ultrasonic sensors
2. Filter and separate the data according to constraints
3. Engage and apply least square estimation procedure to obtain the line segments
4. Based on the obtained edge position, the manipulator on the Omnibot is autonomously moved to align two umbilical plates and mate them successfully (ie. all four edges of the two plates line up and connect with each other).

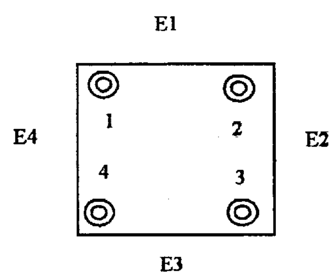


Figure 1. Location of four ultrasonic sensors

This report summarizes the work completed during the summer of 1999. The use of ultrasonic sensors is detailed in Section 2. Section 3 discusses the determination of plate position using the four ultrasonic sensors. The experimental set up and results are presented in Section 4. The discussions and conclusions are presented in Sections 5 and 6, respectfully.

2. ULTRASONIC SENSORS

The ultrasonic sensors work on the principle of sound. Sound is a sequence of waves of pressure which propagates through compressible media such as air or water. Sounds can propagate through solids as well, but there are additional modes of propagation. During their propagation, waves can be reflected, refracted, or attenuated by the medium. A relationship between density and pressure , affected by temperature, determines the speed of sound within medium. The viscosity of the medium determines the rate at which sound is attenuated. For many media, such as air and or water, attenuation due to viscosity is negligible. More information about ultrasonic sensors and their properties are found in [9,10].

The ultrasonic sensors could be used to measure and detect distances to moving objects, impervious to target materials, surface and color; solid –state units have virtually unlimited , maintenance-free lifespan; detects small objects over long operating distances;

and resistant to external disturbances such as vibration, infrared radiation, ambient noise and EMI radiation . Ultrasonic sensors are not affected by dust, dirt or high-moisture environments.

The effect of temperature change [11] that should be considered in calibration is indicated by

$$\mathrm{ADC} = 0.0019 \times \mathrm{D} \times \Delta\mathrm{F} \tag{2}$$

where ADC is the apparent distance change, D is the distance from transducer to target in inches, and ΔF is change in temperature in Fahrenheit.

The ultrasonic waves transmitted by the piezoelectric ring have approximately a cone shaped band [11]. The distance is calculated based on time of flight. To calculate the distance more accurately the sensor needs to be modeled. An approximate mathematical models for the ultrasonic sensors are shown in figure 2. The desired distance D_i depends on the incident angle θ and sensor beam angle β. Assume $\theta \geq \frac{\beta}{2}$ as shown in figure 2a. The desired distance is calculated by

$$D_i = \frac{d_i \cos(\theta - \frac{\beta}{2})}{\cos\theta} \tag{3}$$

The angle θ can be calculate by the law of cosines and sine's by

$$x^2 = s_d^2 + \delta_d^2 - 2s_d\delta_d \cos(\frac{\pi}{2} - \frac{\beta}{2}) \tag{4}$$

and

$$\frac{\delta_d}{\sin\theta} = \frac{x}{\sin(\frac{\pi}{2} - \frac{\beta}{2})} \tag{5}$$

Otherwise if $\theta \prec \frac{\beta}{2}$, as shown in figure 1b , the incident angle θ needs to be determined by

$$\frac{\delta_d}{\sin\theta} = \frac{s_d}{\sin\frac{\pi}{2}} \tag{6}$$

The desired D_i is then calculated by

$$D_i = \frac{d_i}{\cos\theta} \tag{7}$$

Based on the distance information, it is determined which sensors are engaged with the plate during local positioning by

$$D_i - D_s \leq D_t \tag{8}$$

where D_i is the distance calculated from the ith sensor, D_s is the shortest distance read by any sensor, and D_t is the threshold distance. If equation (8) holds for the ith sensor, the ith sensor is considered to be engaged.

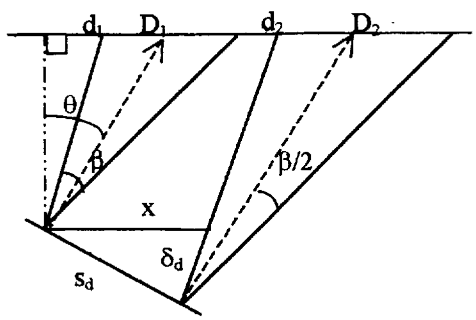


Figure 2a. Ultrasonic mathematical model: $\theta \geq \frac{\beta}{2}$

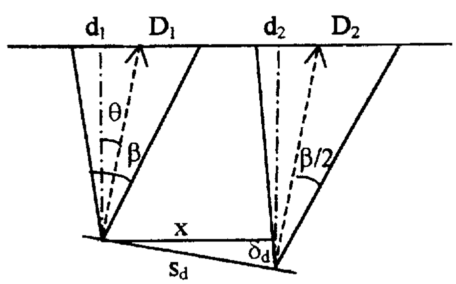
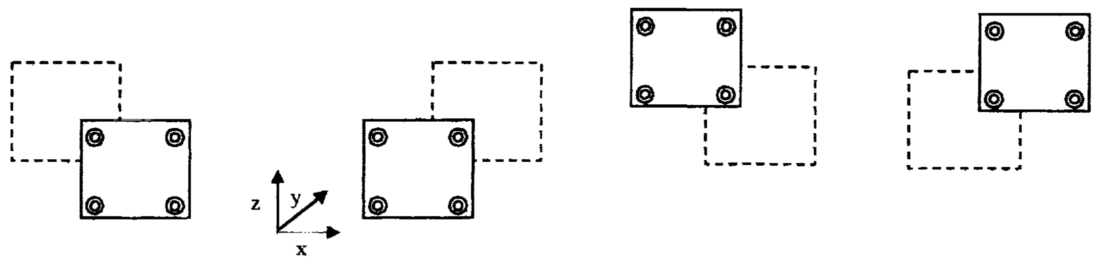


Figure 2b. Ultrasonic mathematical model: $\theta \prec \frac{\beta}{2}$

3. POSITION DETERMINATION OF THE UMBILICAL PLATE

As was indicated earlier the position and orientation of mate to plate needs to be determined. It is assumed that the orientation is known and fixed. The position of the plate to mate to is calculated based on identifying the edge feature of the plate. The procedure to determine the edges of the plate depends on which sensor is engaged as shown in the flowchart in figure 5.

Possible situations when one sensor is engaged are shown in figure 3. For this scenario the motion depends on which sensor is engaged. For example, if sensor 1 is engaged as shown in figure 3a, the strategy to engage four sensors are to move in the positive z-direction(up) to engage sensor 4. Then, the plate is moved in the negative x-direction (left) until all four sensors are engaged.

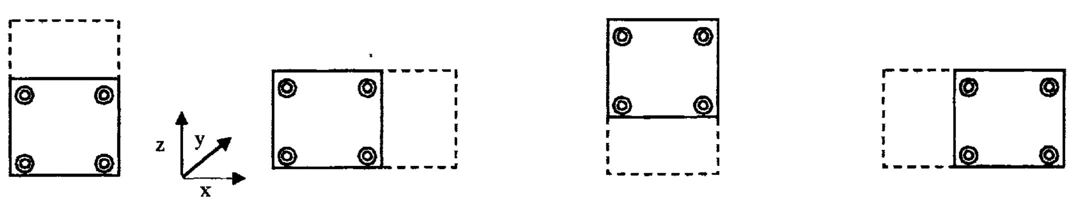


(a) (b) (c) (d)

Figure 3. Possible situations when one sensor is engaged

As shown in figure 4, four possibilities also exist for two sensors to be engaged. The strategy to move such as to engage four sensor depends on which two sensors are engaged. For example if sensors 1 and 2 engaged as shown in figure 4a, the motion command to the 3-axis Cartesian table will be to move in the positive z-direction (up) until all four sensors are engaged.

With the assumption that there is not any orientation mismatch around the y-axis between the two plates around the y-axis, the scenario where three sensors engaged should not happen. In case that happens the strategy is to move the plates closer to each other in the y-direction and recheck the situation.



(a) (b) (c) (d)

Figure 4. Possible situations when two sensors are engaged

The objective of the approach is to engage all four sensors engaged and move the plates to about four inches apart in the y-direction as indicated in the flow chart shown in figure 5. At this point the algorithm to find the edges of the plates are initiated.

To identify vertical edges vertical edges E2 and E4 shown in figure 1, the manipulator is moved in the x-direction until sensors 2 and 3 are disengaged. This position is marked as

$xpos_{23}$. Then the manipulator is moved in the negative x-direction monitoring the sensors until sensors 1 and 4 miss the plate. This position is also marked as $xpos_{14}$. All positions are determined with respect to the home coordinate frame of the table. With the obtained information one point on both vertical edges can be estimated. The same procedure is repeated in the y-direction to estimate a point on the top and bottom edges (E1 and E3) of the plates.

The least square algorithm is used to find the best fit based on the estimated positions. To estimate a line uniquely, with orientation uncertainty, at least two points are needed . To obtain the second point the mentioned procedure is repeated.

4. EXPERIMENTAL SET UP AND RESULTS

An experiment conducted to verify the feasibility of the proposed approach. The objective of this experiment is to align two plates autonomously using ultrasonic sensors during local positioning. The experimental set up is shown in figure 6. In this experiment , four Migatron ultrasonic sensors installed in the four corner of mate in plate are used. The sensors analog output is connected to a multifunction I/O card with 16-bit analog input. The location of receiving plate is fixed . The dimensions of both plates are 12″×12″ with the thickness of 1/8″. The plates are made of aluminum. The other umbilical plate is mounted on a three axis Cartesian table on the Omnibot mobile base.

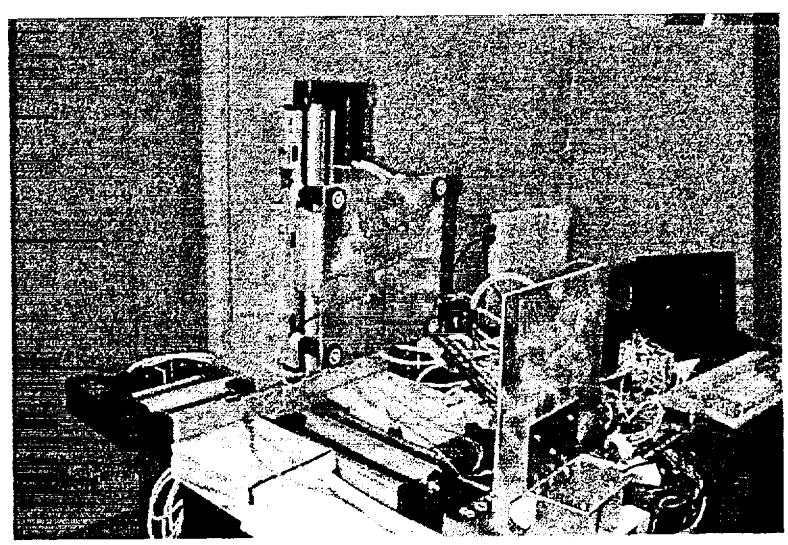


Figure 6. Experimental Set Up

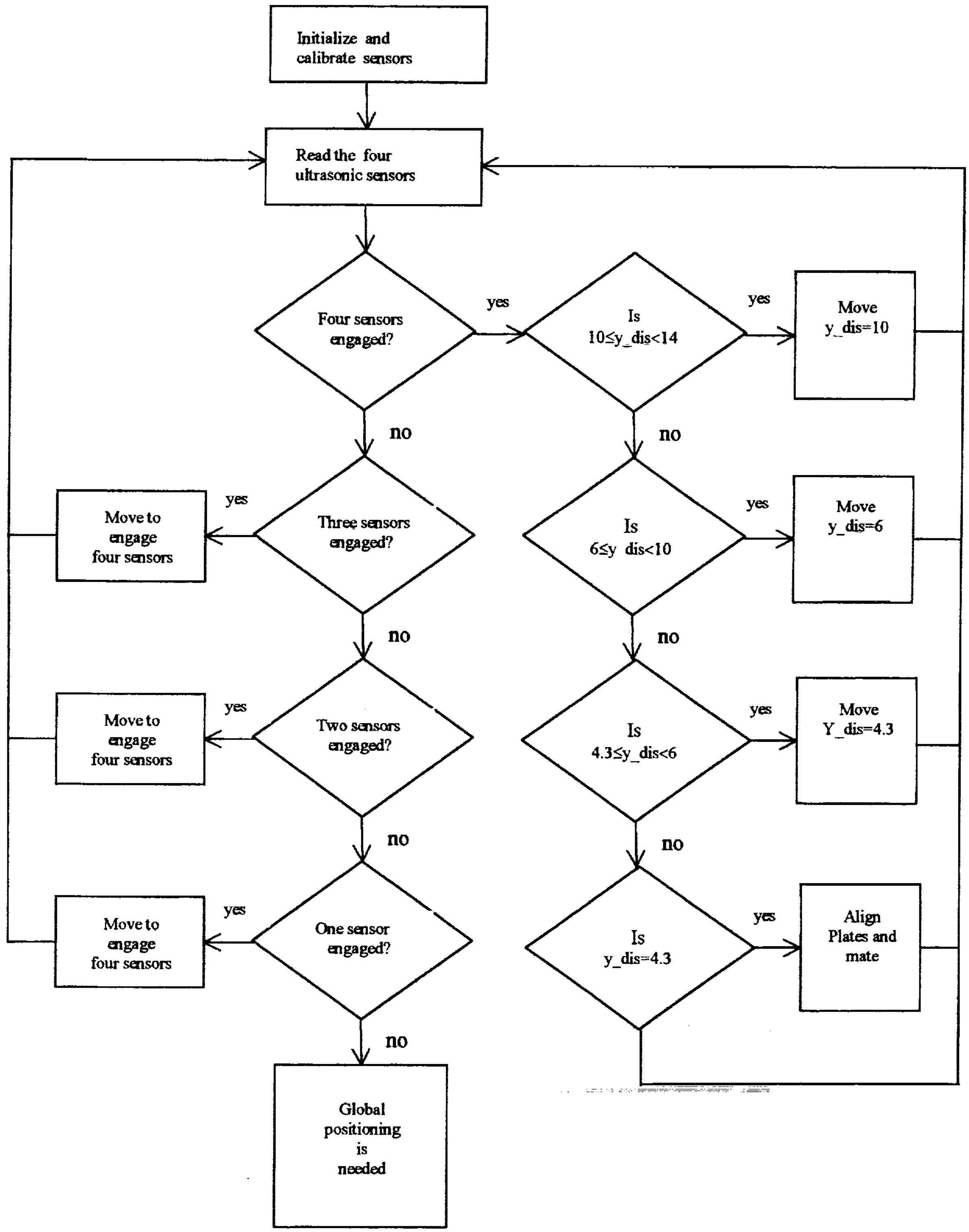


Figure 5. Local positioning software flowchart

A Migatron narrow beam band analog ultrasonic sensor mounted in a self-contained barrel housing is used in this project. It is powered by 20-30 VDC and is reverse polarity protected. The frequency of operation of the sensor is 212 kHz for the 4" to 40" range. The 0-10 VDC analog output of the sensor is connected to 16-bit resolution Versalogic I/O card. The sensor output can easily be scaled over range of 4"-40" by adjusting the zero and the span control.

The Omnibot mobile base [12] is controlled remotely by a operator using a control box. A joystick, an RF transmitter, and number of switches (power, low/high speed, E-stop, and a deadman) make up the control box. The communication between the control box and the mobile base computer is established using an RF modem. The STD-32 star multiprocessing computer system is used to control the wheels of the mobile base and the 3-axis Cartesian table in conjunction with a motion controller. The software program is written using C language on a DOS operating system platform. The operator using the vision feedback [12] will bring the Omnibot within 14 inches of the umbilical plate . Then, the operator will switch the system to the autonomous mode from the command base.

The program is written to perform the autonomous mating based on the flow chart shown in figure 5. The four sensors are engaged and the plate edges determined as described in Section 3. The edges are estimated within ±0.05 inches by using only one point on each edge. By repeating the edge finding for 10 times, the edges can be estimated within ±0.042 inches. We considered the improvement to be minimal and decided to perform the autonomous aligning based on one point.

5. DISCUSSIONS

Other sensors like vision and laser range finder could have been used for this project. The objective of the visual sensing is to locate the receiving umbilical plate using appropriate features. Edge detection techniques could be used to determine plate location in 2-D space. Problem with using vision system is that natural lighting and shadows can distort the information received. The alternative to overcome this problem is active techniques of acquiring images. Images may be acquired by active techniques like ultrasound and laser projection. The ultrasonic sensors are simple to use, provide wider view, and more cost effective. For the future work, considering mars environment, the same approach can be implemented by using the laser sensors.

In the final stage of the project, there will be a passive compliance build into umbilical plate with guided cones. This arrangement will insure to avoid excessive forces during umbilical plates mating and insure the proper alignment. As experimentation showed the umbilical plates are aligned within 0.05 inches. Being able to align the plate this accurately means the guided cones will be small. The passive compliance will also be designed to take care of couple of degree of orientation misalignment in the system.

6. CONCLUSIONS

As was mentioned earlier, the positioning problem of mars umbilical technology demonstrator was divided into global and local positioning control problems. The teleoperated controlled Omnibot [12] provided the solution for the global positioning. my main emphasis was autonomous local positioning which is the main contribution made during the summer of 1999. The system hardware and software platform for local positioning was designed and implemented. The approach verified successfully by experimentation and achieved the goal of autonomous local positioning within specification. As was indicated in the introduction, the ultrasonic sensors are extensively used in mobile robot application for collision avoidance. To the best of the author knowledge, there is not any previous work using the ultrasonic sensors for the fine positioning as explained in this report.

For future work, the following tasks are to be completed for this project: (i) Integrating the three axis Cartesian table hardware and software with Omnibot mobile system hardware and software; (ii) Checking the overall positioning system;(iii) Applying experience gained and concept to the mars environment. Another possible application of this work is automated umbilical mating for the shuttle launch. Umbilicals represent a significant portion of the infrastructure and operational costs associated with launch vehicle turn around. The ability to quickly and reliably mate umbilical connections under automated control would reduce the time and labor hours required preparing for launch.

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