A NEW PROGRAMMABLE 3D RANGE CAMERA

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ABSTRACT

A new programmable 3D laser range camera is developed for Robot Teleoperation in hazardeous environment. The aim was to build a 3D laser range camera with attractive features for users friendly Teleoperation of mobile robot. BERTIN & Cie was in charge of the development of the 3D laser imager and ETNOTEAM was in charge of the development on an user friendly Man-Machine Interface for Teleoperation purpose. The current presentation describes in details the new characteristics and performance of the 3D Laser Range Camera. Furthermore, preliminary results of the system in an environment including shining metal objects are proved.

1. INTRODUCTION

In order to reduce human intervention in hazardeous environment like accidental power plan, the European Economic Community, has initiated a research and development program called TELEMAN.

We describe the development of a 3D laser range camera prototype, ultimately suitable to Mobile Robot Teleoperator in hostile radioactive regions on nuclear plans. The project is one of 16 funded under the European Community TELEMAN program and intends to the development of tools for "Remote operations in hazardeous or desordered nuclear environment.
The programmable 3D laser range camera is shared in 3 mains subsystems.

Firstly :the digital laser telemeter, based on digital phase measurement is able to achieve an high rate measurement of 100 kHz, the precision is greater than 0,5 % of the maximum range (25 meters).
Secondly : the programmable optical scanning system is monted in front of the telemeter and allows th construction of the 3D images. The scanning system, based on galvanometers devices, is entirely programmable trhough a P.C. allowing the control of the frame rate, from 0 (pointing mode) to 4 Hz from the optical zoom (5°-50°) and the optical offset fluctuates between 5° to 50° max.
Thirdly : an interactive users friendly Man-Machine Interface (MMI) is based on windows software : this sofware allows a full real time control of the telemeter parameters, such as frame rate, optical zooming, optical offset of the F.O.V. etc... More than the control of the telemeter, the software includes usefull function of the exploitation of the 3D data.
The current presentation describes in details the new characteristics and performance of the 3D Laser Range Camera. Furthermore, preliminary results of the system in an environment including shining metal objects are proved.

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2. PRINCIPLE OF THE 3D LASER TELEMETER

2.1 - Digital double phase measurement principle

The 3D Laser Range Camera is based on the concept of digital phase measurement. The source (a single mode laser diode) is intensity modulated at a given frequency (few MHz), and the phase difference between the transmitted light and the received light after reflection on a target is measured. This phase difference is directly proportional to the target range :

$$\Delta\varnothing = 4\Pi F \frac{R}{C}$$

Where :

F : Laser diode frequency

R : Range between the target and the receiver

C : Light velocity

$\Delta\varnothing$: Phase difference between the transmitted and collected light.

The maximum non ambiguity range is given when $\Delta\varnothing = 2\pi$

$$2R = \frac{C}{F}$$

For the R = 100 m, F ≈ 1 MHz. In order to resolve few centimeters in the range we need to resolve few milliradians in the phase which is not compatible with digital high data rate computation (100 KHz).

In order to overcome this difficulty the source which consists in one laser diode, is modulated at both low and high frequency (double modulation). The low frequency (≈ MHz) allows a rough measurement of the range, while the high frequency (20-30 MHz) gives the required resolution (few centimeters).

The non ambiguity measurement of the high resolution (few meters) is removed by using the following calculation :

$$\varnothing_L = 4\Pi F_L \frac{R}{C} \quad \varnothing_H + 2k\Pi = 4\Pi F_H \frac{R}{C}$$

where :

$\varnothing_L$: Phase shift due to the low frequency

$\varnothing_H$: Phase shift due to the high frequency

k : Integer number

The non ambiguity is removed in two steps :

$$k = \text{Integer}\left\{\frac{1}{2\Pi}\left(\frac{F_H}{F_L}\varnothing_L - \varnothing_H\right)\right\}$$

Then the range is calculated as follows :

$$R = \frac{C}{2F_H}\left\{\frac{\varnothing_H}{2\Pi} + k\right\}$$

It is obvious to noticed that this algorithme requires a phase measurement resolution no more than 100 mrd possibly achieve with a 8 bits digital phase meter (25 mrd of resolution).

2.2 - Programable fast scanners

The high telemeter performance (good SNR), even with very small entrance pupil (smaller than 20 mm diameters) allows the utilisation of non resonance galvanometer optical scanners of low inertia (1 $g.cm^2$ for the line scanning). This type of galvanometers is compatible with high frequency (200 Hz) as well as for large field of view.

A system composed of two crossed non-resonant galvanometers were build and integrated in the range laser camera.

The main advantages of this technology alternative is that the galvanometer scanner is easy to program in real time. One can modifie frame rate, field of view and obtain a programable scanning systems devices through the modification of the input signal to the scanner's.

3. CHARACTERISTICS AND PERFORMANCE OF THE 3D LASER RANGE CAMERA

3.1 - The range camera characteristics

The main sub-system of the 3D Laser Range Camera are as follows :

* ***Computer programable scanning unit based on two crossed galvanometers***
* ***Transmission/reception optical unit***
* ***Eectronic detection and processing module, providing the range information in both digital and analogic formats.***
* ***Real time visualisation of the 3D image in false colour.***
* ***P.C. work stations, having the capability to control the different telemeter parameters, like zoom, image rate and integration time.***

All this sub-system are integrated in a relative small volume (300x200x150). Figure 1 provides a picture of the L.R.C.
In addition to the classical range measurement the L.R.C. has some attractive features :

➥ **Programable frame rate**

The variable image rate (0-4 Hz) which is controled by the P.C., has the capability to increase the spatial resolution from 100x100 pixels → 1000x1000 pixels.

➥ **Programable zoom**

The variable field of view (0-50°) acting as a optical zoom, can also be modified through the P.C.

➥ **Programable pixel rate**

The basic pixel rate can be reduce from 100 kHz → 12,5 kHz in order to increase the range resolution by paying the price of a much slower image rate.

➥ **Real time data access**

Real time visualisation of the 3D image with quasi real time access to the distance information on the acquisition card memory (delay of one frame).

➥ **Reflectance image synchronized with the 3D image**

From the collected laser beam an reflectance image (simillar to the CCD one) is constructed (example figure 4.b).

The overall achieved performance are as follows :

Principle	:	dual frequency phase shifting
Wavelength	:	830 nm
Optical power	:	100 mW
Range	:	1-35 m
Resolution	:	0,2 %
Pixel rate	:	up to 100 kHz
Image rate	:	up to 4 Hz
Image size	:	128x128 @ 4 Hz
		512x512 @ 0.5 Hz
Field of view	:	5°x5° up to 50°x50°

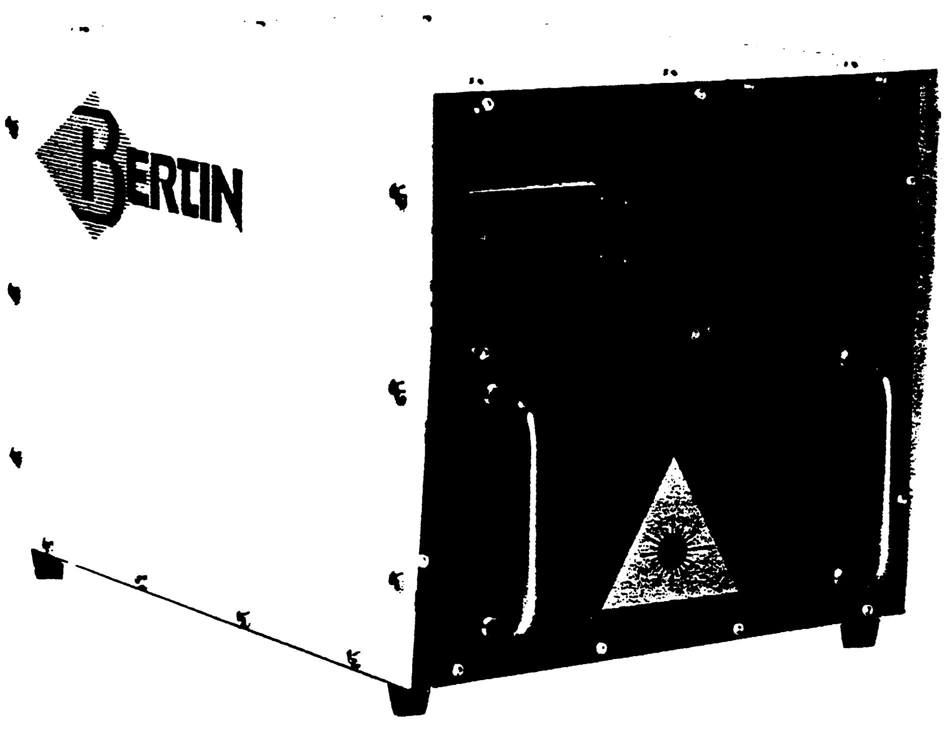

Figure 1 : Picture of the Laser Range Camera

3.2 - The Man Machine Interface (MMI)

The Man Machine Machine Interface allows user friendly utilisation of the above described telemeters parameter. As well the exploitation of the 3D data for Robot Teleoperation comparison between 2D data and 3D data or statistical and metrological analysis of the scene content can be performed easily. The MMI includes the control of CCD camera parameters such as exposure time, Zoom, Focus etc..., and lightening devices for indoor dark working condition.

The MMI is in charge of the control of the following functionality :

Range camera	*CCD Camera*
- *Optical Zoom*	- *Optical Zoom*
- *Frame rate*	- *Integration time*
- *Pointing laser mode*	- *Autofocus*
- *Integration time*	- *Iris*

An useful Image Processing package for 3D/2D data exploitation is developed in the same way (see figure 2 the structure of the whole system).

The Man-Machine Interface constitutes a most important part of software as we mentionned it previously ; attention has been carried to make it easy to use and to learn. It has been designed in order to be coherent and uniform for each functional area.

The interface is arranged like a control panel, with buttons and dialog boxes.

Each functionality is accessible to use menus ; the most frequently used of them are directly activated also by pushbuttons always visible on the upper part of the screen.

The main part of the screen is devoted to Video and Distance images.

Complexes activities are performed using dialog boxes, appearing when requested and disapearing when no longer necessary.

See on the Figure 3 the basic layout of the interface.

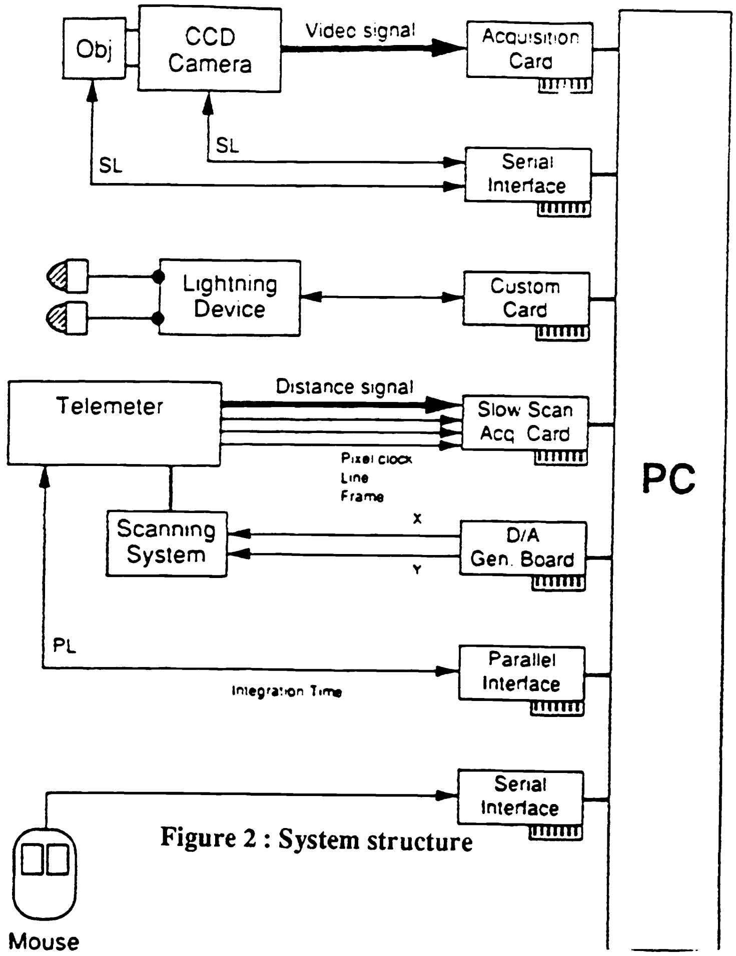

Figure 2 : System structure

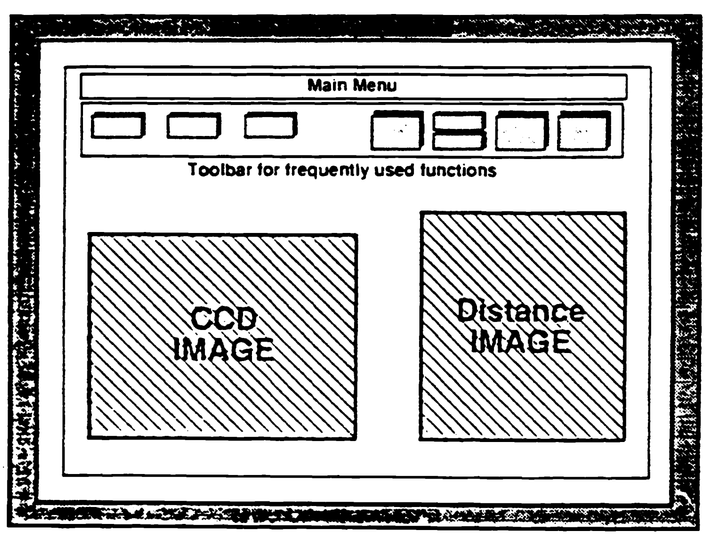

Figure 3 : Screen layout

4. EXPERIMENTAL RESULTS

The range V.S. output voltage signal is given in Figure 4. The measurement is performed with a digital volmeters in order to remove the noise and measure the distortions only.

The correlation to the best straight line is better than 0.9999, and the standard deviation is less than ±2 cm which is equivalent to a distortion less than 0,1 %.

Noise measurement is directly performed on the digital signal output. The fluctuation of the measured distance was recorded for 50 successive frame at a given distance , results are presented in figure 5. The noise was found ±4 cm (peak to peak).

We can conclude that we are mainly limited by the digital noise but not by the shot noise. The rsolution of the Telemeter might be better with an higher digital resolution phase counter.

In Figure 6a, 3D Image in outdoor environment is representing. We can noticed details less than 10 cm. Metal parts as any other object are measured.

The reflectance image is presented in figure 6b. The poor dynamic range is due to the relative low dynamic of the acquisition card in analogic mode.(less than 7 bits)

3D image in outdoor environment is shown in Figure 6c. No observable influence of the sun radiation can be detected.

All the picture are 512x512 pixels resolution at an image frequency of 0.5 Hz.

Figure 7 shown pictures of the Man-Machine Interface. The screen is divided in two parts. One devoted for the 2D image (CCD or telemeter reflectance data), the other one for the 3D range data. All the telemeter parameters can be modified interactivily through the M.M.I.

5. CONCLUSION

A State of The Art 3D range laser has been developped. The results of the characterization of the prototype proved that the main performances, resolution less than ±4 cm, programable zoom, 0-50°, and programable frame rate 0-4 Hz concluding pointing mode) were achieved.

Test in indoor environment, including test on shine parts, were performed and the experimental results were found in accordance with the goals specifications. Outdoor measurement were performed in order to verifie the influence of the sun and natural background (large range of albedo, I.R. absorption) on the 3D laser range measurement.

Experimentation of the M.M.I. proved its large capability for teleoperation manipulation, mainly due to the high level of user friendly of the software.

6. ACKNOWLEDGMENTS

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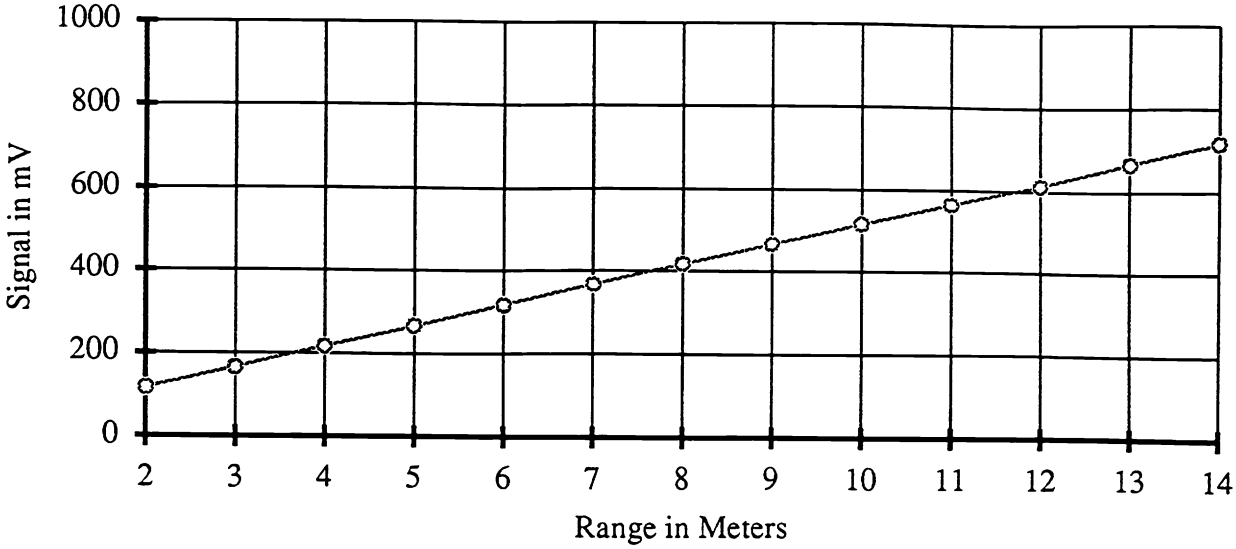


Figure 4 : Range V.S. output voltage signal

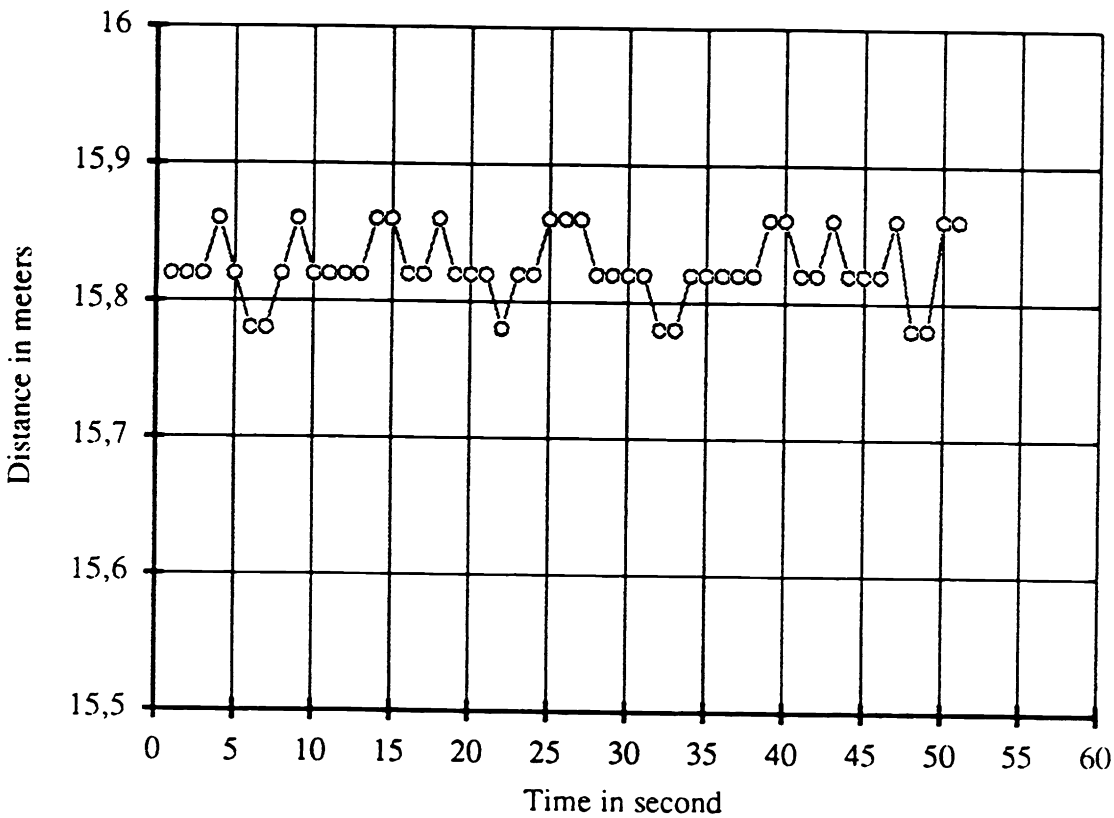


Figure 5 : Noise measurement

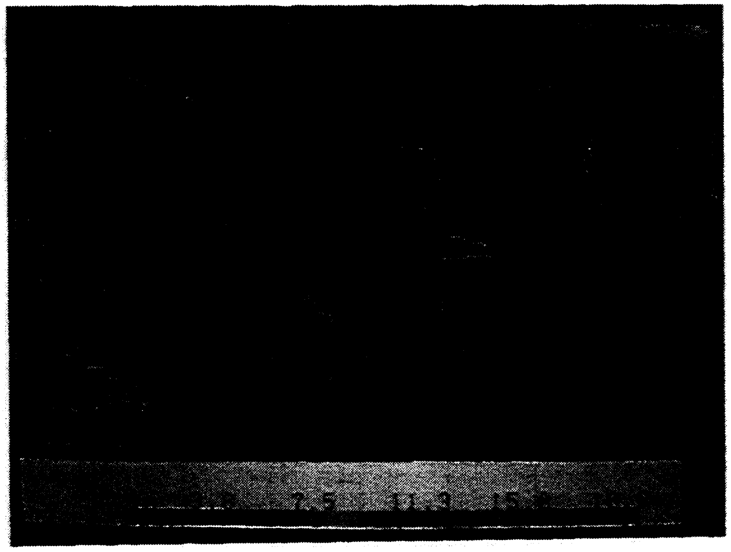


Figure 6a : 3D image in indoor environment

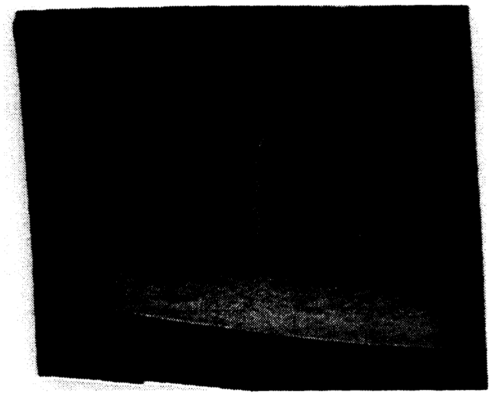


Figure 6b : Reflectance image

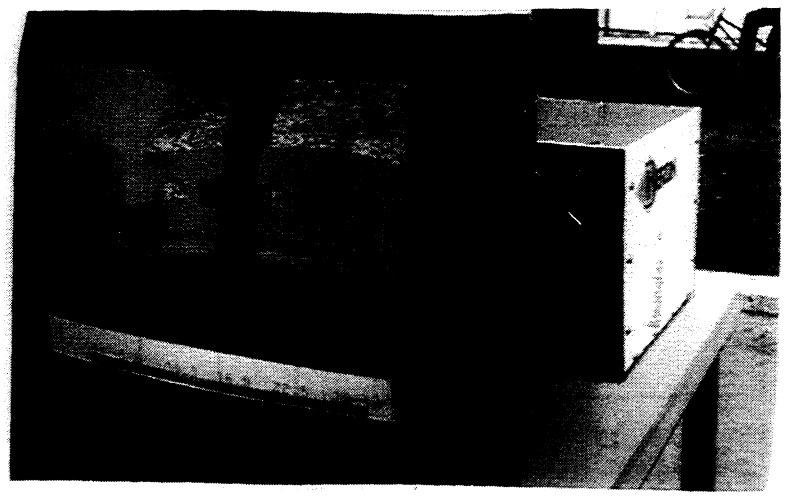
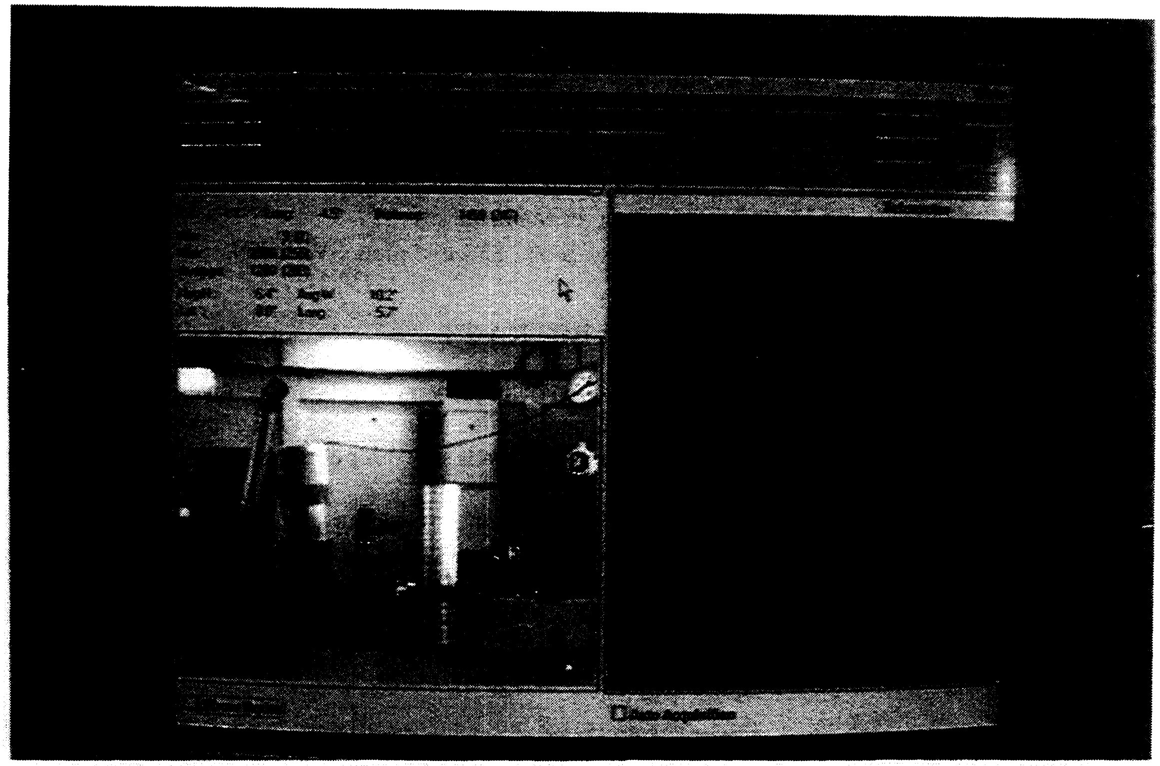


Figure 6c : 3D image in outdoor environment



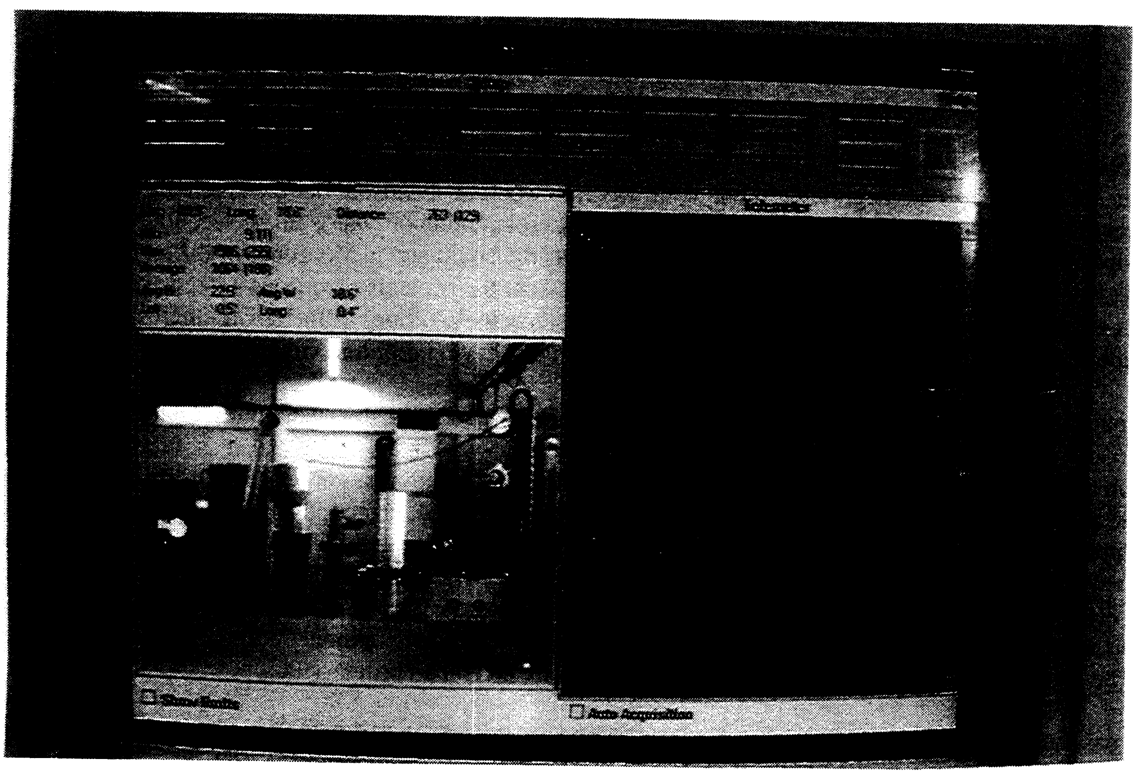


Figure 7 : Man-Machine Interface screen