Real World Application of a Low-Cost High-Performance Sensor System for Autonomous Mobile Robots

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Abstract - *Commercially successful autonomous mobile robot systems demand the development of new methodologies for dealing with "real world" requirements of very low cost and very high performance sensing technology for use in the constantly changing, dynamic, unstructured environments in which society expects such robots to operate unsupervised on a daily basis. This paper presents a new modular sensor system which, based on long term real world field trials appear to meet the basic requirements. Examples of test results in a wide variety of applications in unstructured environments are provided as well as future directions.*

Keywords: Intelligent Motion Control, Autonomous Mobile Robots, Sensory Fusion, Service Robots, Navigation Path Planning, Ultrasonics

DESCRIPTION

A major impediment in the development of commercially successful autonomous mobile robot systems has been the availability of a very low cost, yet very high performance sensor system. The incredible wealth of research on path planning and autonomous navigation architectures often assume either the presence of an "ideal" sensor, or the performance of real sensors in highly constrained environments to which that specific sensor is well adapted (for example, environments with simple or solid polygonal obstacles constructed of vertical surfaces). Hence, the research is of limited value to the real world which is characterized by the ever increasing frequency of novel and extremely creative furniture design which due to material composition and oblique planes often creates severe difficulties for low cost sensors. Even one failure to detect such an object out of a thousand trials would deem the technology commercially unacceptable in real world unstructured environments. Sensors which approximate ideal performance are available at very high cost, but this is of limited value to the real world.

To achieve the dramatically enhanced levels of "human scale performance" demanded in the increasingly unstructured types of environments in which mobile robots are being required to operate, sensor systems must fulfill certain fundamental requirements which include:

a) very low cost
b) very high immunity to ambient noise
c) very high sensitivity
d) immunity to signal loss due to angle of incidence, material composition, colour
e) immunity to cross-talk and multipath interference.

In our evaluations, camera vision systems met all requirements except the first. However, since the ultimate aim of the research was commercial viability, this approach was abandoned. Similarly laser imagers fulfilled all but the first objective and was hence also discarded (note however, that both camera vision and laser systems continue to be a focus of our research).

Conventional ultrasound techniques met the first requirement but required significant development to fulfill the remaining requirements. A novel modular ultrasonic array was developed which satisfied the requirements and which could be installed onto any mobile robot in either a master or slave controller configuration. The system is based on a unique rotating multi-transducer ultrasonic ranging array (Figure 1, 2, 3, 3a) and embedded parallel processing unit (Figure 4). Unlike conventional ultrasonic "rings" which cannot sense objects above, below or at the same level (in the case of oblique orientations) of the ring, the new system covers a 210° arc on 6 non-parallel planes thereby emulating the performance of 96 distinctly located fixed sensors all firing every 0.7 seconds.

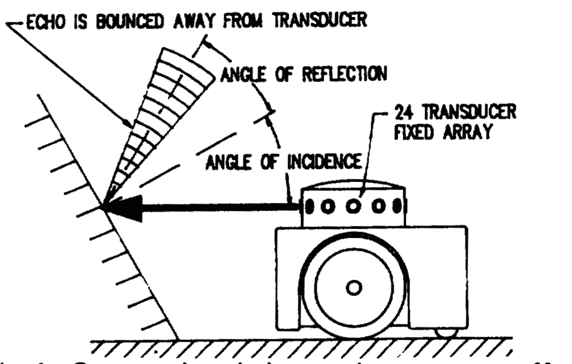

Fig.1: Conventional ultrasonic systems suffer from ray geometry issues (angle of incidence = angle of reflection), leading to sensing errors.

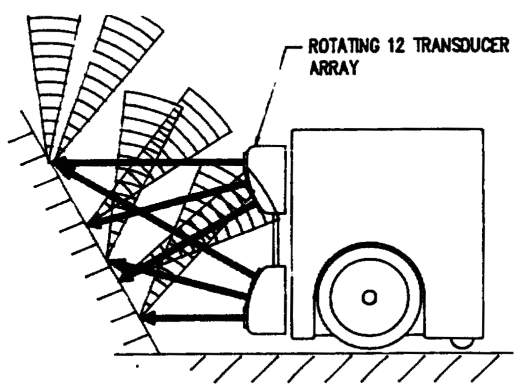

Fig.2: Cyberworks' rotating ultrasonic array ensures that some echoes are returned to the transducer.

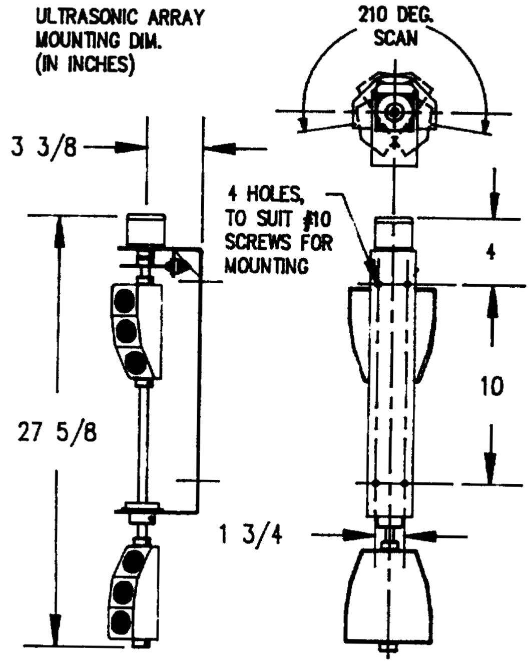

Fig.3: Schematic rotating ultrasonic array

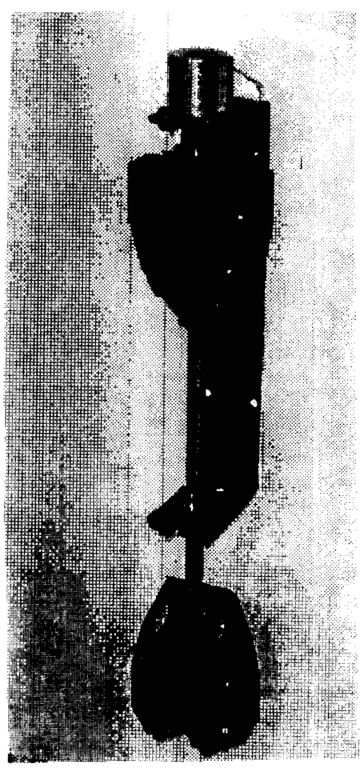

Fig.3a: Actual rotating ultrasonic array

Crosstalk and multipath echo interference problems commonly associated with multi-element arrays were eliminated by dividing the 12 rotating sensors into three banks of four transducers each utilizing two distinct frequencies which are digitally narrow bandpass filtered. The firing order of each bank is staggered and timed in such a way as to reduce crosstalk between sensors and the physical placement of each of the four transducers of each of the three banks further reduces the possibility of such interference problems. This advantage coupled with the system's very high sensitivity enables the sensor array to detect virtually any object regardless of orientation or texture. Multiple frequencies are used to counter specific frequency absorption of certain materials.

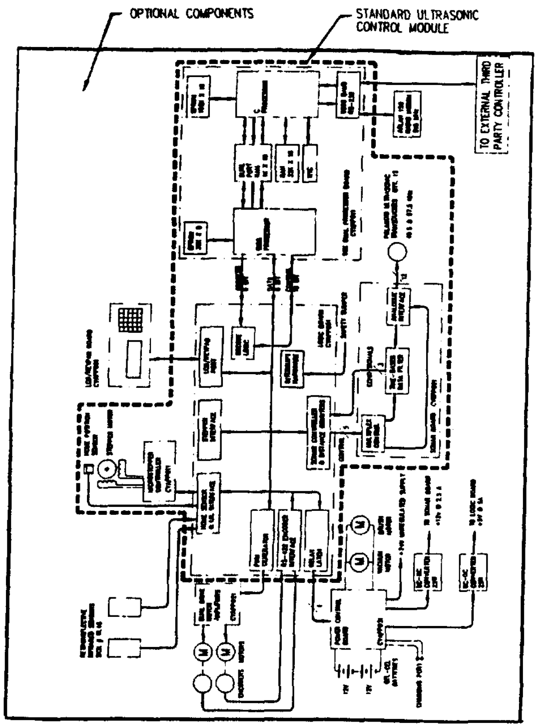

Fig.4: Embedded parallel processing unit

Sensor data can be preprocessed on board the embedded dual processor 8/16 bit tightly coupled parallel processor and sent to the master controller via RS232. Alternatively, the embedded parallel processor can also act as a master controller with full navigation control, I/O, etc.

A rich "Operating system" and "Utilities Tool Box" set was also developed which provides a very high level of navigation and sensory data abstraction while simultaneously providing an abundance of "hooks" to access low level system parameters. Several hundred such operating system functions, parameters and utilities are embedded into the system to simplify third party applications development and system portability for alternate embedded applications. This will permit the very rapid development of new high level applications by university researchers and OEM's.

The ultrasonic frontend sub-module of the embedded parallel processing unit consists of the time/frequency multiplexed ranging circuit, the firing and receiving interface, the time filter, and the ultrasonic driver circuit (Figure 4a). The bank signals control which transducers are used for firing and receiving. Consecutive bank signals have a time delay of 20ms. The /INIT signal is used to initiate the tranducer firing. It lasts for 12ms. The /BINH signal disables the receive circuit for approximately 0.8ms. This allows the transducer vibration caused by firing to dampen out before the receiver circuit is enabled. The bank signals also control which frequency is used for transducer firing. When /BANK0 or /BANK1 are active, 49.5 kHz is used, whereas 57.5 kHz is used when /BANK2 or /BANK3 are active. The transducer interface circuit takes the gated logic-level transducer firing pulses and amplifies them to the 320 V_{p-p} level required to fire the transducer.

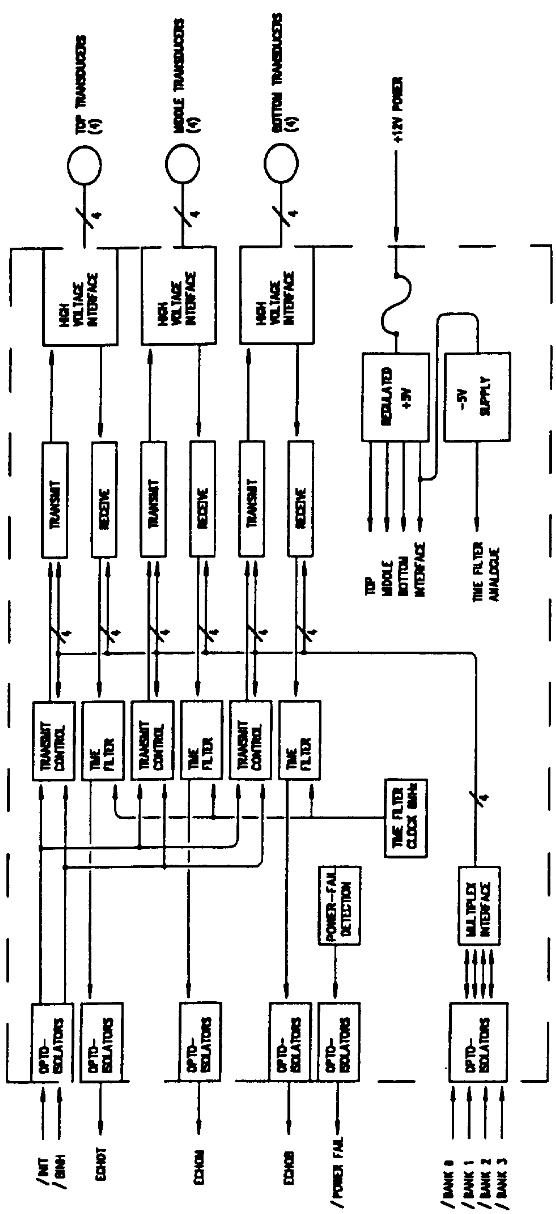

Fig.4a: Function block diagram of the ultrasonic frontend sub-module

REAL-WORLD APPLICATION RESULTS

Although this sensor system is utilized in most of Cyberworks' mobile robot systems, its performance in relation to the autonomous cleaning robot is of particular interest since that specific application utilizes no apriori knowledge of the environment and relies solely on the robustness and quality of the ultrasonic sensor feedback for navigation path planning in an unknown, unstructured and often highly complex real world domain. If the objects in the room are reorganized, or moved unexpectedly, CyberVac is expected to utilize realtime sensor feedback to efficiently and intelligently cover the new floor surfaces without the inconvenience and expense of reprogramming. In this application, an Expert System Module contains the generalized task definition. For example, the "meaning" of "cleaning" in a global sense. This definition is then integrated with the Global Symbolic Data which contains salient domain geometry information gathered in real-time as well as "inferred" on the basis of past data, and fed to the Navigator Module which formulates navigational ideas to best effect the desired task in the given domain. Note that this Autonomous Navigation Control System does not rely on historical or apriori domain specific data of any kind. The vehicle begins to execute the application without foreknowledge of the domain size, complexity, geometry or the nature of objects within the domain.

Utilizing the ultrasonic array sensors, local data are gathered in real-time. Data compressions and "filtering" are executed in real-time to decompose the local data into a series of vectors and symbols such that the character of the local domain is retained without the retention of the original vast set of Cartesian points. The set of symbolic local data are consolidated into a signal global descriptor which is dynamically optimized into a further reduced set of vectors and symbols encompassing not only the original object placement data but additionally, navigational-assistance data for navigational path planning through the domain.

As the environment is scanned, the data is software pre-processed and salient data is stored in RAM. New salient data is then analyzed in order to reorganize and possibly discard portions of past salient data. Inferences are then made based on this process of data reorganization. The inferences are further verified or modified based on new salient data collected.

Some sample plots are provided (Figure 5) schematically depicting the visually based navigation path planning of the robot in real world unstructured environments utilizing purely real-time ultrasonic sensor feedback. Please note that odometry and slippage compensation systems were also present. In this application, the reliability of the real-time data is crucial both in terms of the rejection of "artifacts" (multipath signals, crosstalk, etc.) and the consistent detection of objects which would not have been detected by an ultrasonic "ring" architecture due to sloped surfaces in order to achieve the high efficiency of path planning required by the industry.

SUMMARY

Our research stresses the realization of new concepts which will lead to greater levels of autonomy and lower systems costs. These systems have been implemented and tested on several platforms and are being applied to the real-time execution of various tasks such as cleaning buildings, building sentry and material transfer. As well, the experimental platform itself is being offered for third party research. The ultimate aim of the research is to reach human scale performance levels for certain specific applications while maintaining realistic price/performance ratios.

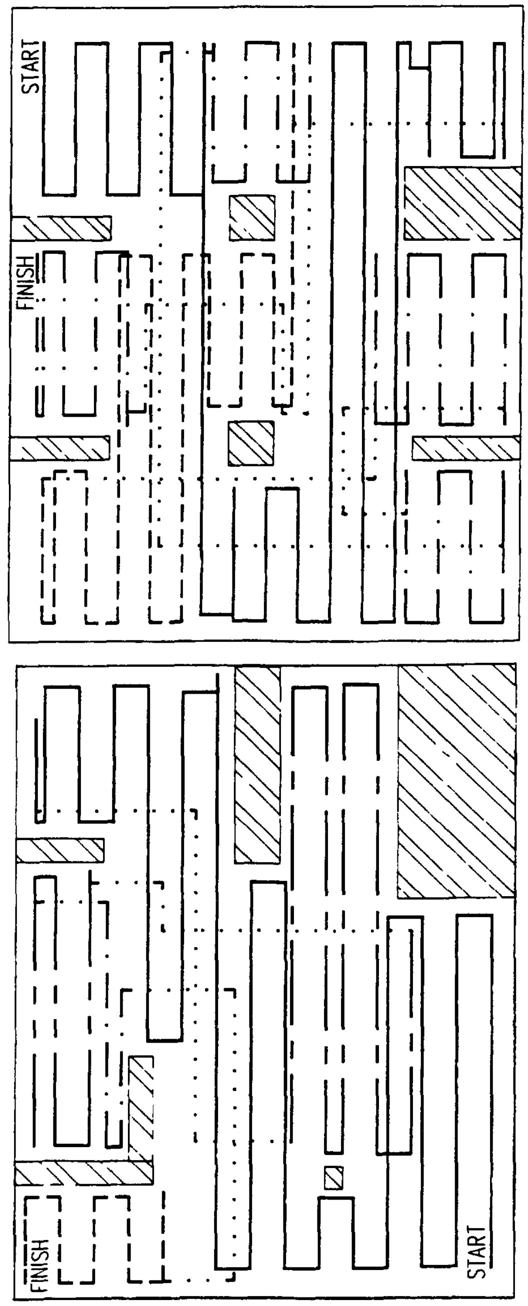

Fig.5: Two schematic representations of navigation paths in unstructured environments