COMMUNICATING WITH COMPUTERS IN HUMAN TERMS

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ABSTRACT

The development of SPASYN--a magnetic position and orientation sensing technology--fosters the notion that the human body can be used to control sophisticated computer processes. In short, body language can be considered as another way of interacting with computers.

SPASYN is a patented concept developed by Polhemus Navigation Sciences, Incorporated, A Subsidiary of The Austin Company, and Advanced Technology Systems, a Division of The Austin Company. The SPASYN concept and its capabilities for interfacing with human motion are described herein.

Key words: Spatial orientation, pointing, interactive computer graphics, head tracking, magnetic fields.

INTRODUCTION

Computers, since their inception, have forced man to communicate with them in their terms. Batch-processing, restrictive formats, and limited I/O capacity have all restricted the use of computers to those highly trained in the computer's own "language."

Now, as computing power increases while cost and size decrease, computers are starting to become truly conversant in our language forms: written, spoken and body. "User friendly" written languages are now commonplace, and spoken language is coming into use with the advent of voice recognition and synthesis. The next step is to execute computer commands in the third mode of human communications: body language.

While written and spoken languages are cerebral processes, body language is a natural mode of human interaction. Movement, position, and pointing are instinctive, and capable of greatly expanding interactive computer applications. However, computer communication through body language is not easily achievable. Sound, light, and mechanical linkages have all been used as three-dimensional transducers. While superior to discrete commands or joysticks, each has proven either cumbersome, awkward, or in some way restrictive.

SPASYN (SPAce SYNchro) is a new technique that overcomes many of these restrictions by offering a natural means of human-computer interaction. SPASYN continuously computes both the position and orientation of its sensor within a defined reference frame. SPASYN's freedom of movement, responsiveness, and high accuracy have evoked a progression of implementations for coupling natural body movements with computerized systems.

SPASYN DESCRIPTION

Three essential components comprise a SPASYN system: a source which generates an electro-magnetic field; a sensor which samples the field; and a computer which performs all required control, calculation, and interfacing tasks. These components interconnect as shown in Figure 1. Both the source and sensor are constructed by winding three orthogonal coils about a ferrite core. The sensor measures about 1 cubic inch while the source is generally large depending on the desired operational range of the system.

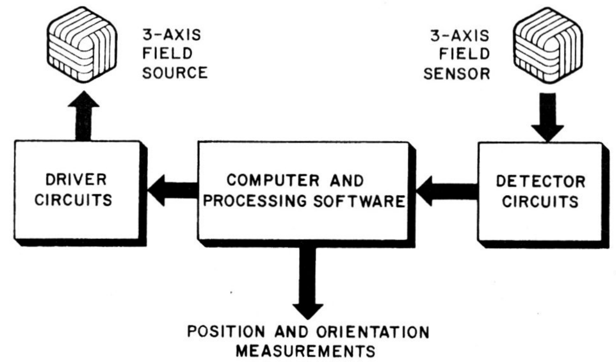


FIG. 1 SPASYN ESSENTIAL COMPONENTS

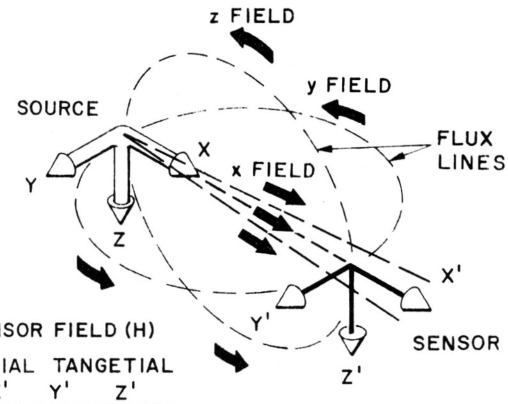
SPASYN operates by generating three orthogonal fields that are well defined in the area of interest. The fields are sampled by the sensor and the resultant data is computer processed to determine position and orientation of the sensor.

The SPASYN concept is theoretically derived from dipolar magnetic field coupling between the source and the sensor. The source's three axes are sequentially excited with a 10 KHz carrier. This produces three orthogonal AC magnetic fields that induce signals in the three axes of the similarly constructed sensor. The sensor outputs are filtered, synchronously detected and digitized to produce nine (9) measurements. The computer then processes these measurements to determine the six (6) position and orientation unknowns of the sensor, relative to the source.

The field coupling between the source and the sensor is dominated by the near field (ρ) component ($\rho << \lambda/2\pi$), where ρ is the source to sensor separation. The separation is kept such that the induction ($\rho \sim \lambda/2\pi$) and far field ($\rho<<\lambda/2\pi$) components are negligible.

For any of the source coils considered as a point dipole source, the maximum tangential field component is half that of the maximum radial component. The resultant composite field, as shown in Fig. 2, illustrates the orthogonal relationship of the radial and tangential fields.

The fixed ratio and orthogonality allow driving the source and sensor either electrically or mathematically so that each point a major axis towards each other. The difference between the true reference frame and the rotated reference frame for the source defines the source to sensor look angles and defines for the sensor its attitude. By measuring the field strengths at the sensor, the source to sensor range can also be calculated to determine all six degrees of freedom.



SOURCE COIL	SENSOR FIELD (H) RADIAL X'	TANGETIAL Y'	Z'
X	1	0	0
Y	0	$-\frac{1}{2}$	0
Z	0	0	$-\frac{1}{2}$

FIG. 2 SOURCE AND SENSOR ALIGNED

SPASYN accuracy in free space depends on true orthogonality and exact commonality between the source and sensor coils for field generation and detection. Consequently, to ease manufacturing requirements, sources and sensors are built to reasonable tolerances and then characterized in a Helmholtz coil. Its uniform magnetic field is used to develop a correction matrix for the sources and sensors that mathematically compensates for the measured variations in true orthogonality and commonality. The driving and amplifying circuitry is also characterized to standard gains for commonality.

In the real world, SPASYN accuracies are additionally influenced by nearby conductive surfaces which are capable of causing distortions in the source-generated magnetic fields. Eddy currents in the conductive surfaces essentially produce counter magnetic fields at a level dependent on their conductivity, permeability, size, and location. Such distortions are generally less than 12° for military cockpits and less than 2° at close ranges for laboratory environments.

Compensation for these distortions is achieved through a magnetic mapping of the operational area. Mapping consists of translating an aligned sensor throughout the motion box in a two-inch grid and recording the SPASYN outputs. These raw outputs are then used to determine correction coefficients. During system operation, these coefficients are used to pre-process the raw outputs for compensating the effect of the distortions.

Since the human body is a poor conductor, it causes only minimal distortion of the fields, and the performance of SPASYN balances well with human dimensions. Coverage, resolution, accuracy, and dynamic response of a person's movements generally fall within the SPASYN specifications. This includes actions ranging from threading a needle and shooting a basketball, to aiming a missile. Typical SPASYN specifications and performance considerations are:

- SPASYN coverage from the source is hemispherical. This results from an ambiguity caused by symmetry of the dipole fields.

- The maximum range from source to sensor is typically two (2) to six (6) feet. In general, range is a trade-off between the magnitude of the generated magnetic fields and the desired accuracy. Longer ranges, however, are feasible, but distortions and low signal-to-noise levels may reduce accuracy.

- There are no restrictions on the attitude of the sensor for SPASYN operations. Accuracy is essentially equal for all attitudes.

- The resolution of the system is dependent on the A/D converter used to measure the sensor outputs, and limited by the S/N ratio. Typically, 12- and 14-bit A/D converters have been used to provide resolutions of 0.1° (0.1 inch) and 0.025° (0.025 inch), respectively.

- Installed accuracies have generally been better than 0.4° at the fifty percent confidence level over the full SPASYN coverage domain. In a relatively clean environment, the measurements are accurate to within 0.2°, as shown in Figure 3.

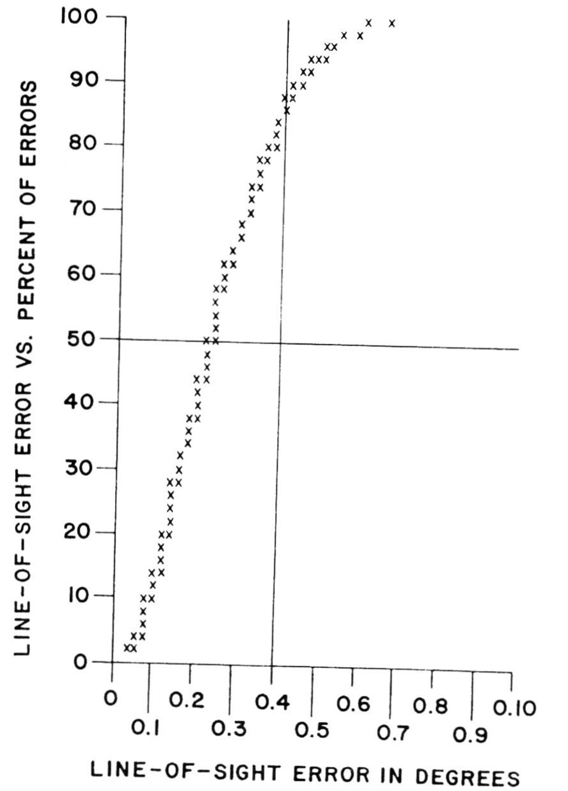


FIG. 3 SPASYN ACCURACY IN A LABORATORY ENVIRONMENT

- The conventional update rate is 60 Hz, or 60 position and orientation measurements per second. At this rate, the outputs lag the sampling measurements by 16.7 milliseconds. This produces a 1° lag for a 60° per second rotation rate of the sensor. Update rates up to 100 Hz have been achieved; higher rates are possible with faster signal and digital processing.

SPASYN PROGRESSION

Helmet Mounted Sights

SPASYN was originally developed as a head tracker for a helmet mounted sight (HMS) system. Initial implementations were designed for evaluation on high performance military aircraft.

The HMS, as shown in Fig. 4, measures the pilot's head orientation as he views a target through a reticle superimposed on his visor. This line-of-sight (LOS) information is then used to interact with highly automated weapons delivery systems and target sensors. SPASYN closes the man-in-the-machine loop by integrating the pilot's kinesthetic skills with the specialized accuracies of a computerized weapons system.

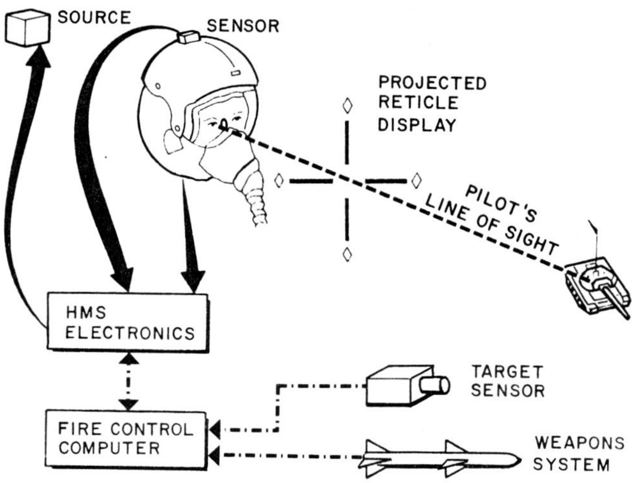


FIG. 4 HMS CONCEPT

Early technologies used in HMS systems either mechanically constrained head movement or were limited in accuracy, area coverage, or weight/size on the helmet. In comparison, SPASYN's magnetic coupling to a sensor on the helmet poses no motion constraints and a negligible weight penalty, even under high-G maneuvers. Installed accuracy is also more than adequate for HMS usage over the full cockpit motion area.

Prototype SPASYN HMS systems have been successfully tested on such high performance aircraft as the F-4, F-101, F-106, and F-16. Because of SPASYN's versatility, the technology is also attractive to the military for such technological studies as visually coupled interactive controls, cockpit CRT curser control, and other areas where man visually interacts with computerized systems.

SIMULATORS

Aircraft simulators strive to present scene imagery that matches the review a pilot would normally see from the cockpit. A high resolution SPASYN head tracking system is used in some simulators to allow an increase in scene detail without greatly increasing the computer generated imagery (CGI) computer requirements.

Characteristically, SPASYN determines where the simulator pilot is pointing his head. Imagery can then be dynamically shifted to coincide with his field of view. To display imagery which covers a wide field of view, resolution must usually be sacrificed because of computer limitations. With SPASYN, the operator's area of interest is defined, and then appropriate high resolution imagery can be displayed.

Since SPASYN head tracking incudes position information, it also solves simulator CGI parallax problems. This enables helmet mounted displays with high scene detail to be superimposed over low detail projected displays.

SPASYN head trackers are now being used, or are proposed for use, in the following training and simulator systems:

- The Advanced Simulator for Pilot Training (ASPT), at Williams AFB.
- The Visual Display Research Tool (VDRT), at the Navy Training Equipment Center.
- The Visually-Coupled Airborne System Simulator (VCASS), at the Air Force Areomedial Research Laboratory.
- The VITAL IV simulator, built by McDonnell Douglass.

SPA-SYN-COM

These military/aerospace applications of SPASYN have paved the way for other head-tracking applications. From them came the conceptualization of SPA-SYN-COM, a communications aid for the severely handicapped. SPA-SYN-COM is being funded by the Veterans Administration to develop a "low cost" direct-selection communications aid and evaluate its applicability.

SPA-SYN-COM, as illustrated in Fig. 5, takes advantage of limited body movement to effect communication and control. It translates head-mounted sensor changes in position and orientation to designate symbols on a passive target board. The technique offers a wide range of flexibility, allowing selection of simple symbols, the alphabet, or complex phonemes.

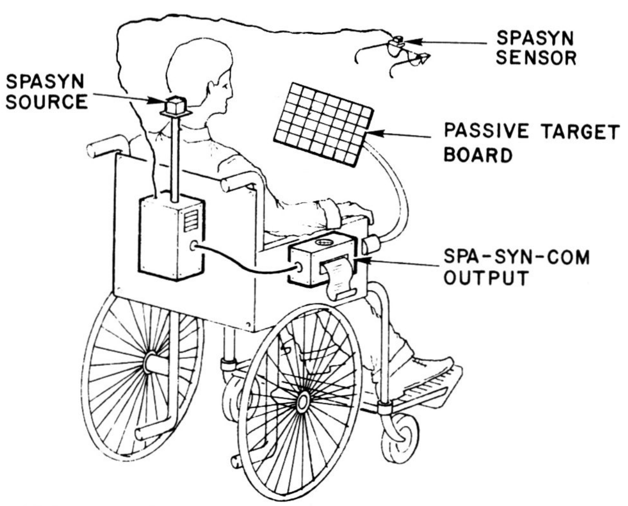


FIG. 5 SPA-SYN-COM
DIRECT SELECTION COMMUNICATIONS AID

A research-grade model of SPA-SYN-COM has been designed, and is currently in developmental test. Present plans call for clinical evaluation of SPA-SYN-COM at Trace Research and Development Center, University of Wisconsin, prior to additional engineering for low-cost production.

Once fully developed, SPA-SYN-COM will provide handicapped users with a portable, direct-selection communication and control aid suitable for use throughout life.

SPATIAL DATA MANAGEMENT

The Architectural Machine Design Group at MIT is developing innovative concepts for computerized spatial data management. In their Media Room, as illustrated in Fig. 6, an operator may interact with a computer by means of: voice recognition, a large screen (wall size) display, and a SPASYN remote position and orientation measurement system (ROPAMS).

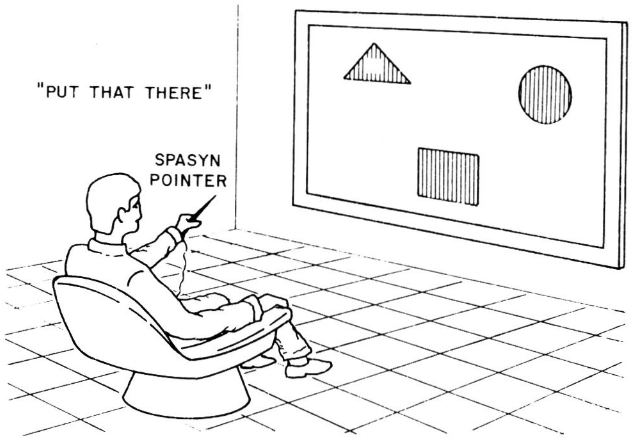


FIG. 6 MEDIA ROOM
MIT ARCHITECTURAL MACHINE DESIGN GROUP

In one demonstration, entitled "Put That There," an operator uses a SPASYN pointer to identify objects on the screen and voice commands to change the display. Other demonstrations include automatic control of text scrolling on the display, and spatial orientation of data files. Both are manipulated with a head-mounted SPASYN sensor.

In other research areas at MIT, a SPASYN "baton" is being proposed to control synthesized music; and SPASYN sensing has been proposed to record and graphically display dance movement for the Joffrey ballet.

While academic, the MIT work spurs the imagination for future applications. In fact, a number of innovative uses are based on the research being conducted there and at PNSI. Some applications already identified by industry and government are:

- Computerized command and control interaction for Navy shipboard battle rooms.
- A method for monitoring human motion during manufacturing time-and-motion studies.

- A system to slave a television camera or other sensor to a user's head motion for use as a navigation or monitoring aid.

- Digitizing scale models for interaction with computer generated imagery.

- GAIT analysis for orthopedic evaluation and rehabilitive therapy.

- Rendezvous and soft docking between space vehicles.

SPASYN DIGITIZER

To date one of the most common uses of SPASYN has been to measure orientation for LOS and pointing applications. But SPASYN also provides positional measurements of similar accuracy. This extends SPASYN usage into the field of computer graphics as a 3-D digitizing device (3SPACE).

SPASYN technology for 3SPACE is concerned with determining the coodinates of an object in free space. The data is then available for automatic input to a computer for storage, manipulation, and graphic display.

3SPACE measures the look angles from the source to the sensor and their separation. This locates the center of the sensor in space, relative to the source. Coupled with orientation measurements, the sensor can be displaced from the point to be digitized and attached on the rear of a nonmetallic stylus.

A typical configuration for 3SPACE is shown in Fig. 7. In one application, the Digitizer will be used to automate the process of taking data points off a scale model of a process piping facility for the generation of isometric drawings and material lists. In a second, the Digitizer will convert object models into visual displays in a computer generated imagery system.

CONCLUSION

SPASYN has proven itself sufficiently versatile to interface almost any human motion with the computer. Its lightweight nature and freedom from positional restrictions on its sensor, ideally suits SPASYN for a wide range of applications.

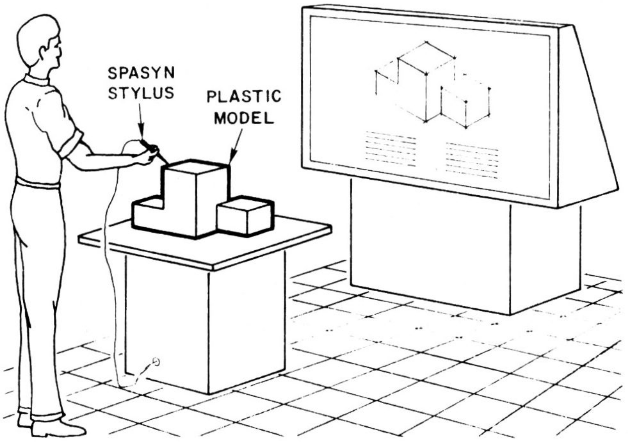


FIG. 7 3 SPACE SPASYN 3-D DIGITIZING DEVICE

Future uses of SPASYN are based on the continuing need for more simple computer communications, especially when the scarce resource is human- rather than memory or processing-time. Interactive keyboard and voice recognition/synthesis have greatly reduced the training and skill level needed for interaction with sophisticated computerized processes. But there is work still to be accomplished. SPASYN is one new means of humanizing the gap between computers and man. As such, it opens the door for the utilization of body language in communicating with computers.

ACKNOWLEDGMENT

This paper describes the derivation and development of SPASYN--a position and orientation measurement concept invented by J. Kuipers. It was reduced to practice by an engineering team at Polhemus Navigation Sciences, over a period of ten years. E. B. Blood, A. R. DeRuyck, H. R. Jones, F. H. Raab and A. G. Rodgers played significant roles in the development and testing of related hardware.

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