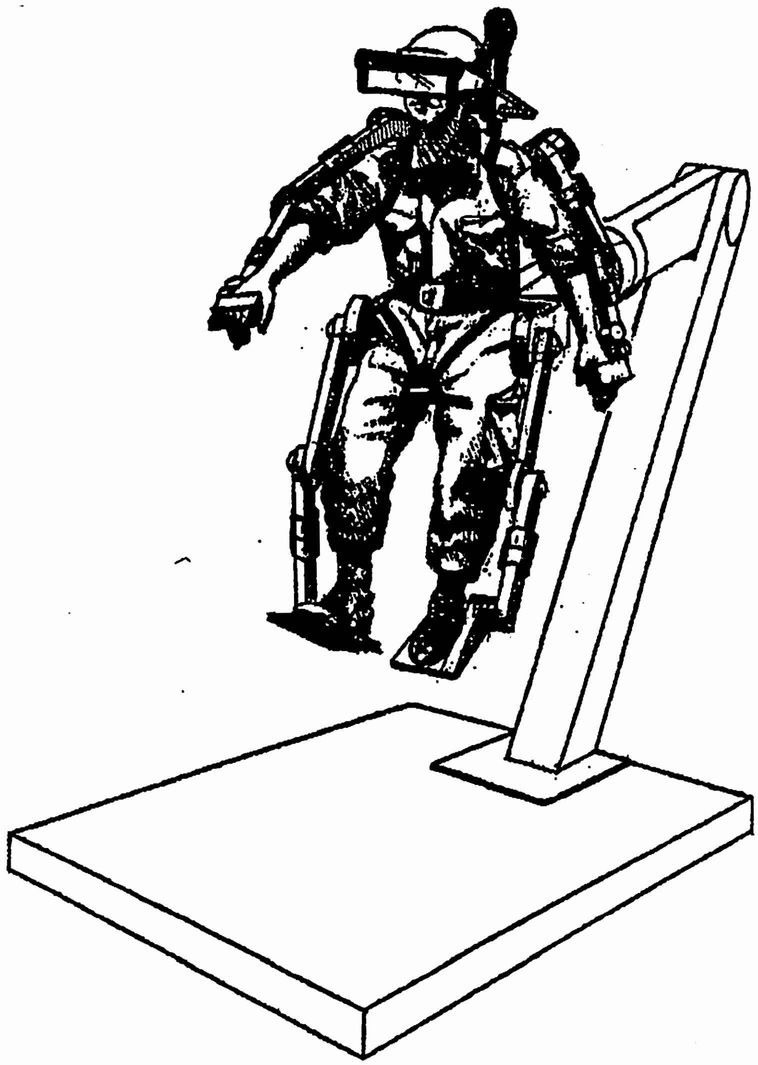
ENGINEERING I-Port



The Individual Portal Into Synthetic Battle Environments

Draft, April 7, 1992

Prepared for the Institute for Defense Analyses

Cardinal Point, Inc.
Afton, Virginia

ENGINEERING I-PORT

CONTENTS

ENGINEERING I-PORT

The Individual Portal into Synthetic Battle Environments

I. "Fly Before We Buy"

A. Advanced Methods of Prototyping

The President's Blue Ribbon Panel on Defense Management (the Packard Commission) urged that before any decision to acquire a novel weapon be made, strenuous effort be directed at prototyping "to determine to what extent a given new technology can improve military capability." The military capability of any weapon system is a function of three main variables, only one of which stems from the engineering and the technology it embodies. Stated as a construct for cogent acquisition policy:

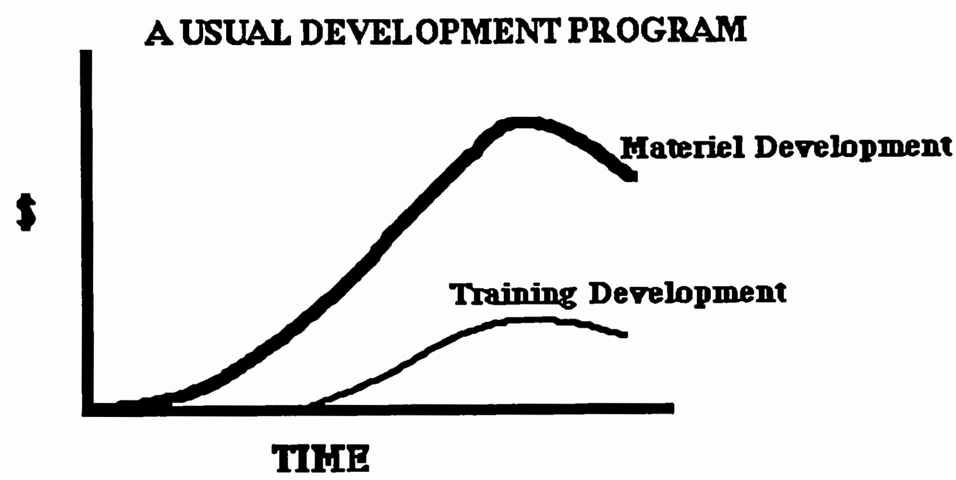
$$C_M = \Sigma\, W, P, T$$

where C_M is military capability, **W** is the materiel, **P** the proficiency of the humans at the man-machine interface, and **T** the tactic or technique by which the weapon is brought to bear on battle outcome.[1]

Regrettably, but understandably, weapon system development programs have accorded first priority to materiel, and have neglected, or postponed until late in the development, consideration of the other factors.[2] If, during the execution of any program, there arises a need to reduce overall expenditures, the materiel itself is protected, and cuts are directed at "softer" parts of the program, of which the training sub-system is usually regarded as "softest." The management logic seems impeccable: development funds spent preparing to maintain the materiel, or to teach how to use it, seem moot until the equipment is in its final configuration, and engineering shortfalls have been identified and ameliorated. Hence, development invariably proceeds from materiel, to maintenance provisions, and finally to the training. Often, by the time training technologists become involved, the Program Manager has spent most of his allocated funds:

---

1. IDA Paper P-2515, The Military Value of Training, prepared by the Institute for Defense Analyses for the Defense Advanced Research Projects Agency, December, 1990, 28-31.
2.IDA Paper P-2374, Supertroop Via I-Port: Distributed Simulation Technology for Combat Development and Training Development, prepared by the Institute for Defense Analyses for the Defense Advanced Research Projects Agency, August, 1990. Section IV.



The Packard Commission deemed the depicted pattern fallacious. From the Commission's examination of successful and unsuccessful procurements, it isolated managerial propensity to postpone methodical examination of behavioral implications until late in the development cycle as a major shortcoming. The Commission strongly recommended, as an antidote, a high priority on early prototyping.[3]

In general, prototyping and testing in the early stage of R&D should be done by the service that would be the primary user of the resulting system. In order to promote the use of prototyping, however, we recommend expanding the role of the Defense Advanced Research Projects Agency (DARPA).

At present, DARPA conducts research and exploratory development in high-risk, high-payoff technologies. DARPA should have the additional mission of stimulating a greater emphasis on prototyping in defense systems. It should do this by actually conducting prototype projects that embody technology that might be incorporated in joint programs, or in selected Service programs. On request, it should assist the Services in their own prototyping programs. The common objective of all of these prototyping programs should be to determine to what extent a given new technology can improve military capability, and to provide a basis for making realistic cost estimates prior to a decision on full-scale development. In short the prototype program should allow us to fly —and know how much it will cost— before we buy.

Central to DARPA's mission is maintaining US technological superiority by exploiting scientific breakthroughs and revolutionary approaches to foster fundamental change in DoD's

3. A Quest for Excellence, Final Report to the President by the President's Blue Ribbon Commission on Defense Management, 30 June 1986, 55-57.

ability to provide for national security.[4] Conventional methods of prototyping are costly and time-consuming. Indeed, some members of the Packard Commission pointed out that bending metal is no longer necessary for exploring issues related to crew proficiency or tactical employment, since computer-based models or simulations with provisions for realistic human intervention provide a reasonable approximation of troop experiments with actual materiel. Responding to the Packard Commission charge, DARPA conducted some propaedutic prototyping , but in pursuit of fundamental change, the Agency also developed a wholly new tool for developers: virtual prototyping in synthetic battle environments to explore any or all of the three significant variables cited above. The DARPA-Army SIMNET-D program[5] has demonstrated a major advance in prototyping methodology, commended by the Defense Science Board Task Force on Computer Applications to Training and Wargaming as follows:[6]

> Possible application of a new idea or breakthrough in technology via earlier acquisition of training prototypes is an effective way to explore future capability early. Based on tested training prototypes, the user can write better acquisition requirements, with more assurance that the acquisition could be more cost-effective. SIMNET is a success in this dimension...Taking full advantage of rapid training prototype technology is not always consistent with the current requirements-development and acquisition processes. Streamlining these processes and introducing the feedback advantages inherent in rapid prototyping can be effective in many acquisition arenas.

Members of the DSB Task Force noted that any prototype is a "simulation" of the eventual system. SIMNET-D has convinced more than a few training technologists that it is now possible to construct a digital model of a developmental system's functions, to embed this model in one or more plywood or fiberglass mockups, and then to evaluate the simulated system on a synthetic battlefield with soldiers, sailors, or airmen. Such simulations, with many "men in the loop," could be used not only to confirm the cogency of engineering, but also to validate requirements for the materiel's eventual configuration, to gain understanding of how to train and evaluate its crews, and to explore tactical concepts for its employment. In instances where SIMNET-D has been so used, defects became evident in what the end-user had asked for, in what the engineers provided, in the tasks one or the other had imposed upon crew members, and in the doctrine that anticipated fielding of the system. Importantly, virtual prototyping allowed for quick, inexpensive revisions, and revaluation. Because of dense data-collection on all effectiveness parameters, especially those relating to human behavior, the doctrinal implications

---

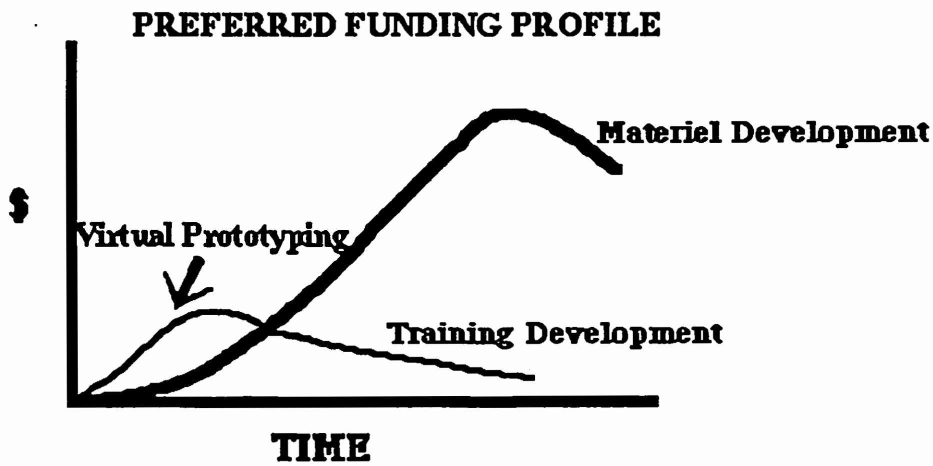
4. Denman, Dr. Gary L., Statement before the Subcommittee on Defense, House Appropriations Committee, March 19, 1992, 2-3.

5. Alluisi, EA The Development of Technology for Collective Training: SIMNET, a Case History. *Human Factors*, 1991, 33(3), 343-362.

6. Report of the Defense Science Board Task Force on Computer Applications to Training and Wargaming, Office of the Under Secretary of Defense for Acquisition, Washington, DC, May, 1988, 28-29.

of the virtual prototype are easier to observe on the synthetic battlefield than they could have been in conventional models or mathematical constructs of war, or in operational tests with actual prototypes.

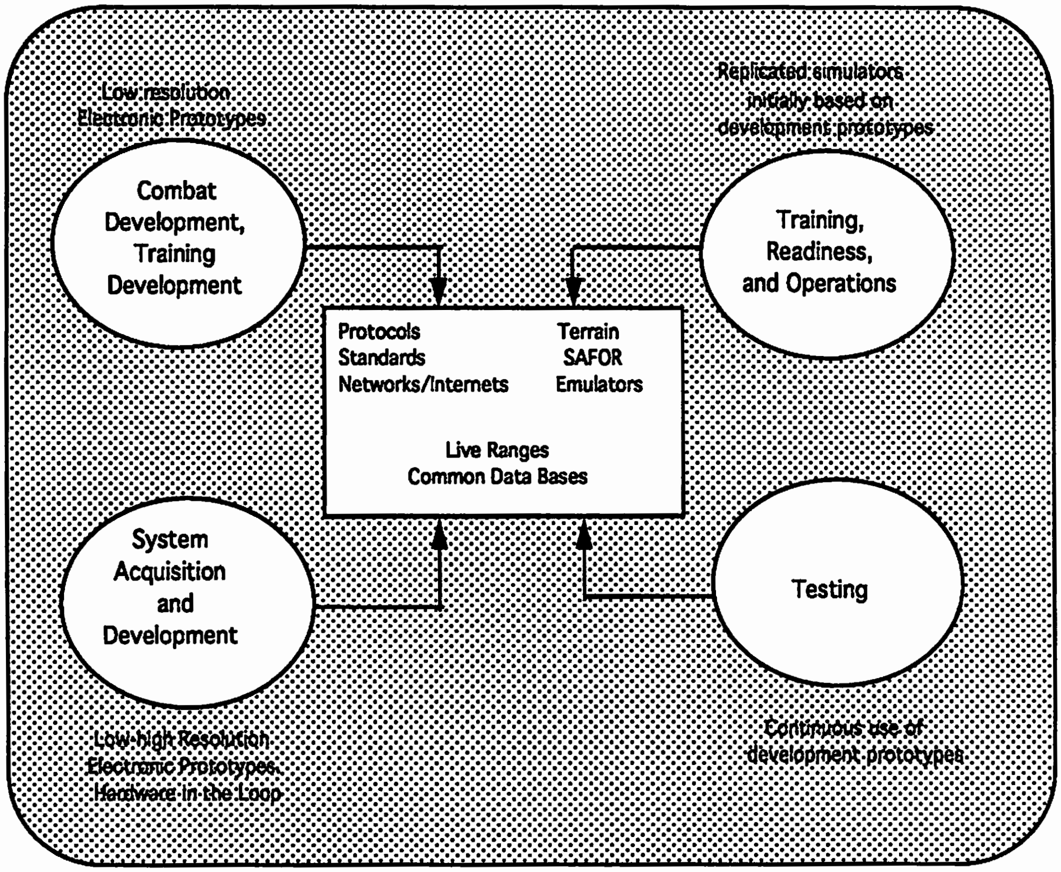
Hence, the preferred allocation of resources for a development program would provide for virtual prototyping, and ought to look like this:



Demonstration of military capability is now pivotal to acquisition strategy. The Deputy Secretary of Defense, in a statement before Congress earlier this year, set a forth as policy that the Department would incorporate advanced technology into existing systems only when "there is substantive need for improved performance or reliability," and into new systems only when "the absolute need for the new system is verified."[7] How to show that a need is "substantive" or "absolute" is now sine qua non for any program.

During the summer of 1991, an Army Science Board Task Force chaired by Larry Lynn examined a set of issues relating to models and simulations, and recommended that the Army resort broadly to virtual prototyping for development of doctrine, training, and materiel, for operational readiness, and for test and evaluation. The graphic that Dr. Lynn used to summarize the recommendations of his group's report is reproduced below:

7. Denman, op. cit., 1.



Prototyping on the "Electronic Battlefield"

General Gordon Sullivan, Chief of Staff of the US Army, has vigorously supported the ideas advocated by the Lynn Panel, envisioning the "electronic battlefield" as a means of making the smaller Army of the future more effective than the Army of DESERT STORM. To explore alternative futures on a broad scale, so that leaders at all echelons will understand how the Army's ability to perform in battle can be enhanced through new applications of technology, he has directed the Army to conduct a new series of "Louisiana Maneuvers" employing advanced simulations. Familiar as CSA is with the history of the maneuvers of 1940 and 1941, he knows that among their significant failures was motivating the foot soldiers participating, and conveying to them some sensing of their tasks in the battles ahead.

B. Serious Shortfall: A Simulator for Foot Fighters

The very idea of a "simulator" for a dismounted combatant is so foreign to the thinking of most military professionals that they have expended little effort in describing requirements for one. Yet few of those professionals would deny that modern technology has chiefly advantaged those who fight mounted in land, sea, or air vehicles, even while it has increased exponentially the vulnerability of those who fight on foot. There have been sporadic attempts to build shootinggallery environments that provide combat-like stimuli for shooters with small arms, but none of these microcosmic simulations approaches the interactive universality of the synthetic battle environment demonstrated in SIMNET, or postulated by the Lynn Panel. To date, advanced simulation technology has largely ignored the foot-fighter, rendering practicable only battle misrepresented by the absence of dismounted infantry, combat engineers and medics, scout-observers, forward observers, man-portable air defense and anti-armor systems, reconnoitering leaders, reconnaissance or combat patrols, or Rangers, SEALs, and other Special Operations Forces engaged in reconnaissance or direct action.

On first reflection, most military professionals would hold that training for such individuals or teams ought to be as "realistic" as possible — by which they would mean that actual terrain and real ordnance ought to figure whenever possible. Especially for those whose workday dress includes face camouflage and rag-festooned helmets, and whose speech is punctuated with grunts, the term "simulation" connotes faking or feigning performance, and implies half-measure, compromised training that leads inevitably to half-hearted, inexact execution under combat stress. These will concede that simulation might usefully portray the contribution of dismounted elements to the mounted battle, but that stems from their concern for the proper training of mounted personnel — they remain persuaded that those who fight on foot must be trained on foot by moving, shooting, and communicating over actual terrain.

Yet this view is as fallacious as the notion that simulators can not be important in the training of a fighter pilot or a submarine commander. As is the case with mounted warriors, many skills can not be practiced with a simulator, but as is also the case, many important tasks can not be practiced without a simulator. Preferably, simulator for foot-fighters would enable each to figure in a synthetic battlefield environment as effectively as could the crew of a vehicle, and like them, to contest therein thinking adversaries that act like potential opposition forces in numbers, weapons, and modes of employment, on terrain like that where such forces could actually be encountered. What is needed is properly described as an Individual Portal into such an environment, or **I-Port**.

I-Port, as the term is used here, is defined as a mechanism for projecting individuals onto the "electronic battlefield," that is, for enabling one or more individual combatants to practice their combat skills in a distributed, interactive synthetic environment.

There are at least seven compelling reasons for moving as promptly as technology will permit to develop **I-Port**:

1. **Threat Depiction**. The surest way to reduce the vulnerability of fighters on foot is to acquaint them with the threats they could face. Few units of any service have the capability of portraying accurately foreign forces and materiel. Moreover, the strategically amorphous world dictates rapid depiction of potential opposition forces, or facilities comprising possible military objectives, to US contingency plans as the emerge.

Special Operations Forces and light infantry are likely to lead future deployments under those plans.

2. **Combined Arms and Joint Operations.** The peacetime stationing and pursuits of the various units of the US armed forces often impair cooperation with other arms and services. For example, Special Operations Forces are normally dispersed over continental distances, and train remote from sites where armored forces or fighter bombers usually operate. Yet US forces will fight as teams of disparate capabilities, and it is essential that they train in the same manner. To be sure, the soldier in an lonely observation post on a mountain, or the SEAL in the water off a hostile shore, rarely concern themselves about joint warfare, but their commanders cannot escape its imperatives, set forth in the new Joint Pub 1:[8]

We fight as we train and exercise...computer simulations add an effective tool for the high quality combat training of command cadres in joint operations (they also have great utility in validating operational planning)...

In years past, the sea was a barrier to the soldier and a highway to the sailor; the different mediums of air, land, sea and space were alien to one another. To the joint force team, **all forms of combat power present advantages for exploitation.**

3. **Varied Terrain.** While some future contingencies will doubtless call for military action at sea or in the upper reaches of aerospace, most will involve land masses, and all the complications that nature and the works of man cause there. Modern information technology now offers the prospect of generating in a matter of hours a highly detailed, digital representation of any portion of the earth's surface as a synthetic battle environment —a capability directly relevant to the present and foreseeable posture of US forces. No longer need first-hand familiarity provide military advantage to the occupier of land, for the power of computer simulation can afford US forces even better ways of appreciating terrain than actual presence thereon.

4. **Urban Settings.** Those areas of the globe of highest interest to the United States are undergoing progressive urbanization —western Europe and northeast Asia in particular. In most nations of the world, the political and economic centers of gravity are concentrated in sprawling metropoles, control of which is militarily decisive. Contesting control of built-up areas is inherently difficult, and requires skilled, dismounted combatants. Given the range of architectural styles, construction techniques and

---

8. Joint Warfare of the US Armed Forces, Joint Pub 1: US GPO, Washington, DC. 11 November 1991, 38, 61.

materials, training for urban warfare presents daunting challenges to any commander constrained to maps, photos, scale models and mockups.

5. **Security**. Not the least among the difficulties confronting trainers of individual combatants is the necessity to mask preparations for particular operations. Routine, intensive training into which operationally specific tasks are inserted provides security in itself, but to the degree that training depends upon physical aids, props or facilities that could come to the attention of an alert journalist, or be detected by a foreign satellite, to that degree the training itself constitutes a danger of compromising a contingency plan. Hence, training exercises or operational rehearsals in a synthetic environment, on an "electronic battlefield," offer distinct advantages for counterintelligence purposes.

6. **Reduced Resources/Higher Expectations.** In any future combat, casualties and collateral damage are likely affect any US commander's calculus quantitatively and qualitatively differently from the way they have influenced commanders in recent campaigns. Grenada (1984), Panama (1989), and the recent Gulf War(1991) have each raised public expectations concerning the timing and costs of future combat that will almost certainly be difficult, if not impossible, for tomorrow's smaller forces to meet, unless those forces be provided with superior means to assure readiness for and efficiency in operations. This is particularly so with respect to casualties. Precedent teaches that most of those killed and wounded in action will be fighting on foot. The distinguished military historian, Trevor Dupuy, has noted that in the large American wars of this century more than 8 out of 10 casualties were dismounted combatants:[9]

Percentage of Casualties by Branch
Principal American Wars of the 20th Century

	World War I	World War II	Korean War
Infantry	87.9	80.3	83.8
Armor	0.2	3.5	2.5
Artillery	4.3	5.6	6.9
Engineer	3.2	3.6	2.4
Air Defense	--	1.9	*
Medical	1.5	2.9	3.0
Other	2.0	2.2	1.4

*During the Korean War, Artillery and Air Defense were combined

7. Dupuy, T.N., Attrition: Forecasting Battle Casualties and Equipment Losses in Modern War, Hero Books: Fairfax, VA, 1990, 59-61.

Dupuy believes that in an intense war between modern armored and mechanized forces, a significant portion of the casualty burden would shift to the mounted participants in direct fire combat, but he would still expect over half the casualties to be infantry by branch:

Estimated Strength and Casualties by Branch: Hypothetical Future War

	Percent of Theater Strength	Percent of Branch Casualties	Percent of Casualties
Infantry	15	26.0	57.0
Armor	10	18.0	26.3
Artillery	8	5.0	5.8
Medical	10	2.5	3.7
Engineer	10	2.0	2.9
Air Defense	12	1.0	1.8
Other	35	0.5	2.6

Hence, if US forces designed for combat on land are to be both smaller and more efficient, technology must reach for a way to train individual combatants for much higher survivability.

7. **Innovative Acquisition.** As has been true throughout recorded history, martial affairs will evolve from the present by measure and countermeasure: each new development in weapons or tactics will inevitably engender a response that mitigates its advantage. There is evidence that, even with the USSR out of the race, the measure-countermeasure cycle is accelerating. Today, US forces enjoy a significant edge over potential foes that the latter —and also, it is important to note, nominal friends— are even now working might and main to offset. Tomorrow, almost certainly, US forces would fight without the near monopoly they enjoyed during DESERT STORM on thermal-imaging weapon sights, laser-guided missiles, and satellite-based reconnaissance and navigation systems. Hence, imperatives for modernization of US forces, far from decreasing, are as urgent as ever.

The Department of Defense has no more serious responsibility at the moment than to foster innovation. Despite the advent of so-called "high-tech" weapons, the military instrument remains a bludgeon. The fundamental purpose of armed forces is to establish or to maintain control; lethal force is a means, not an end. Hence, the Commander-in-Chief, and the Congress that raises and supports the armed forces, ought to charge military leaders with finding ways and means of performing that mission with ever increasing efficiency and dispatch, whatever the force structure. The pervasive, adaptable synthetic battle environment sought by the Dr. Vic Reis, Director of Defense Research and Engineering, is a partial answer to enabling them to do so.[10] Adding to DDR&E's present programmatic objectives a simulator for the individual combatant would assure an entirely defensible goal, exactly because, as the Lynn Panel pointed out, a comprehensive "electronic battlefield" would enhance not only training and operations, but aid in developing doctrine, improving research, informing acquisition decisions, and assuring thorough test and evaluation. Surely, with respect to these undertakings, the Department should do no less for American dismounted combatants than it does for those who man America's vehicles of war.

C. Information Technology to Narrow Acquisition Uncertainty

Dr. Vic Reis, Director of Defense Research and Engineering, has sought to remove some of the aura of mystery around advanced distributed simulation technology by pointing out that its principal utility is enabling us to think more cogently about complex problems. Among the latter facing the Department of Defense are assuredly choices relating to equipping the foot fighter.

1. Example: SIPE

Over the past two decades the Army and the Marine Corps have sought to increase the survivability and effectiveness of foot fighters by issuing items of personal wear, each entirely useful in its own right, but which, taken together, compromises the ability of the wearer to perform his combat mission:

- Ear protectors have become required wear.
- The Kevlar unitary helmet has replaced WWII's steel shell/liner.
- Face camouflage ointments and helmet shape modifiers are worn.
- Night vision goggles (light intensifiers) are routinely used.
- Chemical defenses (gas masks and clothing) have been upgraded.
- Goggles for both ballistic and laser protection have been procured.

To lend coherence to what individuals who fight on foot wear into battle, the US Army has undertaken, through Natick Laboratory of the Army Materiel Command, a development called S*oldier* I*ntegrated* P*rotective* E*nsemble* (SIPE). The SIPE program will seek to

10. Testimony before the House Armed Services Committee, Subcommittee on Research and Development, House of Representatives, US Congress, April 23, 1991. Dr. Reis was then Director of DARPA.

rationalize the various cranial and respiratory protections, and other accouterments. SIPE includes a search for cooling systems for a costume for operating in the presence of chemical agents, or biological or radiological threats. AMC issued the following statement:[11]

The Army is looking to develop a Soldier Integrated Protective Ensemble (SIPE) as a 'head to toe' state of the art fighting system that would improve the survivability of soldiers in a battlefield environment.

The SIPE demonstration would culminate with the field use of the system in the third quarter of FY92, prior to full-scale development. SIPE consists of three major subsystems: Headgear, which would provide complete head, face, neck and eye ballistic protection, soldier-to-soldier short and long range communication, aural protection, vision enhancement/remote weapon sight helmet-mounted display and laser eye protection; Micro climatic Conditioning, which is a power source that currently does not exist, but a generator/alternator design is being sought driven by a Stirling cycle engine; and an integrated modular Advanced Clothing System that will comprise handwear, footwear, load bearing equipment, and a body protective system.

The system would protect against environmental, ballistic, flame, thermal, chemical/biological, detection and directed energy. Approximately 12-36 prototypes are expected for field demonstration.

The SIPE program has proceeded by altering the requirement to embrace advanced technologies as they were proposed, within the constraints of building prototypes for a field evaluation in the current fiscal year. Assuming there is more than one prototype, the tests could have as few as six participants using each design. The testing method will be based on evaluating a non-SIPE equipped control group against SIPE wearers performing individual tasks, under conditions, and to standards defined by the appropriate Army Training Evaluation Program(s).

Had **I-Port** been available, a much broader range of technologies could have been more convincingly examined, over a wider range of tasks, including collective tasks, with significantly less expense, less lead time, and much greater flexibility in modifying a particular design and revaluating same. For instance, the evaluations might have embraced a design tailored for combatants going into action afoot in a Panama-like threat environment —a lighter, less complicated ensemble than the more ample protection designed for mid- or high intensity warfare involving threat of lethal chemical, biological or radiological weapons.

---

[11]Defense Daily, 12 January 1990. *Cf.*, U.S. Army Natick Research, Development, and Engineering Center, Small and Disadvantaged Business Utilization Office, 99X004-90F.

2. Example: On-person Information Technology

For years now, successive DARPA Directors have been talking about computerizing individual combatants —e.g., Dr. Craig Field's "CRAY in a field jacket pocket." Dr. Gary L. Denman, present Director of DARPA, recently stated that:[12]

> The explosion of Information Technologies afford new opportunities to explore fundamental changes in many traditional military activities, for example using personal micro mechanical and micro electronic devices fitted to the soldier to pinpoint battle casualties and facilitate remote triage through continuous monitoring of vital signs.
>
> I believe such devices, and the underlying computer processing and data networking which make them work, form the core of a new generation of on-person technology for which there are many other applications, such as distributed simulation for training and readiness (getting individuals onto large synthetic battlefields), command and control of individuals on battlefields of the future, and training of medical and line personnel for coping with combat casualties (advanced simulation for casualty care).

Army medics have indeed been seeking better ways of locating casualties and facilitating triage,[13] but their developmental approaches to date have been predicated on specific materiel, and inhibited by conventional methods of test and evaluation: what DARPA could proffer them with **I-Port** is a way of simulating their mission on a virtual battlefield, and simulating prototypes of advanced means of performing that mission so that the relative merits and demerits of each can thoroughly be examined.

Within DARPA itself, its High Definition Systems (HDS) program aims at communicating via advanced displays directly to combat personnel facing critical, urgent decisions:[14]

> In FY 1993, the DARPA program will focus on the development of head mounted displays for use in aircraft, tanks, and shipboard applications. Our approach is to develop small (1 square inch), flat-panel, high resolution displays that can be mounted in current military helmets and replace the heavy, bulky, expensive cathode ray tubes that are currently used. Working with the three Services, we have defined a common display module approach that will meet a wide variety of both current and future military needs.

---

12. Letter, March 19, 1992, from Director, DARPA to The Surgeon General, United States Army.
13. Cf., Requirements for a Physiological Monitoring System (PMS) and a Medical Combat Casualty Locator System (MCCLS), stated by the Center for Excellence in Military Medical Research and Education, Office of The Surgeon General and Walter Reed Army Hospital (now the Borden Center), 16 January 1990.
14. Denman, op. cit., 15.

Demonstrations of the head mounted displays are planned for the Fiscal year 1995. Additional plans include the development of graphics algorithms and scalable image processors, data compression techniques, and technology for manufacturing higher resolution, full-color displays.

Were **I-Port** available, DARPA could quickly and inexpensively extend these demonstrations to include fighters on foot, commencing to investigate what information to display for them, as well as how to process and display it.

Displays on-person imply computers on-person. One possible functional description of an on-person information processor is as follows:

MONITOR:
- G Forces
- Locus, Vector
- Posture (erect, prone, supine, other)
- Personal weapon azimuth
- Status weapon, water, rations, ammo
- Physiological homeostasis

PROCESS:
- Compare detected data with threshold values
- Merge and interpret collective sensing (sound-ranging, range determination)
- Select for transmission (data, channel(s), encryption)

COMMUNICATE
- Low probability of intercept
- DIS standard PDU[15]

DISPLAY
- Operational graphics (e.g., boundaries, routes, threat alerts, minefield markings)
- Hybrid display: icons for virtual objects over actual scene
- Complete depiction of a virtual environment

Here is a *prima facie* case for prototyping: through **I-Port**, DARPA could add, delete, or otherwise modify the foregoing through experience on a synthetic battlefield with an inexpensive simulation of the processor and its input/output devices, yielding information concerning the validity and cost effectiveness of each element of the functional description, and permitting

15. Distributed Interactive Simulation Protocol Data Unit, the government-industry packet standard.

quantification of the size, weight, memory, speed, power and thermal conductivity required for the sensors, the displays, the communications suite, or the processor itself —data that could then guide DARPA's further developments.

II. THE I-PORT MECHANISM

The projected **I-Port** is an electro-mechanical device that functions as an individual combat simulator (ICS) expressly for the "electronic battlefield." **I-Port** equips an individual on foot to "drive" an object within a synthetic environment, just as the crew of a tank simulator is represented n that environment by the symbol for their tank. As is the case with the tank's icon, moreover, the icon for the individual will reflect what the individual in **I-Port** does —his posture, his weapon, his movements or other activities. Through **I-Port** that individual would move, shoot, and communicate, be seen and heard, and interact as appropriate with all other objects on that battlefield within sight, hearing, or range of his weapon(s).

I-Port, as the term is used here, is defined as a mechanism for projecting individuals onto the "electronic battlefield," that is, for enabling one or more individual combatants to practice their combat skills in a distributed, interactive synthetic battle environment.

In considering requirement for **I-Port**, it is useful to remember that fighters on foot can generally be divided into shooters and supporters. Shooters consist of (1) infantrymen armed with direct fire weapons designed mainly to extend control over ground, or to deny it hostile foot elements, and of (2) crews of anti-vehicular weapons, such as anti-armor or air defense weapons. Supporters consist of individuals performing combat support and combat service support functions that require them to operate amid close combat between opposing forces. Some supporters, such as forward observers for indirect fire weapons —mortars and artillery— service weapons and thereby directly influence battle outcome; others — for example, communicators, medics, engineers, supply and maintenance personnel— though a source of combat power and important to efficiency over time, do work that is less well related to defeat or victory. These distinctions should not be regarded as rigorous, but they do enable priorities for **I-Port**: simulating shooters is more important than simulating supporters, and of supporters, the most important are those who control indirect fire weapon systems.

Further, it is important to understand that while **I-Port** may be useful for practicing certain individual skills, its primary purpose is to insert individuals into combat so that they can function there as a member of a unit, as part of a combined arms team. **I-Port** must be developed, and managed once fielded, for practice of collective combat tasks.

As a crude approximation of numbers, one might assume need equip the close combat elements of an infantry battalion in any of the Army's light infantry divisions, or any Marine Division, and of a dismounted company in any of the Army's armored or mechanized divisions. SOF units would be equipped commensurate with mission. To optimize utilization, and to exploit distributed simulation to the maximum, the **I-Port** mechanism should be designed as movable equipment, so that the devices could readily be concentrated in those units able to use them most efficiently. Even assuming broad sharing among both active and reserve component users, some 2000 **I-Port** devices could readily be kept busy in peacetime training, let alone supporting operational tests or other activities. So large a number suggests that the cost per **I-Port** will loom in any decision relating to its development and procurement, and that therefore the mechanism should be designed with a definite cost ceiling in view. Worth citing as an analogous development program is the Multiple Integrated Laser Engagement System, MILES, during the 1970s: from the initial Request for Proposal for MILES, design-to-cost was a basic program objective —successfully attained, the passage of the inevitable twelve years before Initial Operating Capability notwithstanding.[16] **I-Port** should be a design-to-cost development.

I-Port will impose burdens, and possibly costs, on other users of distributed simulation. The synthetic battle environment for an infantryman shooter will be categorically different from that for a combatant aboard an air or land vehicle. Micro terrain will be much more important to the former than the latter, for the infantryman's life will often depend on observation by the unaided eye, and on his field of fire. Cover, that is furnishing physical protection, will be a more vital interest, as will concealment, that is, hiding from hostile observation. The works of man will probably also be more important, especially buildings, fences or other man-made obstacles, bridges or other man-made mobility enhancements, and culverts, cellars, or other man-made shelters from ordnance. His vision will be limited commensurate with his optics and weapons, and in general, will be substantially less than that of armored fighting vehicles. Vulnerability afoot will, of course, be more extensive than for mounted personnel, and casualty-causing events will have to be accurately modeled for both indirect and direct weapons, mines, and vehicles themselves. The injection of infantrymen into any synthetic battlefield will therefore increase the terrain data base significantly, but computationally, given the reduced ranges, the differences should be manageable.[17]

Anti-vehicular shooters who view the battlefield through a weapon sight —typically an optic of some power of magnification— will have audio-visual requirements like those of vehicle crews. Their view of the battle, and that of forward observers for indirect fire weapons, will not

---

16. The author was cognizant General Staff supervisor for MILES during its first three years.
17.In the Honeywell Helmet Mounted Oculometer System (HMOS) -- being purchased by the U.S. Army for its Visual System Component Development Program, and in use by the U.S. Air Force -- an eye-tracking oculometer fixes the exact orientation of the eyes, and upgrades the granularity of its imagery specifically where the wearer is looking, leaving periphery and background less well-defined, thus reducing demands on the computer.

be substantially different from that through the optics of an armored fighting vehicle. Still, aural stimuli will be more subtle, and directionality more important for the fighter on foot than for vehicular crewmen. The audio-visual interface with the foot fighter will be one major determinant of **I-Port**'s credibility. The use of close-to-the-eye displays, either helmet-mounted (HMD) or Heads-Up (HUD), has come to be regarded as the signature of virtual reality devices. This is not accurate, for some of the highest fidelity vehicular simulators use domes or arrays of screens to display surroundings; and the best existing ICS are domed buildings for Man-Portable Air Defense (MANPAD) training. Designers of **I-Port** should examine all modes of display before settling on a design.

Kinethesia, providing for a person's sense of moving and performing work, will be the other major determinant of credibility. There are arcade games that project players into virtual battle, notably the booths in *Battletech* in Chicago, and the helmet-mounted screen plus hand-control in the *Quarters* in Kirkland, WA.[18] In the former the player remains sitting; in the latter, players can jump or duck in place to balk an opponent's aim, but they can "move" about the virtual environment only by pushing a button. For military validity, **I-Port** will have to elicit physical exertion commensurate with combat task. E.g., if the latter requires climbing a hill, **I-Port** should exact a tax, in time and in foot-pounds of energy expended, proportional to the slope and height of the hill, and to other obtruding difficulties of transit.

As with vehicular simulators, **I-Port** should mensurate and record behavior, but it should do so without physical invasiveness. The simulator should also capture communications, including hand and arm signals. Metabolic status should be monitored and recorded [this requirement both to foreclose injury from stress, as well as to furnish physiological data as an aid to evaluation]. Records of use of weapons will be little different from that of vehicular weapons (but it should be noted that the presence of personnel on foot will demand careful modeling of anti-personnel weapons on vehicles, conceivably to an unaccustomed precision). Hence, **I-Port** will require an ensemble of sensors significantly different from those for vehicles, and means for translating sensor output into DIS PDU. Much of the foregoing will entail a substantial amount of computing, but as has been the case of vehicular simulators, computing tasks seems manageable so long as the costs of high-speed information processing continue to decline.

III. A PROPOSED TECHNICAL APPROACH

I-Port poses a modest risk for technical development. The **I-Port** mechanism could capitalize, in many of its features, on DARPA's research into robotics, particularly robotic teleoperation.[19] Over the past three years, advances in both processors and micro-electro mechanical systems (MEMS) have advanced that technology significantly.

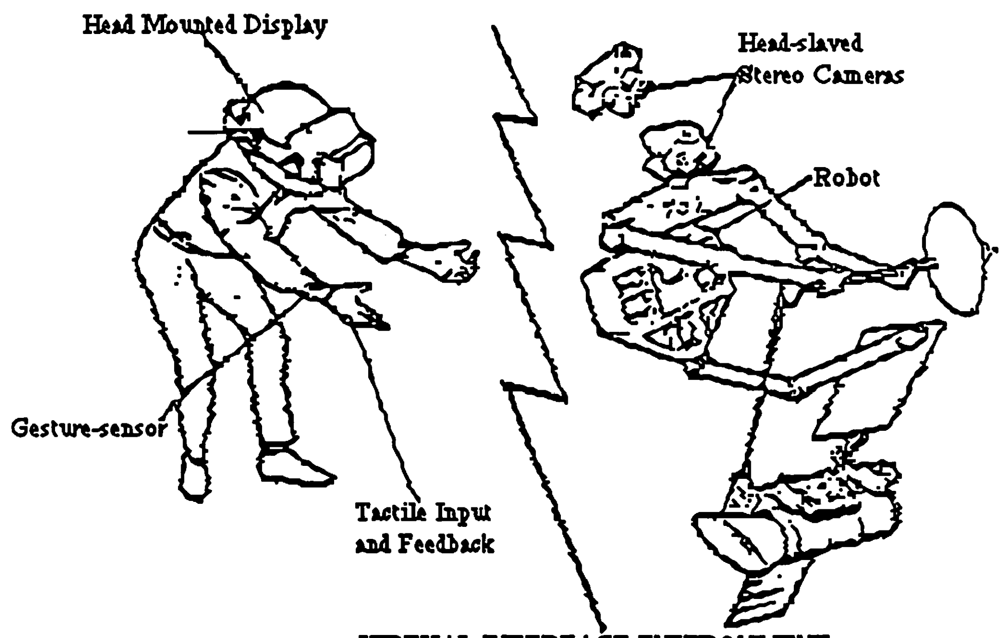
---

18. Carroll, PB "Let the Games Begin," The Wall Street Journal, April 6, 1992, R10.

19. Rosenfeld, RL Robotic Manipulators and Legged Locomotion, DARPA, Arlington, VA, 1988.

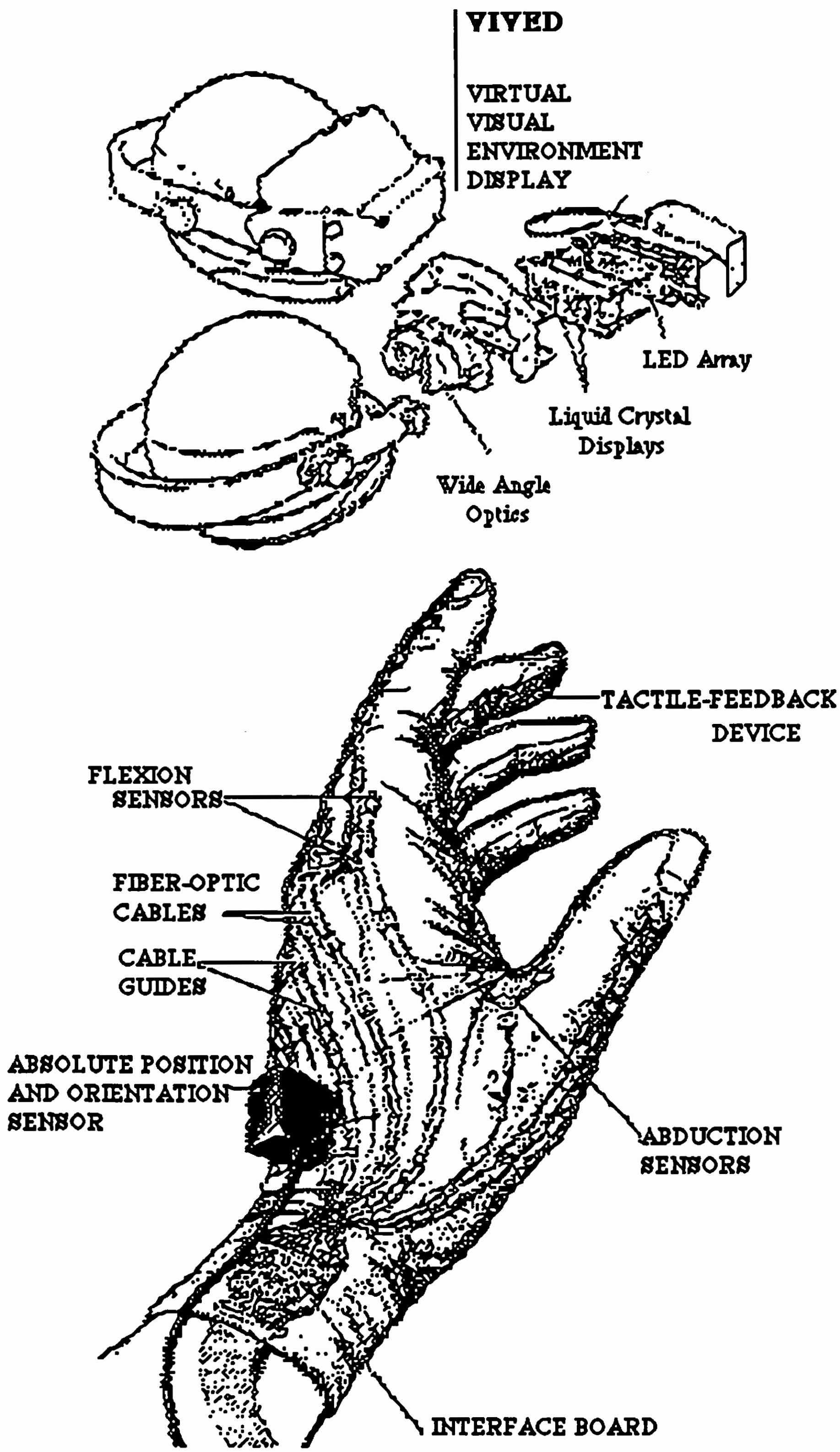
Teleoperation and I-Port both enable an individual to interact with a remote environment. In teleoperation, the mechanism empowers a human to control a robot performing work in the remote environment. I-Port stands that concept on its head: the I-Port mechanism controls a human by portraying to him a remote environment, and stimulating him to perform appropriate work.

Over the past decade the National Aeronautic and Space Agency has also conducted experiments with robotic teleoperation, developing a "helmet-mounted, head-controlled stereo display," and a "telerobot supervisory control interface," each with three-dimensional auditory cuing and voice.[20]



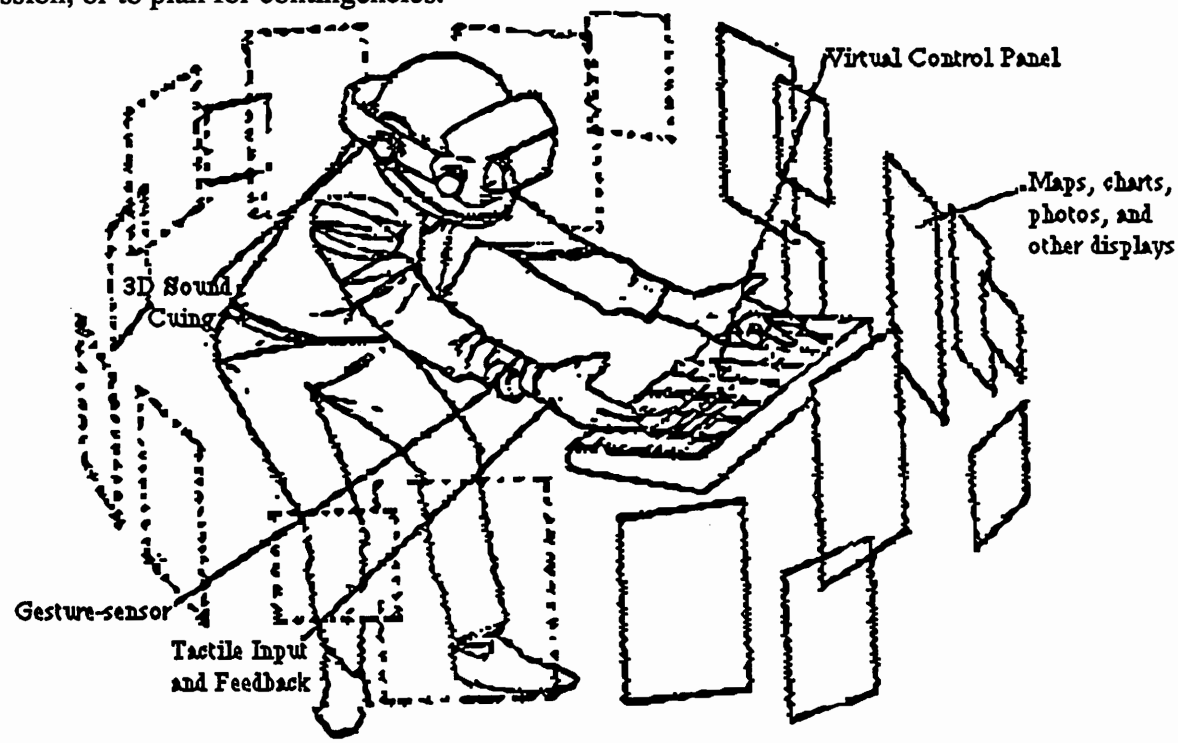
VIRTUAL INTERFACE ENVIRONMENT
Telerobotic Control by "Telepresence"

20. Presentation of Jenkins, Dr. JP, to the Lynn Panel of the Army Science Board, 1991. Fisher, S.S., McGreevey, M., Humphries, J., and Robinett, W., "Virtual Environment Display System", paper presented to the ACM 1986 Workshop on Interactive 3D Graphics, October 23-24, 1986, Chapel Hill, NC. Also, Fisher, S.S., "Virtual Interface Environment Workstations," presentation at the TRADOC Training Technology Workshop, USACGSC, Fort Leavenworth, KS, March 23-24 1989 (NASA-Ames FL:239-3).



NASA Audio-Visual and Tactile Interfaces

NASA has also experimented with using its audio-visual and tactile control interfaces to project, putatively into a spacecraft from Earth, the environment of a virtual office, complete with an apparently real computer keyboard, and surrounding graphic displays, so that even in a cramped spacecraft an astronaut could summon whatever information he needed to control his mission, or to plan for contingencies:



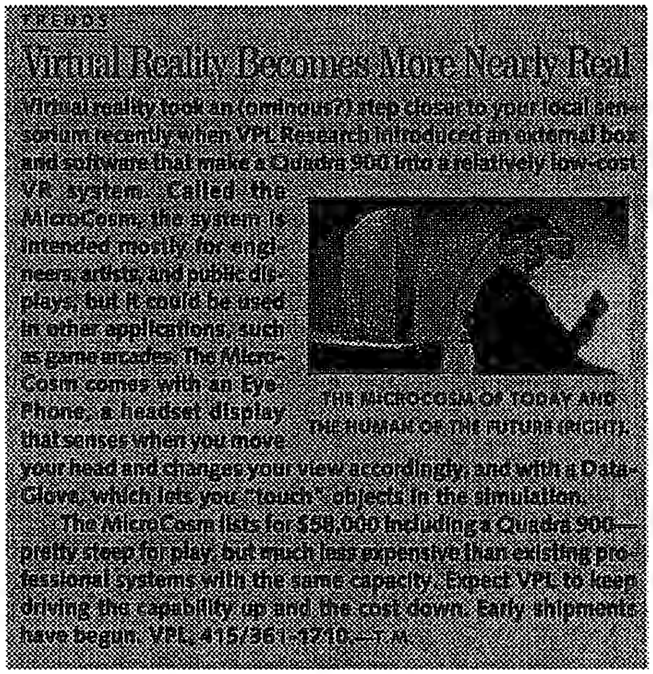
A COMMAND POST IN A HELMET
Virtual Interface for C^3I

NASA Visualization of an "Autonomous Automation Interface"

The information technology revolution now underway had rapidly advanced capabilities to engineer devices for the purposes shown, reduced their cost, and increased their effectiveness. In 1990, virtual reality equipment like NASA used cost as much as $750,000, but could display only cartoon-like images that moved slowly and haltingly. *Sense 8 Inc.*, a small company formed two years ago, now retails a head-mounted display system for $20,000, including a computer based on a 486 chip, goggles, and a controller; an electronic glove is available for another $9000.[21] The latest edition of MACWORLD reported that VPL Research, which numbers NASA among its customers, now sells a powerful computer plus audio-visual and tactile interfaces for $58,000:[22]

---

21. Yamada, K "Almost Like Being There," Wall Street Journal, April 6, 91992, R10.
22. MACWORLD, Vol. 9, No. 5, May 1992, 109.



TRENDS

Virtual Reality Becomes More Nearly Real

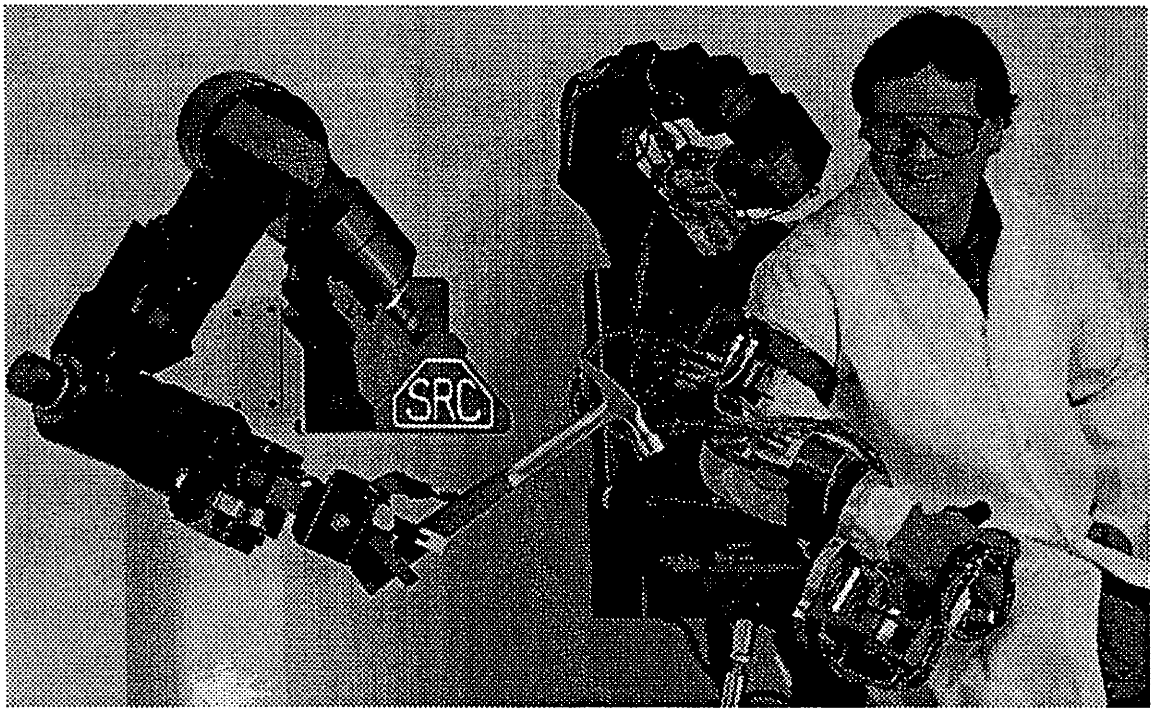
Virtual reality took an (ominous?) step closer to your local sensorium recently when VPL Research introduced an external box and software that make a Quadra 900 into a relatively low-cost VR system. Called the MicroCosm, the system is intended mostly for engineers, artists, and public displays, but it could be used in other applications, such as game arcades. The MicroCosm comes with an EyePhone, a headset display that senses when you move your head and changes your view accordingly, and with a DataGlove, which lets you "touch" objects in the simulation.

THE MICROCOSM OF TODAY AND THE HUMAN OF THE FUTURE (RIGHT).

The MicroCosm lists for $58,000 including a Quadra 900—pretty steep for play, but much less expensive than existing professional systems with the same capacity. Expect VPL to keep driving the capability up and the cost down. Early shipments have begun. VPL, 415/361-1710.—T.M.

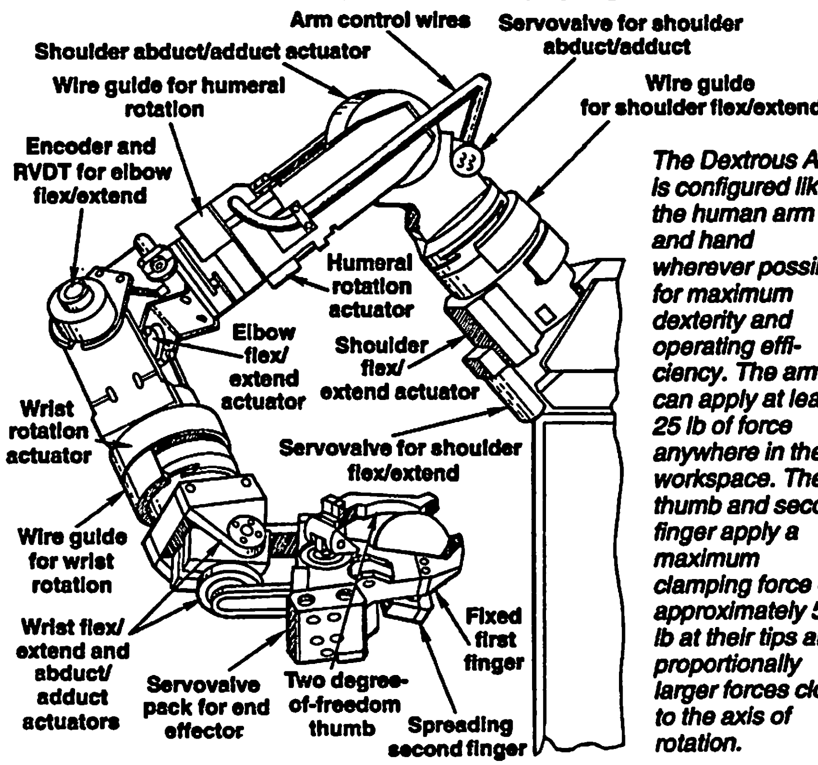
One of the academic centers that has participated in DARPA's research into telerobotics, and in its MEMS development as well, is the University of Utah. In 1991, the University's Center for Engineering Design delivered to the US Navy TOPS (Teleoperations/Telepresence), a device enabling an operator aboard a surface vessel to control a robot working undersea. Central to TOPS is the SARCOS Dextrous Arm, developed at the Center for Engineering Design, and marketed through SARCOS Inc., a commercial funding, technology transfer, and management company with a close relationship with the University. The arm is a high-performance, anthropomorphic manipulator responsive to digital signals conveyed to it, over long distances if desired, from an exoskeletal sensing apparatus worn by the operator. The operator inserts his hand and arm into the exoskeletal framework, activates the machine, and thereafter the slaved robot duplicates his arm, wrist, and finger motions. The robot arm, compensated for gravity, communicates no sensation of weight to the operator, but does provide kinesthesia: he is provided accurate tactile feedback as he performs his tasks. For remote operation, the operator wears a helmet-mounted television display of the scene at the robot's work area. In the laboratory, the operator directly observes the Dextrous Arm and its task; the laboratory configuration is pictured below:[23]

23. Photographs supplied by the Center for Engineering Design, University of Utah.



Dextrous Arm in Action: Operator Can "Feel" the Hammer

The Dextrous Arm Mechanism[24]



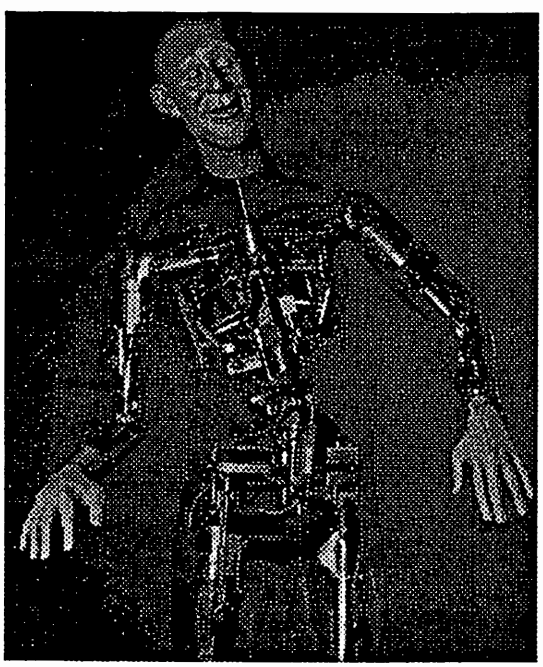
The Dextrous Arm is configured like the human arm and hand wherever possible for maximum dexterity and operating efficiency. The arm can apply at least 25 lb of force anywhere in the workspace. The thumb and second finger apply a maximum clamping force of approximately 50 lb at their tips and proportionally larger forces closer to the axis of rotation.

---

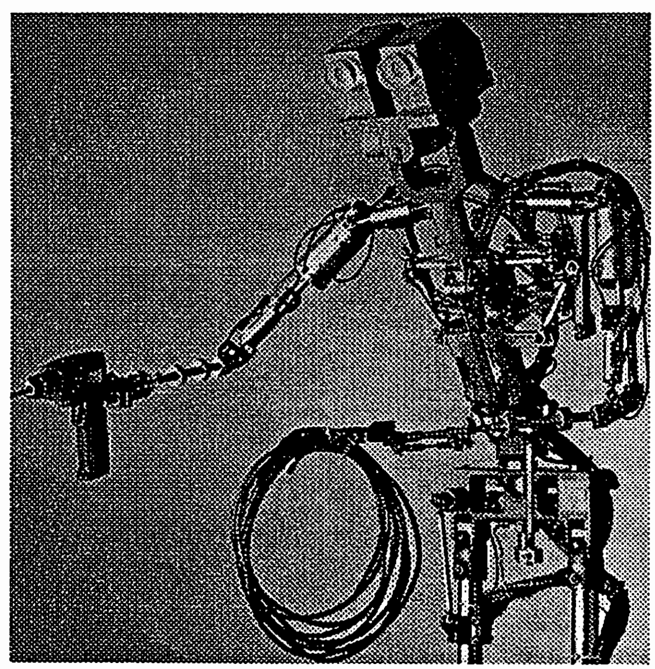
24. Korane, KJ "Sending a Robot to Do a Man's Job," Machine Design, Vol 63, No. 22, Nov. 7, 1991, 46ff.

Dexterity with the system is sufficient to pick up and use hand tools, insert and turn keys in a lock, pour liquid from a beaker, assemble small parts, and screw in light bulbs. The robotic arm measures 31 inches in the upper arm, 26 inches in the forearm, and 19 inches in the hand, with a total mass of about 23 kg. The Center for Engineering Design employs hydraulic actuators in the Dextrous Arm, drawing on several years of experience with hydraulically actuated, digital-controlled anthropomorphic robots for entertainment applications —notably, Disneyland manikins— that have experienced very high reliability under conditions where continuous operation and leak-proofing over periods of months were mandatory. The hydraulic servo-actuators are as small as 0.5 in diameter by 1.84 in length, in three sizes: 250, 880, and 1970 lb.-in. The valves in the system are rated for pressures up to 3000 psi, no-load flow up to 2.0 gpm, and bandwidth up to 700 Hz. Altogether in the system there are 114 sensors and 52 actuators.

The Center for Engineering Design's experience with human-like robots has been useful in computer programming, communication, and in designing exoskeletal controls. The anthropomorphic devices use both hydraulic and pneumatic effectors, embody up to 100 sensors and 52 actuators, and enable 52 degrees of freedom in the figure's motions. They are responsive to computer-control, either through a pre-recorded numerical program —as is the Disneyland application— or through human control via exoskeletal sensing mechanisms, as in the Dextrous Arm. Shown below are two examples of such devices:



Entertainment Robot



Work Robot

The "entertainment robot" might have some limited military applications in deception. The "work robot" might be used as a human emulation for prototyping military accouterments, such as SIPE costumes for chemical warfare, where internal temperature and wear while performing tasks might be at issue; they might also be used to control vehicles or perform other critical tasks in operational tests involving live ordnance. In the present context, their primary significance is that they are a complex of machines responsive to computer control, each relatively very powerful for its size and weight.

The Center for Engineering Design sponsored, two years ago, a conference on **I-Port** at Snowbird, Utah. Based on what its engineers have learned then and since about the military problems that **I-Port** is intended to solve, Professor S.C. Jacobsen, Professor of Mechanical Engineering and Director of the Center, has stated that:[25]

> [As] a result of considerable thought by myself and the SARCOS staff...we believe that a practical mechanical human interface is feasible in the near term. Many of the ingredients for proposed systems have already been developed by us and are used in various robotic systems for Navy, Army, and commercial clients.

Dr. Jacobsen has advanced a preliminary plan for a program of development aimed at a biped **I-Port** embodying multiple input pathways to the individual using it: visual-auditory, musculo-skeletal, metabolic, and psychological. Experience at the Center convinces him that a properly designed **I-Port** will cause all sensory information to be "fused" in the participant, and that the participant will perceive his experience through **I-Port** as real, and react to it accordingly. Therefore, **I-Port** must be able to:

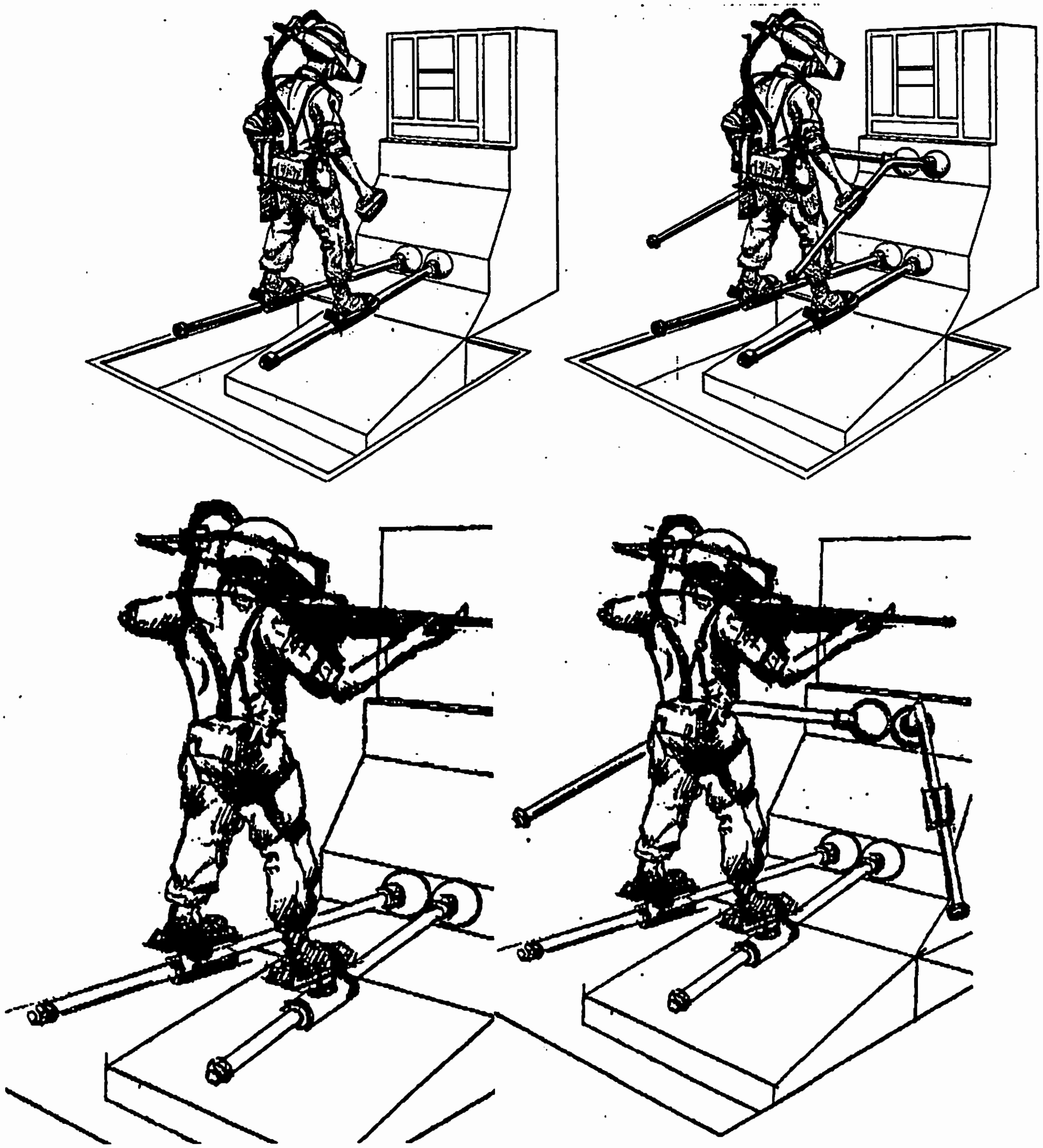
- **Manage exchanges of information and energy between man and machine**
- **Coordinate multiple sources of both information and energy**
- **Cope with requirements for high bandwidth and resolution**
- **Deal with large dynamic loads and ranges of motion**

These requirements raise six major design issues, each deserving of exploration through a progressive, step-by-step development program:

1. Should the device be active (machine-powered), or passive (man-powered)? Both?
2. Design ground-based foot and hand interfaces, or exoskeletal (conformal) controls?
3. What are the alternatives —electric, hydraulic, MEMS— for actuators and sensors?
4. Which form should the audio-visual interface take: HMD, HUD, screen(s)?
4. How much computing and communications will be required?
5. What cost-effectiveness factors bear?

25. Memorandum for the author, dated 28 March 1992, subject: "I-Port Mechanical Interface System"

SARCOS first produced the following design, labeled "A," shown below, in two variants, without and with a direct interface with the hands:

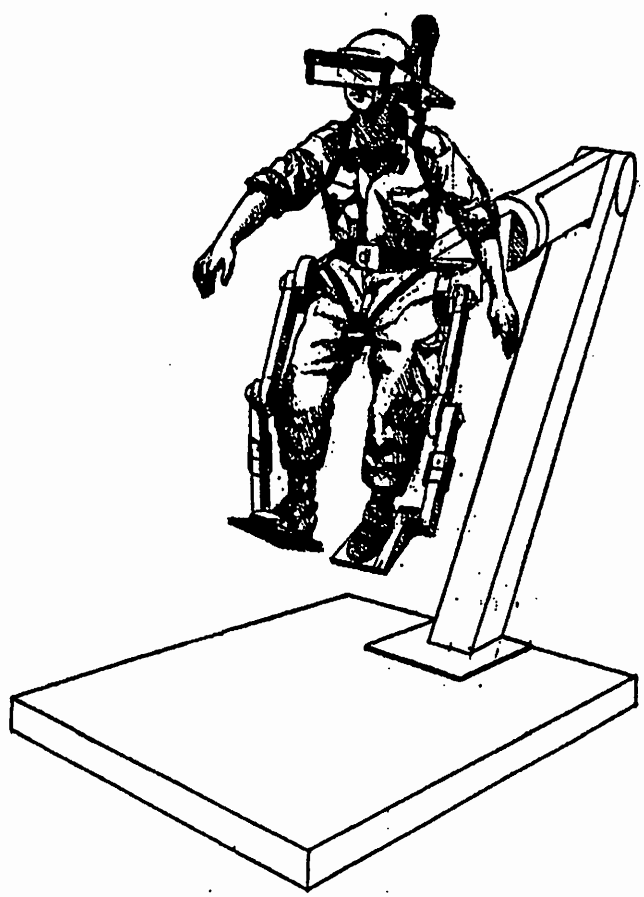


I-Port Design A

Design "A" led to the hypothesis that the answer to Issue 1 is that the mechanism will have to capable of both active and passive operation, governed in large part by terrain data and other environmental limits on movement, or mandates for work. It will be important that hands and feet be able to move freely and naturally as they should in the synthetic environment, but that they be firmly checked by ground, walls, trees, rocks, or other objects present in the that environment. Design A supported the combatant mounted on tubes that establish ground datum, his boots linked to the tube via a loose binding —not unlike that for cross country skiing— that can either permit his foot to move freely, or by rendering the tube rigid and causing the binding to grip, "implant" the foot on the ground.

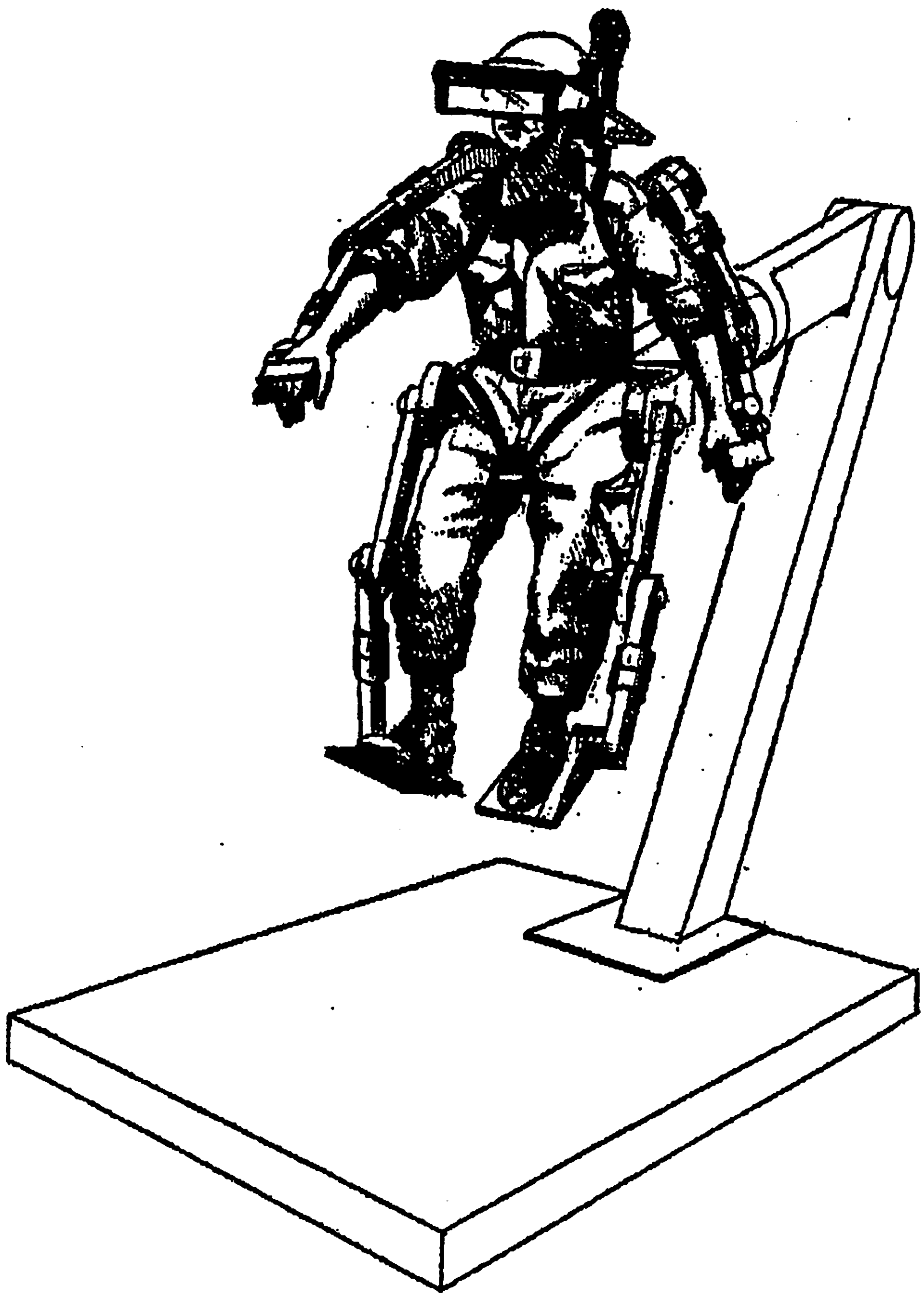
Design A's pit allows the tubes ample vertical clearance. The facing cabinet encloses the control mechanism for the tubes, the computer, and sensors capable of detecting body posture and weapon attitude. For tasks in which the combatant might have to carry some object other than a rifle, upper tubes might be provided to engage his hands and upper body. In either configuration, he could at any time drop his "load," unsling his weapon, and shoot, as shown.

A more promising design then emerged, Design B, a direct derivative of the Dextrous Arm, in which each of the combatant's feet would be supported on a robotic "hand," controlled by the terrain data base for the electronic battlefield:



I-Port Design B With Lower Body Interface

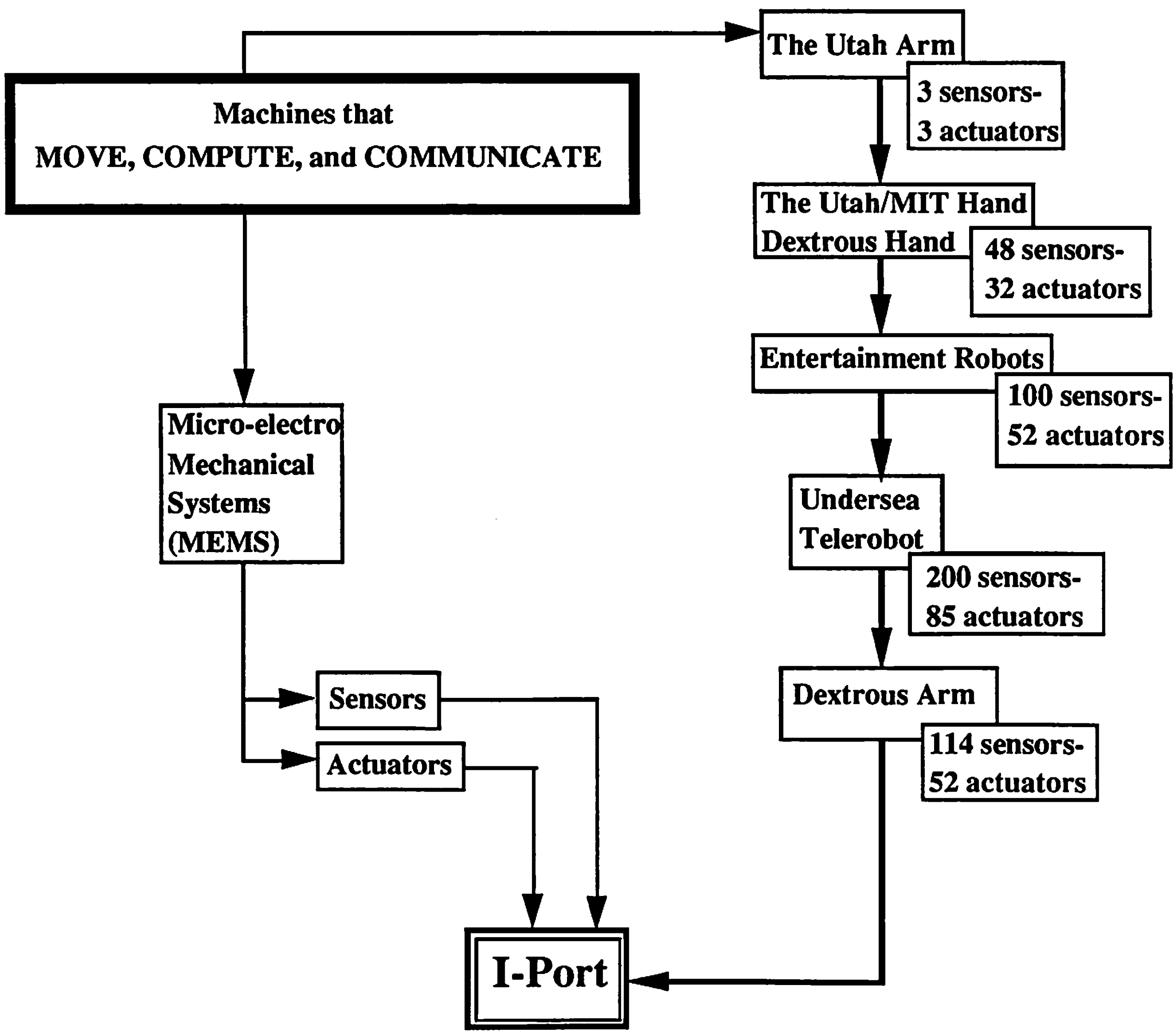
In a second version of Design B, the exoskeletal interface is extended to the hands and arms, so as to define arm loads and limits, and to track motions with arms or hands. Both hands and feet would move freely unless arrested by the model-controlled physical environment of the "electronic battlefield."



I-Port Design B with Full-body Exoskeletal Interfaces

SARCOS could approach this last design with high confidence, since the subsystems of the mechanism would be very similar to those with which it has been working over the past several years. Dr. Jacobsen points out that CED has advanced from successful project to successful project, each significantly more complex than the last, precisely because each new program sought by the Center represented a logical step forward from the previous undertaking. Dr. Jacobsen sees **I-Port** as an experiential bridge between the Center's robotic and MEMS programs:

Center for Engineering Design
Progression through Complexity



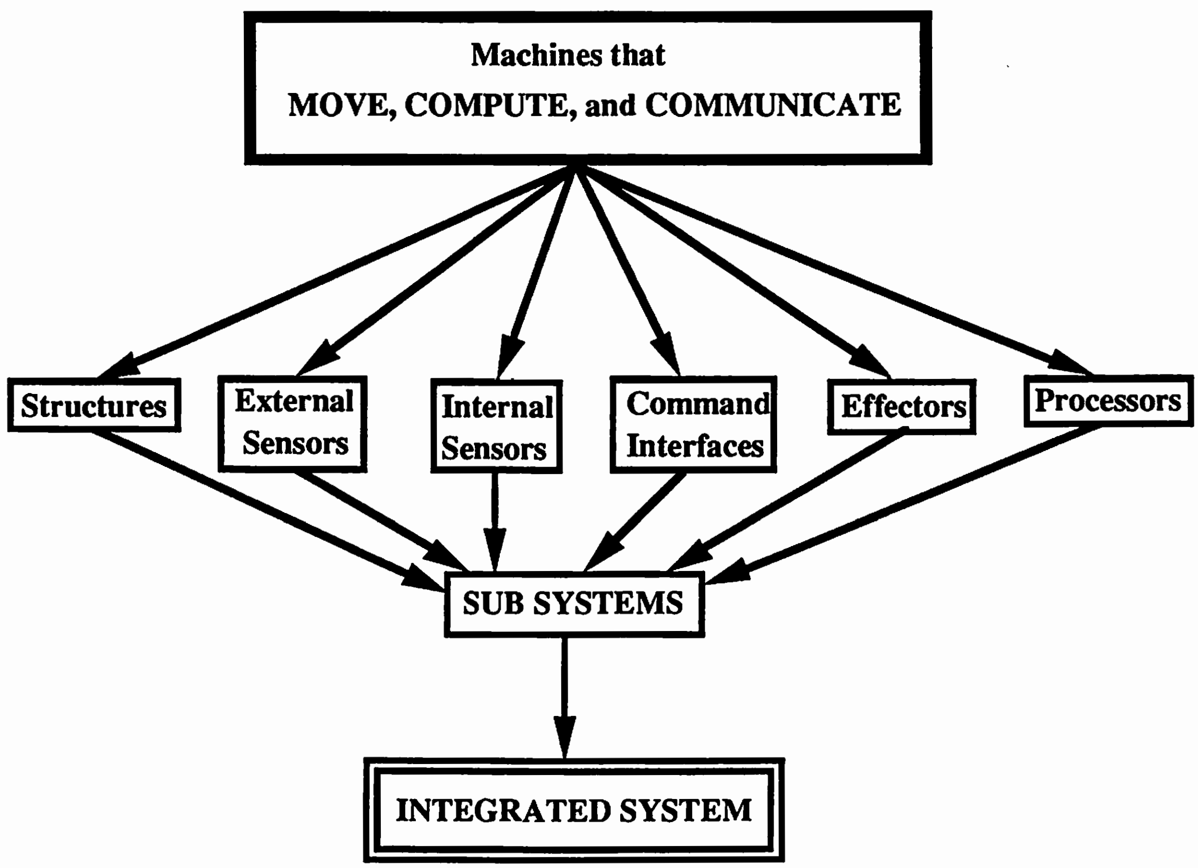
In all previous programs, the Center brought to its engineering a commitment to phased development that has facilitated project focus and management, maintained tight control of costs, and increased assurance of meeting program objectives. CED management has also included:

- **Insistence on strong participation of users**
- **Demand for close collaboration among subsystem developers**
- **Requirement for continual testing and demonstration**

The Center envisions its proceeding with **I-Port** development as follows:

Center for Engineering Design

Focus on I-Port



At this juncture, the Center has clarified two of the six design issues previously identified —resolution will have to await a final plan. In turn, that plan can not be devised without investigation and clarification of the remaining four:

1. Should the device be active (machine-powered), or passive (man-powered)? Both?
2. Design ground-based foot and hand interfaces, or exoskeletal (conformal) controls?
3. What are the alternatives —electric, hydraulic, MEMS— for actuators and sensors?
4. Which form should the audio-visual interface take: HMD, HUD, screen(s)?
4. How much computing and communications will be required?
5. What cost-effectiveness factors bear?

Recommendations

❶ Set as an objective that **I-Port** when in volume production will cost no more than $50,000 per copy, and provide incentives for developers to enable lowering that figure.

❷ Provide the Center for Engineering Design with $150,000 in FY92 funds to develop (1) an estimate of how to resolve remaining design issues, and (2) a plan to construct an **I-Port prototype.**

❸ Allocate $600,000 in FY93 (1) to implement that plan, (2) to conduct a technology demonstration with the **I-Port prototype**, (3) to provide for automated reproduction of **I-Port**, and (4) fix final production cost per unit.

❹ Set aside $3,200,000 in FY94 to fabricate and evaluate 50 **I-Port** operating collectively within the context of a virtual battle among mounted forces.

❺ Program for volume production beginning in FY 95, with IOC that year or the year following.