Robotics: where has it been? Where is it going?

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The history of robotics stretches far into the past, with numerous tales of attempts to create artificial life. The start-up and rapid growth eras, from 1950 till 1985, were dominated by applications in spot welding and spray painting. The current era of disillusionment has occurred because the tasks of assembly and mobility are technologically more difficult than most people had anticipated. The future has many promising applications, from undersea to outerspace. What the future brings will depend on how much of our wealth we invest in it.

Keywords: Assembly; Mobility; World modelling; Intelligent machines; Cranes; Investment.

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I am going to divide the history of robotics into four eras: (1) Pre-electronic, (2) The start up, (3) Euphoria, (4) Disillusionment.

1. Pre-electronic

The pre-electronic era stretches back many decades, even centuries. It produced a few mechanical curiosities; but mostly science fiction. A few representative pieces of that literature are:
The Golem – a 16th century story of a clay figure that came to life. It was supposed to protect the Jews from persecution.
Frankenstein – a 19th century story of an experiment in artificial life that went haywire.
R.U.R. – a 1921 play about robot workers that rebel and kill their human masters.
Robbie the robot – an Isaac Asimov story of a friendly helpful robot.
Star Wars – a movie in which robots are depicted as loyal, lovable, companions.

The most important thing about these stories is that, to the average person, they seem plausible. For many people, the creation of artificial life seems almost easy – something that might be achieved by a single mad scientist. Few people, even those who do research in artificial intelligence, seem to realize how complex living creatures really are, and how difficult it is to duplicate the behavioral capabilities of even a housefly, or an ant, much less that of a human being.

An enormous lack of appreciation for the magnitude of the technical difficulties in building the mechanical equivalent of a human being is the historical backdrop against which industrial robotics developed. It is the cause of much of the media hype and hysterical predictions that have plagued this field from the beginning, and is responsible for much that is wrong today.

The pre-electronic era ended about 1950 with the advent of the electronic computer.

2. The start up

The start up era began in the early 1950's with the development of remote manipulator systems by the Atomic Energy Commission. General Electric was an early leader in this work. The GE labs under Ralph Mosher developed a walking truck, and a man amplifier.

Industrial robotics as we know it today began with George DuVall and Joe Engelberger who brought the first Unimate to market in 1957. Removing parts from die casting machines was the first industrial application. Market penetration was slow, however, and it took more than ten years before Unimation turned a net profit on its investment. Meanwhile, Cincinnati-Milicron, Autoplace, Prab, and several others had entered the market.

Robotics research was begun in the 1960's through DARPA funding of Artificial Intelligence labs at MIT, Stanford University, and Stanford Research Institute. In the late 60s and early 70s NASA began funding robotics work at the Jet Propulsion Lab (JPL) and Ames.

Industrial robotics did not become really profitable until the late 70s when the automotive manufacturers began to use robots for spray painting and spot welding. The rapid spread of these two applications brought the start-up period to a close, and introduced the era of euphoria.

3. Euphoria

During this period, General Motors joined with Fanuc to form GMF. Automatix was founded. General Electric teamed with robotics companies from Japan, Italy, and Germany. Westinghouse, IBM, Bendix, and GCA entered the market. Literally hundreds of startup companies rushed to join what promised to be a multibillion *new industrial revolution* built on robot labor.

In December 1980, the Robot Revolution was the cover story of TIME magazine. Feature articles appeared in Fortune, Business Week, and the Wall Street Journal. Robots were featured on TV news casts all over the country. At that point the United States had a grand total of 3000 robots installed. The industry was producing 1500 units per year, and Wall Street analysts were predicting 35% per year growth through the 1980s. The conventional wisdom was that the U.S. robotics market would hit $2 billion by 1990.

An ASME forecast (reported in Time December,1980) predicted that:
- By 1982, 5% of all assembly systems would use robotic technology.
- By 1985, 20% of the labor in final assembly of autos would be replaced by automation. Also by that year, robot vision for "bin picking" would become significant.
- By 1988, 50% of the labor in small component assembly would be replaced by automation.
- By 1990, the development of sensory techniques would enable robots to approximate human capability in assembly.

During those days, the great concern was whether there would be any work at all left for humans. A well known MIT labor consultant (quoted in Time December, 1980) solemnly predicted that "retraining would be impossible, because there will be no jobs for workers to be retrained for." That's pretty horrible English, but it was an even worse economic forecast.

Let's look at what actually happened. *Fig. 1* shows actual growth in relation to the 35% prediction. Until the end of 1985, the prediction of 35% growth rate seemed correct, maybe even a little conservative. But in 1986 the bust came, and the era of disillusionment began.

4. Disillusionment

Robot sales leveled off in 1986, and in 1987, sales fell by 35%. In 1988 the market was equally dismal. The so-called "shake-out" occurred. A number of companies abandoned robotics altogether. Others underwent severe retrenchment.

'What went wrong? How did so many experts miscalculate the growth potential? Why didn't robotics live up to the predictions?

Well first of all, the technology was unable to deliver on expectations. Robotics is sort of like ice skating – it is a lot harder than it looks. The technical difficulties were masked by the fact that the really easy tasks, like spray painting, spot welding, and press loading, were done first. When these markets became saturated, robotics ran into a technology barrier. The problem was that the optimistic predictions of exponential growth were based on the assumption that robot assembly

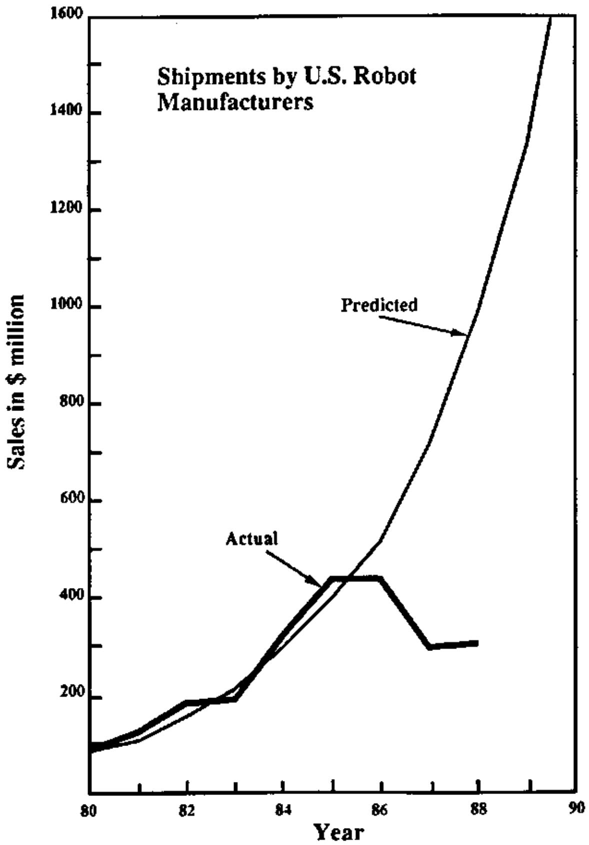

Fig. 1.

would become technically and economically feasible during the decade of the 1980s. This turned out to be almost totally wrong. Robot assembly is much harder than almost anyone (except maybe Brian Carlisle) thought.

It requires lots of sensors to reliably acquire parts, to sense mating forces, to detect defects, and to correct errors. And more than just sensors are required. Sensory data must be processed to extract information about the position, orientation, and state of objects in the world. Software for such processing is difficult, time consuming, and very expensive to write. Software costs can exceed hardware costs, sometimes several times over, and even then the results may be unreliable.

Writing control programs for robots that use sensors is also difficult. Force servoing is computationally expensive. Visually guided assembly programs tend to run slowly, and fail often. Also, software for robots with sensors tends to be application dependent, so software development and maintenance costs reoccur with every installation. Robots with sensors are thus not flexible. They must be custom engineered for almost every application. As a result, robot assembly has not proven economically practical. With few exceptions (such as Adept), robotics has not significantly penetrated the assembly market. Robots that use lots of sensors remain in the laboratory, surrounded by teams of Ph.D. researchers, professors, and graduate students. And even these laboratory robots are not able to perform many tasks that are quite simple for humans. For example, I know of no robot anywhere in the world that can tie a shoe lace.

Meanwhile, outside the factory, there also were unrealistic expectations, particularly in the area of robot combat vehicles. So far, the only real success has been in air vehicles, most notably the cruise missile. The cruise missile is a robot kamakaze. Cruise missiles can be given a map of the ground with a planned path to a target. The cruise missile can then sense the ground, compare what it senses with its map, correct for errors in position, and follow the path on its map to the target. Some cruise missiles can even be programmed to fly alternative paths based on real-time data such as enemy radar activity.

There has also been some success in building robot air vehicles designed to attack air-defense radar systems. Vehicles such as the Tacit Rainbow and Seek Spinner can loiter over a target waiting for an enemy radar to be turned on. When that occurs, it attacks the source of the radar signal.

On the other hand, robotic ground vehicles have not lived up to expectations. The DARPA autonomous land vehicle can follow a dirt road, but at less than 20 miles per hour. It is painfully slow at cross country navigation. In the entire country, there are no autonomous land vehicles with driving skills that remotely compare to human performance. As a result, funding for this type of research has not grown. It has, instead, been sharply reduced.

So that's where we have been. Where are we now? It seems to me that right now the world is divided into two groups:

Half of the people are unaware of the problem. They do not know that a technology barrier exists. They still believe the science fiction premise, that robotics is relatively easy. These people still worry about robots taking over completely.

The other half of the population knows there is a problem. They are, more or less, aware of the immensity of the technical difficulties. They are convinced that robotics is impossible. There is nothing that can be done, and we should not waste any more money.

As usual, the truth lies somewhere in the middle. Again, robotics is like ice skating – It is hard, but not impossible. It simply takes more work than one first thought. We now know that building an intelligent robot requires more than hooking a microcomputer to a mechanical arm. We now know there are problems of real-time planning, world modeling, and sensory processing. There are problems of software development, testing, and validation. There are problems of mobility, communications, and systems architectures. There are issues of how to achieve reliability, and what to do with lots of redundancy. We realize we need a better theory and more engineering methodologies.

These problems are formidable, but not insolvable. We now know how to do real-time planning. The Intelligent Task Automation (ITA) project [1], the Autonomous Land Vehicle (ALV)[2], Pilot's Associate [3], the Multiple Autonomous Undersea Vehicles (MAUV) project [4], and several battle management projects [5,6] have taught us how build real-time planners. These and other projects have taught us a lot about world modeling. We now know how to represent maps, and knowledge about objects, space, time, and states of the world. We also have a lot of new hardware and software for processing sensory information. We have real-time, multi-tasking, multi-processor operating systems and software development environments. We have numerous system architectures, at least some of which, are adequate to the task at hand.

Assembly can be done robotically. There are lots of assembly tasks that robots can do well. These range from microelectronics, to electronic boards and buckets, to small mechanical parts. Methods are also being developed for large scale robot assembly, in airframe manufacture, ship building, and construction of office buildings, bridges, highways, tunnels, sewer systems, and homes.

The potential market for robots is bigger than ever. The prospects for a new industrial revolution still exist. It is just that robotics poses bigger and more fundamental problems, which will take more time and money to solve, than a lot of people previously realized.

What we need to do now is to take a broader perspective on robotics. We need to think beyond the single manipulator with a microcomputer, and focus instead on integrated, intelligent, man-machine systems. We cannot build artificial human beings, and we should not try to replace human workers with robots on a one-for-one basis. We should instead try to build systems that improve productivity, and take advantage of what humans and machines do best. The real economic pay-off is to be found in integrated, intelligent, man-machine systems.

5. Manufacturing

Consider for example, improvements that have been achieved by installing CIM systems in five American companies are reported in a National Academy of Sciences Manufacturing Studies Board report [7]:

Reduction in engineering design cost	15–30 percent
Reduction in overall lead-time	30–60 percent
Increase in product quality	2–5 times
Increase in engineering productivity	3–35 times
Increase in production productivity	40–70 percent
Increase in equipment productivity	2–3 times
Reduction in work-in-process	30–60 percent
Reduction in personnel costs	5–20 percent.

Note that the reduction in personnel costs is the smallest factor listed.

These improvement are from single installations. The cumulative gains of total system integration should be expected to build on these results exponentially. Thus, CIM plants of the future may achieve several hundred percent productivity improvement over current practices.

The manufacturing sector contributes about $1000 billion to the GNP each year. A factor of two improvement in manufacturing productivity would have a trillion dollar impact on the economy.

6. Construction

We also need to think seriously about moving robotics beyond the confines of the factory floor. We need to make robots mobile, and take them

Fig. 2.

into the shipyard, and onto the construction site. *Fig. 2* shows a robot hanging from a six cable suspension system. This cable arrangement provides a kinematically rigid platform from which the robot can work [8]. If the six cables are suspended from an overhead crane, the robot then becomes mobile over the entire 3-dimensional working volume of the crane. *Figs. 3*, and *4* show how a similar arrangement can be provided for tower cranes and boom cranes. Other construction robotics opportunities include computer controlled grading and digging machines, computer integrated large-scale metrology systems, real-time as-built databases, data driven cut-to-fit machinery, and large-volume high-precision lift and position devices.ing intelligent machine technology to the construction industry (including the manufacture of building materials) could significantly improve the quality and reduce the cost of commercial and industrial buildings, utilities, roads, bridges, tunnels, and eventually homes. Construction is more than a $350 billion per year industry in the United States. The potential market for construction robots is enormous.

For those who worry about the loss of construction jobs, it is important to point out that there is not a fixed amount of things to be constructed in the world. Improved productivity in construction would not reduce the number of construction jobs – *it would increase the number of construction projects.* Reduced construction costs would make it possible for this nation to afford to address its huge backlog of needed infrastructure repair, such as repair of bridges, construction of public utilities, water supply systems, sewers, storm drains, sewage treatment plants, power generation plants, and public buildings, such as prisons, schools, libraries, and courts. Cost reduction in the construction sector would have the effect of multiplying the capital available for renovating

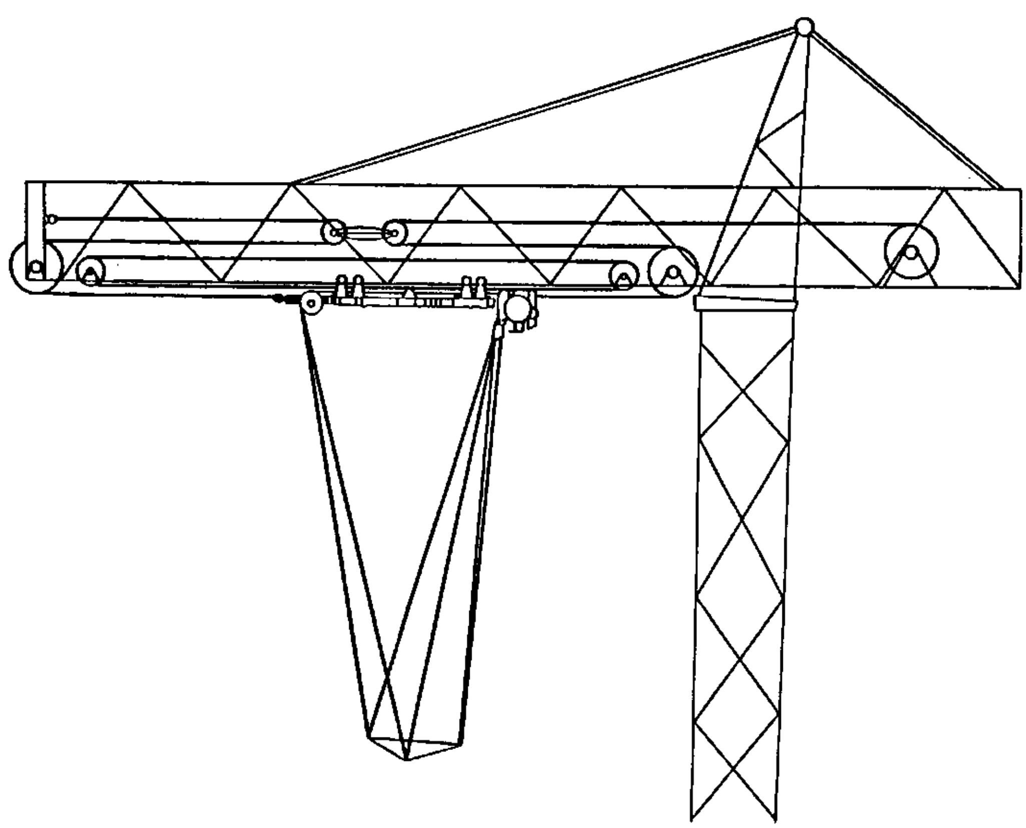

Fig. 3.

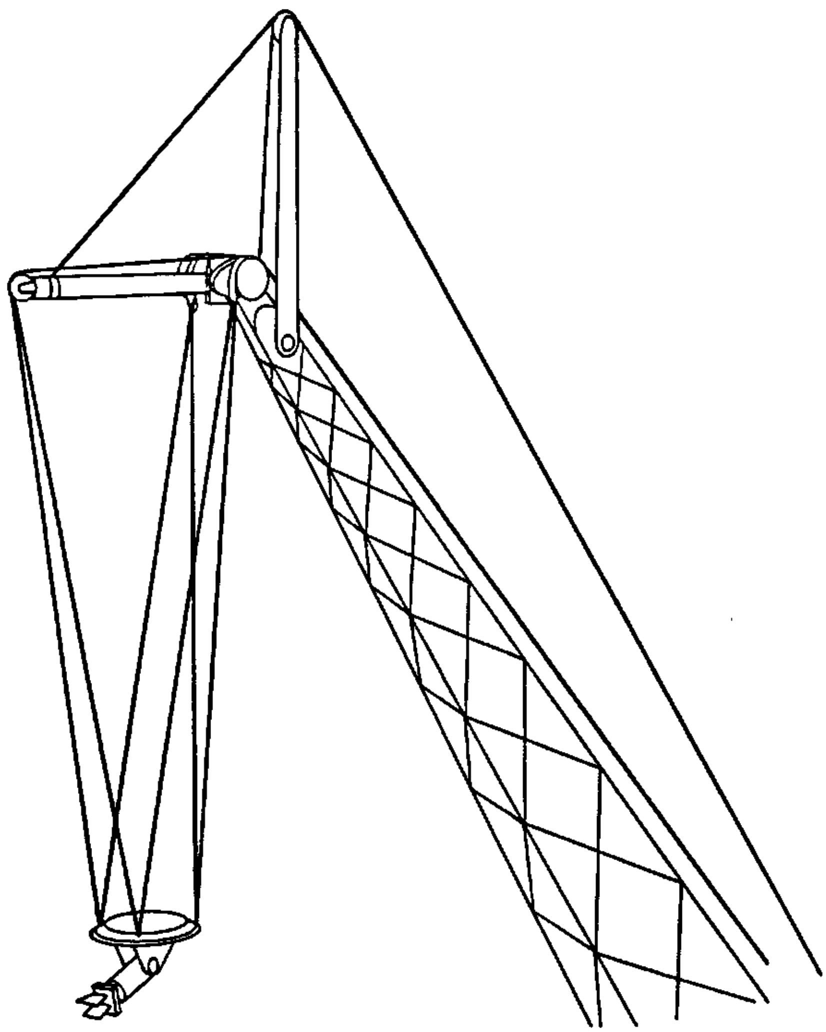

Fig. 4.

and replacing our outdated manufacturing plants so as to make our industrial base more competitive.

We also need much more housing in the United States. Particularly low cost housing. We have upwards of 3 million homeless Americans today. Entire families are living in cardboard boxes and abandoned automobiles. This is a national disgrace.

There is no shortage of things that need to be constructed. What is in short supply is the real wealth to pay the cost of what needs to be built.

7. Ocean Resources

Let me suggest another untapped application for robotics – undersea resource development. The ocean bottom comprises over two thirds of the earth's surface and is virtually unexplored. There are more than 3 million square miles of seabed within the U.S. Exclusive Economic Zone [9]. Although this territory is almost entirely unexplored, it is known to contain significant amounts of strategic minerals, such as manganese, cobalt, nickel, platinum and molybdenum. It also con-

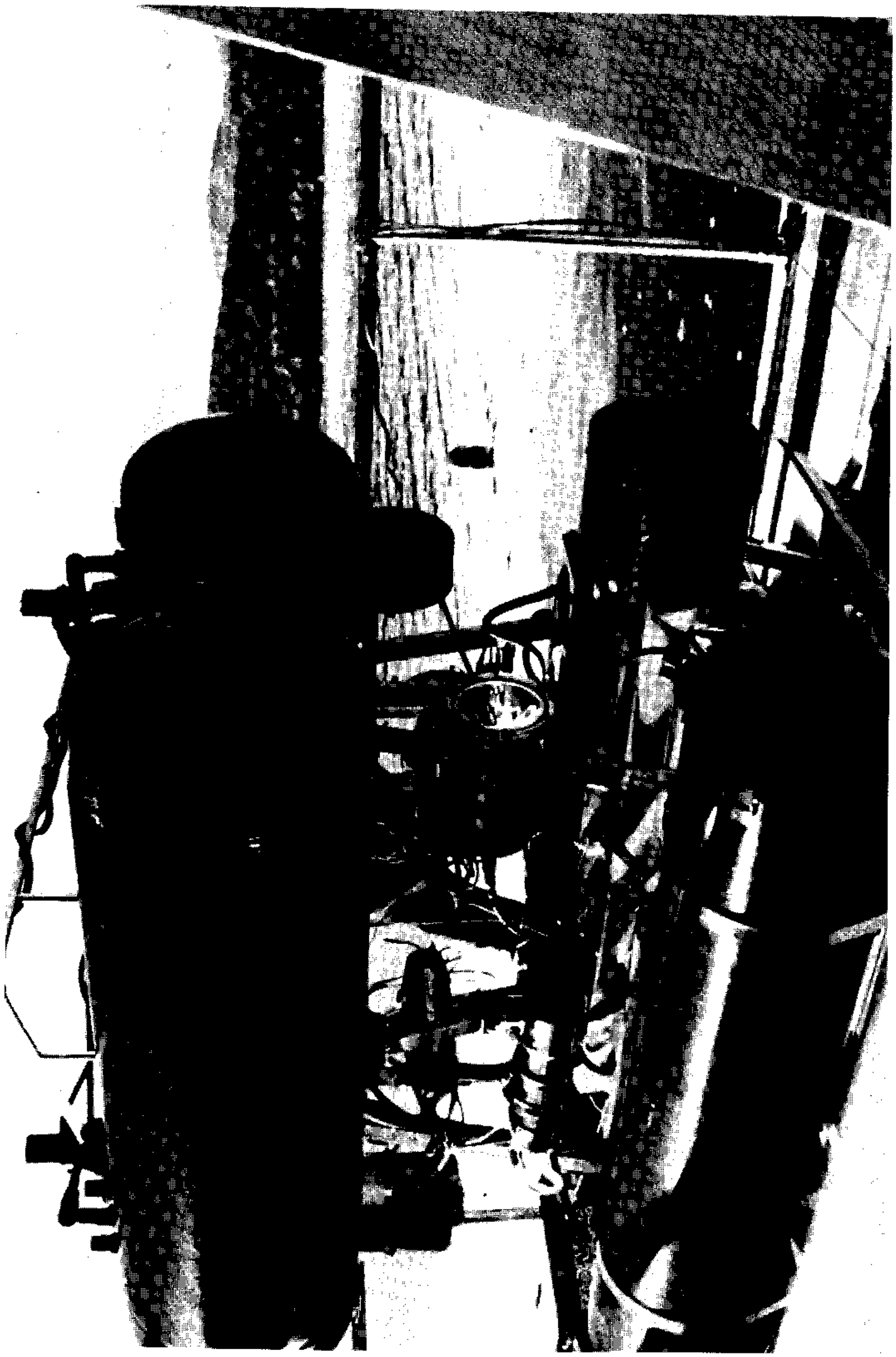

Fig. 5.

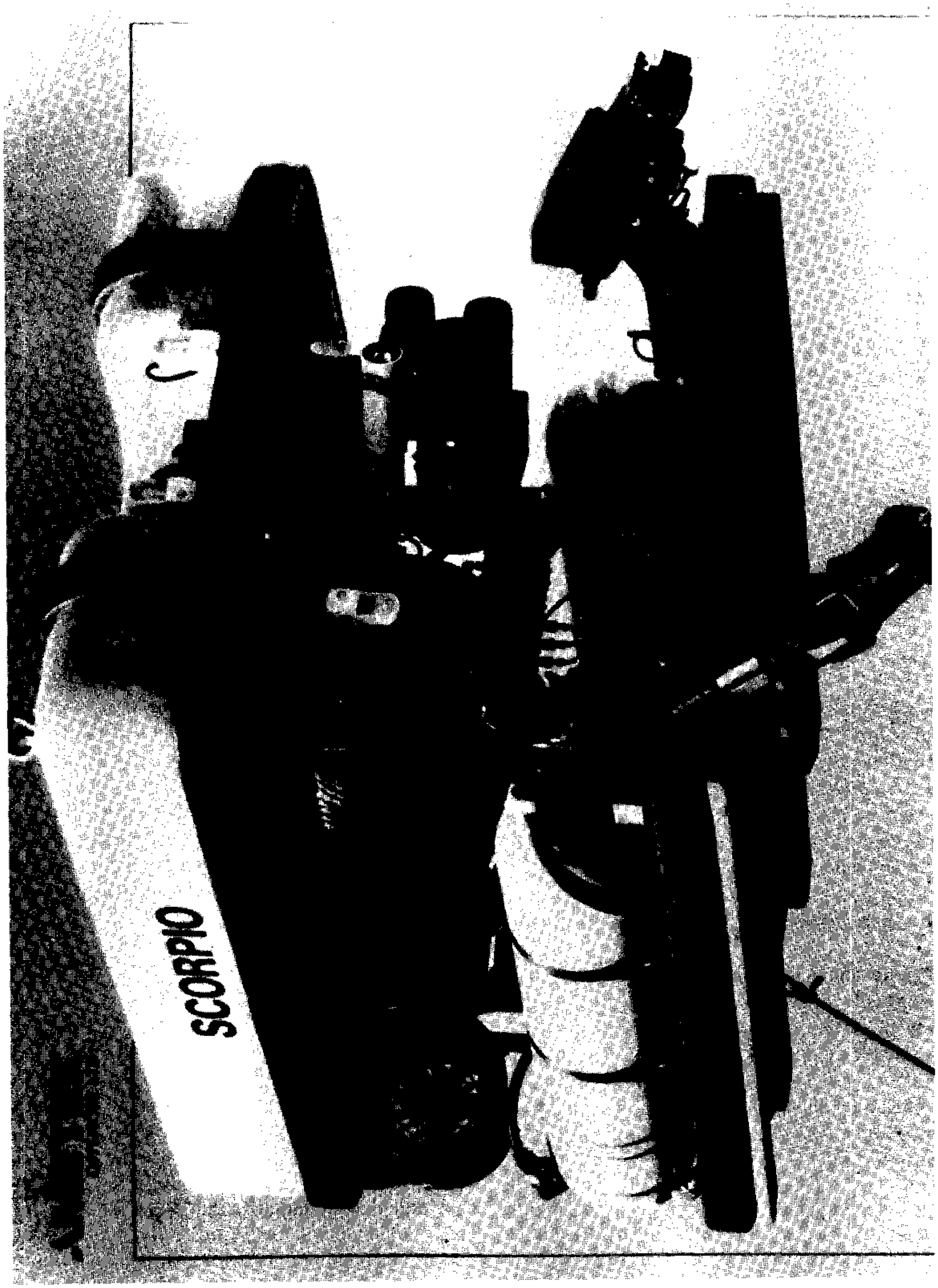

Fig. 6.

tains oil, gas, sulfides, diamonds, and gold deposits which have never been touched.

The potential economic impact of using robots to exploit the oceans is beyond estimation. *Fig. 5* shows an autonomous undersea robot vehicle developed by the University of New Hampshire for the MAUV project. The result of this project was an intelligent control system architecture for Multiple Autonomous Undersea Vehicles [4]. *Fig. 6* shows a commercial teleoperated underwater manipulator system.

Intelligent undersea robots could make deep ocean oil drilling and mining operations cost effective. Entirely new industries could emerge, such as ocean farming and ranching, and production of non-polluting alcohol fuel from seaweed.

8. Space

Robotics will play an increasing role in space. Telerobotics will play a major role in maintenance and servicing of communications and weather satellites, and possibly in manufacturing in space.

9. Defense

In defense, intelligent robotic systems have the potential to produce order-of-magnitude improvements in the performance/cost index of combat vehicles. Unmanned air, land, and undersea vehicles can be smaller, less expensive, more effective, and can be used more aggressively and in larger numbers than comparable manned systems. They will require less training, and will have more consistent performance under fire than manned systems.

Intelligent semi-autonomous weapons systems could eventually render ineffective and indefensible conventional aircraft, armor, subs, and surface ships. Intelligent machines may provide a defense just as effective as tactical nuclear weapons, with much less undesirable side effects. The market for military robotics will be many $ billions per year in the near future.

10. Services

In the service sector, robotics technology will enable new approaches to transportation safety, underwater pollution monitoring and clean-up, commercial cleaning, toxic and radioactive waste handling, home and business security systems, hospital and nursing home support, as well as education and entertainment services.

The application of robotics technology to the manufacture of drugs, the diagnosis of disease, the operation of hospitals and medical laboratories, and the care of the sick and aged could significantly reduce the nation's more than $300 billion per year medical bill. *Fig. 7* shows a mobile robot designed by Transitions Research Corporation, Danbury, Connecticut for delivering supplies and running errands in a hospital [10].

For the elderly, intelligent machines could provide simple home cleaning, food preparation, security, and entertainment services. Such services would make it possible for many elderly people to put off the day when they must enter a nursing home. The potential market for semi-automatic devices that assist the elderly in their homes is enormous.

Finally, the long awaited development of robots for domestic service is rapidly becoming feasible. Commercial floor cleaning robots are under active development, and will soon be common in the commercial cleaning marketplace. As the cost of computers and electromechanical devices continues to decrease, home applications for such machines will become economically feasible. The future market for household robots could exceed the current market for automobiles. Intelligent machines for service sector applications in transportation, hospital, and home services could easily become a multi-billion dollar per year industry early in the next century.

11. Foreign competition

The future world markets for intelligent machine products are beyond estimation. The implications for international balance of trade are enormous. These potential applications are being seriously addressed by our international trading partners, most notably the Japanese and Europeans. They are systematically making the investments necessary to assure that their countries will be among the first to exploit the vast potential of intelligent machine systems.

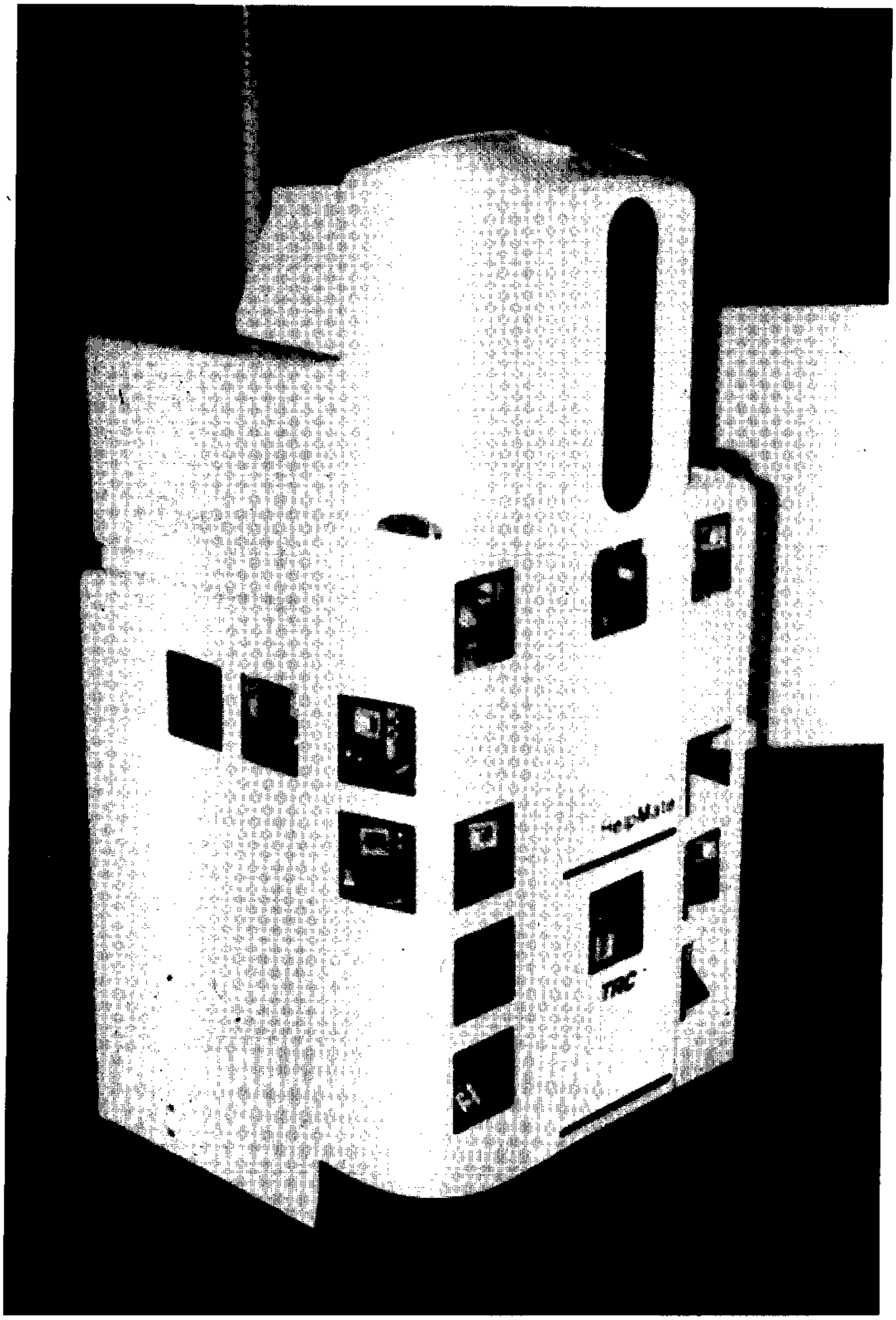

Fig. 7.

Europe

For example, for the past five years, the European community has committed about $350 million per year to the ESPRIT program, a Strategic Programme for Research and Development in Information Technology [11]. ESPRIT is focused on microelectronics, information processing, and computer integrated manufacturing systems. Starting next year ESPRIT will double in size, and continue for another five years. The total ten year program will thus total $5 billion. Half of this amount is government funding, with 50% private industry matching funds. ESPRIT involves about 500 companies and 3000 full-time researchers.

The Europeans have also recently launched a seven year $1 billion program called EUREKA/PROMETHUS to develop intelligent automobiles and highway systems [12]. Among the technologies being developed are automatic collision avoidance systems, dashboard map displays, computer assisted route planning systems, and high speed car-train systems for highways. If successful, this project could revolutionize automobile transportation. American auto manufacturers are specifically excluded from participating in this project.

One of the projects funded by PROMETHUS has already demonstrated a visually guided robot vehicle that can achieve 100 km per hour on the Autobahn. This vehicle can also function on two lane roads with underpasses, intersections, and on-coming traffic. It can even operate in the rain with windshield wipers going.

Japan

On the other side of the world, the Japanese are spending comparable amounts on Advanced Robotics and related technology [13]. Projects include devices for firefighting and nuclear plant servicing, as well as underwater bulldozers and walking machines (shown in *Fig. 8*) for working on the ocean floor. A series of such programs have been in progress since 1966, with total government spending on the order of $1 billion.

The Japanese are actively pursuing construction robots, household robots, and have an intelligent automobile project comparable in size to the European PROMETHUS program.

Of course, most of the industrial robots in the world are manufactured in Japan, and the market for Japanese robots continues to grow. Public and private Japanese spending for research and development in robotics has been estimated at $300 million per year with a $5 billion cumulative total.

It should be noted that the programs being funded in both Europe and Japan, are for civilian commercial technology development, not for military programs or basic research.

There are, of course, similar projects in the U.S. The Automated Manufacturing Research Facility (AMRF) at National Institute for Standards and Technology (NIST) has been spending about $12 million per year since 1981 on measurement techniques and interface standards for the factory of the future. The National Science Foundation has been investing about $16 million per year on Engineering Research Centers. NASA spends about $12 million per year on robotics. The Air Force has been spending about $80 million per year on Integrated Computer Aided Manufacturing (ICAM) and other related projects. The Army, Navy, and other defense agencies have been funding additional manufacturing technology programs at about $90 million per year. Thus, total U.S. government funding in the Intelligent Machines research area is on the order of $210 million per year.

The Air Force has recently embarked on a program to develop a Next Generation Controller for robots, machine tools, and workstation controllers. The Army has recently begun development of a Standard Army Vehicle Electronics Architecture, that will provide the basis for combat vehicle automation. There are a number of autonomous air and undersea vehicle projects being funded by DOD [14]. NASA has begun work on the Flight Telerobotic Servicer (FTS) for Space Station Freedom [15]. Product Data Exchange Specification work (PDES) [16] is being supported by NIST and DoD and a consortium of about 400 companies. NIST is also working on a Standard Architecture for Real-Time Intelligent Control Systems.

Overall, except for military autonomous air and undersea vehicles and the NASA FTS, program funding in comparable areas is less than what our overseas competitors are spending. Even the NASA funding for space station telerobotics development is modest, considering that most of the

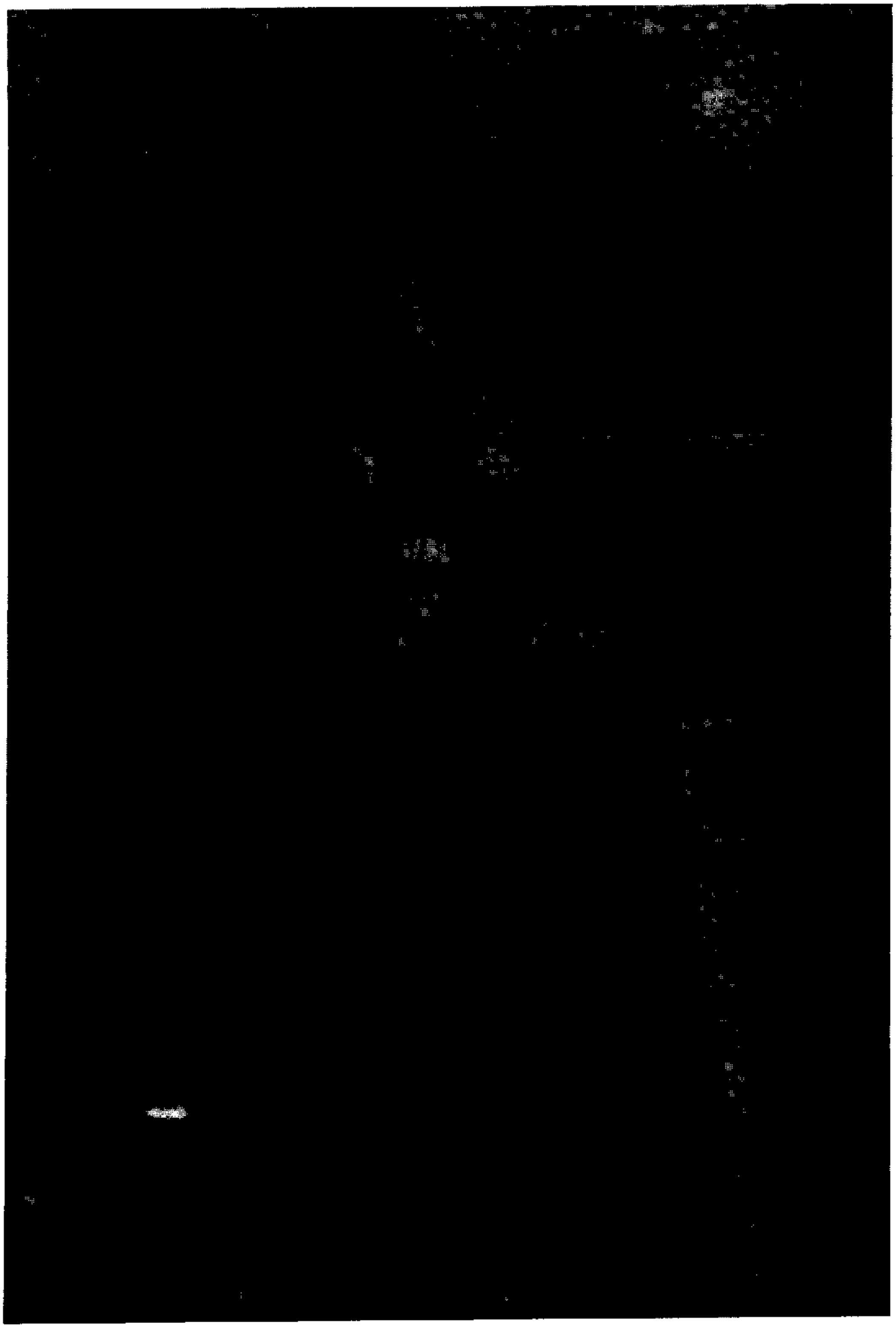

Fig. 8.

FTS cost is for building flight quality hardware. More important, foreign government investments are almost entirely in civilian manufacturing technology, while the U.S. government investments have been almost entirely for military manufacturing and basic research.

Thus, the real question becomes, "Is America going to be competitive in intelligent machines technology for civilian applications, or are we going to let intelligent machines go the way of consumer electronics? If we are going to compete, "Where are the civilian R&D funds and investment capital going to come from?"

One possible source is private industry. But not many companies are able to compete with foreign government programs like ESPRIT. For intelligent machines, research costs are high, and return to the individual firm is uncertain. There are almost always better investment opportunities elsewhere, e.g. junk bonds and leveraged buyouts. For an individual firm, the best business strategy is to wait for someone else to do the R&D and develop the market before investing heavily.

Another possible source is the federal Government. But the government is broke, and few look to government for solutions any more. There certainly is no indication of voter interest in major new government spending programs.

I personally believe the government should take a leadership role for two reasons:

(1) This technology is critically important to the future economic and military security of the country.
(2) The government is the only entity with a sufficiently broad and long range interest to fund what needs to be done.

I would like to see a new partnership between government, industry, and universities at the national, state, and local levels that would bring the necessary resources to bear on the problem. I would like to share with the reader my ideas as to what the government component of that partnership might be. I must, however, make it clear that my opinion in no way represents the official position of the U.S. government. It is simply my personal view of what I think this country should do to assure its future prosperity and security.

12. Objectives

My plan addresses three application areas, and has an objective in each area:

(1) For commerce and industrial applications, the objective is to enhance productivity and competitiveness.
(2) For defense applications, the objective is to revolutionize the art of war.
(3) For service sector applications, the objective is to improve the quality of life.

The plan is to implement a coordinated program of research, simulation/gaming, demonstrations, and technology transfer. This program would be funded jointly through federal, state, and local government agencies and private industry and conducted cooperatively through private industry, university, and government laboratories. I would suggest a budget that ramps up to about $400 million per year between 1991 and 1994, and remains at that level until 1996. The total cost would be about $1.5 billion. A little less than half of this would address civilian applications, and the rest military applications.

13. Research

Research is needed in at least the following areas:

Theory of intelligent machine systems
Goal selection, planning, and task decomposition
World modeling
Sensory processing
Value assessment and confidence estimation
Sensors and actuators
Vehicles and structures
Dexterous manipulation
Communications and real-time operating systems
Operator interfaces
Machine learning
Software development methods and tools
Telepresence
Performance measures
Information management technology
Design theory and methodology

These research areas are generic, and support industrial, defense, and service applications alike.

14. Demonstrations

There should be a series of demonstrations in each of:

1. Commerce and industry

For commerce and industry, manufacturing demonstration projects should include data-driven micro-factories for machining metal, fabricating composites, and assembling mechanical and electronic devices. Commerce demonstrations should also include intelligent mining and construction machinery and a family of intelligent underwater vehicle systems for undersea drilling and mining, navigation hazard charting, and underwater pollution monitoring and cleanup.

2. Defense

For defense, demonstration projects should include a set of "hyper-performance" vehicles (i.e. vehicles which far exceed the performance of any manned vehicles that exist, or could exist) for air, land, and undersea applications. Examples of hyper-performance vehicles for several combat domains are:

(a) to air combat vehicles that can pull 15 g-turns.
(b) Close air support of ground troops, air vehicles that can fly between 20 and 200 feet above the ground at 200 miles per hour and perform precision bombing and strafing missions.
(c) Armor and anti-armor, land and air vehicles that operate in pairs, or packs, with the air vehicles providing an eye-in-the-sky, enabling the land vehicles to see around corners and through hills, and hence to drive at high speeds and shoot on the move without direct line of sight.
(d) Sea control, undersea vehicles that can dive to 20,000 feet, navigate, hunt in packs, and loiter at less than one knot for years, sprint to 60 knots for short periods, and carry torpedo sized warheads.

All of these vehicle types, air, land, and undersea, should be able to operate in groups and use group tactics (with or without manned supervision).

3. Service sector

For service industries, demonstration projects should include:

Automobile, rail, and air safety
Outer space and planetary exploration
Ocean exploration
Commercial and home cleaning
Trash removal
Waste handling
Security guard duty
Patient care
Home care services for the elderly
  preparing meals
  cleaning
  calling for help when needed.

15. A deeper problem

Unfortunately, even if such a plan were implemented with the full $1.5 billion over the next five to seven years, and even if all the projects were completely successful, there is no guarantee that the United States would be the primary beneficiary of the results.

The current rate of savings and investment in this country is so low that we simply do not have the capital necessary to exploit the technology which is available. *Fig. 9* shows the rate of saving in America as reported by the President's Commission on Industrial Competitiveness [17].

It has long been recognized that our fundamental problem is not technology. In most areas, we still lead the world in basic research. What we lack is a willingness to save our money and invest in the future. Technology can only provide us with the means to create a new industrial revolution. It will not automatically produce a revolution unless we make the necessary investments. Unless capital resources are committed to commercial develop-

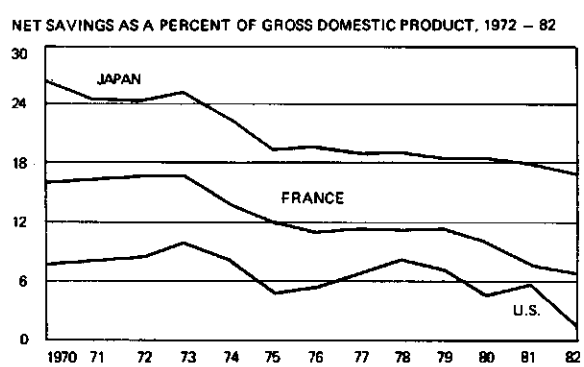

Fig. 9.

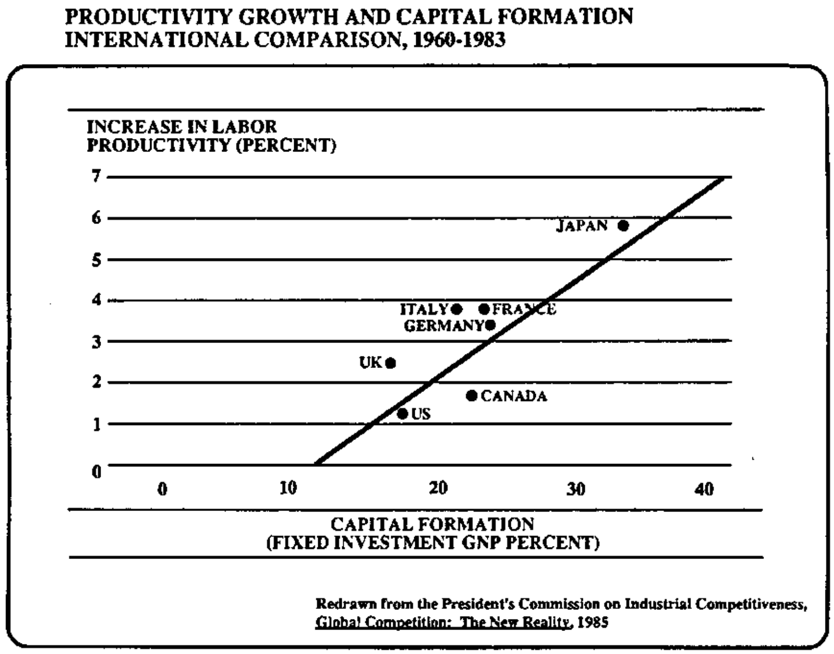

Fig. 10.

ment and exploitation, technology alone produces nothing.

Fig. 10 shows the relationship between investment and economic growth as reported in [17]. As one would expect, a high rate of investment produces a high growth rate, and a low rate of investment produces low growth. As you can see from this chart, the U.S. has the lowest investment rate of all industrialized countries in the world. This has been the case ever since the end of WWII. Our investment rate is little higher than some third world, underdeveloped countries. This is the real reason for our slow economic growth. It is also the root cause of our balance of trade deficit. All the talk about Japanese management techniques, quality circles, worker motivation, all may be true, but it is largely irrelevant. The real reason we are falling behind the Japanese is that they are saving and investing twice as much of their GNP as we are. And we can never hope to do much better until we address this central fact.

Edward Demming was once asked in an interview if there weren't some way that America could leap-frog the Japanese. His response was, "How do you leap-frog someone that is running twice as fast as you are?" Our Japanese friends have demonstrated for us that the limits to growth are not in resources, or technology. Japan has no natural resources, and until very recently the Japanese were far from world leaders in technology. What the Japanese have is a national willingness to forego current consumption and invest in the future. The Japanese propensity to save and invest has demonstrated to the world that the real limits to growth are set by the percentage of its income a society is willing to save and invest in the future.

Fig. 10 shows what can be achieved by a high rate of investment supported by a high rate of savings. Specifically, it suggests that 6% real economic growth can be achieved in any country willing to invest 30% or more of GNP. *Fig. 10* also shows the magnitude of our problem. The reason we are lagging the Japanese is that they "out save" us and "out invest" us by a factor of two. The amount of additional investment capital needed for us to match the Japanese investment rate is about $680 billion per year. This amount is more than half of the entire federal budget. It is about four times the current budget deficit. That is why spending a billion or two over seven years

on research and development is not going to fix what is wrong with the U.S. economy. In the context of a $680 billion annual shortfall in our investment rate, a program for spending $400 million per year on R&D pales into insignificance. The total amount needed to fully implement a new industrial revolution in this country will be many trillions of dollars. What is required is nothing less that the total renovation, or replacement, of the nation's entire productive capacity! And this will need to be done several times over, because it is not possible to implement the most advanced technologies immediately. They do not even exist yet.

Where will all this money come from? What conceivably could be done in this nation to raise $680 billion per year? The first step, of course, is to recognize the nature and magnitude of the problem. Unless we are content to become a third rate economic power, our savings and investment rate must be drastically increased – not by a few percent, but by a factor of two! In order to accomplish this, we would need to divert about 17% of our current gross income away from consumption and into investment for the future.

We are a consumer oriented and self indulgent society. "Buy now, pay later", is our motto. To compete with the Japanese we need to become much more production oriented and self disciplined. We need to adopt the motto, "Save now and invest in the future." This truth is not widely recognized, and until it is, no effective action can be expected. However, if and when we ever do recognize the necessity of saving more and investing more, there are at least three mechanisms available for marshaling the investment capital needed to create the new industrial revolution.

I am now going to outline a plan which I originally published in 1976 under the title of Peoples' Capitalism: The Economics of the Robot Revolution [18]. This plan also does not represent the viewpoint of the U. S. Government. It represents only my own personal opinion of more than 20 years.

In order to raise the necessary investment capital, I propose we:

(1) Sell government Industrial Development Bonds. These would be five year bonds, paying interest indexed at 4% above inflation.
(2) Borrow from the Federal Reserve bank.
(3) Legislate a savings tax.

The money raised through the savings tax would be placed in non-transferable Industrial Development Bonds. It would thus be repaid with interest to its original owners when the bonds mature.

It is widely recognized that Americans do not save enough. Clearly a nation that spends $3500 billion per year on consumer products could and should save more than 6% of its disposable income. It is also clear that doubling the savings and investment rate cannot be accomplished by voluntary incentives. The tax code is already full of incentives. The trouble is, one man's incentive is another man's loop-hole. Any set of incentives that could conceivably increase the rate of saving by a factor of two are politically unrealizable.

If the savings rate in this country is to be doubled, it must involve a savings tax. A savings tax, implemented as a progressive surcharge on income taxes would be broadly based, and would fairly place the heaviest burden of reducing consumption on the wealthy. It could be phased in over a period of several years, so as to minimize the impact on everyone. It would produce the maximum results with the minimum of overhead cost. It would do so in a fair and equitable manner.

What would be done with the money? My proposal is that a new investment institution be established, that I will call the National Mutual Fund (NMF). The NMF would be a semi-private for-profit investment corporation operating within the free market economy. It would invest all the money raised from selling government bonds, borrowing from the Federal Reserve, and imposing a savings tax. It would invest this money in private industry through existing banks, brokers, and venture capital channels. These investments would be subject both to federal banking regulations and to public scrutiny. All transactions would be public information.

The operation of the saving tax and the proposed National Mutual Fund is illustrated in *Fig. 11*. Sales of bonds and the savings tax withheld from consumer income would go into Industrial Development Bonds to be used by the National Mutual Fund for investment. Additional Funding for the National Mutual Fund would be obtained through loans from the Federal Reserve.

The amount of investment made by the National Mutual Fund would begin with a few hundred million per year, and ramp up over a five to seven year period to the amount needed to

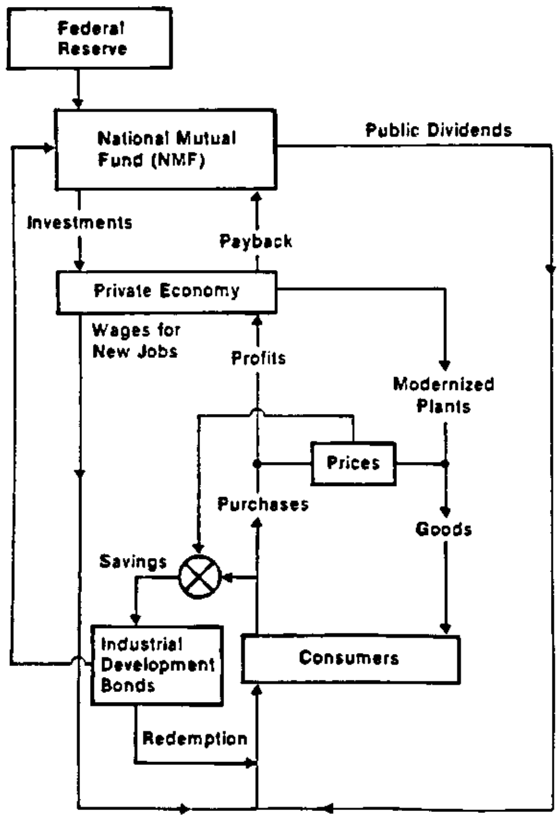

Fig. 11.

produce a national investment rate of about 34% of GNP. These investments would create new productive capacity. They would speed the development and implementation of new technology. NMF investments would create new industries, new jobs, and new opportunities. They would finance the building of modernized plants to produce new goods and services. They would assure rapid and sustained economic growth with low unemployment. In the long run such investments would be deflationary, because they would lead to more efficient productive capacity, higher quality, and lower cost products. However, in the short term, they would generate strong inflationary pressures. New wages would appear in the pockets of consumers many months before new goods from new plants would appear in the market place. This provides yet another, perhaps the most important, rationale for the savings tax. If the savings tax withholding rate were indexed to the consumer price index, then the savings tax would act like a servo feedback governor on inflation. For example, if prices were rising, the savings rate would rise to reduce consumer demand and force prices down. If prices were falling, the savings rate would be reduced so as to stimulate consumer demand, and cause prices to stabilize. The overall effect would be that the rate of inflation could be controlled under all economic conditions.

The National Mutual Fund would, of course, earn profits on its investment portfolio. These would be distributed in two ways:

First, everyone would receive interest on their Industrial Development Bonds, whether purchased voluntarily, or by savings tax withholdings. This interest would be paid at the end of five years when the bonds matured.

Second, the remaining profits would be declared a social dividend, and distributed directly to the public in the form of equal per capita monthly cash payments.

Every citizen above the age of 21 would receive an equal share in the public dividend. Thus, every citizen would, in effect, be a shareholder in the National Mutual Fund.

The NMF could operate under the control of the Federal Reserve Board, or could be independent. In either case, its directors would be directly elected by the public. Like shareholders in any private corporation, each citizen would be eligible to vote for the executive officers. This would assure that the National Mutual Fund management would be primarily motivated to return the highest possible dividend to their stockholders, i.e. the entire citizenry.

16. Anticipated results

The effect of doubling the investment rate would be dramatic. *Fig. 12* shows the predictions of a computer model of the U.S. economy if the rate of investment were gradually raised between now and 1995, from its current rate of 17% of GNP, to the desired rate of 34%. The most important effect would be that real GNP growth, would rise to 6.3% per year, stimulated by investment spending through the National Mutual Fund. The savings tax indexed to the inflation rate would stabilize prices even in the face of 6.3% real economic growth.

The impact on the average citizen would be profound. 6.3% real economic growth would cause the average per capita income in the U.S. to rise

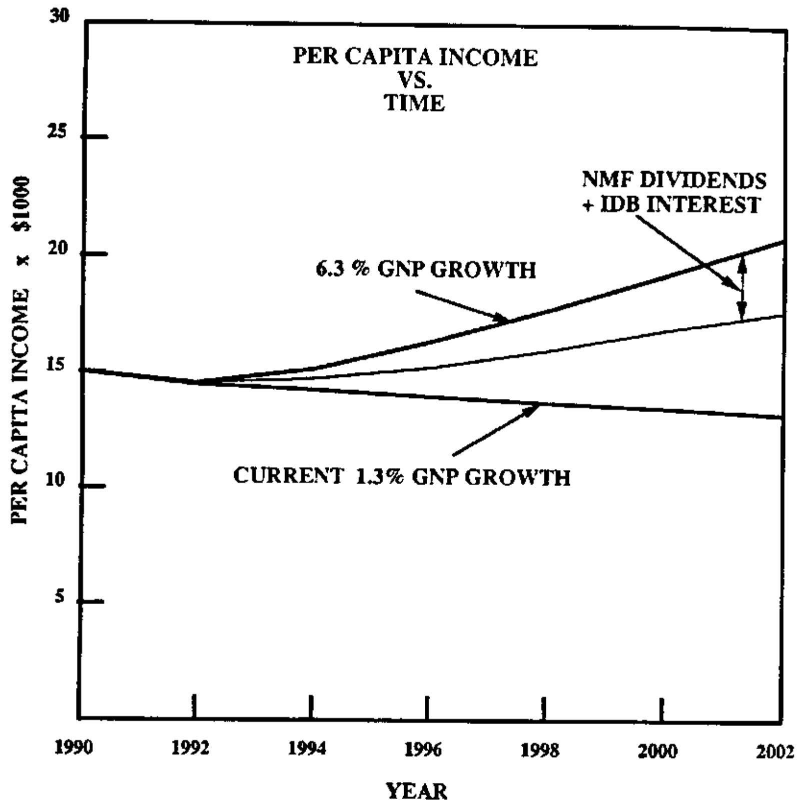

Fig. 12.

from its current level of about $15,000 per year to more than $20,000 by the year 2002. Of that amount,$2,500 would be NMF dividends and IDB interest.

Alternatively, if the current growth rate of 1.3% continues over this same period, average per capita income will fall to about $14,000, because the population is growing faster than real economic output.

Fig. 13 shows that over a longer period, the effects would be even more impressive. It indicates that by the year 2020, average per capita income would rise above $43,000 per year, and by 2030 would reach $66,000. In 2040, average per capita income would reach $100,000 per year. (All dollar figures are in constant 1989 U.S. dollars.) It should be noted that the year 2002 is only thirteen years away, and the year 2040 is within the expected lifetime of about half of the people living today.

Although the above example relates to the United States, the implication is, given an investment rate of about 34% of GNP coupled with equitable wealth distribution, virtually any country on earth could make all of its citizens economically secure and self-sufficient.This would create an "Everypersons' Aristocracy" based on intelligent machines.

17. The choice

The principal point I wish to leave is that we have the power to choose from a wide spectrum of possible futures. What the future will bring depends in large measure on how much we invest in it.

If we continue our current economic policies of debt financed consumption, with inadequate sav-

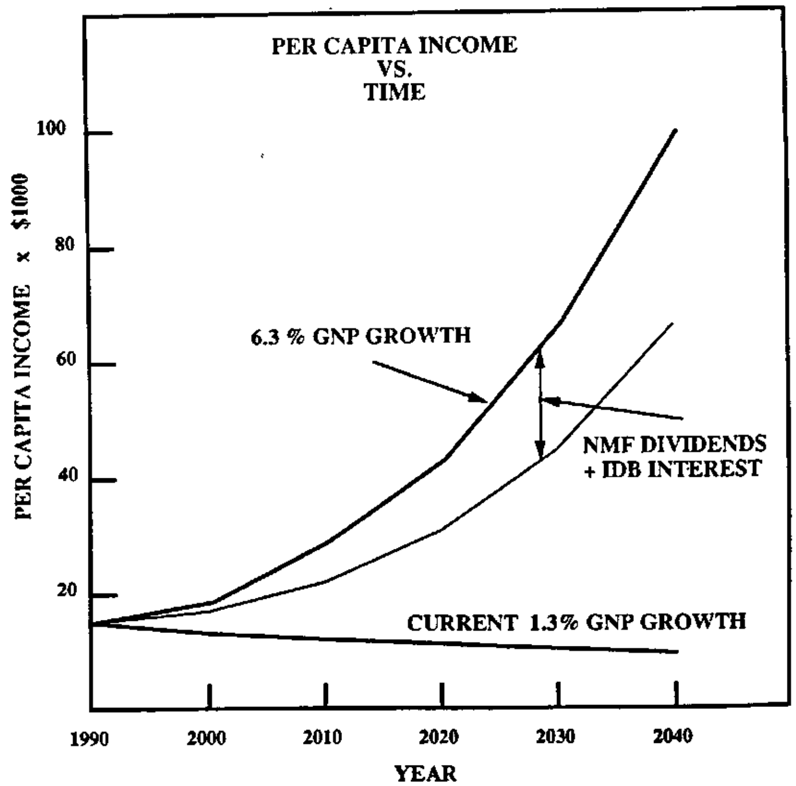

Fig. 13.

ing and investment, it is almost certain that economic growth will remain slow. Inflation and unemployment will continue to be chronic problems. Incomes and living standards will drift downward as growth in the population outpaces growth in the economy. On the other hand, if we have the wisdom and self discipline to change our ways – if we devise strategies for saving more of our income and investing it in the technologies of the future – we could move rapidly into the next industrial revolution. We have the technology to create an era of unprecedented prosperity.

Where have we been? That is pretty clear. Where are we going? I really do not know. All I can say is where we could be going. That is anywhere from 6.3% growth, to 0.7% decline. We have before us a wide choice of possible futures. They range all the way from slow economic decline to a golden age of humankind. My hope is 6.3% growth. My guess is that our future is much closer to 0.7% decline.

David Broder in a May 7, 1989 Washington Post editorial, said, "We need to start disciplining ourselves, to start saving and investing instead of borrowing and spending – if there is not to be a fearful day of reckoning for our reckless habit of living beyond our means."

I am convinced that the Robot Revolution will take place. It is already taking place – but not here, not in this country. I find that sad. This nation is wasting an unprecedented opportunity for greatness. Since the end of WWII, we have squandered our economic wealth and power on consumerism and self indulgence. We now sink deeper and deeper into debt, while the losers in that war, the Japanese and Europeans, are leading the world into the next industrial revolution.

I believe it is not too late. I believe the future is still ours to make. We have the economic and technological capacity to eliminate poverty, to house the homeless, to care for the sick and elderly, to educate our people, to defend our nation, and

make every citizen economically secure and independent. We also have a national tradition of self indulgence which over the last four decades has squandered our advantage of being the world's dominant economic power, and now is in the final stages of mortgaging our national inheritence. America in the 21st century could be rich, or it could be poor, we have the power to choose.

The question is, Which future will we choose?

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