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NEXT GENERATION SPACE ROBOT

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Abstract

This paper outlines our recent research effort on the next generation space robots. The goals of this research are to develop the fundamental technologies and to acquire the design parameters of the next generation space robot. Visual sensing and perception, dexterous manipulation, man-machine interface and AI techniques such as task planning are identified as the key technologies. In addition, the design study of the ground testbed model and the simulator to evaluate the performance of the integrated technologies are now under way.

1. Introduction

The advent of the Space Station and the space platforms in late 1990s will increase the necessity for the in-orbit servicing activities such as assembly, inspection, equipment exchange, resupply, repair and maintenance. To meet these various in-orbit servicing demands with much safety and efficiency, the development and the application of the intelligent and flexible space robots are required.

The National Space Development Agency of Japan (NASDA) started the research and development of the Remote Manipulator System attached to the Space Station Japanese Experiment Module (JEM) in 1985. We have also initiated the study on the advanced space robots, -Next Generation Space Robot-, based on the technologies developed in the JEM Remote Manipulator System project. The phase 1 research was started in 1988 and is scheduled to end in 1991. This research encompasses mission analysis, identification of key technologies, system architecture, and performance demonstration by the ground testbed model.

2. Generation of the Space Robot

We classify the space robots in three generations according to the degree of autonomy as given below :

First generation : programmed control and/or proximately operated manual control robots such as Space Shuttle Remote Manipulator.

Second generation : teleoperation with some some autonomy (semi-autonomous) robots.

Third generation : highly intelligent and autonomous robots.

JEM Remote Manipulator System which is a 10-meter-long, 6 degree-of-freedom and master-slave/programmed control manipulator is evidently a first generation space robot. Our research efforts are concentrated on the second generation space robots. The characteristics of each generation of the space robot are summarized in Table-1.

Table-1. CHARACTERISTICS OF EACH GENERATION OF THE SPACE ROBOT

CHARACTERISTICS	1st GENERATION	2nd GENERATION	3rd GENERATION
OBJECT	KNOWN	KNOWN	UNKNOWN
SERVICING AREA	IN AND AROUND THE VEHICLE	·EARTH ORBIT ·SPACE LABORATORY	·DEEP SPACE ·LUNAR AND MARS SURFACE
MISSION	·ORU EXCHANGE ·ASSEMBLY (STANDARD AND COOPERATIVE PARTS) ·BERTHING ·VEHICLE TOW	·AUTOMATED SPACE EXPERIMENT ·ASSEMBLY (FLEXIBLE, FRAGILE PARTS) ·PLATFORM MAINTENANCE RESUPPLY INSPECTION REPAIR ·RETRIEVAL	·CONSTRUCTION ·FULL EVA ·EXPLORATION ·MANUFACTURING
MAN-MACHINE I/F	·MASTER-SLAVE CONTROL ·VISUAL IMAGE ·FORCE FEEDBACK	·TASK LEVEL LANGUAGE CONTROL ·TELEPRESENCE	·NATURAL LANGUAGE INTERFACE
MANIPULATION	·SINGLE ARM ·STANDARD END EFFECTOR ·GRIPPERS	·COOPERATIVE ARMS ·INTERCHANGEABLE DEXTEROUS HANDS ·FLEXIBLE ARM	·ROBOTS COOPERATION ·NON-CONTACT MANIPULATION (APPLICATION OF THE ELECTORO-MAGNETIC FORCE)
SENSING & PERCEPTION	·VISION ·FORCE/TORQUE ·PROXIMITY/TOUCH	·VISUAL RECOGNITION (DATA BASED MATCHING) ·SENSOR FUSION ·TEXTURE	·ENVIRONMENT RECOGNITION
SYSTEM EXAMPLE	JEMRMS	OSV	LUNAR ROVER

3. Mission of the Second Generation Space Robot

Three different types of the second generation space robots are considered to analyze the mission of the future space activities around 2000.

Fixed based robot : This type of robot conducts routine services and rather simple, repetitive space experiments mainly to save the human workload in space.

Truss mobile robot : This type of robot moves along the truss structure of the large spacecraft like MSC (Mobile Servicing Center : Canada) and conducts the external activities in place or in support of manned EVA.

Free Flying robot : This type of robot has the capability of orbital maneuvering / changing , and conducts the in-orbit services to the unmanned platforms.

The possible missions and tasks of the above systems are summarized in Table-2. Fig.-1 shows one concept of the free flying robots temporarily named OSV (Orbital Servicing Vehicle).

Table-2. MISSION OF EACH TYPE OF THE SPACE ROBOT

MISSION	TASK	FIXED BASED	TRUSS MOBILE	FREE FLYING
SPACE EXPERIMENT	MONITOR, SAMPLE AND EQUIPMENT EXCHANGE, EQUIPMENT HANDLING AND OPERATION	○	–	–
MAINTENANCE	VISUAL, ELECTRICAL AND MECHANICAL INSPECTION, ORU AND MODULE EXCHANGE	○	○	○
RESUPPLY	PROPELLANT, FLUID AND GASES TRANSFER	–	○	○
ASSEMBLY	TRUSS CONSTRUCTION AND EXTENSION, MODULE LOADING, CABLE MATE/DEMATE	–	○	○
REPAIR	FAILURE UNIT EXCHANGE, THERMAL BLANKET REPLACEMENT	–	○	○
BERTHING	PLATFORM, HOPE AND LOGISTICS VEHICLE BERTHING AND RELEASING	–	○	–
CAPTURE	SPACE DEBRIS AND FAILURE SATELLITE RETRIEVAL	–	○	○
SPACE TOWING	RENDEZVOUS DOCKING WITH PLATFORMS AND LOGISTICS VEHICLE, ORBITAL TRANSFER	–	–	○

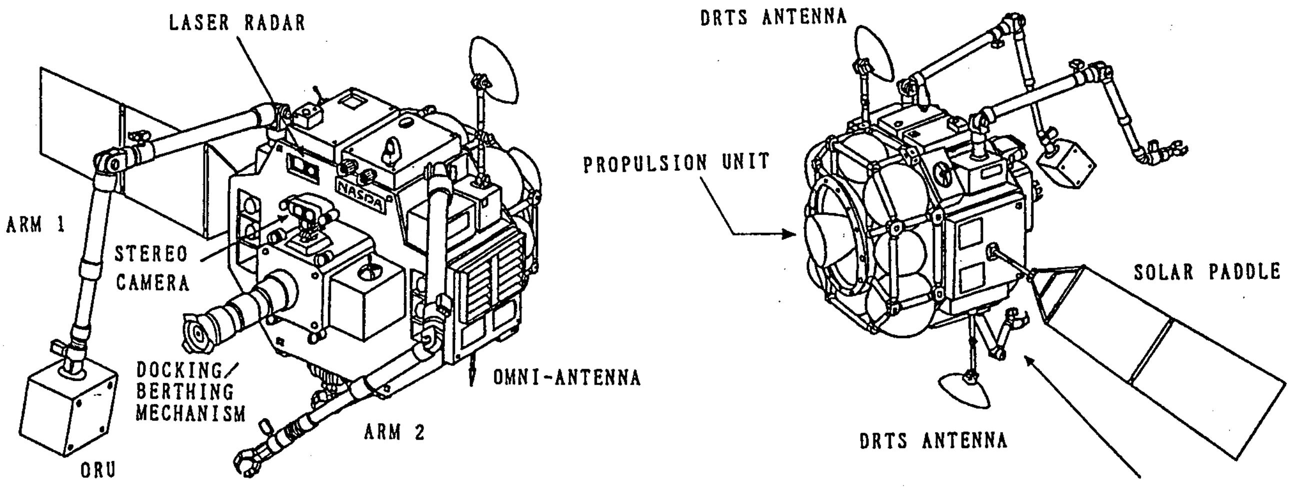


Fig.-1 CONCEPT OF THE OSV

4.Key Technologies

Based on the mission analysis, key technologies needed for the second generation space robots are identified as shown in Fig.-2. Teleoperation combined with some autonomous control function, which is called supervisory control or telerobotics, is the primary concern to relief of the human workload and to compensate for the time delay in the remote control loop of the second generation space robot. Dexterous manipulation is also essential to increase the applicability of the robots to the various space activities.

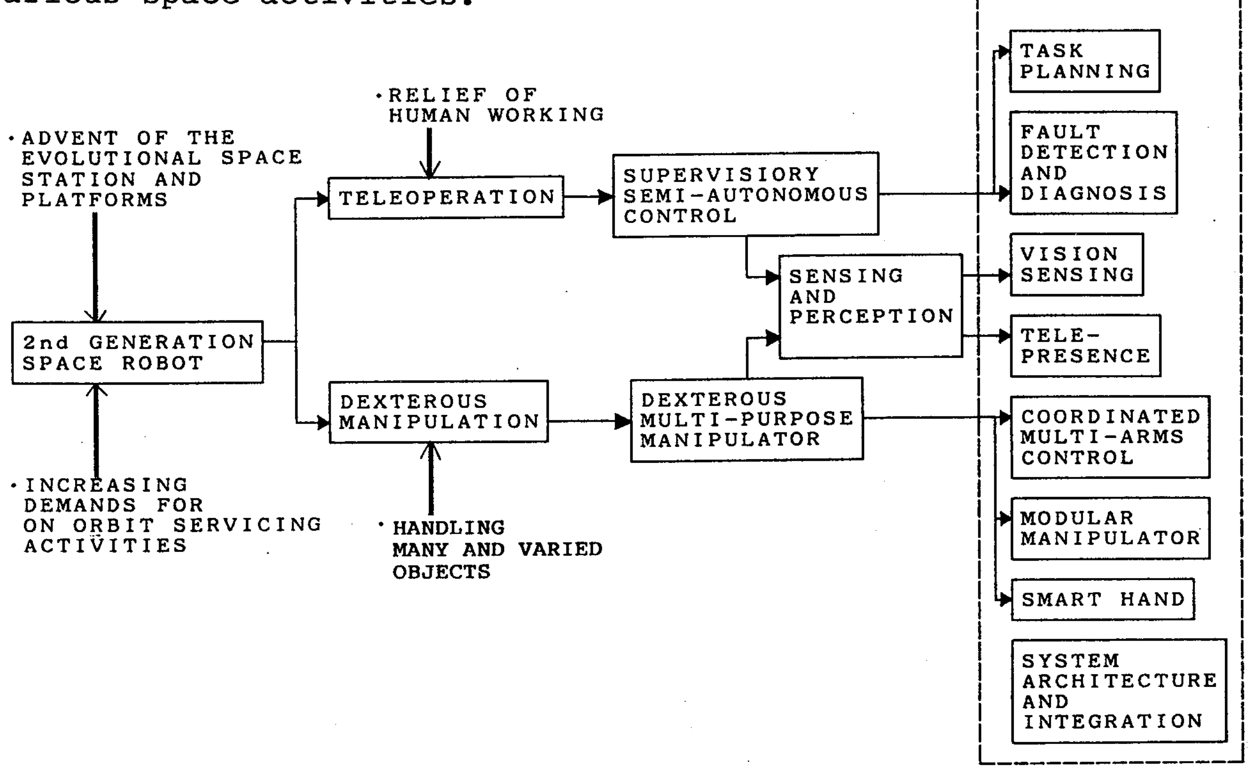


Fig.-2 KEY TECHNOLOGIES OF THE SECOND GENERATION SPACE ROBOT

The goals of our phase 1 research on those key technologies are as follows.

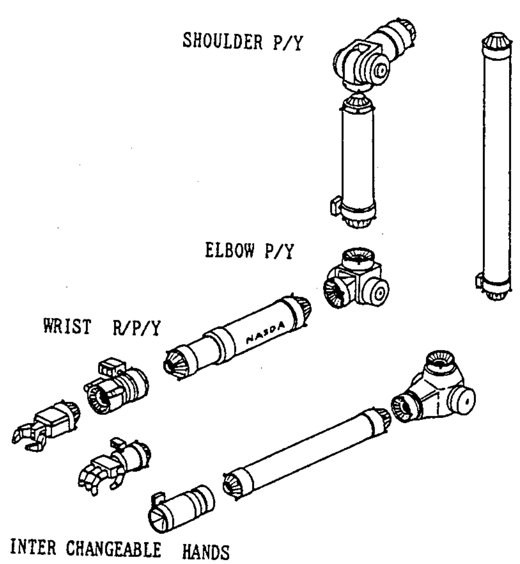
Task planning : Task planning covers path planning which generates the sequence of the robot motion and the obstacle avoidance using task rules, geometric data base and sensor data. The most important point is the robustness of the planning system against the uncertainties of the real world.

Vision sensing : Acquisition, tracking and recognition of the marked or known objects by the vision sensor under the conditions of the simulated orbital lighting.

Telepresence : The objectives of this work are to develop and evaluate the advanced man-machine interface technologies such as the application of the 3-D vision and predicted simulation vision.

Dexterous manipulation : This work covers the development and the evaluation of the coordinated multi-arms control, modular reconfigurable manipulator and the smart hands. Fig.-3 shows the concept of the modular manipulator. The manipulator system is reconfigurable by exchanging standard sized arm links, actuator units and hands.

In addition, the evaluation of the system architecture and integration with the ground testbed model is the major concern in this phase.



EXAMPLE FEATURES OF THE MANIPULATOR CONFIGURATION FOR THE OSV

ARM LENGTH	4-5m/arm
DEGREE OF FREEDOM	8 (1: trnaslational / 7: rotational)
TIP SPEED	200mm/sec (max.)
TIP FORCE	100N (max.)
TORQUE	50Nm (max.)
ACCURACY	less than 2mm
OBJECT MASS	1 ton
HAND	interchangeable
COMPLIANCE	passive & active (software) control
ARM MASS	250kg/arm
POWER	500W/arm (max.)

Fig.-3 CONCEPT OF THE MODULAR MANIPULATOR

5.Testbed model and the simulator

The objectives of the ground testbed model and the simulator are to evaluate the performance of the key technologies and the applicability of the semi-autonomous robots to the near-future space activities. The system configuration and the block diagrams of the testbed model and the simulator employed in the phase 1 research are shown in Fig.-4 and Fig.-5 respectively.

The simulator consists of the testbed model, experimental work bench ,man-machine interface system and work stations for the task planning and graphic simulations. The experimental work bench is easily reconfigurable and applicable to the various in-orbit servicing simulations. The testbed model which consists of manipulators , visual sensors and local control unit is mounted on the mobile platform of the motion simulator. In the experiment of the free flying target capturing, this system can simulate the relative 6 degree-of-freedom motion between the target and the testbed model by the coordinated motion between the gimbal system of the target and the mobile and rotational platform.

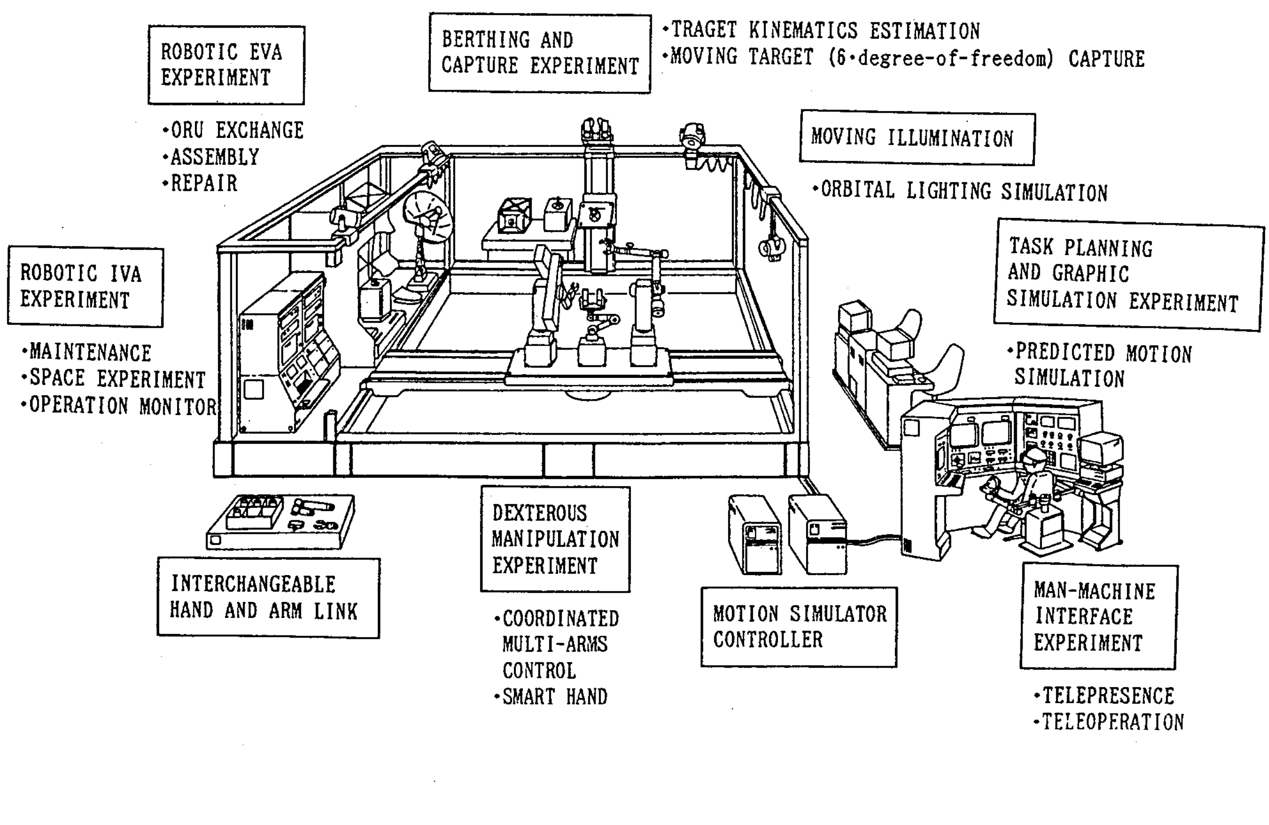


Fig.-4 SYSTEM CONFIGURATION OF THE TESTBED MODEL AND THE SIMULATOR

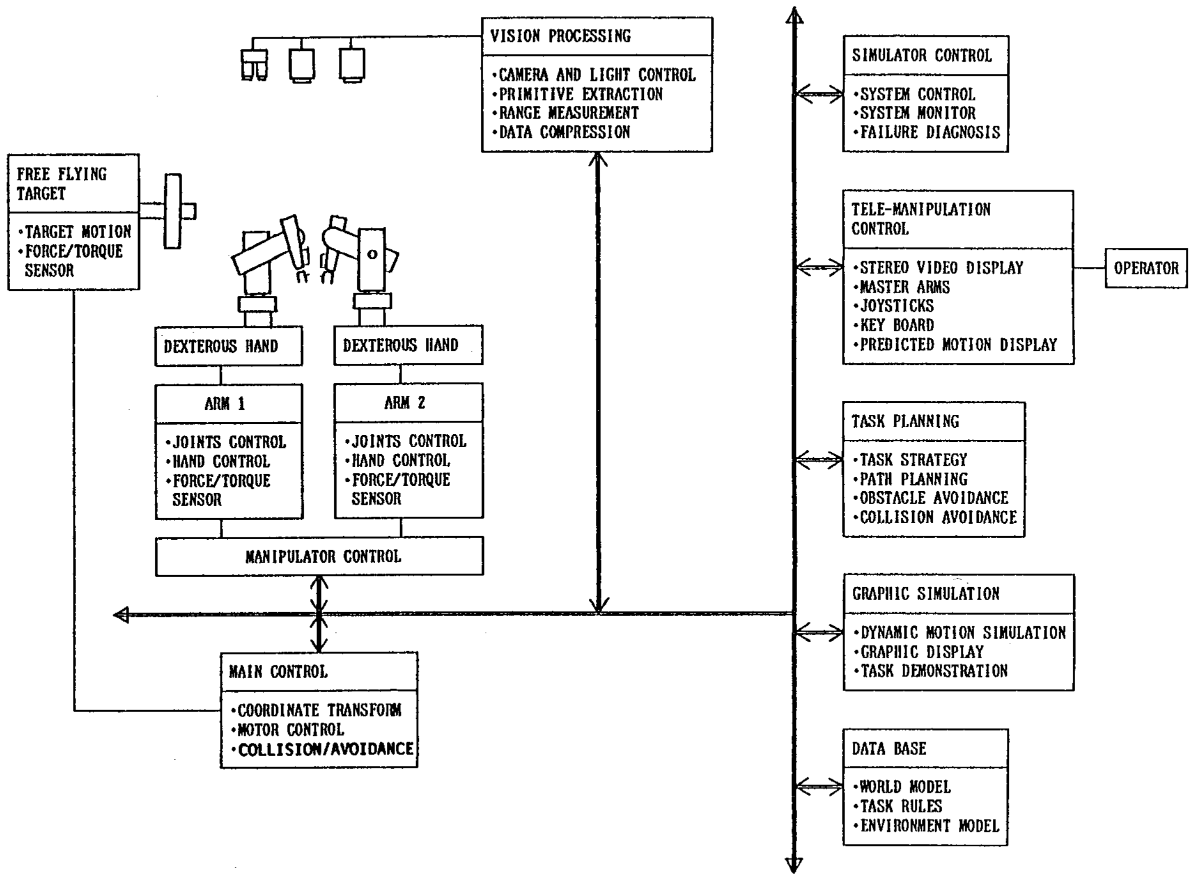


Fig.-5 BLOCK DIAGRAMS OF THE TESTBED MODEL AND THE SIMULATOR

6. Research and Development Scenario

Fig.-6 shows the research and development schedule of the second generation space robots. The research and development is divided in two phases. The major objectives of the phase 1 research are given below.

- obtain the system concept of the second generation space robot
- analyze the in-orbit robotic servicing tasks
- research and development on the semi-autonomous and the dexterous manipulation technologies
- evaluate the performance of the integrated technologies by the ground testbed model and the simulator

The feasibility study on the specific robot systems and the subsystem development will be conducted in the phase 2 research planned to start in 1992. In addition, the in-orbit robotics experiment with the Space Technology Experiment Platform (STEP) and the JEM is planned around 1997. The performance and the applicability of the integrated robotic technologies , a sequence of the task procedures,and the teleoperation/semi-autonomous control scheme will be verified in the in-orbit experiment.

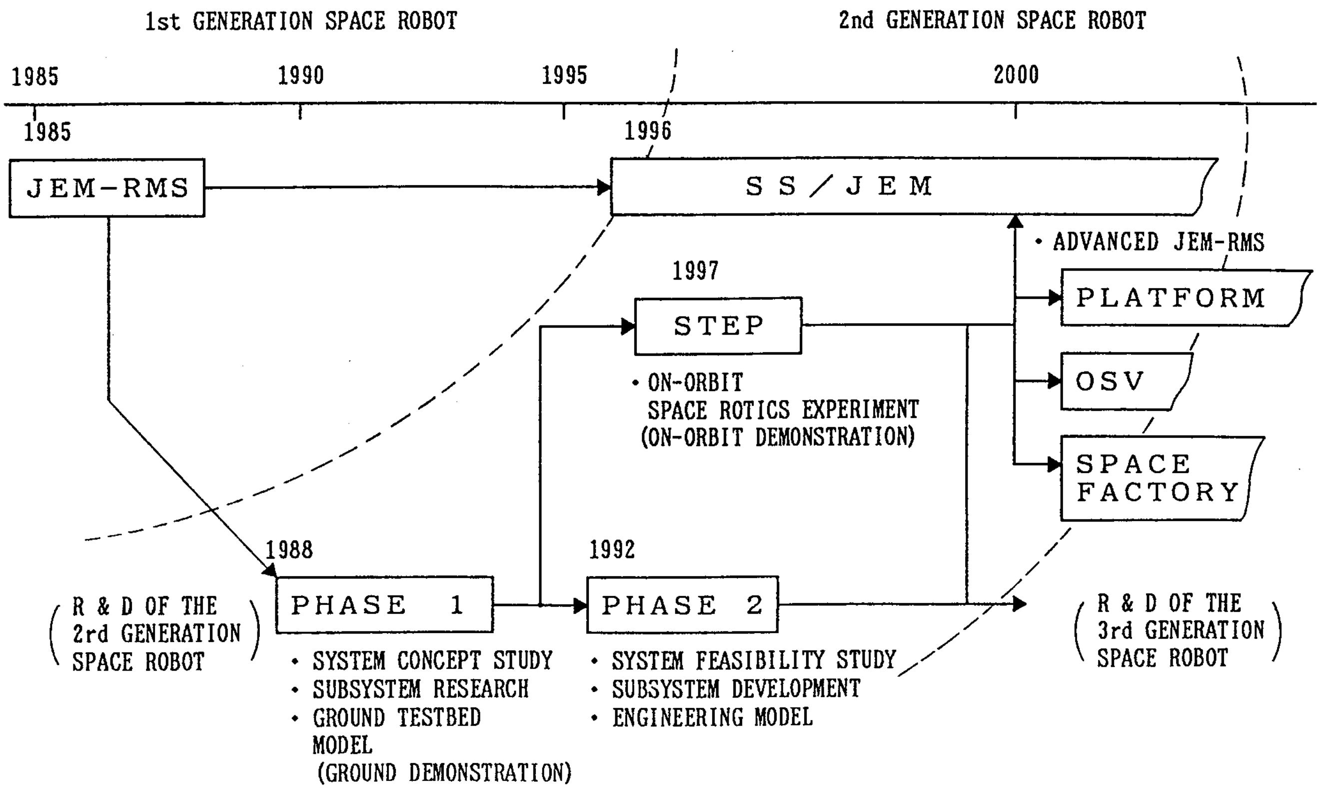


Fig.-6 RESEARCH AND DEVELOPMENT SCENARIO

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