



1
00:00:07,730 --> 00:00:04,970
as part of the NASA teller robotics

2
00:00:09,980 --> 00:00:07,740
program the Jet Propulsion Laboratory is

3
00:00:12,520 --> 00:00:09,990
pursuing advanced technology and remote

4
00:00:16,390 --> 00:00:12,530
manipulation in to discipline areas

5
00:00:19,849 --> 00:00:16,400
tella operation and supervise Donna me

6
00:00:21,830 --> 00:00:19,859
intelli operation an operator uses hand

7
00:00:25,429 --> 00:00:21,840
controllers to command the robots

8
00:00:27,830 --> 00:00:25,439
motions directly in supervised Donna me

9
00:00:29,900 --> 00:00:27,840
an operator interacts with the system at

10
00:00:31,669 --> 00:00:29,910
a much higher level while relying on the

11
00:00:33,770 --> 00:00:31,679
robots information of the task and

12
00:00:36,799 --> 00:00:33,780
environment to generate its own motion

13
00:00:39,139 --> 00:00:36,809

commands the results of this research

14

00:00:41,450 --> 00:00:39,149

will help to develop the technologies

15

00:00:52,580 --> 00:00:41,460

required to fulfill NASA's potential

16

00:00:54,260 --> 00:00:52,590

future needs 4 space robotics so we

17

00:00:57,260 --> 00:00:54,270

could we could machine since its

18

00:00:59,840 --> 00:00:57,270

beginning in 1985 the broad objectives

19

00:01:01,849 --> 00:00:59,850

of the JPL program have been to develop

20

00:01:04,310 --> 00:01:01,859

the robotic technologies that would be

21

00:01:07,399 --> 00:01:04,320

used in space operations and to

22

00:01:09,260 --> 00:01:07,409

integrate them into systems these

23

00:01:11,480 --> 00:01:09,270

technologies would be used to increase

24

00:01:13,880 --> 00:01:11,490

the productivity of astronauts conduct

25

00:01:18,530 --> 00:01:13,890

operations too dangerous for humans in

26
00:01:21,080 --> 00:01:18,540
space or perform boring repetitive tasks

27
00:01:23,180 --> 00:01:21,090
to date the integration of these new

28
00:01:25,190 --> 00:01:23,190
technologies has resulted in the

29
00:01:27,520 --> 00:01:25,200
development of a single robotic system

30
00:01:30,200 --> 00:01:27,530
that can operate intelli operation or

31
00:01:32,510 --> 00:01:30,210
supervised dote on ax me in the future

32
00:01:34,940 --> 00:01:32,520
the system will be able to operate in

33
00:01:39,230 --> 00:01:34,950
hybrid modes that combine features of

34
00:01:41,450 --> 00:01:39,240
both called shared control this teller

35
00:01:43,310 --> 00:01:41,460
robotic test facility provides an

36
00:01:49,130 --> 00:01:43,320
environment for research and development

37
00:01:51,800 --> 00:01:49,140
of key robotic technologies several

38
00:01:54,280 --> 00:01:51,810

features will be highlighted tella

39

00:01:57,700 --> 00:01:54,290

operation with force reflection

40

00:02:00,260 --> 00:01:57,710

autonomous compliance strategies and

41

00:02:03,490 --> 00:02:00,270

operator designate to support the

42

00:02:06,380 --> 00:02:03,500

operators use of supervised Donna me

43

00:02:08,480 --> 00:02:06,390

this demonstration will simulate the

44

00:02:11,030 --> 00:02:08,490

removal of an orbital replacement unit

45

00:02:14,720 --> 00:02:11,040

an o are you from an Earth orbiting

46

00:02:16,850 --> 00:02:14,730

satellite an arm will remove the oru and

47

00:02:19,040 --> 00:02:16,860

will then hand it to another manipulator

48

00:02:22,310 --> 00:02:19,050

arm which will insert it into a storage

49

00:02:24,170 --> 00:02:22,320

rack this sequence represents a portion

50

00:02:25,790 --> 00:02:24,180

of an in-flight maintenance operation

51
00:02:29,390 --> 00:02:25,800
similar to those which will be performed

52
00:02:31,430 --> 00:02:29,400
on the space station this demonstration

53
00:02:33,789 --> 00:02:31,440
utilizes a combination of tella

54
00:02:36,860 --> 00:02:33,799
operation and supervised dote on ax me

55
00:02:39,020 --> 00:02:36,870
these two manipulators left and right

56
00:02:41,630 --> 00:02:39,030
arms are used for grasping and

57
00:02:44,090 --> 00:02:41,640
manipulating objects this third

58
00:02:46,720 --> 00:02:44,100
manipulator is the camera arm and is

59
00:02:49,850 --> 00:02:46,730
used to position and orient four cameras

60
00:02:52,250 --> 00:02:49,860
these four cameras combined with three

61
00:03:00,450 --> 00:02:52,260
wing cameras provide the operator with

62
00:03:05,040 --> 00:03:02,790
two of these cameras are used to provide

63
00:03:11,460 --> 00:03:05,050

the operator with a color 3d stereo

64

00:03:13,470 --> 00:03:11,470

display this truss structure simulates

65

00:03:15,750 --> 00:03:13,480

the body of a satellite or the space

66

00:03:18,450 --> 00:03:15,760

station and supports a mock-up of a no

67

00:03:20,040 --> 00:03:18,460

are you to simulate the uncertainties

68

00:03:22,830 --> 00:03:20,050

that may exist in the space environment

69

00:03:27,120 --> 00:03:22,840

the initial location of the trust is not

70

00:03:29,640 --> 00:03:27,130

known to the robot beforehand the module

71

00:03:33,180 --> 00:03:29,650

represents an o are you and has to

72

00:03:35,880 --> 00:03:33,190

grapple lugs the robot carries a picture

73

00:03:38,730 --> 00:03:35,890

of this module in its database however

74

00:03:40,770 --> 00:03:38,740

one of the grapple lugs the left one has

75

00:03:42,690 --> 00:03:40,780

been intentionally misaligned to

76

00:03:44,610 --> 00:03:42,700

simulate a modelling error the

77

00:03:48,180 --> 00:03:44,620

experiment will show how the robot deals

78

00:03:50,040 --> 00:03:48,190

with this in addition a cylinder has

79

00:03:51,930 --> 00:03:50,050

been placed around the grapple lug to

80

00:03:54,750 --> 00:03:51,940

simulate occluded viewing conditions

81

00:03:56,910 --> 00:03:54,760

that might be expected in space the two

82

00:03:59,370 --> 00:03:56,920

arms used for grasping have wrist

83

00:04:01,770 --> 00:03:59,380

sensors which detect forces and torques

84

00:04:04,350 --> 00:04:01,780

the information received from these

85

00:04:08,940 --> 00:04:04,360

sensors is used in force reflection and

86

00:04:11,040 --> 00:04:08,950

compliance because the position of the

87

00:04:13,230 --> 00:04:11,050

trust is not known to the robot at the

88

00:04:15,540 --> 00:04:13,240

beginning the operator will first need

89

00:04:19,710 --> 00:04:15,550

to determine where the actual oru is

90

00:04:21,660 --> 00:04:19,720

located the operator begins the task by

91

00:04:23,850 --> 00:04:21,670

using a procedure called operator

92

00:04:26,550 --> 00:04:23,860

designate to determine the position of

93

00:04:28,770 --> 00:04:26,560

the module body when the module body is

94

00:04:30,480 --> 00:04:28,780

located the position of the grapple lug

95

00:04:32,130 --> 00:04:30,490

can be determined from the picture of

96

00:04:34,470 --> 00:04:32,140

the module carried in the robots

97

00:04:37,800 --> 00:04:34,480

database even though the grapple lug

98

00:04:40,230 --> 00:04:37,810

cannot be seen on two monitors each

99

00:04:42,450 --> 00:04:40,240

showing a slightly different view the

100

00:04:46,920 --> 00:04:42,460

operator overlays a line drawing of the

101
00:04:49,170 --> 00:04:46,930
module the operator then specifies the

102
00:04:51,540 --> 00:04:49,180
true locations of several corners of the

103
00:04:53,730 --> 00:04:51,550
module body by indicating which corner

104
00:04:58,159 --> 00:04:53,740
of the overlay corresponds to which

105
00:05:03,689 --> 00:05:01,709
no object location based on four point

106
00:05:06,089 --> 00:05:03,699
because the camera images have been

107
00:05:07,859 --> 00:05:06,099
carefully calibrated this information

108
00:05:16,889 --> 00:05:07,869
can be used to update the robots

109
00:05:19,619 --> 00:05:16,899
database 78.6 new object location based

110
00:05:21,659 --> 00:05:19,629
on eight points with the modules

111
00:05:24,329 --> 00:05:21,669
accurate position stored in its database

112
00:05:31,289 --> 00:05:24,339
the robot can then locate the grapple

113
00:05:33,299 --> 00:05:31,299

luck with this accomplished the system

114

00:05:40,850 --> 00:05:33,309

then moves the left arm toward the left

115

00:05:47,759 --> 00:05:44,219

actually gripper on remote site using

116

00:05:50,339 --> 00:05:47,769

left term moving the arm too near the

117

00:05:53,429 --> 00:05:50,349

object this is the lug that was

118

00:05:55,499 --> 00:05:53,439

intentionally misaligned using active

119

00:05:57,629 --> 00:05:55,509

compliance the left arm gently and

120

00:05:59,909 --> 00:05:57,639

autonomously moves in several directions

121

00:06:02,189 --> 00:05:59,919

to accommodate the misalignment and

122

00:06:05,040 --> 00:06:02,199

allow the grasping action to be

123

00:06:15,570 --> 00:06:05,050

completed actually a gripper on remote

124

00:06:21,689 --> 00:06:19,170

since October 1989 the speed with which

125

00:06:24,420 --> 00:06:21,699

these operations can be performed has

126
00:06:26,040 --> 00:06:24,430
been increased by a factor of three this

127
00:06:27,899 --> 00:06:26,050
is because we have introduced the

128
00:06:30,050 --> 00:06:27,909
capability to plan actions at the

129
00:06:32,640 --> 00:06:30,060
operators site while simultaneously

130
00:06:36,899 --> 00:06:32,650
executing other commands at the remote

131
00:06:39,089 --> 00:06:36,909
site intelli operation the operator uses

132
00:06:41,850 --> 00:06:39,099
the force reflecting hand controllers

133
00:06:43,770 --> 00:06:41,860
and looks at the 3d display to view the

134
00:06:47,219 --> 00:06:43,780
workspace while he removes and

135
00:06:49,350 --> 00:06:47,229
transports the module dr. Henry stone a

136
00:06:51,959 --> 00:06:49,360
force reflection is a mode of tele

137
00:06:54,719 --> 00:06:51,969
operation in which the forces that are

138
00:06:57,480 --> 00:06:54,729

sensed at the end effector of the arm

139

00:07:00,719 --> 00:06:57,490

are reflected back to one of these hand

140

00:07:03,689 --> 00:07:00,729

controllers here and that provides the

141

00:07:06,420 --> 00:07:03,699

operator with a sensation of contact

142

00:07:08,430 --> 00:07:06,430

with the environment should the geometry

143

00:07:10,439 --> 00:07:08,440

prevent the left arm from storing the

144

00:07:19,589 --> 00:07:10,449

module the module would have to be

145

00:07:22,260 --> 00:07:19,599

handed off to the right arm in this case

146

00:07:24,240 --> 00:07:22,270

the left arm holds the module and the

147

00:07:27,450 --> 00:07:24,250

right arm performs a grasp sequence

148

00:07:29,399 --> 00:07:27,460

identical to that just executed we have

149

00:07:31,559 --> 00:07:29,409

not placed a cylinder around the right

150

00:07:33,659 --> 00:07:31,569

grapple ough so we can provide a better

151
00:07:36,600 --> 00:07:33,669
view of the upcoming autonomous error

152
00:07:39,119 --> 00:07:36,610
recovery sequence because the left

153
00:07:40,950 --> 00:07:39,129
grapple ugh was misaligned the actual

154
00:07:42,930 --> 00:07:40,960
position of the right grapple lug is

155
00:07:45,990 --> 00:07:42,940
significantly different than the robots

156
00:07:51,510 --> 00:07:46,000
model would predict this causes the

157
00:07:53,579 --> 00:07:51,520
automated grasp to fail the operator is

158
00:07:55,649 --> 00:07:53,589
informed of the failure and decides to

159
00:07:57,149 --> 00:07:55,659
check the database by displaying the

160
00:08:01,200 --> 00:07:57,159
image of the module on the video

161
00:08:03,450 --> 00:08:01,210
monitors the error is apparent because

162
00:08:05,430 --> 00:08:03,460
the right grapple lug line image on the

163
00:08:08,219 --> 00:08:05,440

video monitor and the module do not

164

00:08:10,320 --> 00:08:08,229

coincide the operator can see that the

165

00:08:13,829 --> 00:08:10,330

cause of the failure is due to the Miss

166

00:08:16,079 --> 00:08:13,839

positioning of this grapple ugh to

167

00:08:18,600 --> 00:08:16,089

recover from this failure the operator

168

00:08:21,050 --> 00:08:18,610

again chooses object designation to

169

00:08:23,369 --> 00:08:21,060

correct and update the database model

170

00:08:25,709 --> 00:08:23,379

with this new information in the

171

00:08:27,570 --> 00:08:25,719

database the operator execute the

172

00:08:31,879 --> 00:08:27,580

autonomous sequence successfully and

173

00:08:37,110 --> 00:08:34,889

the operator uses tella operation to

174

00:08:46,410 --> 00:08:37,120

release the left side of the module and

175

00:08:48,449 --> 00:08:46,420

move the left arm away the operator also

176
00:08:50,639 --> 00:08:48,459
uses tella operation to move the right

177
00:08:53,189 --> 00:08:50,649
arm inserting the module into its

178
00:08:58,769 --> 00:08:53,199
storage location and completing the oru

179
00:09:01,470 --> 00:08:58,779
removal task in addition to tella

180
00:09:03,809 --> 00:09:01,480
operation and supervised Donna me this

181
00:09:06,360 --> 00:09:03,819
system is also capable of combining the

182
00:09:08,970 --> 00:09:06,370
two modes into one called shared control

183
00:09:11,579 --> 00:09:08,980
at this time it has been partially

184
00:09:13,619 --> 00:09:11,589
integrated into the system during shared

185
00:09:16,050 --> 00:09:13,629
control the operators using the hand

186
00:09:19,050 --> 00:09:16,060
controller to basically guide the

187
00:09:21,019 --> 00:09:19,060
position of the end effector whereas the

188
00:09:23,249 --> 00:09:21,029

autonomous system at the same time is

189

00:09:26,100 --> 00:09:23,259

controlling forces and torques to

190

00:09:28,619 --> 00:09:26,110

maintain a particular profile shared

191

00:09:31,639 --> 00:09:28,629

control will now be used to simulate an

192

00:09:35,280 --> 00:09:31,649

optical cleaning task this dome

193

00:09:36,929 --> 00:09:35,290

represents an optical surface the

194

00:09:39,090 --> 00:09:36,939

operator sits at the console and

195

00:09:46,199 --> 00:09:39,100

commands the arm to grasp the cleaning

196

00:09:48,269 --> 00:09:46,209

pad autonomously the operator commands

197

00:09:51,540 --> 00:09:48,279

the movements of the pad using a hand

198

00:09:53,519 --> 00:09:51,550

controller the autonomous system ensures

199

00:09:55,679 --> 00:09:53,529

that the pad follows the contour of the

200

00:09:59,620 --> 00:09:55,689

dome and controls the pressure exerted

201

00:10:02,260 --> 00:09:59,630

on it during this operation

202

00:10:04,360 --> 00:10:02,270

only the planar motions of the hand

203

00:10:07,510 --> 00:10:04,370

controller that I'm making are being

204

00:10:10,390 --> 00:10:07,520

mapped into motions of the pad about the

205

00:10:12,160 --> 00:10:10,400

dome the other degrees of freedom are

206

00:10:14,860 --> 00:10:12,170

being controlled by the autonomous

207

00:10:17,410 --> 00:10:14,870

system in order to maintain certain

208

00:10:21,310 --> 00:10:17,420

forces and torques which are required

209

00:10:23,800 --> 00:10:21,320

for the actual polishing to occur the

210

00:10:25,870 --> 00:10:23,810

demonstrations you have seen represent

211

00:10:29,890 --> 00:10:25,880

technologies being advanced to meet the

212

00:10:32,590 --> 00:10:29,900

needs of NASA's Space Program these

213

00:10:34,540 --> 00:10:32,600

demonstrations at the JPL teller robotic

214

00:10:37,360 --> 00:10:34,550

test facility showed a state-of-the-art

215

00:10:39,010 --> 00:10:37,370

integrated robotic system capable of

216

00:10:41,530 --> 00:10:39,020

performing complex sequences of

217

00:10:44,020 --> 00:10:41,540

operations using a mixture of autonomy

218

00:10:46,120 --> 00:10:44,030

and tella operation where the operator

219

00:10:49,810 --> 00:10:46,130

has the ability to select the mode which

220

00:10:52,570 --> 00:10:49,820

is best suited for the task at hand in

221

00:10:54,460 --> 00:10:52,580

the oru exchange task the system coped

222

00:10:56,470 --> 00:10:54,470

with uncertainties and inaccuracies in

223

00:10:59,670 --> 00:10:56,480

its database by using the features of

224

00:11:02,320 --> 00:10:59,680

active compliance and operator designate

225

00:11:04,330 --> 00:11:02,330

operator designate was used to update

226

00:11:07,920 --> 00:11:04,340

the position of the oru so that the

227

00:11:10,480 --> 00:11:07,930

occluded grapple ugh could be found

228

00:11:12,610 --> 00:11:10,490

active compliance then permitted the

229

00:11:18,400 --> 00:11:12,620

grapple ugh to be grasped even though it

230

00:11:20,890 --> 00:11:18,410

was misaligned later operator designate

231

00:11:22,450 --> 00:11:20,900

was used again to overcome the error in

232

00:11:24,730 --> 00:11:22,460

the assumed position of the right

233

00:11:30,520 --> 00:11:24,740

grapple ugh caused by the misalignment

234

00:11:32,740 --> 00:11:30,530

of the left one with the operator

235

00:11:34,630 --> 00:11:32,750

controlled polishing of the dome we

236

00:11:36,790 --> 00:11:34,640

showed one example of where supervised

237

00:11:38,920 --> 00:11:36,800

Donna me was combined with tella

238

00:11:41,080 --> 00:11:38,930

operation to tailor specific

239

00:11:43,960 --> 00:11:41,090

capabilities to specific task

240

00:11:45,640 --> 00:11:43,970

requirements this system and the robotic

241

00:11:48,100 --> 00:11:45,650

technologies that are integrated within

242

00:11:50,170 --> 00:11:48,110

it as direct application to a variety of

243

00:11:52,750 --> 00:11:50,180

operations that will be required in

244

00:11:54,400 --> 00:11:52,760

space in the future in particular it can

245

00:11:56,200 --> 00:11:54,410

be used for satellite servicing and

246

00:11:59,410 --> 00:11:56,210

repair and maintenance of the Space

247

00:12:01,840 --> 00:11:59,420

Station freedom flexibility and

248

00:12:03,880 --> 00:12:01,850

adaptability will be essential

249

00:12:06,140 --> 00:12:03,890

capabilities needed for teller robots

250

00:12:09,470 --> 00:12:06,150

used on future space missions

251

00:12:13,100 --> 00:12:09,480

as shown by these demonstrations these