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Minimizing Attitude Control Fuel in Space Manipulator Systems

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\bstract - Techniques are presented for finding space manipulator motions which result educed spacecraft dynamic disturbances. Although a spacecraft's attitude control reacti ets can compensate for these disturbances, reaction jet fuel is a limited resource a xcessive disturbances would limit the life of a space manipulator. A graphical tool call he Enhanced Disturbance Map (EDM) is presented and is demonstrated as an aid leveloping planning and control algorithms to solve this complex problem.

INTRODUCTION

A number of telerobotic manipulator ystems have been proposed as an lternative to costly and hazardous Extra 'ehicular Activity (EVA) in future space nissions [1]. The development of such obotic systems creates a number of echnical challenges, including some in he dynamics and controls areas. These esult from the dynamic disturbances ma- ipulator motions cause to their pacecraft's attitude and position [2]. ystem performance could be seriously legraded if the resulting spacecraft notions are not controlled. To control hese spacecraft motions by using the ystem's attitude control reaction jets, ould require substantial amounts of ttitude control fuel, thus limiting the iseful "on orbit" life of the system [3].

The dynamic coupling between a pace manipulator and its spacecraft has een studied using a method called the 'irtual Manipulator (VM) [4,5]. The VM ias simplified the modeling of this phe- iomenon and resulted in the develop- ment of a tool called the Disturbance M [4,5]. The original form of the Disturbar Map was inadequate to plan paths redı ing the dynamic disturbances caused manipulator motions. The present stu has developed the Enhanced Disturbar Map (EDM); this permits planning pa to reduce such disturbances, which turn, reduces the need for a space manip lator system to carry large amounts costly attitude fuel. Three methods ha been proposed that use the EDM to sugg paths for a given manipulator which sult in less attitude fuel consumption The first uses the EDM to position a orient a spacecraft so that a zero dynan disturbance path can be found betwe given end-point positions in inert space. The second, the “Hot Sp method, selects reduced disturbance pa by avoiding regions in a manipulato joint space where small manipulator m tions cause large disturbances to the spa craft. Finally, the third method uses t EDM to find zero disturbance paths for dundant manipulators. In this paper t Hot Spot method is presented.

'HE ENHANCED DISTURBANCE MAP

The Enhanced Disturbance Map EDM) derives from studying disturbances t an arbitrary point in joint space for a wo DOF manipulator. This study shows hat there will always be a direction of notion in joint space for a given nanipulator configuration which will not ffect the orientation of a manipulator's ehicle, in the infinitesimal sense [4].

These results suggest that paths that ollow the lines of zero disturbance result n less fuel usage than those that are not. 'he EDM is structured in Figure 1 to show he lines of zero disturbance, see Figure 1. 'his form also permits the representation f three DOF manipulators on graphic omputer terminals, such as Iris worksta-ions. The magnitudes of the maximum listurbance are shown by coloring the ines proportional to the maximum dis-urbance magnitude at that point. This oloring makes high and low maximum listurbance areas called hot and cool spots, espectively. Unfortunately, it is not pos-ible to reproduce the colors in the figures f this paper, and therefore, where eeded, they are represented by back-round shading.

Motions of a manipulator parallel to a ero disturbance line will result in zero pacecraft disturbance. Motions across or perpendicular to such a line will result a local maximum spacecraft disturban Manipulator motions which cross a z disturbance line in a red area, or hot sp will result in large disturbances of the hicle. Manipulator motions that cross t lines in cool areas will result in smal disturbances. These observations play important role in the development of t path planning strategy discussed below.

A TECHNIQUE FOR MINIMIZING FUI THE HOT SPOT METHOD

The EDM aids in understandi spacecraft dynamic disturbances caused manipulator motions and in finding ne optimal manipulator paths to minimi these disturbances. These paths can used directly or as "good" starti solutions to decrease the computatio effort required by numerical optimizati methods, and to increase the likeliho that such methods will converge to t true global optimal solutions.

Several algorithms for planning a control have been developed using t EDM to find paths which result in l attitude fuel consumption [3]. The H Spot method selects paths using the ED which avoid regions where small motic of the manipulator cause large dist bances to the spacecraft. Another al rithm uses the EDM to find zero dist bance pa for redundant manipulat s. Space d not perr their complete presentatio

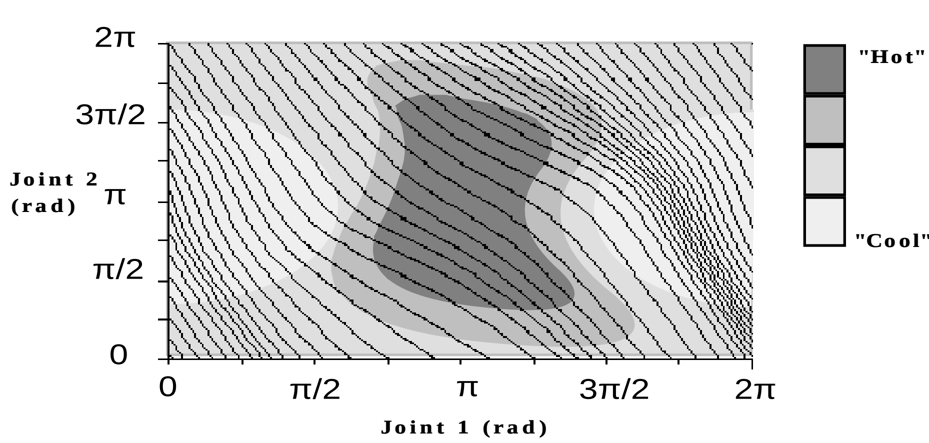

Figure 1: The Enhanced Disturbance Map

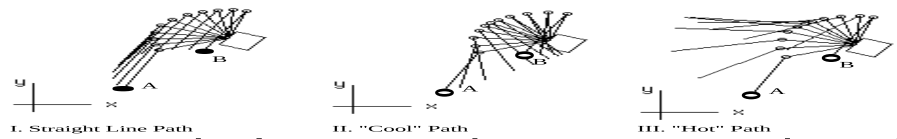

Figure 2. Path Selection Using the Hot Spot Approach - Work Space

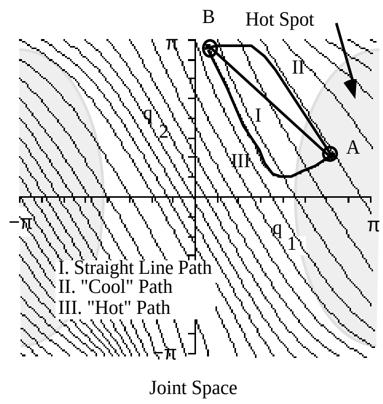

Figure 3. EDM Hot Spot Path Selection.

The Hot Spot approach is that a path hould, when possible, avoid regions of ıigh disturbance. When it must enter uch regions, it should follow the zero disurbance lines as closely as possible. Vhen disturbances are low, at Cool Spots, he path may move across disturbance ines. Clearly this can be more effectively lone when the EDM is plotted in color vhere finer degrees of the maximum disurbance can be seen. Figure 2 shows a wo-link nonredundant space manipulaor, with its desired initial and final posiions, points A and B respectively. Its EDM vith pseudo coloring is shown in Figure . The spacecraft is assumed to have an atitude control system which keeps it staionary during the manipulator's motion. \s the manipulator moves from points A o B in inertial space, its joint angles move rom the corresponding points A and B hown in the Disturbance Maps also conained in Figure 3. Dark areas of the EDM epresent hot spots, or areas of higher naximum dynamic disturbance. Notice hat the initial configuration or point A in his example lies in a hot spot.

Three paths were considered for the system and are shown in Figures 2 anc to demonstrate the effectiveness of t Hot Spot method. The first is a straiş line from A to B; the second is contour to follow the zero disturbance line in t hot region; the third moves across t zero disturbance lines in the hot region.

The total amount of reaction jet cc trol fuel required to hold the spaceci stationary for each of the three cases w computed using an independent simu tion program, and is shown in Table Recall that fuel usage is a function of t velocity profile of a manipulator along path, as well as the shape of the path the EDM. The same velocity profile w used in each case in this example. T manipulator started from rest at point and moved with a specified constă acceleration until midway along the pa then used the same constant decelerati to come to a stop at its final position at E

Table I clearly shows that using t Hot Spot approach reduces the amount fuel consumed below the simple straiş line path. Moving across the disturbar lines in high disturbance regions cons erably increases fuel consumption.

Path	Attitude Fuel
Path I (Straight Line)	50.3 Kg
Path II (“Cool” Path)	15.5 Kg
Path III (“Hot” Path)	210.2 Kg

Table I Attitude Control Fuel Requirei for Three Paths

In this study several other algorith were developed using the EDM, and measure of fuel usage to shape paths lucing spacecraft disturbances [3]. These ›aths can be used either directly or as nitial values in numerical optimization ›rocedures which can optimize the veloc- ty profile as well as the manipulator's ›ath. While the EDM and its zero distur- ance lines can be displayed for three DOF nanipulators using modern computer raphics terminals, it cannot be displayed ffectively for more than a three DOF nanipulator. For such systems one must ely more on computer algorithms to trace heir way through the multi-dimensional oint space. Fortunately, except where a nanipulator carries a large payload, it is enerally the effects of the first three joints ›f a manipulator which have the largest ffect on the disturbances produced by a pace manipulator.

CONCLUSIONS

'he Enhanced Disturbance Map has been hown to aid in understanding the prob- em of dynamic disturbances to spacecraft aused by space robotic system motions. 'his EDM also can be used to obtain near- ›ptimal paths which minimize these dy- ıamic disturbances. These paths can be ısed directly, or as "good" starting solu- ions for the numerical optimization nethods; they decrease the computational ffort for such methods and increase the ikelihood that they will converge to true lobal optimal solutions.

ACKNOWLEDGMENTS

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