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# A Proposal of Hyper- Redundant Manipulator for an Unmanned Aerial Vehicle

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**Abstract**— Manipulators are machines which consist of degree of freedom from 1 to infinity depending upon the applications, unmanned aerial vehicles (UAV) are the machines which can access certain typical location whereas ground vehicles can't access. In these work a dissicusion for proposal to employing an UAV with a hyper redundant manipulator, which results to have a mobile manipulating UAV. This proposal can help in structural and other repair, disaster and medical emergencies, cargo supply and resupply etc. Hosting a manipulator in an UAV has few challenges like manipulator movements and interaction with objects which may lead to negatively impact for the host platform stability. The control of the host platform of UAV has many aspects like motion capture system for position control, as compared with the control in a fixed objects host is poor. To overcome such issues the implementation of Hyper- Redundant Manipulator is necessary as it can reduce the negative impacts on the host platform as the ability to move in free space, the redundancy of the arm affords highly approachable workspace for the end effector i.e. allowing the end effector to work with the objects smoothly regardless host platform motions.

**Keywords**— Hyper Redundant, Unmanned aerial Vehicle, Denavit Hartenberg, Jacobian, Heuristic Inverse Kinematics, Manipulator, Degree of Freedom(DOF)

## INTRODUCTION

The roles of UAV are to deploy bombs missiles rocket, surveillances in areas for intelligences report, distribution of good (used by few e-commerce industries) etc, many other uses for civilian and military operation. As past is concern UAVs have been operated in many ways to interact with environments in every means, and the advantage of carrying objects that expands the workability of UAVs. Robots with higher degree of freedom could lead to transformative applications in any workspace allotted. A proposal for attaching a dexterous robot with an UAV could lead to a massive innovative idea to help in many odd circumstances like in disaster, battle field, on spot medical emergencies(operations treatments), agricultural, nuclear plants, or in outer space also etc.

Few developments like aerial grasping by employing 1 DOF [1][2]. But in this work the main proposal is to host a manipulator in a UAV, where the research is associated with the reaction forces and torque associated with the UAVs while interacting or facing with the environment. It will be possible to host a manipulator on a Roto-motion SR 20 robotic helicopter. Nasa's Robonaut, University of Massachusetts and CMU's HERB their area of research was on dual manipulators fixed to a mobile base, this type of related work have been also studied in DAPRA's ARM Robot, Massachuseets's Dexter robot. This type of design need dynamically balance mobile base while operating a task. The humanoid PRIE developed and hosted by Drexel University are experimenting on full scale, mini, and virtual HUBO platforms to study bipedal locomotion and grasping [3]. Anatomy for rotary-wing unmanned air vehicles is being studied in many universities, research organizations and private companies which will help to stabilize the platform, advances in materials and electronics have allowed researches to achieve small form-factors and light weights [4] [5], there are number of factors to study single and multi-robot coordination and perform algorithm testing[6][7]. Improvements of mobile manipulation techniques implemented to ground robots have been done earlier and these improvement techniques are also employed in aerial vehicles [8]. The Yale Aerial Manipulator can grasp and transport objects using a complaint gripper attached to the bottom of a T-Rex 600 RC helicopter [9]. University of Pennsylvinia study on multiple quadrotors to transport payloads using cables or a gripper [9]

There are numerous ground vehicles that use highly dexterous arms, most of the UAV manipulators imitate a bird or claw opening and closing in a 1 degree of freedom movement. But in this work a proposal to integrate a bulbous head with multiple arms similar to octopus, in addition to it leverage the state of the art in ground- based mobile manipulator and apply that to aerial vehicles.

## HYPER REDUNDANT MANIPULATOR

### A. Arm Description

The hyper redundant manipulator is mounted with a dynamixel servo motor and brackets as described in fig 1. The denavit-hartenberg parameter representing nine joints of this arm are listed in table 1. This proposal is implemented in matlab [12] as shown in fig 2 for developing the model as proposed and to test the motion controllers, accurate torque sensor for to each joint to measure ground truth.

| Link Number | θ(rad) | d(mm) | a(mm) | A(rad) |
|---|---|---|---|---|
| 1 | 0 | 0 | 96.8 | -Π/2 |
| 2 | 0 | 0 | 90.5 | -Π/2 |
| 3 | 0 | 0 | 90.5 | -Π/2 |
| 4 | 0 | 0 | 88 | -Π/2 |
| 5 | 0 | 0 | 88 | -Π/2 |
| 6 | 0 | 0 | 77.8 | -Π/2 |
| 7 | 0 | 0 | 71.8 | -Π/2 |
| 8 | 0 | 0 | 0 | -3Π/2 |
| 9 | 0 | 190.2 | 0 | -Π/2 |

Table 1: Denavit- Hartenberg parameter for the Hyper-redundant manipulator

Fig 1: Hyper Redundant manipulator

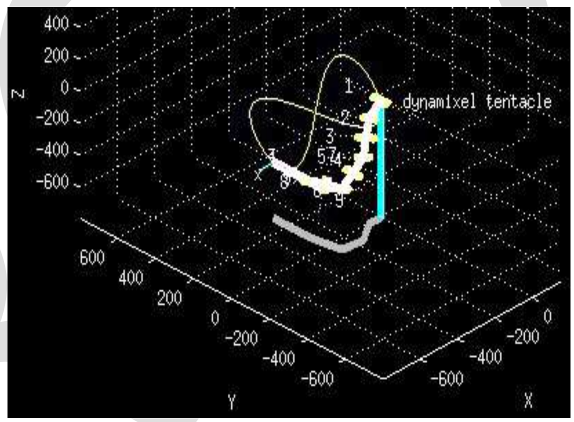


Fig 2: Model of the hyper redundant manipulator sweeping through a figure "8" test pattern

### B. Description of Hand

The hand consist of custom designed griper with 2 degree of freedom and 1 degree of control, with a Dynamixel servo motor which controls the opening and closing of the fingers. The design also includes a finger tips which close inward after a knuckle joint comes in contact with the object for performing pinch grasp operation.

### C. The Position Control

Inverse kinematics deals with positions for each joint in a manipulator (q), redundant manipulator have higher degree of freedom which is very dexterous which results in achievement of desired position in end effector through a very large number of unique joint configuration hence making the identification of desirable joint space solution elusive.

### D. The Pseudo- Inverse Jacobian Inverse Kinematics analysis

It is an iterative method to minimize the error between the desired and current end effector positions, in results solving q

$q = q_{previous} + \alpha \times \dot{q}$ (1)

The value of α starts at 1and if there is a diversion their and hence the value starts decreasing

$q = J^{\#} \times [X_0 - X]$ (2)

$[X_0 - X]$ is the freedom error of 6 DOF between the desired and current end effector positions and $J^{\#}$ is the pseudo inverse of the manipulator Jacobian which can be defined as

$J^{\#} = J^T \times (J \times J^T)^{-1}$ (3)

### E. The Weighted Pseudo- Inverse Jacobian Inverse Kinematics analysis

Except $\dot{q}$ other terms are similar i.e. pseudo- inverse Jacobian is similar to weighted pseudo- inverse Jacobian, hence the equation is

$\dot{q} = W^{-1} J^{\#T} (J^{\#} W^{-1} J^{\#T})^{-1} [X_0 - X]$ (4)

Where W is

$W = K_W |(q+\dot{q}| - |q_{previous}|)|$ (5)

$K_W$ = weighting gain

If $K_W$ is 1000 than satisfactory results can be achieved for the hyper redundant manipulator.

### F. The Heuristic Inverse Kinematics analysis

Heuristic algorithm helps to calculate joint angles to achieve the desired end effector pose and position [12].

1. The displacement between the end effector and the goal position can be calculated using forward kinematics.
2. As each joint is independently move up and down from its original position by an angle $\Delta\theta$ without exceeding the joint limit. So calculate the impact on end effector closeness. $\Delta\theta = \pi/4$.
3. After obtaining the results of step 2, the results are analyzed by selecting the joint and direction.
4. If there is any error arises in step 3, then return to the step 1 otherwise divide $\Delta\theta$ by ½ and return to step 2.
5. At final the end effector is closer than a desired threshold to the goal position.

G. **Evaluation of Reach ability**

The joint angles are solved such that the end effector could reach a series of randomly generated, but no reachable points in a space. The ratio of success to attempts for reaching the points is described previously in inverse kinematic algorithm where success boundary is within 1mm of the goal position without violating joint angle limits. From "8" pattern figure has been broken into 1000 test points have been considered within the success boundary to achieve a good solution. Whereas the percentage of 1000 test points that are within 1mm of the goal. The times calculated are shown in Table II which is calculated on the same computer, as this time could vary longer or shorter on other computers. While following a pattern the convergence may lesser time than the randomly accessed end effector poses as the end effector position is very close to current position calculation. The random end effector positions calculations are done near to the current end effector position of interest. The inverse Jacobian algorithm is fastest way to analyze the following and accessing random points in space, but the performance limitation can be observed when the end effector is subjected to actually reach the desired end effector poses. Perhaps the Heuristic approach is more reliable for overcoming the limitation of the end effector to reach the desired positions but in slowest taking seconds to converge on solutions makes the dynamic positioning requirements for the UAV. The weight inverse Jacobian algorithm is powerful and is more reliable than the inverse Jacobian algorithm. The joint angle is not concentrated while calculating joint positions whereas de-weights joints are moving towards limits when concerned in weight Jacobian, but it doesn't grantee's that joint s will be command to valid ranges between the limits, but at last improvement in successfully converging on solutions, the heuristic algorithm is guaranteed to return only valid joint angles.

| Algorithm | Pattern | Time | Random | Time |
|---|---|---|---|---|
| Pseudo-Inverse Jacobian | 96.6% | 0.047s | 48.0% | 0.192s |
| Weighted Pseudo-Inverse Jacobian | 99.8% | 0.089s | 82.6% | 0.465s |
| Heuristic | 100.0% | 2.121s | 84.1% | 3.031s |

Table II:- Inverse Kinematics performance while following a figure "8" pattern and reaching random location and orientation

H. **Control of Force**

From the analysis of the vehicle and object position obtained from the motion capture systems which is having relative motions between the UAV and the object to manipulate provide challenges that the position only controllers are poorly mounted to handle. But the aerial vehicle without a motion capture system making the uncertainties, highlighting the need for compliant manipulation approaches more worse and unpredictable. Implementation of hardware compliance has been done [1] for addressing the problems of using rigid, redundant manipulator, and force control. The interaction force at the end effector is presented as follows

$F_{int} = K[X_0 - X]$ (6)

Where $F_{int}$ is the desired interaction force applied to the end effector

$[X_0 - X]$ is the position error

K is stiffness gain (which map between position error and interaction force)

When $[X_0 - X]$ is considered as spring compression than K is considered as spring constant.

Rearranging the equation 6 pseudo goal position, which provide commands to the end effector to use the position controller such that it can impart desired amount of force. To obtain the desired expression we have to calculate required torque at each joint

$T_{act} = J^{\#T} F_{int}$ (7)

Combination of equation 6 and 7

$T_{act} = J^{\#T}[X_0 - X]$ (8)

**A PRELIMINARY DEMONSTRATION**

The redundant manipulator capability is performed by picking up a block from a peg, then stacking it onto a neighboring peg, the demonstration had been implemented in a manipulator explain the proposal in fig 3

1. The manipulator starts in ready position shown in fig 3a
2. The waypoint to move to 2cm above in fig 3b, such that to conform that the manipulator doesn't collides
3. The gripper is commanded to open the fingers
4. The commanded to bring the end effector down to the base of the source peg in fig 3c

5. The block is lifted up and off of the peg as shown in fig 3d
6. The manipulator is above 2cm above the destination peg as shown in fig 3e and 4f
7. Repetition have limitation in the manipulator so the block is not well aligned with the destination peg to, in other words the block is down over the peg, a way point 5mm below the top of the peg.
8. When the block is placed to the destination peg the end effector proceeds to waypoint as shown in fig 3g
9. When the block is placed in desired position the gripper open command is activated hence releases the block at final it moves above the destination peg and finally returns to the manipulator's ready position as shown in fig 3h

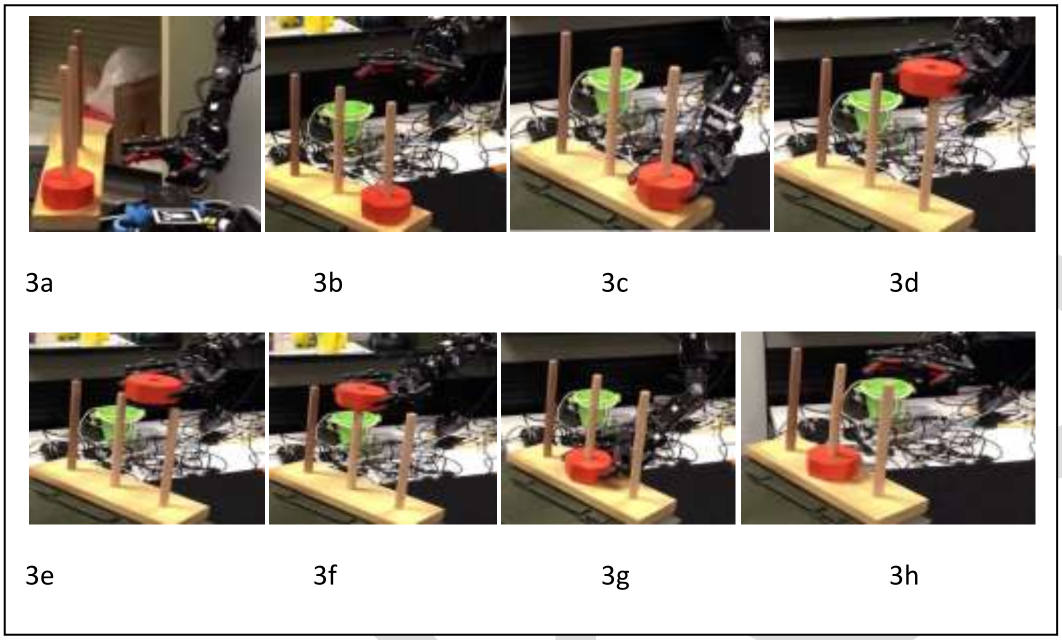


Figure 3: Frames of the manipulator where the proposal have been implemented

## CONCLUSION

Initial design proposals have been described along with the experiment with a hyper redundant manipulator. The proposal describes about a fully functioning flying prototype that uses a multiple similar hyper-redundant manipulator to perform wide variety of autonomous tasks, mimicking and teleported manipulator hosted to ground vehicles. In this work multiple inverse kinematics solvers along with weighted pseudo-inverse Jacobian method to best fit with the UAV mounted with a hyper redundant manipulator, as it have ability, reliability and can quickly achieve desired poses.

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