VERSATILE ROBOTIC INSTRUMENTS FOR NDT/NDE DATA ACQUISITION

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INTRODUCTION

The central theme of the research program at the Center is the development of novel versatile NDT data acquisition systems which combine the best feature of the human operator which is versatility i.e. the ability to perform many different NDT tasks in different environments, with other advantages which are characteristic of automated systems. At the same time these versatile systems avoid the worst features of human operators i.e. inaccuracies and slowness in repetitive tasks and inability to work in hostile environments.

EXPERIMENTAL DETAIL

The central feature of any instrument which satisfies the above requirements is that it consists of a compact robotic vehicle (with a payload of NDT/NDE tools) which can roam relatively freely over large surfaces, floors, ceilings or walls, can adapt to non-flat surfaces and is readily transportable (typically carriable by only one to two operatives) from task to task. Depending upon the NDT task to be performed the instrument may carry a static array of one or more NDT sensors. Alternatively it may carry a movable array including a multiaxis NDT tool manipulator which emulates the uniquely flexible scanning abilities of the human arm - and thus, is able to work relatively easily with complex structures such as pipework with bends and nodal joints. The instrument may also possess self navigation capability i.e. some kind of vision system providing feedback to the control system which determines the vehicle trajectory.

RESULTS

Such measurement instruments contribute in several ways to improvement in the overall quality of NDT data and their quantitative interpretation. For example an industry standard robotic arm can produce a high standard of repeatability of contact pressure, thus permitting repeatable absolute amplitude measurements (suitable for defect sizing) with dry contact rubber buffer and wheel probes. Furthermore by their ability to collect data rapidly using infinitely variable scanning routines improved signal to noise ratios after image processing are possible.

These flexible instruments, in many cases, also have the potential to reduce inspection costs because of their ability to replace several current automated systems, each capable of operating only in fixed locations and on fixed structural geometry, and nevertheless often quite bulky and expensive. Figures 1 to 6 show six examples of development prototypes, variously displaying some or all of the above characteristics and for ease of cross reference brief functional descriptions are given in the captions rather than in the text. The instruments shown in Figures 1 to 4 have been described in more detail elsewhere [1-6], whilst the captions of Figures 5 to 6 give the first published descriptions of the prototypes illustrated.
Figure 1. Low cost Laboratory ultrasonic C scan imaging system using a 5 axis robot arm costing less than £1k. A standard analog broad band pulser-receiver (PANAMETRICS) and a PC with DSP card for image display lead to a total system cost of typically £8k. The system is also illustrated (lower photograph) with the low cost robot arm replaced by a high quality 6 axis arm (PUMA 260) having a positioning repeatability of 50 µm.
Figure 2. First prototype wall and ceiling climbing NDT vehicle with a 490 x 380 mm chassis cross section and 15kg mass [1]. It uses pneumatic suction (for operation on sufficiently smooth surfaces of any material). Linear plus rotational movements permit omni-directional motion. It is shown carrying a low mass 5-axis arm costing less than £1k and capable of manipulating ultrasound or eddy current probes operating in a non-contact mode. However the arm cannot deliver a force adequate enough for either wet or dry contact testing.
Figure 3. Second prototype wall and ceiling climbing NDT vehicle with a 700 x 530 mm chassis cross section [2-6]. In the photograph on the right hand side the payload mounting platform is shown empty for clarity. In the photograph on the left hand side the platform carries a 13.5 kg 6-axis industrial arm (PUMA 260) which has an end effector able to carry a 1kg NDT tool (e.g. ultrasonic dry-contact roller probe as illustrated) placed with a repeatability of 50μm, and providing a contact force of up to 15, which is adequate enough for contact ultrasonic testing including the use of dry contact rubber buffer techniques. Linear plus rotational movements permit omni-directional motion. All-pneumatic power allows climbing over sufficiently smooth wall and ceiling surfaces made of any material and operation in hazardous environments requiring intrinsically safe operation. The vehicle mass is 23kg and with the PUMA on-board payload and an umbilical mass of 0.5 kg m⁻¹, the maximum climbing height is 35m with a safety factor of 2. The maximum climbing speed under the above conditions is 2.5 m min⁻¹ with a novel double stroke action. Alternatively a conventional single stroke action using 8 instead of 4 suction cups produces half the speed but doubles the mass carrying capacity.
Figure 4. Third Prototype wall and ceiling climbing NDT vehicle with a 750 x 700 mm chassis cross section and 45kg mass. This is a larger version of the second prototype vehicle illustrated in Figure 3, with more suction feet and a stronger rotational torque, and again is shown carrying a 6-axis PUMA 260 arm fitted with ultrasonic roller probe. With this onboard payload and an umbilical mass of 0.5 kg m\(^{-1}\) it is capable of climbing to a height of 30 m over a sufficiently smooth surface of any material with a safety factor of up to 3 providing depending upon the surface roughness. This concept is under further development with a 2.3M ECU Brite Euram Program with the partners listed in the acknowledgement.
Figure 5. Miniature vehicle (270 x 220 mm chassis cross section) able to move in any direction via steered wheels over ferrous walls and ceilings with adhesion produced by permanent magnets. It is shown fitted with a single ultrasonic dry contact roller probe.
Figure 6. Self Navigating Steel Plate Testing Robot capable of complete traversal of steel plates of unlimited size in a raster scan. A novel independent inner and outer chassis arrangement (only the inner chassis turns to permit sideways movement) ensures minimum stress and flexure of the umbilical and the simplest scanning strategy. Fitted with an array of 16 ultrasonic twin crystal probes controlled via an on-board multiplexer the robot inspects to all the relevant BSI standards with 100% plate edge coverage, data being displayed in the form of a line scan display on the screen of a ruggedised industrial PC screen. The chassis cross section dimensions are 680 mm x 430mm and the maximum speed is 10 m min\(^{-1}\), implying an area inspection rate of 175 m\(^2\) h\(^{-1}\).
THEORETICAL PERFORMANCE CONSIDERATIONS

It will be useful in this general paper to give an overall feel for the maximum range and payload capabilities of wall and ceiling climbing vehicles. If there is a need for a vehicle to climb over non-ferromagnetic surfaces; for example in the inspection of stainless steel reactor pressure vessels, storage tank walls made of concrete or fibre glass, or concrete or brick civil engineering structures, then pneumatic suction is needed. The maximum normal suction force per unit area of suction cup is the standard atmospheric pressure i.e. 101 kPa. From manufacturer's specifications, on ideal surfaces, the coefficient of friction will be a maximum of 0.37, implying a maximum friction force per unit area of suction cup of 37.4 kPa. To produce equal suction during every vehicle step a maximum of half the vehicle chassis cross sectional area is useable in theory for suction at each step, but detailed calculations suggest a practical maximum of 23%. Thus for a cross sectional area of A, the maximum friction force available to support the vehicle and its payload is 37,400 x 0.23 A = 8600A N.

So the mass carrying capacity is 8600A/9.81S = 880A/S kg, where S is the desired safety factor. Detailed calculations based on the family of prototypes also suggest the the minimum feasible vehicle mass, M, arising when attempts are made to maximise the area available for suction, increases with area according to the empirical formula M = 81.3 A kg. Thus we can arrive at a rough performance equation P = 880A/S - 81.3A - UH, where P is the on-board payload capacity, U is the umbilical mass per unit length and H is the climbing height. It is clear that the minimisation of umbilical mass is a crucial factor in optimisation of system performance: once the requirements for P and H are determined, the minimum possible vehicle cross section that will meet these requirements is evidently fixed by U.

For a vehicle using permanent magnets for adhesion to ferromagnetic surfaces the maximum available suction force per unit area is about 40 kPa and almost all the chassis cross sectional area can be made available for adhesion. Assuming the same coefficient of friction as previously but approximating the vehicle mass to zero (because most of the mass of a pneumatic vehicle resides in the actuators whilst permanent magnets in thin strip form add little to chassis weight), a rough performance equation is P = 1500A/S -UH kg, i.e. the payload capacity is better than the pneumatic case by a factor of up to 2.

CONCLUSION

As already stated, by their ability to multi-task in different locations, these compact robotic instruments hold promise of being more cost effective in the long run than currently available more conventional automatic systems dedicated to single task/single site operation.

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