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Progress Report on ONR Contract No. N00014-91-J-1054
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Work on the contract is progressing well and on schedule in accordance with the funded proposal entitled "Camera-Based Manufacturing Control." In addition to a number of publications stemming from research conducted under the grant, we have identified with cosupporter Chrysler Corp. a task which serves the purposes of the first year of the proposed research extremely well and which is described two paragraphs below. Further below is a description of the very significant progress on two of our vision-based tasks which require nonholonomic systems (in this case wheeled systems.)

The underlying theme of the research centers on addressing a practical and generic problem in manufacturing automation: the realization of highly precise, three-dimensional positioning (for assembly, welding, machining, etc.) without the need to preposition the workpiece. Workpiece prepositioning, while the usual approach with existing manufacturing automation, is quite costly and restrictive to achieve, and is for some things impractical, but it offers the advantage of requiring no more of the manipulator control scheme than simply repeating a (usually taught) maneuver trajectory. While machine vision offers the most promise for the unobtrusive and general sensing needed to automate without workpiece prepositioning, in the most common approach to its use, calibrational requirements, sensitivity to common manufacturing environmental disturbances, and precision limitations have been prohibitive. Our alternative to calibration, "camera-space manipulation", has been shown to produce highly accurate and robust relative positioning and is being further investigated and generalized for transfer to practical factory-floor use.

Work on the "wheel mounting" task (see attached letters) has proceeded very well over the course of the last two months. The task, which consists simply of the automated positioning and mounting of a wheel onto a 5-bolt brake plate, with arbitrary positioning of the receiving piece, was suggested to us by Chrysler which has donated to us the required wheel and plate.

The task has received considerable attention in the industry and we understand from Chrysler that no practical solution has emerged due to the calibration-related inability to "locate" the receiving piece with adequate precision and reliability. In addition to the notoriety of the task, it offers an excellent opportunity to fulfill one of the proposed objectives of the first year: to investigate the application of edge-detection-based image analysis to camera-space manipulation for cue location (in lieu of artificial, painted-on cues of the kind we have developed for earlier work. See attached paper "High Resolution Camera-Space Manipulation.")

We have proceeded with the wheel-loading task on two parallel tracks: The first involves achieving the required geometric and tolerance objectives making use of our artificial "ring cues." The second involves developing image analysis software specifically for the two joined components and testing it for accuracy and robustness in locating key features in each of our two image planes. Although additional refinement and testing is ongoing, we have succeeded quite easily with the first of these. On the second, we have concentrated primarily on the brake plate, and have found very encouraging preliminary indications. Our best judgment is that a full demonstration using the MA 2000 robots with cues will be ready later this spring and that a demonstration without the cues will be ready some time during the summer of 1991.

Significant modification to the method of camera-space manipulation is required to adapt to the differential kinematics of a nonholonomic positioning system such as a forklift. The advantages of the method, however, are retained, including the ability to use arbitrarily and distantly positioned cameras which may be panned, tilted, and zoomed separately to achieve adequate, independent framing. (We have identified the hardware for starting to automate this pan/tilt/zoom procedure later this first year in accordance with the contract.) The hardware and most of the software is now in place at subcontractor Iowa State University to demonstrate the pallet-stacking maneuver using ring cues painted on the pallets and a forklift-type of vehicle. These tests should begin during the summer of 1991. We have already completed successfully simple three-dimensional point positioning using "nonholonomic camera-space manipulation" and a revision of a full paper is under review at the IEEE Journal of Robotics and Automation (paper, expanded as per journal request, attached).

Finally, an additional, substantially different, task involving a nonholonomic (vehicle) device - that of precise, vision-based floor maintenance - has reached quite an advanced stage in a nine month period. Based on an extended Kalman filter and ring cues, it performs complex "cleaning-type" maneuvers in real time with consistent sub-inch precision. (See attached paper "Precise Vision-Based Tracking of an Autonomous Floor-Maintenance Vehicle.")

Three PhD students are currently being supported half time (20 hrs. per week) on the contract as specified.