A Sensor-Based Robotic Gripper for Limp Material Handling

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Abstract

A series of prototype flat-surfaced apparel grippers, based on the operational principle of suction and pressure differential, have been designed and experimentally tested. The prototype grippers are proven adequate to pick and place fabric material accurately and reliably without causing any distortion and/or folding of fabric.

The developed grippers have been mounted on the AdeptOne and AdeptThree robot arms for experimental and reliability analysis. Integration of vision and proximity sensor based information enhances the gripper functionality. It has been experimentally shown that the functionality of robot/gripper system meets requirements related to pick and place of single cut plies of several types of fabric, as set by the American Apparel Manufacturers Association (AAMA).

I. Introduction

The reported research has been motivated by the challenge to remove a major technology barrier within the U.S. textile/apparel industry, by automating the process of limp material handling. The process includes picking and placing limp fabric material from a cutting table without causing any fabric deformation and/or folding. Automatic fabric manipulation is currently an unsolved problem in the textile/apparel industry.

In an apparel job floor, fabric material is first spread using a spreader, and transferred to the cutting table. It is then cut, either manually or using an computer controlled automated cutter. Fabric material is spread and cut according to the dimensions of the marker. The marker is a CAD file, known within the apparel industry as "cut" file, which provides the dimensions and shape of a single garment or a stack of garments to be cut. Upon the completion of a batch, the cut panels are manually transported to a sewing environment for further processing.

Lack of automation, among other things, is one of the main reasons preventing the U.S. apparel industry from being globally competitive. One of the major research projects defined by the American Apparel Manufacturers Association (AAMA) and by the Textiles and Clothing Technology Corporation, $[TC]^2$, - the organization which coordinates all apparel related research within the United States - is the complete automation of removing cut panels from the cutting table.

As a consequence of the above initiative, a robotic gripper is developed, capable of picking and placing single and/or multiple plies of limp fabric material, without deformation or folding.

Existing industrial robotic grippers normally consist of two/three, single-acting/double-acting, parallel/radial jaw fingers. They possess single or two degrees of freedom, and though not versatile, are adequate for component manipulation in robotic assembly lines, usually specializing in one particular task [1–2]. However, such grippers are totally incapable of handling limp material.

Most multi-fingered research grippers have been motivated by anthropomorphic considerations [5] which, while providing several degrees of freedom and versatility, add tremendously to the complexity of controlling such hands. The Salisbury hand [3–4] and the Utah/MIT hand [5–7] are two of the most popular research grippers. Both the Salisbury Hand and the Utah/MIT hand have applications in the areas of robotics, teleoperation and prosthetics. However, from the viewpoint of apparel manipulation, these hands are incapable of a distortion-free fabric manipulation.

The rest of this paper is organized as follows: In Section II, existing apparel grippers are reviewed and their advantages and limitations are discussed. In Section III the design and operational principle of the developed robotic apparel gripper is presented. Section IV presents the results of the exhaustive reliability and speed analysis tests, performed after integrating the apparel gripper with the AdeptOne and AdeptThree industrial robot arms. Finally, in Section V a summary of the accomplishments and limitations of the developed apparel grippers is presented.

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II. Existing Apparel Gripper Technology

In general, the techniques applied to pick up fabric can be classified as suction, gripping, friction, penetration, and adhesion [10]. Some of the better known grippers in the fabric pickup technology include the **Clupicker**, the **Polytex** gripper, the **Littlewood** gripper, and the **Walton** picking device. The interested reader is referred to [8–9] for a detailed study of these mechanisms. None of the mentioned grippers/pickers manipulates fabric without causing fabric distortion/folding. These grippers do not address the question of what is to be done after fabric pickup. They are not designed to pick up multiple plies of fabric, and since they use incisive and/or abrasive techniques, their application could result in fabric damage.

Further, a single-ply handling gripper using electrostatic properties of fabric materials has been developed at the University of Hull, by Prof. P.K.Taylor and his group [10–13]. The advantages of this gripper are that it uses non-intrusive techniques, thereby not damaging the fabric, and, it uses a flat plate as the gripping surface. Consequently, there is little or no deformation of fabric, since the area of contact in the case of a flat surface is maximum. However, the electrostatic gripper has some serious limitations. This approach involves the use of high voltages which may result in secondary effects arising from accidental arcing causing malfunction of electronic equipment. Thus, it is unacceptable for integration in an industrial environment.

III. Design of the Robotic Apparel Gripper

The Apparel industry continues to move towards automation of the several processes involved in garment manufacture. A major endeavor, called the "Rapid cutting initiative project", aims at developing high-speed, laser-based single-ply cutting machines. Therefore, and after consulting $[TC]^2$, the developed prototypes at the RAL are mainly capable of handling single plies of fabric material; however, as justified, the prototype grippers are capable of additional functions.

The benchmark goals set by $[TC]^2$ are: i) Reliability of around 99%, and, ii) Fabric manipulation rates of about 8 to 9 single panels per minute.

The developed prototypes are capable of the following functions:

i. Ability to manipulate single pre-separated plies of fabric, reliably without causing component distortion/folding,
ii. Ability to separate or join, and manipulate dissimilar sized stacked plies,
iii. Ability to integrate with commercial/industrial robotic systems like the AdeptOne and AdeptThree robot arms, and,
iv. Ability to integrate with robotic vision system and utilize sensory information to aid fabric handling.

Based on existing technology, and, based on conversations with $[TC]^2$ and some apparel manufacturers, the following two conclusions were reached in order to design and test the prototype grippers:

i. Develop a flat-surfaced, fixed-dimensioned gripper, to pick and place a single pre-separated fabric panel, without causing component deformation and/or folding, from atop several surfaces, and,
ii. Utilize the effect of pressure differential to create suction through the gripper to assist fabric manipulation.

The system design consists of two phases: the design of the Robot/Gripper system, and, the mechanical design of the gripping unit.

Design of the Robot/Gripper system:

The central elements of this subsystem are the robot arm, the robotic controller, the vacuum generation unit, and, the gripper, which is mounted as a tool on the wrist joint of a robot arm.

The robot arms used are the AdeptOne and AdeptThree industrial robot arms. The Adept robot controller has binary I/O ports which provide the controller with a means of interfacing with external devices, which in the discussed experimental setup consists of the diverter valve integrated with the vacuum generation unit. Figure 1 represents the Controller block diagram. It can be seen that the Vacuum unit, consisting of the diverter valve and the vacuum generation unit is integrated into the Controller structure through a binary I/O port. A DC output module is connected to one of available 32 I/O ports. This makes possible for the Adept controller to trigger software signals which control the activation and de-activation of suction through the apparel gripper. The Adept robot controllers are capable of generating such software signals within a millisecond and are well suited for our goals. The AdeptVision AGS, which consists of a vision multiplexer, vision software and a gray scale CCD camera, performs image processing, locating objects in the scene, and aids in tracking objects/components on a moving conveyor.

In detail, the apparel gripper/robot system's physical configuration consists of the following:

i. An AdeptOne or an AdeptThree industrial robot arm,
ii. Adept robotic controller - controlling motion of the robot arm, and triggering software signals

to accurately control the timing to open and to close the diverter valve,

iii. A 9″x12″x2″ gripper unit integrated with the industrial robot,

iv. A ribbed, flexible hose connecting the robotic gripper with the source of vacuum,

v. A continuously operating 2.5 HP industrial air blower,

vi. A heavy-duty vacu-breaker to control the air blower,

vii. A 3–way diverter valve integrated with the blower to alternate between activation and deactivation of suction through the gripper,

viii. AdeptVision system integrated with AdeptOne robot arm for training, recognition and handling/tracking of fabric components on a moving conveyor, and,

ix. A low-level control unit to interface the vacuum subsystem with the robotic subsystem, which contains electrical circuitry to integrate the external device to the robot controller's binary I/O.

Figure 2 shows the configuration of the experimental testbed. The input to the system consists of the robot control programs, number of fabric panels to be manipulated and the locations at which fabric panels should be picked up and placed down. Figure 3 provides a schematic representation of the testbed.

The Mechanical design of the gripper unit:

The design and fabrication of the gripper prototypes follows. A single-chambered, flat surfaced, fixed dimensioned gripper has been designed and built in order to demonstrate the ability of the apparel gripper to reliably and efficiently manipulate single pre-separated plies of fabric, without causing component deformation/folding.

The prototypes have been built with lexan, to keep the self-weight of the gripper as low as possible, and also to have good structural strength of the gripper body. The interior of the gripper has been designed in order to minimize the effect of turbulent air flow within the gripper body. Sharp rectangular corners within the gripper have been rounded off, by using layers of fiberglass. A perforated bottom sheet with symmetric hole pattern and uniform hole sizes constitutes the gripping surface. The design incorporates a central inlet which integrates with the vacuum unit through a ribbed, flexible connecting hose. A long rectangular column constitutes an integral part of the gripper body, which serves the purpose of integrating the gripper with the robot tool flange.

Operation of the Robotic Apparel Gripper

The apparel gripper integrated with an Adept robotic system constitutes a powerful limp material handling device, capable of "pick", "place" and "align" of a range of fabric materials. The accuracy and the repeatability of the Adept robot/controller system contributes to the reliability of the Robotic Apparel Gripper.

The operation of the gripper in the absence of external sensory devices is as follows: The gripper is mounted on the robot arm, whose power is then enabled and the robot arm with the gripper integrated to it is calibrated. The vacuum unit is activated. A single, pre-separated fabric panel is placed on the conveyor or a cutting table block at pre-determined locations, which are known to the robot (previously taught). A robot program determines motion/operation sequence, number of cycles and the timing of external signals. A software signal (positive and negative) from the robotic controller trigger the diverter valve integrated with the vacuum generation unit. Triggering of the diverter valve alternately enables and disables suction through the gripper. The robot, under the effect of the control program is moved to a point directly on top of the fabric. A software signal enables suction through the gripper. The fabric panel is picked up and is rapidly transported to a designated "place down" point, at which point suction through the gripper is turned off. This causes the fabric panel to disengage from the gripper surface. Since the fabric panel is held over its entire area, against a flat surface, there is very little scope for fabric deformation and/or folding.

Sensor Aided Fabric Manipulation

In the aforementioned experimental setup, fabric panels are always placed at a pre-determined location, and the robot is moved to that location to pick up fabric and then is moved to another pre-defined location, where the fabric is placed down. However, in an industrial and realistic environment, it is not necessary that fabric panels that need to be handled appear at the same location all the time. Sensory data/information regarding the cut fabric panels is vital in order to automate the process of fabric manipulation in such a non-structured environment. The desired information is location and orientation with respect to the robot arm, shape and size of each fabric panel.

Vision Sensor: The vision sensor consists of the AdeptVision System with its hardware (frame grabber, vision bus, vision processor, GFX processor) and software (AdeptVision AGS Application software called Adept VisionWare), with which a Pulnix TM-540 series gray level CCD camera is integrated.

The vision system must be first "trained" (by example) how to recognize each of the prototypes. This is called "Prototype Training" which is necessary to later perform automatic component recognition. The camera can grab a single frame of data, digitize it into gray scale or binary images and then process the image. The vision system then performs a feature-based object recognition, where the features are pieces of image boundaries. Knowing what the prototypes looked like during training, the vision system locates them in a given new camera image, by recognizing combinations of their features.

The prototype apparel gripper has been integrated with the AdeptOne robot arm to perform fabric tracking and manipulation using this vision system. A pre-separated fabric panel is placed on a conveyor belt within the viewing area of the camera. After fabric recognition is performed, a scftware signal turns on the conveyor. Once the fabric panel is positioned directly under the apparel gripper, a software signal automatically triggers the diverter valve into an 'on' position. The fabric panel is picked up due to suction and is securely transported to the "place down" area. Upon reaching this area, another software signals closes the valve, thus releasing the fabric from the gripper. Thus, integrating the vision system into the loop results in a flexible and more realistic industrial manufacturing line.

From the foregoing, it can be seen that fabric panels placed on a conveyor belt are recognized and dynamically tracked to perform reliable manipulation. The conveyor belts that exist in the laboratory were unidirectional and constant speed, moving at the speed of the driving motor. It is desired to automatically control and regulate the speed of the conveyor, in order to facilitate the process of tracking of objects on the moving conveyor. The original conveyor configuration consisted of the conveyor belt being driven by an OMEGAPAK frequency controller. A potentiometer is used to manually control the conveyor belt, which varies the potential of a 10 volt source. Varying the voltage changes the speed from 0% (@ 0 volts) to 100% (@ 10 volts). To control the conveyor belt electronically, a single board computer is used - a 16 bit 8096 embedded controller. The speed of the conveyor is electronically controlled by generating a variable 10 volt DC voltage on the frequency controller. The direction of the conveyor is controlled by a toggle switch. Forward direction of conveyor results when the contacts of the switch are closed and reverse direction, when the contacts are open. To electronically control the direction of the conveyor, a switch (relay) is required. A bi-directional conveyor has applications in fault-tolerant and intelligent error-recovery systems.

Proximity Sensor: Proximity sensors are nonvisual noncontact sensors that detect the presence or range of an object. Proximity sensing usually involves detection of a disturbance brought to a monitored signal by the presence or absence of an object within a specific volume around the sensing element. In contrast to the range sensors, which provide the actual distance between the targeted object and the sensor, proximity sensors generate a binary output indicating if the distance is above or below a preset threshold. Proximity sensors are inductive, capacitive, magnetic, optical, or ultrasonic.

The proximity sensors used in this experiment are inductive, which are very effective for sensing within a few millimeters range. The proximity sensors are configured such that they trigger the diverter valve on the vacuum unit upon reaching a close proximity to the fabric. The use of proximity sensors helps in controlling the exact timing of triggering the software signals to the diverter valve.

IV. Experimental results

To meet industrial standards, the proposed gripper has to be reliable as well as capable of rapid fabric manipulation.

Reliability Analysis

Exhaustive experimentation has been performed in order to test the applicability of the developed robotic apparel grippers in an apparel job floor. The tests have been performed on a wide variety of fabric materials, different pick up surfaces, and, two different robots moving at different speeds, to prove the functionality and versatility of the developed gripper.

Table I provides the system variables for reliability analysis.

Table I. Variables for Reliability analysis

Fabric materials used:	cotton, rayon, velvet, linen, satin, polyester, rayon, china silk, knit, denim, corduroy, cotton suiting fabric, etc.
Pick up surface:	Bristled cutter blocks, Conveyor belt, Perforated metal plate.
Robot used:	Adept Three, Adept One.
Robot speed:	50%, 60%, 70% and 80% of maximum robot speed.

The AdeptOne robot is much lighter and faster than the AdeptThree robot. The fabric manipulation rates depend on the speed of movement of the robot and the distance through which the robot arm joints move during the process of fabric manipulation. When the gripper is integrated with the AdeptOne and AdeptThree robots, the following maximum joint speeds as shown in Table II may be obtained. However, exhaustive reliability analysis has been performed at various robot speeds.

Table II. Maximum Joint Speeds

Joint #	AdeptOne	AdeptThree
Joint 1	540 °/sec	250 °/sec
Joint 2	540 °/sec	275 °/sec
Joint 3 (Vertical Z)	19.7 in./sec	19.7 in./sec

The spanned distance has been fixed for each experimental set up. The "pick up" and "place down" locations have been defined for each of the robot programs. The AdeptThree robot is located centrally between two conveyors placed at a relative distance of two feet. The robot has been used to pick fabric from one conveyor and place on the other. Table III illustrates the distances through which each joint has been moved during a fabric "pick and place" operation using the AdeptOne and AdeptThree robot arms.

Table III. Distances Spanned during one "pick and place"

Joint #	Adept One Robot	Adept Three Robot
Joint 1	74°	83°
Joint 2	4°	17.3°
Joint 3	20 mm @ pick 40 mm @ place	35 mm@ pick 65mm @ place

Experimental results with the AdeptThree robot indicated a gripper assembly reliability of a 99.9%, when operating at robot speeds under 80–90% of the maximum speed capacity.

Using the blower/diverter valve configuration, fabric manipulation rates of about 15 panels per minute have been accomplished using the AdeptThree robot at 80% of its maximum speed. Using the AdeptOne robot at 80% of its maximum speed, fabric manipulation rates of about 22 panels/minute have been accomplished.

During the course of the experimentation, it has been seen that the surface against which the fabric manipulation is performed has an effect on the reliability of the operation. Consequently, the experiments have been performed atop three surfaces: the conveyor surface, bristled cutter block surface and on the top of a perforated metal sheet. It has been found that the operation of fabric manipulation was most efficient and reliable on the top of the cutting table blocks and the perforated metal plate. It is to be noted that the experiments have been carried out on a wide variety of fabric materials, ranging from denim to lace.

The rates of fabric manipulation and the reliability values at various robot speeds for fixed movement spans are shown in Tables IV and V. These results have been obtained when the gripper picked fabric from the top of bristled cutter blocks. However, the gripper has been tested and found efficient on the three surfaces it was tested upon. Each experiment has been repeated for a cycle consisting of 30 fabric panels.

Table IV. Reliability and Speeds using Apparel Gripper/AdeptThree Robot Configuration

Robot Speed	Panels / min	Trials	Reliability
50%	12	50	100%
60%	13	50	100%
70%	14	50	100%
80%	15	50	100%

Table V. Reliability and Speeds using Apparel Gripper/AdeptOne Robot Configuration

Robot Speed	Panels/ min	Trials	Reliability
50%	16	50	100%
60%	18	50	100%
70%	20	50	100%
80%	22	50	99.6%

Figure 4 gives a generic representation of the timing diagram which depicts the time required for each sub—operation involved in a single fabric pick and place.

Tables VI and VII give the recorded time values for a single fabric manipulation operation using the AdeptOne and AdeptThree robots.

Table VI. Recorded Time values for one pick and place using the AdeptThree Robot

Time (secs)	Gripper operation	@ 50% Speed	@ 80% Speed	@ 100% Speed
t_0	Move pick	0.016	0.016	0.032
t_1	Move pick1	0.032	0.032	0.032
t_2	Suction On	0.624	0.560	0.512
t_3	Move pick	0.032	0.032	0.032
t_4	Move place	2.288	1.616	1.440
t_5	Move place1	0.032	0.032	0.032
t_6	Suction Off	0.752	0.640	0.608
t_7	Move place	0.032	0.032	0.032
Time /cycle		3.808	2.96	2.720

Table VII. Time values for one pick and place using the AdeptOne Robot

Time (secs)	Gripper operation	@ 50% Speed	@ 80% Speed	@ 100% Speed
t_0	Move pick	0.016	0.018	0.006
t_1	Move pick1	0.016	0.016	0.016
t_2	Suction On	0.160	0.144	0.224
t_3	Move pick	0.032	0.032	0.016
t_4	Move place	1.924	1.396	1.228
t_5	Move place1	0.016	0.016	0.016
t_6	Suction Off	0.240	0.160	0.192
t_7	Move place	0.016	0.032	0.016
Time /cycle		2.42	1.81	1.714

The tests prove that fabric manipulation is performed with a reliability of almost 99.9%. Further, fabric manipulation is performed at a rate of about 15 panels per minute using AdeptThree, and, 22 panels per minute using AdeptOne at robot speeds of 80% for the specified robot movement spans.

V. Conclusions

The use of robotic technology in the apparel industry for automatic fabric manipulation is a novel and a challenging application. This paper presented the design and development of a robotic apparel gripper which integrates with commercially available robot arms like the AdeptOne and AdeptThree. In the conclusion, we present the achievements and the limitations of the developed prototypes. A brief insight into our future research directions is also provided.

The accomplished project objectives have been based on a fixed size gripper. Consequently, the inherent limitation is that fabric panels greater than the gripper dimensions can not be manipulated using the apparel gripper, without resulting in fabric deformation.

The above requirements entail the need for a reconfigurable multi-degree-of-freedom apparel gripper which can manipulate single panels of fabric regardless of their shape, size and dimensions. This constitutes the central project objective of the future phases of the project.

Specific future objectives include:

- Design a reconfigurable apparel gripper capable of manipulating fabric components of various sizes and shapes,
- Obtain the fabric lay out information from a cut file or marker file, and/or by using a vision system and transfer this information to the robot - gripper controller for fabric manipulation,
- Integrate robotic vision and other sensory equipment like the force sensor, weight sensor, variable remote center compliance wrist, proximity sensors, tactile sensors etc., with the robot-gripper system to enhance and improve fabric handling,
- Utilizing the developed fixed size / reconfigurable gripper with design enhancements and modifications for manipulating an entire fabric stack, and,
- Utilizing the enhanced apparel gripper and sensory information to pick up a desired/specific number of fabric panels.

VI. References

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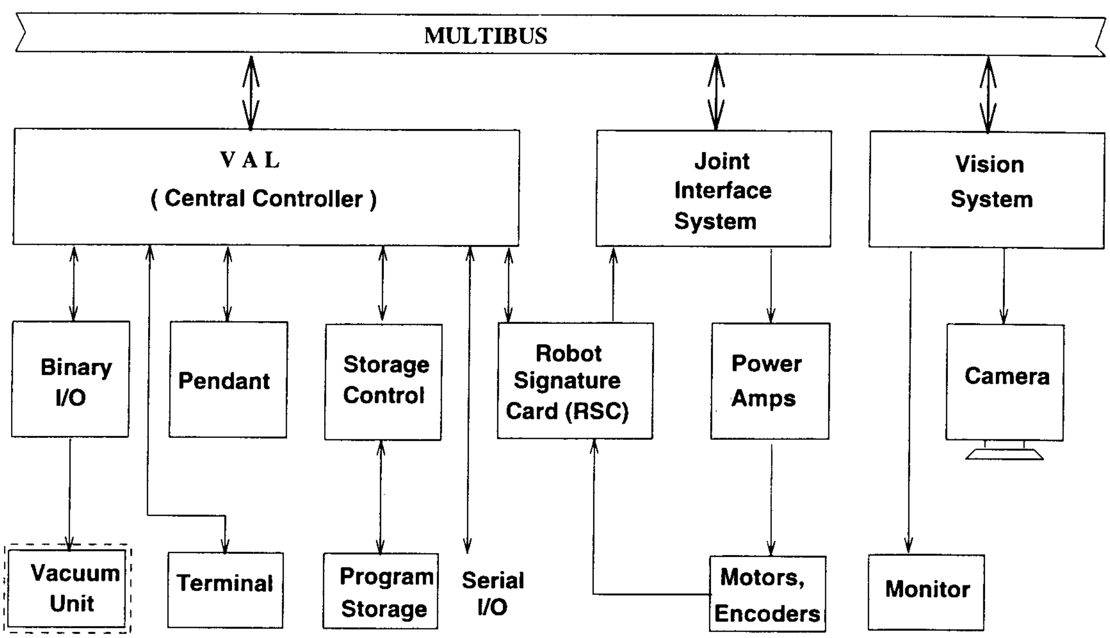

Fig 1. Controller Block Diagram

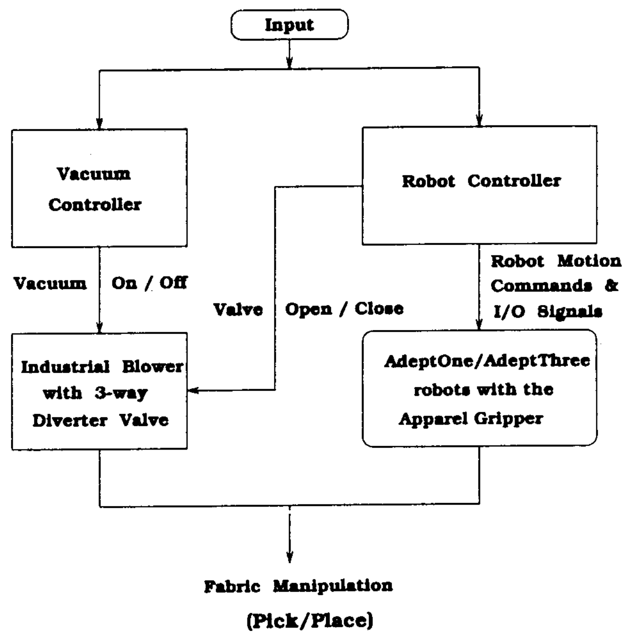

Figure 2. Block diagram of the testbed

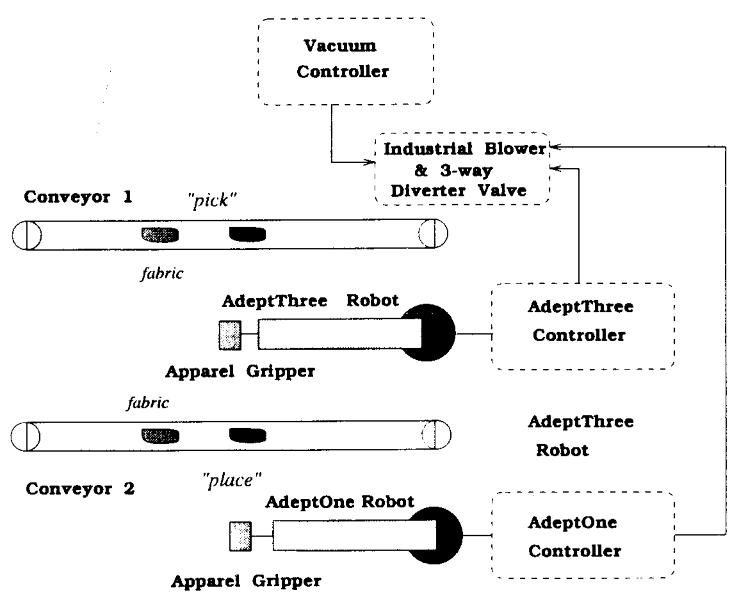

Figure 3. Schematic Representation of the testbed

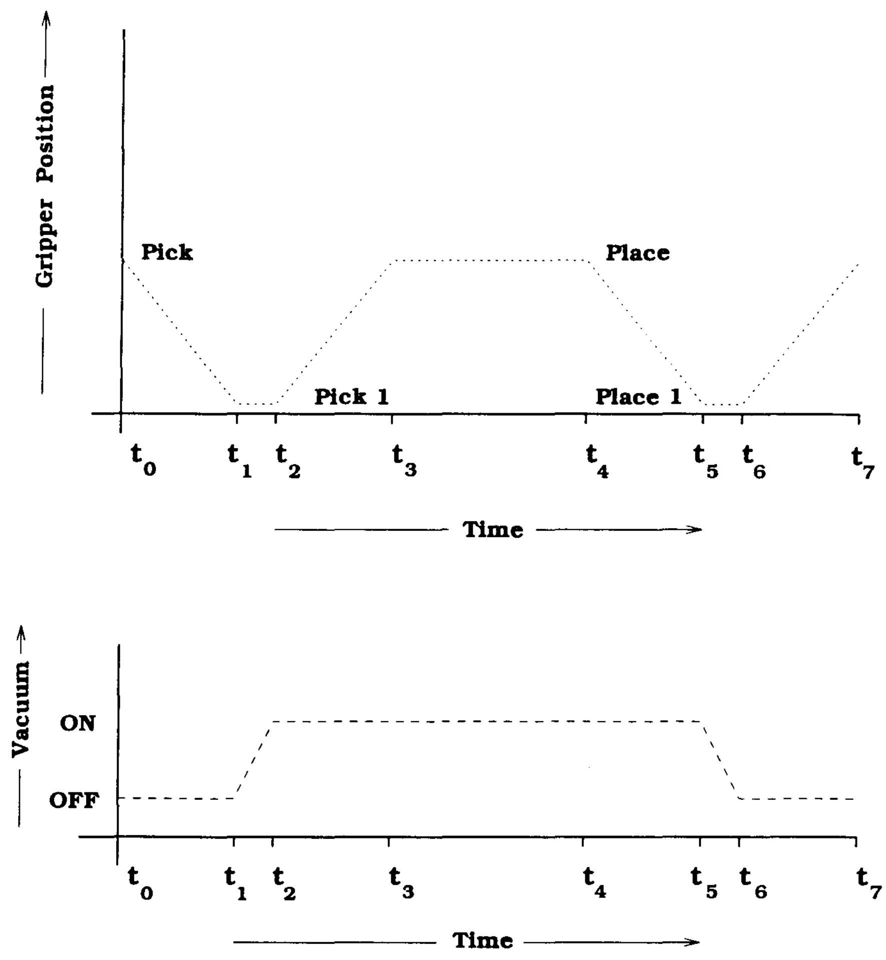

Figure 4. Timing Analysis of a Pick-and-Place Operation