MAINTENANCE AND CONTROL OF AN
INDUSTRIAL ROBOT
SERIES UNIMATE 2300

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DEDICATION

To those who fight all difficulties on my street,
My dear parents
To my brothers, my sister, and my relatives
To all fellows and friends
To the greatest family in the world,
all Muslims
شكر و تقدير

الحمد لله على جميل التوفيق، و الشكر له على هداية الطريق. اللهم صلى على سيدنا محمد في كل لحظة و نفس عدد ما وسعه علم الله صلاة تخرجنا بها من ظلمات الهم و توضح لنا ما أشكل حتى الفهم، إنك تعلم ولا نعلم أنت علام الغيوب.

الشكر موجه للدكتور/ عبد الرحمن كرار - قسم الهندسة الكهربائية و الإلكترونية جامعة الخرطوم على إشرافه على هذا البحث و على توجيهاته التي كانت عوننا و سنداً لإكماله.

الشكر أجزله إلى قسم الهندسة الكهربائية و الإلكترونية جامعة الخرطوم، إذ لهم الفضل في ما تحصلنا عليه من علم و معرفة خلال ما إنقضى من سنين.

الشكر الجزيل لكل من المهندس خالد عبد السلام و المهندس أحمد عطروني و المهندس ابوبكر عثمان وكل العاملين بالمجمع الصناعي، على مجهودهم المقدر لإنجاز المشروع و خروجه بالصورة المطلوبة.

و لابد من الشكر للسلام الذين أوفوا الزمالة حقها و أكل بالشكر الزملين مازن يوسف و ماجد مجدي سانلا الله أن يسدد خطاهما و يجزيهما عنا كل خير.

و الشكر لكل من ساهم أو شارك في أي من مراحل البحث، فلله يجزيهما خير الجزاء.

وصلى الله على سيدنا محمد وعلى آله و صحبه أجمعين . . .
ABSTRACT
In 1997 the management of an industrial complex bought six industrial robots to be used for carrying heavy loads on its various factories. They were secondhand and nobody knows how to operate them. Great efforts were done by the complex maintenance engineers to repair these robots by contacting the manufacturer. Unfortunately they made in USA, by UNIMATE Company and for politic reasons the connection was cut.
The problem was to study how they work; it was a problem because there was only one source for information, the attached manual. In addition to the manual you must take a course in UNIMATE institute to be able to just operate the robot and carryout the periodic maintenance. So, to repair the original system or change it you will face many difficulties, starting from the spare parts until the required software.
Therefore, from the beginning our opinion was to change the old control system, in spite of that we try to repair the old system but we failed.
The next step was to focus our efforts on operating the robot manually, new problems appear here, the type and amount of the input signal and to which terminals it must be supplied. All the work was done on one robot and we succeeded in operating it. A manual control panel was designed.
Finally a general design is introduced to the new control system in which we use the microcontroller. We introduce both the structure of the new system and the algorithm which can be used to program the microcontroller.
المستخلص

في عام 1997 قامت إدارة مجمع صناعي بشراء ستة أذرع آلية لتم استخدامها في حمل الأحمال الثقيلة في مصانعها المختلفة. وقد كانت هذه الأذرع مستعملة من قبل، ولم تكن تعرف طريقة عملها. تم بناء جهد مقدر من قبل مهندسي الصيانة بالمجمع لإصلاح وإعادة تشغيل الأذرع، وذلك عن طريق الإتصال بالشركة المصنعة، وسواء الهدف كان الشركة المصنعة هي شركة المكانيونج الأمريكية، ولأسباب سياسية تم قطع الإتصال.

كانت المشكلة في معرفة كيفية التشغيل، حيث كان هناك مصدر محدد لمعرفتها وهو الدليل المرفق مع الأذرع، إضافة إلى هذا الدليل يجب أن يتلقى العامل فترة تدريبية بمعدة الشركة ليتمكن فقط من تشغيل الأذرع وإجراء الصيانة الدورية اللازمة، عليه لكي يتمكن من تشغيل الذراع المعطالة أو تغيير نظام التحكم الأصلي ضرورة من الهواج.

العديد من المناهض، ابتداء من اندلاع أو ندرة قطع الغيار وانتهاء ببرامج التشغيل اللازمة.

عليه فقد كانت الفكرة منذ بداية المشروع هي محاولة تغيير نظام التحكم الأصلي، رغم ذلك فقد تمت محاولة تشغيل النظام القديم ولكن ساءت المحاولة بالفشل. كانت الخطة التالية هي محاولة تشغيل الذراع بدءاً ولكن ظهرت هنا مشاكل جديدة، فمقدار نوع الإشارة الكهربائية اللازمة لم يكن معروفاً، بل وحتى منفذ الإشارة لم يكن معروفاً.

تم تركيز العمل في المشروع على ذراع واحدة من تلك الأذرع وبحدد الله تم تشغيلها بدءاً، كما صممت لوحة تتحكم جديدة للتشغيل.

أخيراً تم وضع تصميم التحكم الجديد حيث تم فيه استخدام التحكم الدقيق، حيث تم وضع التصور لنية النظام ودكماه اضافة إلى المخططات اللازمة لإنشاء البرنامج.
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CHAPTER 1
INTRODUCTION

This project is operation and control of an industrial robot (APPENDIX FIGURE A). It is a hydraulic arm using electricity in two fields; the power to the pump motor and the control signals to the valves.

1.1 PROJECT OBJECTIVES

One of the great objectives of this project is to build a connection line between the university and the important Industrial corporations in the Sudan. The project also aims to get use of the unused robots by first applying all experiments and tests on one of them; if the tests succeed they can be generalized to other robots. There is another special aim of the project is that it provides a good chance to deal with work environment.

1.2 STATEMENT OF THE PROBLEM

The problem is that there was no sufficient information about the system; the UNIMATE is attached with a manual written for the operator, so the available information is only about how to operate the robot and how to perform periodic maintenance.

There is a teach hand supplied with the UNIMATE consisting of several push buttons one for each motion (APPENDIX FIGURE B), it is used on TEACH mode. We connected it and depressed all push buttons, and there was no response. When changing the mode to REPEAT only one motion gave uncontrollable response, the Rotary moved to the left. On the manual there is a maintenance guide for several problems. One of them is our problem, if the UNIMATE does not move. The solution was to replace some relays. They were replaced and there was also no result. The next problem was how to connect valve socket terminals and also what is the supply voltage.

24 VDC was applied to each valve. First only two motions gave response Bend & Yaw. The problem was purely mechanical, after solving this problem all motions gave response with only 2 VDC input. There was still a problem concerning the Rotary
motion. When UNIMATE rotated right it returned left before ordering. The problem was that the valve inclined to the left in no signal. After nulling the servo valve the rotary motion operates well. A new control panel was design consisting of 11 switches, 10 switches for the five motions (switch for each direction) and the last switch for clamp/unclamp, [APPENDIX FIGURE G].

1.3 PROJECT LAYOUT

In the next chapter a general description to the original system is introduced containing a general introduction, the motions, the hydraulic power, the servo valves, the memory and the operation of the original system. In chapter 3 a detailed description is introduced to the two major components used in controlling the robot movement; the servo valve and the encoder. The problem that has not been solved yet is the automation. Chapter 4 gives the proposal for the new control system. This chapter divided into two partitions; the first partition introduces the hardware of the new system and the reasons for selecting the microcontroller. The second partition introduces the flow charts that can be used to develop the microcontroller program.
CHAPTER 2
THE ORIGINAL SYSTEM DESCRIPTION

2.1 INTRODUCTION

The Unimate 2030 series is a universal industrial robot designed and manufactured by Unimation, Westinghouse Company of Danbury, Connecticut.

It’s an industrial robot with a hydraulically powered arm having six programmed articulation and either a pneumatically operated clamping/tooling device or weld gun (usually called the “hand” at its outer end. A built in digital memory system in combination with an all solid state electronic system, control servo drives to move the arm and the hand.

2.2 MOTIONS

UNIMATE has six different basic types of movement (figure 2.1). Three of these are arm motions:

O- out-in (radial extension or refraction)
D- Down – up (vertical rotation)
R- Rotary (waist rotation).

The other three are motions of the wrist assembly:
B- Bend (depression or elevation).
Y- Yaw (rotation clockwise or counter clockwise).
S- Swivel (rotation clockwise or counter clockwise)

In each of the six motions, the prime moving force is generated by a hydraulic actuator under control of servo valve. In the series of our project there is no swivel motion. Hydraulic actuators for out-in and down-up motions are connected directly to their respective loads. For rotation, a rack and ring gear convert linear travel of pressure- balanced hydraulic pistons into rotary motion. Forces generated by bend swivel and yaw actuators are transmitted by system of chains, shafts and gears to the respective load. Since the wrist moves in and out with the arm, A ball-nut and spline-
shaft arrangement provides means for transmitting power to these motions through the entire range of arm (boom) out-in motion. Bevel gears permit compact arm geometry.

2.3 SERVO VALVES

Hydraulic power for operation of the UNIMATE is provided by a completely self contained hydraulic system, [APPENDIX FIGURE D]. The control on the hydraulic power is achieved through servo valves [APPENDIX FIGURE E]; each servo valve is a four way infinite portion value that is controlled by electrical signal generated by the electronic section of the UNIMATE. The direction of motion is determined by the direction called for by electrical signal. The magnitude of the electrical signal determines how far the valve will open and therefore how fast the actuator will move. Basically for one direction of travel, the servo valve directs fluid under pressure to one side of a hydraulic actuator and opens the opposite side of the actuator for return flow. For the other direction of travel, connections to the actuator are reversed. There are two exceptions to this basic operation. The rotary motion actuator consist of two actuators at opposite ends of the rack; thus fluid is admitted and returned from the piston side of each actuator just as though there was a single piston in a single actuator.

2.4 THE HAND

The hand of the robot depends on pneumatic power to clamp heavy loads, a source of compressed air may be connected to the UNIMATE through a fitting located at the lower right side of the base, adjacent to the housing for the main electric disconnect switch.
Figure 2.1    Unimate motions.
2.5 ELECTRICAL POWER

APPENDIX FIGURE F shows the electrical schematic diagram for the motor and power control circuits. Three-phase 230- or 460-volt, 60 – cycle electrical power is connected to the UNIMATE at the supply side of a-fused main disconnect switch, the three phase power is connected to contacts in the magnetic motor starter and single phase power is to connected to the primary winding of the starter transformer in the main junction box.

Three phase power from the load side of the magnetic motor starter contacts is connected through overload relay elements to the motor terminal connections on the terminal strip. In addition L2 and L3 from the load side of the magnetic motor starter contacts are also connected through fuses and an RFI filter, to power supply connections on the terminal strip, to provide single-phase power for the supply.

The secondary winding of the starter transformer (x₁ and x₂) provides control power for the motor start and holding circuit.

One leg x₁ is connected directly to the starter solenoid 1M through a 1- Ampere fuse. The second leg x₂ is connected through the normally closed contacts of the stop switch through a jumper if no remote stop is used, to one side of normally open contacts on the start switch (PB1) and relay 1CR.

With the main disconnected switch closed and the start button depressed, the starter solenoid is energized through the start switch and normally closed magnetic starter coil overload contacts OL-C, OL-B and OL-A. Power is also applied to the motor and the power supply through the starter contacts. When the start button is depressed the normally open contacts of relay ICR will close in response to +28 volts OLC from the power supply. The starter hold contacts (2 and 3) and relay ICR contacts now act as a holding circuit for the magnetic starter coil. In the event magnetic starter trips out on thermal overload, the power to the starter coil will be interrupted. This action also occurs to shut down the UNIMATE when the stop button is depressed.

The UNIMATE power supply provides four different voltage outputs used to power and control the electronic and electromechanical components. The design of this supply is such that each of two outputs tolerates only limited current drains. When the current limits are exceeded, the power interlock is interrupted and the unimate shuts down.
2.6 INTERLOCK CIRCUITS

In many installations, the UNUMATE must depend on external signals to synchronize with its environment. Properly designed interlock circuits keep UNIMATE in synchronization with other production operations. These circuits can also protect personnel, equipment, and the UNIMATE itself from damage. Any system of interlocks must be designed with safety in mind, but reliability and production output must also be considered. Too many interlocks make a system less reliable and more difficult to understand. Therefore, only necessary interlocks should be used. How the interlocks are implemented, what they sense, and how they are connected, are factors which have a great influence on the speed capability of a system.

Interlocks are normally made to start an event or verify completion of an event. In the interest of speed, it is often desirable to start a second event before completion of the first. In such cases, precautions must be taken to avoid compromising safety. UNIMATE should not perform steps that depend on completion of an external action without first confirming such action has taken place. For example, it is poor planning for UNIMATE to signal a hydraulic press to open, and then enter the press, without first confirming the press has really opened. In this example, the press might receive an opening signal from UNIMATE, but fail to open because of lack of hydraulic pressure. Without interlocks prevent it, UNIMATE would attempt to enter the closed press after issuing the signal for the press to open.

Programming the operation of safety clearance steps through interlocking circuits need not delay production steps. It is often possible to check safety through interlocking circuits simultaneously with other production steps preceding the critical point in operations. In some procedures, however, it is not advisable to check safety interlocking signals in advance. If the presence of a hot billet from a furnace is verified in advance of need, example, a delay in operations could permit the billet to cool before it was used. Such safety interlock circuits should be verified at the time of application in the UNIMATE sequence of operations, even if programming such a verification step slightly increase the time required for completion of the operation.

Safety interlocks:
Safety interlocks may provide reasonable protection for parts and equipments. However for safety of personal, the UNIMATE working area should be enclosed by either fence or chain. Personal should also be prevented from inadvertently walking into the reach of the UNIMATE. Consideration should also be given to any failure which could cause the UNIMATE arm to be extend outside its normal working area.

Safety for equipment is provided by well-designed operational interlocks. Careful design of these interlocks can minimize or eliminate additional time required. For example, in loading a punch press, a safety interlock circuit can inhibit UNIMATE from loading the die until the previous past is ejected. If the circuit is designed to sense the return of the ejection plunger after discharging a part from the die, a fraction of a second may be lost at each loading. Alternatively, time would be saved by sensing the discharge of the past and safety would not be compromised.

## TIMING OF INTERLOCK SIGNALS

The criteria for timing of the interlock signals are presented in the following paragraphs.

- **Wait External.** For the WX function, a signal must be present or occur after the time that the UNIMATE is ready to receive the signal. This is after the UNIMATE arrives at the step at which the WX has been taught and total (position) coincidence (has been completed. For example, if a limit switch is sensing the up motion of a press ram and is actuated by a cam on the ram, the cam must be long enough to sustain the signal when the ram is in the top position, if the cam is short, resulting in a signal short duration, the UNIMATE might miss a short signal given as the cam passes the switch.

  Operate External. The duration of an OX signal is a function of the time taken by the UNIMATE to perform the step on which the OX was taught. The OX signal becomes present at the beginning of the step at which the signal was taught. Even when the machine is operating one step at a time under manual control, the OX signal will be maintained for the duration of the step. Regardless of how short the program may be, the relay will be energized long enough to operate most equipment. The duration of the signal must be considered in relation to the duration of the signal required to operate specific external equipment.
2.7 THE UNIMATE CMOS MEMORY

The CMOS memory is both electrically and physically interchangeable with the conventional plated wire memory. Sizes and part numbers for the CMOS memories are: 2K CMOS (924F3); 4K CMOS (924F4); 8K CMOS (924G1); 16K CMOS (924G2).

The CMOS memory employs battery backup power to supply the voltage needed to retain stored information when UNIMATE power is out or switched off. Failure to maintain charge and/or replace the batteries when required could eventually result in loss of memory when the UNIMATE power is turned off.

2.8 THE OPERATION

The system has two modes of operation; TEACH and REPEAT. On teach mode the robot taught the positions by moving the robot to the desired positions and then pressing RECORD pushbutton. A teach hand is used for this purpose [APPENDIX FIGURE C]. When returning to the repeat mode there is a selector switch to select a program to be run. The program then follows the taught steps step by step. Also the program can be loaded to the memory from a tape using the tape loader attached with the robot.
CHAPTER 3
CONTROL OVER A HYDRAULIC SYSTEM

BRIEF
This chapter is a first step to design the new control system for the robot. In this chapter the hydraulic system will be studied in general, it touched upon the major components and parts of the reliable system. Also it will exposure to servo valve and control valve and the difference will found between them and clarify the mechanical mechanism of each. Finally the encoder as mechanism of the feedback will be studied in more detail.

3.1 INTRODUCTION
A typical position controlled hydraulic system consists of a power supply, flow control valve, linear actuator, displacement transducer, and electronic servo-controller. The servo controller compares the signal from the feedback displacement transducer with an input demand to determine the position error and produces a command signal to drive the flow control valve. The control valve adjusts the flow of pressurized oil to move the actuator until the desired position is attained: a condition indicated by the error signal falling to zero. A force controlled hydraulic system operates in a similar way, except that the oil flows adjusted to achieve an output force, measured by a suitable transducer.
3.2 HYDRAULIC POWER SUPPLY

All hydraulic systems require a supply of pressurized fluid, usually a form of mineral oil. The choice of system oil pressure depends on various factors. Low pressure means less leakage, but physically larger components are required to develop a given force. High pressure systems suffer from more leakage, but have better dynamic performance and are both smaller and lighter: significant advantages in mobile and aircraft applications. In many high performance systems 3,000 psi (approximately 210 bar) is a standard choice of system pressure.

3.3 FLOW CONTROL VALVE

The electro-hydraulic flow control valve acts as a high gain electrical to hydraulic transducer, the input to which is an electrical voltage or current, and the output a variable flow of oil. The valve consists of a spool with lands machined into it, moving within a cylindrical sleeve. The lands are aligned with apertures cut in the sleeve such that movement of the spool progressively changes the exposed aperture size and alters differential oil flow between two control ports.
Figure 3.2 Diagram of Three Land, Four-way Flow Control Valve Spool

The Figure above shows the spool configuration of a typical “3-4” flow control valve. The ports are labeled P (pressure), T (tank), and A and B (load control ports). The spool is shown displaced a small distance (xv) as a result of a command force applied to one end, and arrows at each port indicate the direction of fluid flow which results. With no command force applied (Fv=0), the spool is centralized and all ports are closed off by the lands resulting in no load flow. In the context of hydraulic servo-systems, flow control valves fall broadly into two main categories: proportional valves and servo-valves. Proportional valves use direct actuation of the spool from an electrical solenoid or torque motor, whereas servo-valves use at least one intermediate hydraulic amplifier stage between the electrical torque motor and the spool.

A major advantage of proportional valves is that they are largely unaffected by changes in supply pressure and oil viscosity. However, the relatively large armature mass and large time constant associated with the coil means that these valves generally have poorer dynamic performance compared with servo-valves of equivalent flow characteristics. In recent years, “servo-proportional” valves have begun to appear with shorter spool displacements and lighter spools, giving dynamic performance which approaches that of true servo-valves but at a much lower cost. The
basic servo-valve produces a control flow proportional to input current for a constant load.

While the dynamic performance of a servo-valve is influenced somewhat by operating conditions (supply pressure, input signal level, fluid and ambient temperature and so on) a major advantage is that load dynamics do not affect stability, unlike single stage proportional valves. Servo valves usually have superior dynamic response, although their close internal machining tolerances make them relatively expensive and susceptible to contamination of the hydraulic fluid.

Two stage servo-valves may be further divided into nozzle-flapper and jet pipe types. Both use a similar design of electromagnetic torque motor, but the hydraulic amplifier circuits are radically different. Nozzle-flapper type servo-valves are currently by far the most common in high performance servo applications and the description which follows is based on this type of valve.

A cross sectional view of a typical nozzle-flapper type servo-valve is shown in Figure 3.3. High pressure hydraulic oil is supplied at the inlet pressure port (P), and a low pressure return line to the oil reservoir is connected to the tank port (T). The two hydraulic control ports (A and B) carry the control oil flows to and from the load actuator.
3.3.1 Flow Control Servo Valve

The two stage nozzle-flapper servo-valve consists of three main parts: an electrical torque motor, hydraulic amplifier, and valve spool assembly.

**Figure 3.4 Valve Torque Motor Assembly (illustration courtesy of Moog)**

**Figure 3.5 Valve Responding to Change in Electric Input**
Lateral movement of the spool forces the ball end of a feedback spring to one side and sets up a restoring torque on the armature/flapper assembly. When the feedback torque on the flapper spring becomes equal to the magnetic forces on the armature the system reaches an equilibrium state, with the armature and flapper centered and the spool stationary but deflected to one side. The offset position of the spool opens flow paths between the pressure and tank ports (Ps and T), and the two control ports (A and B), allowing oil to flow to and from the actuator.

Figure 3.6 The possible electrical connections for a servo valve

3.4 LINEAR HYDRAULIC ACTUATOR

A hydraulic actuator is a device which converts hydraulic energy into mechanical force or motion. Actuators may be divided into those with linear movement (sometimes called rams, cylinders or jacks), and those with rotary movement (rotary actuators and motors). Linear actuators may be further sub-divided into those in which hydraulic pressure is applied to one side of the piston only (single acting) and are capable of movement only in one direction, and those in which pressure is applied to both sides of the piston (double acting) and are therefore capable of controlled movement in both directions.

3.5 DISPLACEMENT TRANSDUCER

Position transducers are usually collocated with the actuator, and often attached directly to the piston rod. Various types of feedback transducer are in use, including incremental or absolute encoders, inductive linear variable differential transformer (LVDT’s) and rotary variable differential transformer (RVDT’s), linear and rotary
potentiometers, and resolvers. In industrial applications employing linear displacement control, the LVDT is a common choice of feedback transducer due to its accuracy and robustness. All the displacement transducers used in UNIMATE are rotary variable differential transformers because all the motions are in a circular path except IN-OUT, and it is itself converted by gears to rotary motion in the transducer input.

### 3.5.1 The Robot Encoder

The encoder is a sensor attached to a rotating object (such as a wheel or motor) to measure rotation. By measuring rotation your robot can do things such as determine displacement, velocity, acceleration, or the angle of a rotating sensor.

![Figure 3.7 An Encoder](image)

A typical encoder uses optical sensor(s), a moving mechanical component, and a special reflector to provide a series of electrical pulses to the controller. These pulses can be used as part of a feedback control system to determine translated distance, rotational velocity, and/or angle of a moving robot or robot part.

For instance encoder used, in case of a wheel rotating to measure the time it takes to rotate exactly certain degree, or know when to traveled X distance. The sensor would be fixed on the robot, and the mechanical part (the encoder wheel) would rotate with the wheel. The output of an encoder would be a square wave, so when hooked up this signal to a digital counter then it will count the pulses. Knowing the distance/angle between each pulse, and the time from start to finish, this makes it easily to determine position or angle or velocity or whatever. Encoders are necessary for making robot arms, and very useful for acceleration control of heavier robots.
3.5.1.1 Calculating Robot Motion with an Encoder

Wheel circumference and counts per revolution must be given.

\[
\text{wheel circumference} / \text{counts per revolution} = \text{distance traveled per encoder count}
\]

\[
\ldots\ldots(3.1)
\]

Now velocity is just distance divided by time . . . So using the answer in the above equation, divide that by the time passed determined from your microcontroller timer:

\[
\text{distance traveled per encoder count} / \text{time} = \text{velocity}
\]

\[
\ldots\ldots(3.2)
\]

After calculating distance and velocity, then a feedback control algorithm must be run so that the robot can match a desired (pre-determined) distance and velocity.

![Encoder wheel with reader](image.png)

**Figure 3.8 Encoder wheel with reader**

To expect a motor rotation to often go to a certain angle, you can also put interesting patterns on your encoder wheel to make processing simpler. To read all the patterns simultaneously can use an IR LED array IC.
Quadrate encoders have 2 IR sensors reading two slightly out of phase patterns to determine if the wheel is rotating clockwise or counterclockwise.

3.5.1.2 Typical Problems with Encoders

There are several problems with using encoders for robot position control. First, just because the wheel rotates does not mean the robot is moving. Ever driven a car in snow. Error can quickly build up. This is why it is not recommended to use encoders for position feedback. Second, encoders have a finite accuracy. Suppose your encoder has a 360 count resolution. That means your accuracy will be off by up to an entire +/- degree. Inaccuracy multiplies over distance... If we have a robot arm that is 3 feet long, with several joints each with encoders, one degree could mean inches of inaccuracy.
CHAPTER 4
DESIGN OF NEW CONTROL SYSTEM

BRIEF
This chapter contains the reasons for replacing the original control system, the reasons for selecting the microcontroller among PLC and PC, the two configurations for the new system structure and design, the inputs and outputs to the system and the flowcharts for programming the new system.

4.1 MICROCONTROLLER SYSTEM STRUCTURE

4.1.1 Introduction
As said in the thesis introduction, we decided to replace the obsolete control system which uses analogue components fixed in printed cards (ten cards) each card contains between 50 to 100 components (capacitors, resistors, and various ICs). Also the robots were stored for 10 years without use, therefore the probability of failure in each IC is high, so it is impossible to check each IC and it is also impossible to replace the cards due to politic reasons.

4.1.2 The New System
The new system consists of a microcontroller as basic controlling element, servo valves to convert the commands of the controller to mechanical motion, and sensors to convert the mechanical motion to digital numbers. The sensors can be either resistors changing value with motion [figure 4.2] or encoders converting the mechanical motion to digital numbers [figure 4.1]

4.1.2.1 Why Selecting the Microcontroller
- Cost: the microcontroller is very cheap compared to the PLC or PC.
- Programming: the microcontroller can be programmed using C or Assembly languages while PLC uses only digital logic, so the robot application is full of functions those can hardly be converted to digital logic.

The PLC is better than the microcontroller in two cases:
- The industrial environment is tough and the microcontroller may be damaged on it.
- The robot is synchronized with a system that having large number of I/O.

4.1.2.2 System Inputs
- 11 inputs for movements and clamp switches.
- 1 for START: starting repeat or teach operations.
- 1 for STOP: instructing the program to stop the motor.
- 8 inputs for encoders.
- 4 inputs for limit switches (2 for up-down movement & 2 for rotary). No need to add limit switches to other motions because they are not dangerous.
- Safety and protection sensors (overheat – Overload – etc).
- 4 wait external signals: can be extended.
- 1 for mode of operation (teach/repeat).

Total 34 inputs so we can use 5 ports for input which provides 40 inputs to support any extension in the input.

4.1.2.3 System Outputs
- 11 outputs for movements & clamp.
- 3 selection lines for enables of encoders.
- 8 operate external.
- 1 for the motor start: can be used to trap the motor in case of emergency.

Total 23 output so we need 3 ports for output.

The microcontroller must have 64 I/O pins. There is one port unused can be used for any extension in the input or output it is noted in the figure 4.1 by (control port or control signals).

The block diagram for the microcontroller is shown in the next page:
Figure 4.1: The block diagram for the microcontroller system (first configuration).
The first configuration has the following disadvantages:
- It needs more input/output pins.
- It assumes that the original encoders of work well; if they do not work they must be replaced.

To solve these problems instead of replacing encoders by other encoders we can use variable resistors as a feedback for the position of movements so the value of the resistor depends on the position. The five movements' feedback is now only five pins and the input here is analogue instead of digital. No need for buffers, also no need here for selection lines.
4.1.2.4 Safety & Protection

Four pins on the microcontroller input can be used for safety & protection purposes (e.g. overload, overheat, etc…) when one of them energized the program energizes PORTG.3 causing trap to the motor.

4.1.2.5 Limit Switches

When the robot installed, there may be some limits on the surrounding area that the robot must not reach, the limit switches must be used here. There are four pins left for this purpose.

4.1.2.6 Operate External & Wait External

These signals are used for synchronization with the field. For example if we want the to take an object from a box and put it in another box in a production line, we use wait external to prevent the robot picking or putting the object before the desired box reaches the desired point. Also we use operate external to tell the production line that the object has been picked or put on it and it is now allowed to move. 8-bit are left for operate external & 4-bit for wait external, they can be extended.

4.1.3 Operation

When pressing START push both the microcontroller and the motor will start operation. The microcontroller should have a control on the motor; so the motor input passes through a normally closed relay. The relay coil is energized by a signal coming from the microcontroller. The circuit which implements that is shown on figure (4.3)

![Figure 4.3](image)

Movement switches are all connected to the microcontroller we can wire the switches directly to the servo valves and only recording the feed back position, but to make the
movements under control it is better to wire them to the microcontroller and then from it to the valves.

Figure 4.4: Switches and relay coils.

The output of the microcontroller is identical to each movement, while the inputs of servo valves vary from movement to another depending on the speed needed. Relays are used here to solve this problem. The input of all relays is identical while the output is as we need. The circuit of figure (4.5) bellow illustrates this.

Figure 4.5
4.2 THE NEW SYSTEM PROGRAMMING

4.2.1 Program Specifications

The program consists of mainly two fields:

- Teach
- Repeat

On TEACH mode the program does the following:

- When RECORD switch depressed the microcontroller should read the position of all motions and save them in a record, and then generating an array of records to save the program steps. Also we can save each motion in a single array, name of array indicates its motion e.g. BEND(i), YAW(i), INOUT(i), UPDOWN(i), CLAMP(i), and ROTARY(i). The counter (i) indicates the number of the step. Wait external and operate external signals are also saved within each step in TEACH process.
- Delays of time can be entered between steps.

On REPEAT mode the program does the following:

- First sets the counter to step one.
- Implements the desired function (clamp/unclamp).
- Reads the position of each movement and sets the corresponding output to logic 1 on the desired direction.
- When the feed back from the position input matching the saved value, the program resets the corresponding output to logic zero.
- Increments the counter to the next step.
- After completion of program cycle (set of steps) the program counter can be set again to step one.

4.2.2 Programming Example

To illustrate how the UNIMATE can be programmed we will consider a small example, the UNIMATE should take an object from a product line and put it in a small container or box. We will consider here the first configuration of the microcontroller system (figure 4.1); which uses encoders.

4.2.2.1 Loading the Program from a Computer:

We can either teach the program to the robot or write the program in a computer and load it to the microcontroller. In both cases the program is loaded from the
computer but here we mean the positions of the steps; are they stored in the program or they must be taught to the robot. When writing the program to the computer we must know the encoder feedback to the desired positions.

Returning to our example – taking an object from a product line and put it in a box in another product line – we need here to know the position of both the object and the box, name them in numbers, 1 and 2. the following program will perform the example

Repeat
  Clamp=0   // unclamp
  Move (1)  // causing the robot to go to position 1 (the object)
  If WX1=1 // wait external signal connected to the sensor of the object
  OX1=0    // operate external signal causing the product line to move or stop
  Clamp=1  // take the object
  Move (2)  // go to the next position (the box position)
  OX1=1    // allowing the first product line to move
  If WX2=1 // the box reached the desired position
  OX2=0    // stopping the second product line
  Clamp=0  // putting the object in the box
  OX2=1    // allowing the next product line to move

Forever

4.2.2.2 Teaching the Program to the Robot

This section is illustrated through flow charts below:

- First the program should check the emergency signals; if any of which is energized the robot must be stopped.
- If no, the program should determine through mode input in which mode the robot should work; teach or repeat. Figure (4.6) illustrates this starting procedure.
- In figure (4.7) teach function is illustrated.
- In figure (4.8) repeat function is illustrated.
- In figure (4.9) save function is illustrated.
- In figures (4.10) and (4.11) move function is illustrated.
Figure 4.6 Program modes
Teach function sets the step counter to 0, then it implements save function and increments the step counter, it continues until the start switch goes off.
Repeat function sets the step counter to 0, and then it implements move function and increments the step counter. Before implementing each step the wait external signals must be energized to match the saved conditions, after the movement completed the program should set operate external output to match the saved conditions. Repeat function continues until the start switch goes off.
START

CLAMP(i)=PORTB.X

Selection lines = 000

ROARY(i)=PORTE

S.L.=001

UPDOWN(i)=PORTE

S.L.=010

INOUT(i)=PORTE

S.L.=011

BEND(i)=PORTE

S.L.=100

YAW(i)=PORTE

S.L.=101

OX(i)=PORTE

S.L.=110

WX(i)=PORTE

END

Figure 4.9 Save function
Save function saves the input of PORTE in the corresponding array depending on the value of selection lines. It is used on TEACH mode.

Figure 4.10 Move function

Move function compares the feedback of each motion from encoders with the saved desired position. If the saved value greater than the feedback value then the program...
sets the corresponding output pin ON; causing NIMATE to move to the desired position and reducing the difference, but if the saved value is smaller the program will set the output pin of the opposite direction ON. When the saved and feedback values are matched the program resets the output pin. Because the UNIMATE must take an object and then move, or put an object and then move, the first operation which performed within each step is CLAMP/UNCLAMP.

The following figure illustrates how the process MOVE TO ROTARY (i) is performed:

Figure 4.11 Move to rotary (i).
4.3 THE DIFFICULTIES

Many difficulties faced this project, it must be considered to avoid or deal with them in the future, they are:

- Lack of knowledge about the old system specially most of web site have been blocked from the Sudanese IPs that to political issues.

- Lack of knowledge about the robots in general and especially the UNIMATE robots.

- Lack of suitable spare parts specially mechanical, this waste most of project time.

- The project time was divided to mechanical and electrical studying. This let the electrical portion about three months only.

- The work place is very far from the University Of Khartoum, it takes about two hours to reach the robot.
CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

The greatest objective that have been achieved is that the robot is now operating but manually through the control panel [APPENDIX G] that have been designed and tested. (Refer to video 0 through 4). Partially project objectives have been achieved; confidence has been built on the university ability to solve engineering problems. Also we benefited from the project on having a good training to deal with the work environment.

FUTURE WORK

- The control design proposal should be checked, modified if necessary, and finally implemented on the robot.
- UNIMATE does not respond to any supplied signal unless the (TEACH/REPEAT) switch put on REPEAT position, so it must be known what is the valve that is controlled with this switch.
- The START & STOP push buttons are still on the old control panel. It is not a problem if we need to operate it manually, but for automation purpose we need to control START & STOP switches by the controller.
- The signal that is supplied to the servo valves is taken from an external DC power supply, so we need to take it from the UNIMATE power supply if it is possible or there must be a DC supply associated with the UNIMATE.

RECOMMENDATIONS

- All the efforts made and the proposals introduced should be applied to other robots.
- Mechanical and economical studies should be done on the possibility of manufacturing industrial robots in the Sudan, electrically it is possible.
REFERENCES


APPENDIX

APPENDIX A: FIGURES

FIGURE A  RIGHT SIDE TO UNIMATE

1. Yaw Encoder J34
2. Air Solenoid J31
3. Yaw Servo Valve J28
4. Swivel Servo Valve J44
5. Down-Up Encoder J25
6. Test Connector J40
7. Teach Control J38

Figure a-4  UNIMATE Right Side Electrical Connector Location
FIGURE B  LEFT SIDE TO UNIMATE
FIGURE C  THE TEACH HAND

Figure a-5  Teach Control, Folded Out
FIGURE D  THE HYDRAULIC AND PNEUMATIC SYSTEMS
Figure E  THE MEMORY

Figure B-1. UNIMATE CMOS Memory Enclosure
FIGURE F  TYPICAL MOTOR AND POWER SUPPLY CIRCUITS
FIGURE G  THE NEW CONTROL PANEL
FIGURE E

The SERVO VALVE and its Terminals

FIGURE F

From left to right: the memory, control cards, and the power supply
## APPENDIX B: TROUBLESHOOTING TABLES

<table>
<thead>
<tr>
<th>SYMPTOM</th>
<th>SERVICE PROCEDURE</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>UNIMATE will not move in Teach; one or more degrees of freedom.</strong></td>
<td><strong>Possible Causes:</strong></td>
</tr>
<tr>
<td><strong>UNIMATE moves in Repeat.</strong></td>
<td>a. Faulty Teach Control.</td>
</tr>
<tr>
<td></td>
<td>b. Faulty relay.</td>
</tr>
<tr>
<td></td>
<td>c. Faulty switch.</td>
</tr>
<tr>
<td></td>
<td><strong>Procedure:</strong></td>
</tr>
<tr>
<td></td>
<td>a. Replace Teach Control.</td>
</tr>
<tr>
<td></td>
<td>b. Replace relay SCR.</td>
</tr>
<tr>
<td></td>
<td>c. Replace TEACH/REPEAT switch.</td>
</tr>
<tr>
<td><strong>UNIMATE will not move in Teach and Repeat; one or more degrees of freedom.</strong></td>
<td><strong>Possible Causes:</strong></td>
</tr>
<tr>
<td></td>
<td>a. Mechanical binding</td>
</tr>
<tr>
<td></td>
<td>b. Faulty drive train component.</td>
</tr>
<tr>
<td></td>
<td>c. Faulty board(s).</td>
</tr>
<tr>
<td></td>
<td>d. Faulty servo valve.</td>
</tr>
<tr>
<td></td>
<td><strong>Procedure:</strong></td>
</tr>
<tr>
<td></td>
<td>a. Check for drive train binding due to excessive load or contact with external equipment.</td>
</tr>
<tr>
<td></td>
<td>b. Check for failure of taper pin, gears, actuator, etc.</td>
</tr>
<tr>
<td></td>
<td>c. Replace Servo Amplifier (S) board.</td>
</tr>
<tr>
<td></td>
<td>d. Replace Total Coincidence (T) board.</td>
</tr>
<tr>
<td></td>
<td>e. Replace servo valve of faulty motion (paragraph 5-5-2-10).</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>SYMPTOM</th>
<th>SERVICE PROCEDURE</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>UNIMATE will not move in Repeat; inhibit and parity error indicators on Write/Read (W) board are lit.</strong></td>
<td><strong>Possible Causes:</strong></td>
</tr>
<tr>
<td>Teach operation is normal.</td>
<td>a. A lamp in any one of the six encoders is faulty.</td>
</tr>
<tr>
<td></td>
<td>b. Faulty board.</td>
</tr>
<tr>
<td></td>
<td><strong>Procedure:</strong></td>
</tr>
<tr>
<td></td>
<td>a. If Tester is not available, remove covers and observe encoder lamps.</td>
</tr>
<tr>
<td></td>
<td>Replace lamp as required.</td>
</tr>
<tr>
<td></td>
<td>b. If Tester is available, check Groups 3 through 8,</td>
</tr>
<tr>
<td></td>
<td>A faulty encoder lamp will cause all MEMORY INPUT indicators to be on. Refer to paragraph 5-3-8-4, or the</td>
</tr>
<tr>
<td></td>
<td>Tester Equipment Manual, Unimation Part No. 397F1 or 2.</td>
</tr>
<tr>
<td></td>
<td>c. Replace Write/Read (W) board.</td>
</tr>
<tr>
<td><strong>UNIMATE will not move in Repeat; inhibit and parity error indicators on</strong></td>
<td><strong>Possible Causes:</strong></td>
</tr>
<tr>
<td>Write/Read (W) board are lit.</td>
<td>a. Faulty board(s).</td>
</tr>
<tr>
<td>Teach operation is normal.</td>
<td>b. Faulty memory.</td>
</tr>
<tr>
<td></td>
<td><strong>Procedure:</strong></td>
</tr>
<tr>
<td></td>
<td>a. If UNIMATE had been operating in Repeat when problem appeared,</td>
</tr>
<tr>
<td></td>
<td>replace in the following order:</td>
</tr>
<tr>
<td></td>
<td>(1) Input (1 or 12) board</td>
</tr>
<tr>
<td></td>
<td>(2) Write/Read (W) board</td>
</tr>
<tr>
<td></td>
<td>(3) Buffer Register (B) board</td>
</tr>
<tr>
<td></td>
<td>(4) Weld Operator (K) board or Clamp Operator (C) board</td>
</tr>
<tr>
<td></td>
<td>(5) Memory.</td>
</tr>
</tbody>
</table>
### Table b.1 pare of troubleshooting table

All the above functions done and the Unimate didn’t response, ensuring that the problem in the memory.
APPENDIX C: Manual Operation Figures

The following results had taken in 900 psi pressure. It achieve the best performance

<table>
<thead>
<tr>
<th>No</th>
<th>Movement</th>
<th>Voltage</th>
<th>Volt</th>
<th>Current</th>
<th>Amper</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Rotary Left</td>
<td>2.06</td>
<td>.023</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Rotary Right</td>
<td>2.06</td>
<td>.023</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>UP</td>
<td>2.11</td>
<td>.024</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>DOWN</td>
<td>1.12</td>
<td>.012</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>IN</td>
<td>2.39</td>
<td>.026</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>OUT</td>
<td>2.39</td>
<td>.026</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>YAW cw</td>
<td>1.473</td>
<td>.016</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>YAW ccw</td>
<td>1.42</td>
<td>.016</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Bend Up</td>
<td>1.42</td>
<td>.015</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Bend Down</td>
<td>1.42</td>
<td>.015</td>
<td></td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>CLAMP/UNCLAMP</td>
<td>28 to clamp</td>
<td>.05</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The manual control panel voltages = 1.7 V, and this achieve a good performance.

When the pressure decrease to lower degree the voltages must be increase to make the robot operate at the same level of service, or the resistor value decrease this lead to better performance also, therefore using variable resistor is recommended to balance the hydraulic instability.
Move(i) //the parameter (i) indicates the step number
{
  clamp output = clamp(i)
  PORTF.5=0 //these are the selection lines which selects one ...
  PORTF.6=0 //encoder to be read by the microcontroller ...
  PORTF.7=0 // 000 selects ROTARY motion
  /* a problem appears here, the microcontroller ports and registers are 8-bit while the encoder input is 12-bit, so the most significant bits can be taken which represented here by port E and leaving the 4 least significant bits */
  while PORTE > ROTARY(i)
    PORTH.0=1 // ROTARY right
    PORTH.0=0 // after reaching the desired point the ...
    // corresponding output de-energized
  while PORTE < ROTARY(i)
    PORTH.1=1 //ROTARY left
    PORTH.1=0
    PORTF.5=1
    PORTF.6=0
    PORTF.7=0 //001 selects UP/DOWN motion
    while PORTE > UPDOWN(i)
      PORTH.2=1 // up
      PORTH.2=0 // after reaching the desired point the ...
      // corresponding output de-energized
    while PORTE < UPDOWN(i)
      PORTH.3=1 //down
      PORTH.3=0
    PORTF.5=0
    PORTF.6=1
    PORTF.7=0 //010 selects IN/OUT motion
    while PORTE > INOUT(i)
      PORTH.4=1 // out
      PORTH.4=0
    while PORTE < ROTARY(i)
      PORTH.5=1 //in
      PORTH.5=0
    PORTF.5=1
    PORTF.6=1
    PORTF.7=0 //011 selects BEND motion
    while PORTE > BEND(i)
      PORTH.6=1 // bend up
      PORTH.6=0
while PORTE < UPDOWN(i)
    PORTH.7=1  //bend down
    PORTH.7=0
    PORTF.5=0
    PORTF.6=0
    PORTF.7=1  //100 selects YAW motion
    while PORTE > YAW(i)
        PORTG.0=1  // yaw cw
        PORTG.0=0
    while PORTE < UPDOWN(i)
        PORTG.1=1  // yaw ccw
        PORTG.1=0

The next important function is save(). It is used on TEACH mode, when the robot be
moved to a certain position and pressing RECORD pushbutton, all the encoders
inputs are saved on the microcontroller memory.

Save()
{ PORT F.5=0
    PORTF.6=0
    PORTF.7=0  // select rotary encoder
    ROTARY(i)=PORTE  // PORTE is the encoder input
{ PORTF.5=1
    PORTF.6=0
    PORTF.7=0  // select up/down encoder
    UPDOWN(i)=PORTE
{ PORTF.5=0
    PORTF.6=1
    PORTF.7=0  // select in/out encoder
    INOUT(i)=PORTE
{ PORTF.5=1
    PORTF.6=1
    PORTF.7=0  // select bend encoder
    BEND(i)=PORTE
{ PORTF.5=0
    PORTF.6=0
    PORTF.7=1  // select yaw encoder
    YAW(i)=PORTE
    CLAMP(i)=. . . . // clamp input