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Control software and hardware for a wall climbing robot

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Abstract

A control system based on the STE bus system (IEE 1000 1987) has been developed in the construction robotics unit at the University of the West of England for the control of wall climbing robotics equipment. A modular design approach has been adopted which allows components to be updated individually. The resulting system has the benefits of a rugged and highly cost effective computer architecture. The paper also describes the software which was written, using modular design methods with an incremental approach to testing. A secondary aim at this phase of the development was to research genetic algorithms and their application to methods of walking and the ways in which these algorithms could be applied to route planning and obstacle negotiation.

1. INTRODUCTION

The inspection of buildings and structures is carried out in a hostile and hazardous environment that creates a high level of risk from a safety viewpoint due to difficulties of access particularly to multi-storey buildings and buildings that may be contaminated eg, nuclear power stations. A feasibility study (1) undertaken for the UK Department of Trade and Industry by CIRIA - the Construction Industry Research and Information Association - between May 1986 and July 1987 identified the inspection of civil engineering and building structures as having the greatest potential for developments in automation and robotics.

Research at the University of the West of England on automated Surface Transversing Vehicles (STV's), for the inspection of buildings has now reached an advanced stage, and three prototypes (2,3) have already been developed. As part of this research an adaptable computer controller based on the rugged STEbus system (IEEE 1000 - 1987) has been designed and assembled and is the subject of this paper.

2. DESIGN CONCEPT

The prototype wall climbing robot (3) was designed to carry instrumentation for measuring defects in structures and tools for carrying out remedial work. To achieve this, the following criteria were established. The robot should:

(i) be able to travel quickly to the points requiring inspection using the long stroking piston.
(ii)be able to move in smaller steps with the short stroking pistons when using the measuring equipment.

(iii) turn, incrementally, on its own axis.
(iv) have as high a power to weight ratio as possible so that reasonable payloads can be carried and to ensure that the robot is as stable as possible when using the tools and end effectors fitted to it.
(v) enable the tools and measuring equipment to be easily fitted and interchanged.
(vi) be able to check the feet for vacuum so that if any foot cannot get a grip, a decision can be made to either short stroke it to another position, or to assess the possibility of making the foot redundant for that particular move.
(vii) carry the pneumatic controllers on the robot so that pressure losses are kept to a minimum and the weight of the umbilical, which can be significant on tall structures, kept as light as possible.
(viii) having gained its position the robot must be able to use its Sensors to monitor the condition of the surface. Initial tests involve the use of a Cover Meter, to measure the position, depth, and size of rebars. An analogue voltage is fed back to the base station for storage and logging.
(ix) The software developed must both be maintainable and sufficiently flexible to allow changes to be made and modules added to allow expansion of the routines and all the options of both the PIO and A/D convertor to easily be used. The idea of modularity, low coupling and good cohesion should be followed throughout the development cycle.
(x) Although the project is primarily for research it will also be used as a laboratory instrument, therefore, the user interface must be taken into consideration, including the requirements for control and the presentation of data in real time. A full technical description is necessary to allow users to amend parts of the software and hardware and to operate the vehicle.

3. CONTROLLER HARDWARE DESIGN

3.1 STEbus System

The computer hardware is based on the STEbus system (IEEE 1000 - 1987) (4). This approach has the benefits of a rugged and highly cost effective computer architecture. The system allows components to be updated individually whilst retaining a modular design approach. In the first stage of the project the following major components of the controller were acquired and consisted of the following:

P188 Processor	Processing Unit
SPIN STE PIO	Parallel Input, Output Device
STE DRAM	Additional Dynamic Memory.
SCB16D High Current Driver	High Current Board for Solenoids.
SADC12-16 12BIT ADC	Analogue to Digital Convertor.

During the second and third stages of the project the following boards were purchased to increase the speed of the processing and allow data to be displayed, in colour, on a separate monitor.

SCIM88 Processor	Improved Processing Unit.
SPCOM Board	Communication Board
SPVGA	Colour Screen Drive Board.

3.2 Technical Description of STE Hardware

3.2.1 SCIM88 Processor

The SCIM88 is a powerful, all CMOS single board computer based on the 80C188 microprocessor CPU. It is a low cost microprocessor using the STE standard bus. The board operates at 16MHZ and has 320 KB of user addressable RAM. The CPU also features an interrupt DMA controller, three timers and a real time clock is also available on Board together with two RS232 interface channels. The SCIM88 allows full implementation of the STEbus across the back plane and may be configured to operate in a multiprocessor system, thus, master and slave CPUs can be used as controllers in a hierarchical situation.

3.3.2 STE Parallel I/O Interrupt Controller (PIO) Operation.

The movement of the feet of the STV is controlled by a parallel input/output PIO board. This uses two Zilog Z8536 CIO (counter/ timer parallel I/O) chips. The 16 I/O lines can be configured (in groups of 8) for either input or output (output is used to control foot motion and suction). All lines are buffered by 245 driver receiver chips. The direction of the 245s can be changed under software control. The SPINC occupies 16 STEbus locations and the base address can be set by onboard jumper links.

3.2.3 High Current Output Digital Opto Isolated Signal Conditioning Board

The SCB16D allows high current drive from the PIO to the solenoids which control the pneumatics used for operating the feet pistons and ejectors. This is a signal conditioning board which provides 16 channels of opto-isolated digital output for driving solenoids. The SCB16D can provide up to 200 mA of current per channel at up to 50 V.

3.2.4 SADC 12/16 STE 12-Bit ADC (Analogue to Digital Convertor)

The SADC is a peripheral board with 16 analogue inputs which plugs into the STE backplane. The board provides highly accurate analogue to digital conversion with good resolution. It has 12 bit resolution with a 13th bit used to signify the sign of the voltage. The noise and error level margins are less than one bit. The board uses an integrating convertor which has differential inputs with a high impedance. Sixteen inputs are multiplexed by two differential multiplexers into the A/D inputs. After conversion the reading is available as two 8 bit-bytes, one being the 8 LSB's (least significant bits), the other giving the 4 MSB's (most significant bits), plus a polarity sign and over range bit. The board is I/O mapped taking three I/O locations. The analogue to digital convertor has the following specifications:

-	Input Voltage Range	+/- 4.096 Volts
-	Noise Level	15 uV
-	Conversion Time per Channel	30 mS (approx.)
-	Resolution	12 bits plus sign
-	Offset Drift	1 uV/^{o}C (max.)

3.2.5 SPCOM Board

This is a multifunction peripheral board which interfaces directly with the STEbus computer system. Based around a Chips & Tech 82c712 'Combo' chip, it provides a PC compatible communications environment. It can provide a centronics parallel printer port and two RS232 serial communication channels. Each is capable of transmitting at rates up to 115.2 Kbaud synchronously. Serial communications port to the terminal PC. Data transmission rates are set up by Procomm. The data transmissions rate is set at 19200 baud with 8 data bits, no parity and two stop bits.

3.2.6 SPVGA Board

The SPVGA Board is based around the Trident TVGA8900 chip which provides a resolution of up to 1024 x 768 with up to 256 colours on analogue monitors. The board will support IBM EGA, CGA, VGA and Hercules modes. To alter the capability only the configuration software needs to be changed. In our application the SPVGA is fitted with 256 Kb of onboard video DRAM, this allows, with standard resolution VGA, the ability to display 256 colours.

4. HARDWARE CONFIGURATION

Figure 1 shows the hardware configuration and the development set-up. In the final configuration the need for the PC could be alleviated as the programme could be blown into ROM, a keypad (joystick) plus a control panel would control the device.

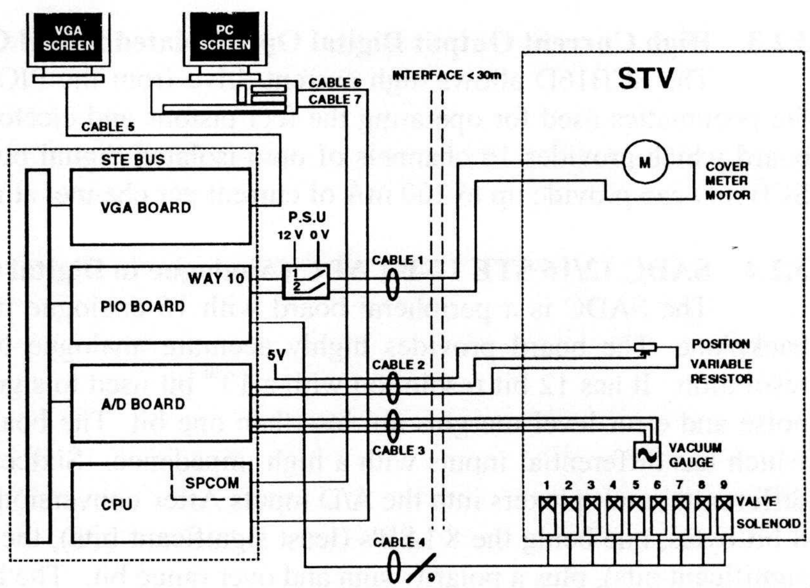

Figure 1 Hardware Configuration

5. SOFTWARE DESIGN

5.1 Design Methodology

A modular design approach (5) was adopted using the waterfall principle to design and test (Figure 2). This allowed modules to be individually developed, tested, and integrated into the final programme.

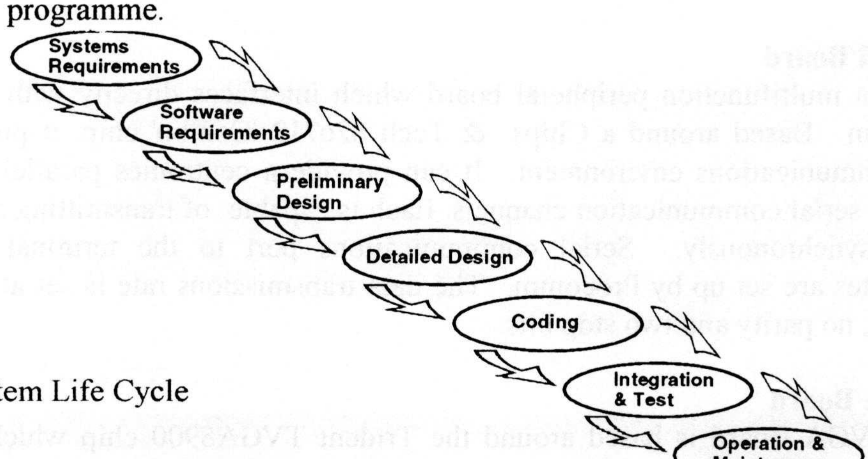

Figure 2 System Life Cycle

It was recognised throughout the design stage that the structure of the programme needed to be easily understood by other members of the team. To fulfil this aim global variables have been used in the movement routines to aid the understanding and amendment of the programme in later development phases. It was also recognised that for full modular design leading to object orientated design each module should be autonomous. The passing of complicated parameters and re-use of constants was rejected in favour of global variables for this reason. It had to be remembered that the STV projects are a continuing entity and that the computing hardware and software would be tools for laboratory use and as such there was a need for easily modifiable code.

5.2 Phase One

The first phase of the project involved programming the PIO to drive the high current output board to switch on the solenoids. The feet may then be operated to make the robot climb. A test rig of 10w lamps was devised for the initial tests instead of using the solenoids and compressed air. This allowed the lights to be turned on and off as required. A keyboard menu was written to switch each PIO way on in turn, finally leading to sequences with time delays being written. The software used for this phase was ARCOMs "AZTEC C", a cut down version of Turbo C.

5.3 Phase Two

The second development phase involved research into improved ways of programming and utilising the existing hardware. The problems found in phase one were highlighted as:

(i) The software was a poor subset of C
(ii) The performance was slow
(iii)There was no ability to utilise the graphic capabilities of Borland Turbo C.

After consultation with ARCOM the hardware was enhanced with a SCIM88 running at 16 MHz, a communications board, SPCOM, was added. SourceVIEW was run which allowed software to be created using Borland C. Thus a more user friendly 'front end' and a wholly more powerful development tool could be utilised. SourceVIEW software allows code to be written, compiled and linked on the PC and downloaded to the target STEbus system at 19200 baud. The transfer time was approximately a minute for an 80k file. Utilising the Turbo debugger software, the code may also be debugged on the Target system.

5.4 Phase Three

The third phase involved the programming of the analogue to digital convertor (SADC 12/16). This board has 16 analogue inputs and yields an effective resolution of 13 bits, it is used to gain values of vacuum pressure, the output from the cover meter and the feedback from the cover meter head positional sensor. The sequence of operations is as follows:

(i) Select a channel for conversion
(ii) Start the conversion
(iii) Check to see if conversion has finished by polling the board
(iv) Stop the conversion process
(v) Read the data bytes
(vi) Combine the data bytes to form the data value.

To represent the outputs from both the cover meter and the vacuum gauges in real time sourceGRAPH was introduced that allowed Borland C graphics to be used on the target system. A colour VGA monitor was also added to the system for displaying the results. The output of the vacuum gauge is displayed as a bar chart. The outputs from the cover meter, lateral position and cover over the rebar, were displayed as an x:y line graph. The y value gave the cover and the x axis was the relative horizontal position of the cover meter head transducer. The structure of the programme is shown in Figure 3.

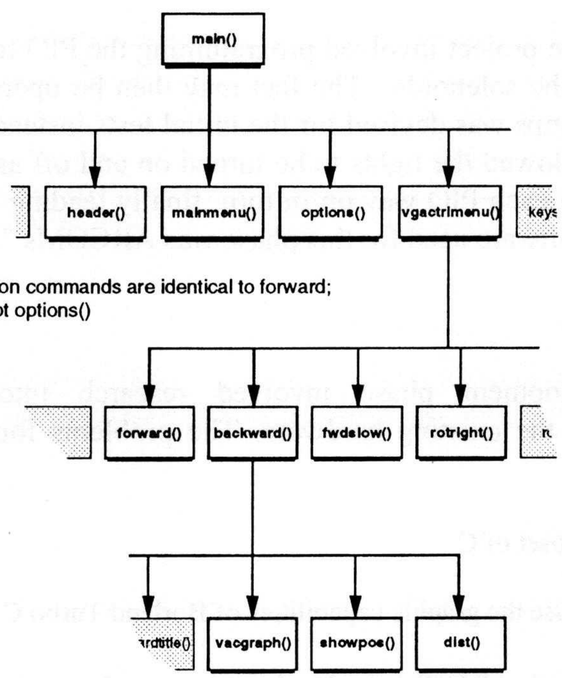

Figure 3 Structure of the Software Program

6. GENETIC ALGORITHMS

6.1 Introduction

These are search algorithms based on the mechanics of natural selection and natural genetics (6). They combine the Darwinian theory of the survival of the fittest with a structured yet randomised information exchange to form a search algorithm with some of the innovative flair of human search. In every generation a new set of artificial creatures (strings) is created using parts of the fittest of the old. An occasional new part is tried for good measure. Although randomised, genetic algorithms are no simple random walk, they efficiently exploit historical information to speculate on new search points with expected improved performance. GAs have been developed by John Holland and his colleagues at the University of Michigan. The goals of their research have been twofold:

(i) To abstract and rigorously explain the adaptive processes of natural systems.

(ii) To design artificial systems software that retains the important mechanisms of natural systems.

6.2 The Genetic Algorithm

The genetic algorithm comprises the following steps:

1. Initialise a population of chromosomes.
2. Evaluate each chromosome in the population.
3. Create new chromosomes by mating current chromosomes; apply mutation and recombination as the parent chromosomes mate.
4. Delete members of the population to make room for the new chromosomes.
5. Evaluate the new chromosomes and insert them into the population.
6. If time is up, stop and return the best chromosome, if not then go to 3.

6.3 Application to STVs

The genetic algorithms are applied to the STVs in two different ways ie. to enable the STV to learn to walk and, also cope with areas of poor grip.

6.3.1 Walking

The ability to walk can be achieved by representing the functions of each individual foot to a bit position within a string. Table (1) below shows all the solenoid functions:

Bit Position	Name
1	Big Centre Rotate
2	Rear In
3	Big Centre Slide
4	Rear Up
5	Front In
6	Forward Up
7	Forward Vacuum
8	Big Centre Vacuum
9	R R Vacuum

Table (1) Bit Positions of the Walking Functions

The minimum set of combinations for a complete short or long step appears to be approximately 10 movements, with the number of functions this gives a total string length of 90. All possible combinations are linked together to form one movement or step, this gives a total combination value for the whole 90 Bit string to be $2^{90} = 1.237$ E+027.

6.3.2 Poor Grip Areas

The big centre rotate function may be employed to deviate away from an original path to negotiate an area of poor grip. The algorithm would allow circumnavigation of the point if this was the 'best fit' ie. the best possible solution. The STV has four basic movements:

small step   long step   rotate right   rotate left

Any combination could be employed to either step over or skirt the area of floor grip. The bit pattern versus movement would be:

Bit Pattern	x	x	x	x
Small Step	x			
Large Step		x		
Rotate Right			x	
Rotate Left				x

Table (2) Bit Pattern V Movement

Strings can then be built up to provide the steps and rotations required to avoid the area of poor grip (see figure 4). It can be seen that the algorithm for poor grip areas are the easiest to visualise and manipulate. To date this situation has only been modelled. However much more sophisticated methods of navigation would be required before the method could be employed on the STV.

	SHORT	LONG	RIGHT	LEFT
LONG STEP FORWARD	0	1	0	0
MEET OBSTRUCTION				
GET NEW CHROMOSOME	0	0	1	0
TRY NEW CHROMOSOME CAN STV MOVE?				
IF NOT, MUTATE CHROMOSOME, TRY AGAIN	0	0	0	1
IF YES MOVE AND STORE CHROMOSOME				

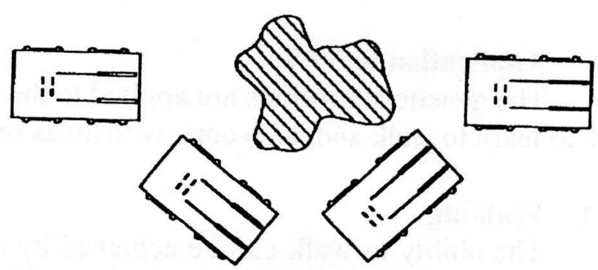

Figure 4. Psuedo code for generic algorithm

CONCLUSIONS

Hardware - The control system has proved to be efficient. It has been used to operate an STV in an indoor (smooth point surface) and outdoor (pre-cast concrete) environment. The STV was controlled at a speed of climb of 1 metre per minute, this speed can be doubled when the vacuum sensors are fitted and sensed by the STEbus. Control was via the PC keyboard using a colour menu system together with the auxilliary screen showing the graphical view of the cover meter output. **Software** - The coding has been developed and proved over a long field trial phase with no major problems. The technical staff have had no difficulty recoding parts of the programme due to its modular approach and adequate labelling of modules. **Genetic Algorithms** - These algorithms have been shown to be useful as a strategy for crack and rough surface avoidance. Their use for walking strategies is limited due to the slowness of operation.

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