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A Human-Like Semi Autonomous Mobile Security Robot

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Abstract

The Mechatronics Group of the University of Waikato have developed a fleet of five mobile robots capable of autonomous operation. These robots are constructed to traverse a variety of terrains including farms, forests, underwater and smooth indoor surfaces. MARVIN (Mobile Autonomous Robotic Vehicle for Indoor Navigation) is designed to act as a security agent for indoor environments and consequently must interact with people who may have little or no knowledge of robotic devices. It is essential that this interaction be as natural as possible in order for the human to be comfortable communicating with MARVIN. To facilitate this, in association with Robotechnology, MARVIN has been substantially redesigned and provided with speech recognition and speech synthesis software as well as the ability to verbally and non-verbally convey emotional states.

Keywords: mobile robots, security robot, robotic emotion

1 Introduction

It is well accepted that mechatronic devices such as video players, dishwashers and washing machines only gain acceptance with the general public when their interface is simple and intuitive (and the price is acceptable). The same is true for the public acceptance of semi-intelligent mobile robotic devices. If a human interacting with such a machine feels uncomfortable, then that person is likely to avoid future contact with that machine. It is reasonable to assume that the most natural interaction a human has is when they are communicating with another human. Specifically, we expect to be able to make ourselves understood primarily by verbal means, and similarly we expect the other person to verbally respond to us (with some obvious exceptions for the hearing impaired). However, there are many non-verbal queues associated with communication, some obvious, such as the person we are communicating with should be facing us, others more subtle, for example, a human physically indicating that they are listening to us by perhaps nodding their head, raising their eyebrows, changing their body position, etc. Consequently, in order for a human to feel most natural interacting with a robot, the robot should exhibit as many of these features as possible.

MARVIN is designed to be a security agent, operating in an indoor environment. It can not be assumed that the people interacting with MARVIN will have had any previous association with mobile robotic devices, and so the interaction MARVIN has with the people it encounters should be as "natural" as possible.

A number of robotic security devices have been developed[2], and work on developing human-like robots is progressing rapidly, as evidenced by the remarkable progress in bipedal robots since ASIMO first appeared. Other robots such as KISMET (by MIT) and WE-4 (by Takanishi Laboratories) have endeavoured to portray facial emotions, though this is a mechanically complex and expensive task. MARVIN will not have a human-like face, but will communicate verbally and non-verbally (via a variety of body postures) with human users.

2 Background

Development on MARVIN began in 2000 [1] with the initial design and construction of the locomotion system and chassis. Past experience of the Mechatronics Group has been that a mobile robot must have a significant physical presence in order to be treated seriously by the casual public. Consequently, MARVIN was designed to have a height of between 1.5 and 1.7 m, depending on how the head unit was attached.

As MARVIN's operating environment is confined to smooth, flat indoor surfaces, a simple wheel-chair configuration was selected, with stabilising castors front and rear [2]. Such a configuration is mechanically relatively simple to construct and control, and is highly manoeuvrable (a requirement for some of the cluttered environments that MARVIN is expected to negotiate).

2.1 Sensors

MARVIN is provided with a variety of sensors in order to avoid obstacles. Long range sensing takes the form of a custom-developed laser range finder that operates by projecting a laser through a cylindrical lens. The reflected beam is focussed onto a linear CCD array and the deviation of the received image from the centre of the CCD is converted into a range value [3]. This system requires the laser to be offset from the camera, with the whole unit being able to rotate 360º in order to map the environment. This system was originally placed in MARVIN's head unit and was connected by a long shaft to a stepper motor that provided the head's angular position.

Intermediate ranging initially was of the form of a custom built infrared intensity based sensor. However, the range resulting from this system depended on the colour, texture and orientation of the reflecting surface, and so these sensors were replaced with Sharp GP2Y0A02YK position sensitive devices (PSDs). These PSDs have a range of 20 cm to 150 cm independent of the reflecting surface. For indoor applications these sensors work well although they need to be recalibrated to operate in bright sunlight. Two pairs of these sensors are located on each side of MARVIN to provide heading information when traversing a corridor, and a front and rear sensor provide obstacle avoidance information (MARVIN is reversible).

Short range (< 20 cm) detection takes the form of four contact sensors placed at the bottom corner of MARVIN's frame. These sensors are activated when their attached wand contacts some surface, triggering a contact switch. If these sensors are activated, then a collision is imminent, though it is expected that the long and medium range sensors would have previously detected the obstacles and initiated some avoidance routine.

Odometry information is provided in the form of two HEDS 5500 optical encoder modules attached to each motor. These encoders provide 512 slots per revolution (two channels in quadrature), resulting in a resolution of 25 pulses per mm of travel.

2.2 Processing Power

MARVIN was initially powered by an Intel 8051 based embedded microcontroller. Such a system is extremely limited, and so was replaced with a PC motherboard operating an Intel Celeron 533 MHz processor with 64 MB RAM. A National Instruments LabPC+ data acquisition (DAQ) card was plugged into the ISA slot of the motherboard to communicate with the hardware. An upgrade in 2003 replaced this system with an Athlon XP 2000+ processor, 512 MB RAM and a National Instruments 6025E DAQ card attached to the PCI slot [4].

Communication with a remote PC is facilitated by a Wireless LAN card. A Windows XP operating system is employed, with most of the high level control algorithms coded in MATLAB, though for historical reasons LABVIEW forms the software interface to the DAQ card [5]. Regrettably, real-time control of hardware through the Windows operating system has been problematic, and so an embedded 8051 core microcontroller is implemented to generate a pulse-width modulated motor driver signal from a parallel digital instruction signal originating from the DAQ card (section 5.2).

2.3 Power

MARVIN's power is supplied by two series wired FLA 12 V d.c. automotive batteries. An H-bridge motor driver circuit takes the PWM input signal (from the microcontroller), and applies the required power to the two motors.

Power to the computer board originates from a commercial ATX dedicated power supply. Sensors and additional electronics have their own linear voltage regulators, though these could be replaced with a direct tapping from the ATX power supply if required. For prototyping and development purposes it is convenient to keep these peripheral boards independent of the main motherboard supply.

2.4 Performance

Under full power, MARVIN is capable of speeds approaching 35 km/hr. For safety reasons manual control is restricted to only 20% of this power value. As expected for a device using a wheelchair configuration, the robot is highly manoeuvrable. This combined with MARVIN's low centre of gravity (achieved by locating the batteries and motors close to the ground) results in the robot being able to perform high-speed integrated turns without risk of tipping.

The batteries are sufficient for MARVIN to operate for over one hour continuously, though these standard FLA batteries could be replaced by deep-cycle versions to dramatically increase operating time. Additionally, MARVIN would not be expected to be moving non-stop during an extended patrol period, and so it would not be unreasonable to expect an eight hour operating period.

3 Human Interfacing

As discussed in section 1, the most natural way for a human to communicate with another human is verbally. To facilitate this on MARVIN, Microsoft speech recognition software was employed. Whilst this can not be considered "state-of-the-art", it is less expensive than the more powerful "Naturally Speaking", and is sufficient for prototyping purposes. In response to a verbal command, MARVIN converts the recognised speech into a text format, where a keyword match is made. In order to limit the number of verbal responses received, MARVIN verbally guides the user through a range of options. For example, if MARVIN has identified a user as being permitted to be in the area, then MARVIN will ask if the person wishes to be shown to a particular location. MARVIN is searching for keywords such as "yes", "no" or "ok". Other responses will prompt MARVIN to reissue the invitation. If the response is "yes", MARVIN provides the user with a list of possible locations. At this stage, due to the limitations of the speech recognition, this list of options is presented in a similar manner to telephone banking topology. A list of options are read with a number following it. For example, "If you want to go to Dr Carnegie's office, say '1', if you want to go to the electronics laboratory, say '2'…". Whilst somewhat cumbersome, it does allow development of MARVIN's other functions, and this stage can be redeveloped once better recognition software is purchased.

MARVIN was originally equipped with voice synthesis in the form of Microsoft narrator. At this early stage it was decided to give MARVIN a classical robotic voice as we were taking it on a tour of North Island secondary schools and we wanted the stage presence of a robot that the students have seen in movies [4].

For our new, more serious applications, we require MARVIN to sound more human-like, since, as discussed previously, it is important to make interaction with MARVIN as natural as possible.

A number of voice synthesis options were examined, but none offered the naturalness that we required. Consequently, the decision was made to use pre-recorded .wav files. This dramatically reduced MARVIN's vocabulary to a fixed number of pre-determined responses, but will be used until voice synthesis algorithms improve.

3.1 MARVIN as a Security Guard

In operation, MARVIN scans its environment, waiting until it has detected a dynamic (moving) obstacle. Once this is confirmed, the laser ranger can help determine if this dynamic feature is possibly a human. If so, MARVIN endeavours to get close to this feature, and interrogate it. If it is a human, MARVIN expects a proximity identification card to be shown. MARVIN then searches its database to find the owner of this card, and will prompt the user with a specific question that should result in the user speaking a pre-arranged password (disguised in this way to mask deliberate password eavesdropping). MARVIN will try three times to elicit the password from the user. If unsuccessful (either because it is the wrong word, or because it is simply not recognised), MARVIN will become more aggressive (section 4), and request/demand the user leave the premises. Although not implemented at this stage, the plan is for MARVIN to also notify a remote human security agent via the on-board wireless LAN that an intrusion has taken place, and send a picture of the intruder (using a standard web cam).

It is also anticipated that the laser ranger will be used to ensure that the identified human is at least of the same height as the person on MARVIN's database.

4 Non-verbal communication

Many of these features were incorporated into the first design of MARVIN [5], pictured in Figure 1. However, there are some immediate issues with MARVIN's shape. Notably, it resembles 1960 style robots, such as the Daleks from the BBC series "Dr Who", but also is not too dissimilar some of the original autonomous security robots, for example Robart I [6]. To have the public relations effect that we desire, an extreme makeover was required.

Figure 1: The original form of MARVIN

Such a makeover is completely outside the existing expertise of our Department, and so assistance was sought from Robotechnology, a significant animatronics company based in Wellington, New Zealand.

Robotechnology has multiple movie credits, including the robotic sheep from the movie Babe (that were so natural, even the executives of Universal Pictures were unable to distinguish between the movement of these robots and real sheep, even in close-up and in the same scene). Other credits include robotic sharks for Jackie Chan's First Strike, the octopus from 20,000 Leagues Under the Sea, and multiple others.

With assistance from a Technology in Industry Fellowship, an MSc student from our Department spent 12 months working with Robotechnology.

Robotechnology were hugely instrumental in guiding the redesign of MARVIN, considering and rejecting a number of proposals. An important design criterion was that the robot retain the original physical motive layout within the lower body whilst challenging the historical form of autonomous robots. It was also desirable that the robot have the capability to be able to portray particular non-verbal communication traits. It was felt that this would significantly increase the public's acceptance of the robot (and hence their willingness to interact with it). For the student, being exposed to such a creative team was the opportunity of a life-time, and after four prototypes, the new form of MARVIN, Figure 2, appeared.

Figure 2: The New MARVIN

Particular features implemented on the new MARVIN are the ability to face the person who is speaking (by a directional microphone array) and the provision of non-verbal indications that the person is being listened to (in MARVIN's case, a tilting of the head). To facilitate these features, the torso unit is designed with the ability to tilt forward and backward, as well as side to side. An extension of this feature is to provide MARVIN with the ability to indicate other "emotional states". Figure 3 shows three head and shoulder shots of people non-verbally expressing the emotional states of happiness, sadness and tiredness. Underneath is MARVIN's attempt to replicate these body postures.

To maintain the ability of the laser scanner to perform 360° scans, the torso is mounted in such a way that it can rotate about the base (that contains the batteries, motors, and locomotion system).

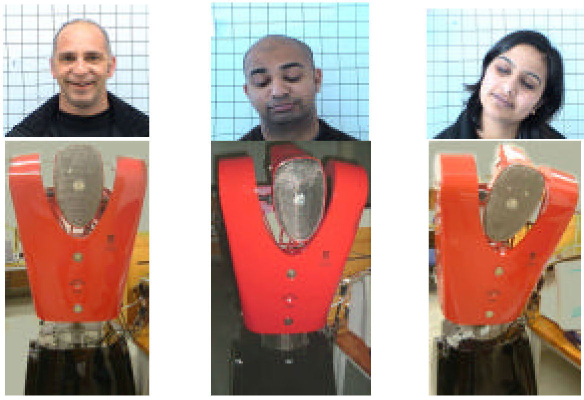

Figure 3: .MARVIN: Happy, sad, tired

The head unit, rather than being statically supported on the torso unit, can project upwards and outwards. This gives MARVIN the ability to express other emotions. For example, Figure 4, shows two forms of MARVIN, in an intimidating mode (head extended and out, body titled forward) and an intimidated mode (head and torso retracted).

Figure 4: MARVIN (a) Intimidating (b) Intimidated

5 Hardware

5.1 Actuators

For the movement of the head, and to provide precision positioning, three Hitec HS-815 servo motors are employed [8]. These tilt the head, turn it left or right, and nod it up and down. Operating from 4.8 to 6.0 V, these devices have a torque of 19.8 – 24.7 kg-cm (dependent upon input voltage). The Hitec servo motors are connected to a Mini SSC II servo controller that controls up to eight pulse-proportional servos by way of instructions sent via the serial port of the motherboard.

Four Linak LA12 linear motors were chosen to move the torso unit. These motors sway the torso from side-to-side, move the right shoulder forwards and backwards, move the left shoulder forwards and backwards and raise the head up or down to give MARVIN the aggressive or shy impression. These actuators run from a 24 V d.c. power supply, have a 100 mm stroke length, a 200 N maximum thrust and a typical speed of 28 – 40 mm/s (full load – no load). The Mini SSC II is designed only to run standard servo motors, therefore motor driver circuitry had to be implemented to connect and run the LA12 actuators.

5.2 Microcontroller

As mentioned in Section 2.2, real-time control using the Windows operating system has proved problematic. This affects both the validity of the odometry information as well as the ability to provide an accurate pulse width modulated (PWM) signal to the motor drivers. It is essential that odometry information is obtained with an accurate time stamp in order to determine velocity. To facilitate this, an embedded microcontroller forms an interface between the shaft encoders and the DAQ card [9]. This micro' directly counts the odometer pulses and transmits this with a time stamp as a parallel digital signal to the DAQ card. It also receives a parallel digital byte from the DAQ card concerning the desired motor direction and power (two bytes, one for each motor). The micro' translates this into two PWM signals to feed to the H-bridge motor drivers, and hence power MARVIN. A block diagram of this system is illustrated in Figure 5.

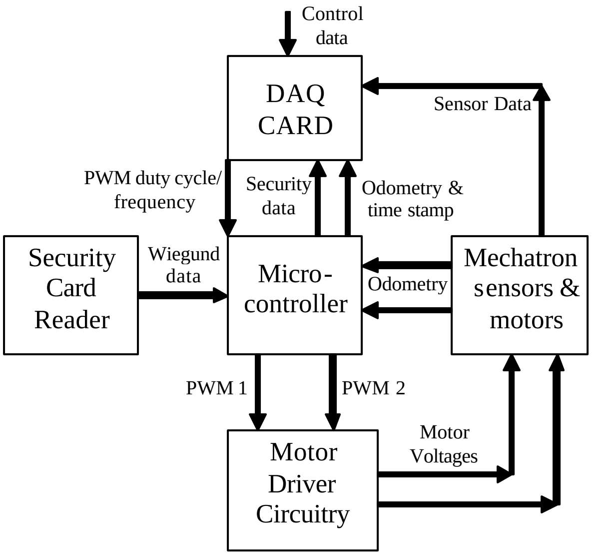

Figure 5: Hardware Control of MARVIN

5.3 Proximity Card Reader

The Smart Card Reader (proximity identification card – not a swipe device), requires 13.6 V d.c. (± 15%) at 160 mA. The reader employed has dimensions of 105 mm × 35 mm and is placed at the centre of MARVIN's torso unit. The aperture exposing the reader appears something like a "naval" on MARVIN, and so is not visually obvious.

The card reader outputs the date according to the Wiegand protocol, which in 36 bit mode comprises a leading even parity bit, 34 bits of data and a trailing odd parity bit. The two interrupt lines of the microcontroller are used to read the card data every 2 ms. This data is then conditioned and presented to the DAQ card for processing by MARVIN's main control program.

6 Software

6.1 Torso and Head Movement

To command one of the eight head or servo actuators to a new position, three bytes (sync. marker, servo number and servo position) must be sent via the serial port to the Mini SSC II. The positioning of these motors must be carefully orchestrated, else MARVIN's movement could look jerky and unnatural. Two forms of motion are employed, direct movement where each motor moves immediately to its destination, and proportional movement where each motor is moved in small steps until the desired position is achieved [10]. This is illustrated in a simplified form in Figure 6.

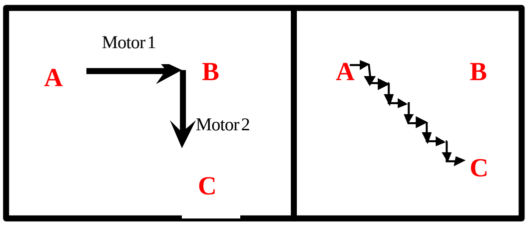

Figure 6: (a) Direct Movement (b) Proportional Movement

The direct movement, although potentially creating an abnormal ("robot-like") motion, can be useful when there is a need for fast movement to convey a particular emotional state, or to nod or shake the head in response to a question. The proportional movement is more human-like, though is slower.

6.2 System Control and Navigation

The control and navigation software is constructed in a hierarchical structure as has been detailed elsewhere [11]. Due to prototyping and development issues (all closely related to budget), a variety of software packages are integrated together. The speech recognition of Microsoft Word forms the front end interface (section 3). This produces a text file containing the key responses that MARVIN will act upon. The task division, task planning, and overall system control of MARVIN is implemented in MATLAB. Interfacing between Word and MATLAB is facilitated using ActiveX. The Mini SSC II controller (and hence the actuators that move MARVIN's head and torso) is commanded through the PC's serial COM port.

The remaining sensors and drive motors are interfaced through the DAQ card using LabVIEW, though the PWM generation and odometry (as previously mentioned) are conditioned by a microcontroller (programmed using HiTech C) due to the operating system limitations.

This software structure has several inherent limitations. First, and significantly, it is undesirable to have so many different software packages running together. Significant benefits would result if only one (or at the most, two) systems were employed. Second, MATLAB is not suitable for running multiple tasks in parallel, a necessity as MARVIN becomes more sophisticated, though the toolboxes of MATLAB are valuable to quickly examine and prototype different software options. We are in the process of converting much of the existing control system to C, and in the process replacing the LabVIEW hardware interface. Top level AI development will still use MATLAB.

7 Summary

MARVIN has undergone a dramatic transformation from his original form. The outer casing has been transformed from a 1960's design, to a modern, attractive outlook. The redesign of the torso and head units has provided MARVIN with the ability to alter its posture. This allows MARVIN to respond to humans in a more natural way, and provides the potential for MARVIN to portray a "emotional states" (however artificial those states might be).

The user interface has been further developed so that MARVIN can understand verbal commands, and respond with a natural voice. The implementation of a security card reader and the ability to communicate with remotely based human security guards gives MARVIN the functionality to perform simple security tasks.

Further work is necessary to unify the software and investigate the public's perception of interacting with MARVIN.

8 Acknowledgements

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