

# CONVERTING A REMOTE CONTROL CAR INTO AN AUTOMATIC GUIDED VEHICLE

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## Abstract

*Recently, a lot of research has been published in the field of Automatic Guided Vehicles. One of the crucial starting points is to decide what base to use for the vehicle. The development of the base seldom forms part of the research and usually researchers try to obtain an existing base to start from. In this paper the possibility to use a remote control car as an Automatic Guided Vehicle base will be investigated.*

## 1. INTRODUCTION

Robots are part of our lives, making many tasks much easier to perform. Especially when it comes to automation, robots are used to do what humans used to do. In a factory a robot might be used to transfer some parts from one location and deliver it to the next location. These robots are called Automatic Guided Vehicles (AGVs).

In this study a remote control car will be converted in order to operate as an AGV base. To complete the AGV, sensors will be added so that the AGV can detect/avoid objects, as well as doing intelligent navigation.

## 2. AUTOMATIC GUIDED VEHICLE BASICS

AGVs were first introduced in the 1950s. An AGV is a “driver-less” vehicle powered by an electric motor and batteries. Initially AGVs were used as tuggers (trailer AGVs) and for carrying small loads. This has changed dramatically; today AGVs can be equipped with tools like robot arms and grippers. AGVs can be different sizes and can carry different loads, from no load up to a few tons. The environment in which AGVs function can differ from air-conditioned offices with carpet floors, hospital hallways, factories with concrete floors and even outdoors working on harbor docksides.

The modern AGV is controlled by a microprocessor and sensors. Several methods of guidance and navigation are implemented. Initially AGVs were guided by using inductive guide wires in the floor. Since it was not always possible to change the environment and install guide wires other methods had to be utilized for guidance and navigation, this includes [1]:

- Laser scanners
- Microwave transponders
- Inertia gyros
- Ultrasonic sensors
- Embedded magnets
- Camera vision

AGVs are normally powered by batteries. To get optimum working time from the AGV, battery

power must be used effectively.

### 3. REMOTE CONTROL CAR

The car being used for this project, is a TAMIYA. See Figure 1 for the remote control (RC) car before any changes was made.



*Figure 1: Remote Control Car*

The car is powered by a 7.2 V 1500mAh NiCd battery. It has one DC motor for moving forward and back and a servo motor for steering. It has a remote control that works at 27 MHz. The receiver unit is the control unit of the car. It transfers the received commands to the motor and servo.

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### 4. HARDWARE

The hardware of the AGV consisted of the following

- DC motor and H-bridge circuit
- Servo motor
- Control unit with a microcontroller
- Bluetooth modules for communication

It is important to have a base that is light; a heavy base will consume too much power [2].

The first step in changing the RC car into an AGV is to decide how the motors will be controlled.

The choice of a motor for an AGV helps to define the capabilities of the rest of the system [3].

- The torque determines the maximum weight of the AGV and the ability of the AGV to go uphill easily. Torque is the force applied to an object on an axle that causes the object to rotate about the axle [3].
- The motors maximum loaded RPM along with the torque, size and weight of the AGV and the wheel size determines the maximum speed that the AGV will be able to travel.

- The motors' voltage determines the battery voltage required.
- The motors, minimum, average and maximum currents will determine the size of the battery needed.

See Figure 2 for an example of a DC motor.



Figure 2: DC motor in RC car

The DC motor inside the RC car is kept as it is, but the speed control of the RC car is replaced by an H-bridge circuit (see Figure 3).

The H-bridge circuit makes it possible to run the dc motor in both directions with only one power supply [3]. The output voltage is controlled by pulse width modulation (PWM).

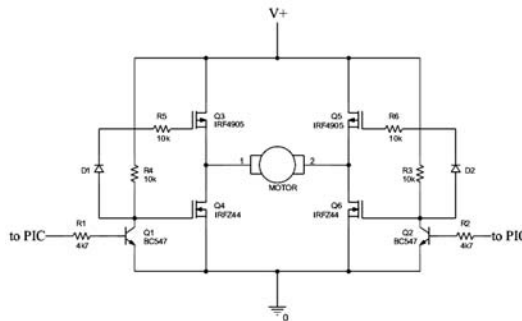


Figure 3: H-bridge circuit.

Only two of the Metal Oxide Semiconductor Field Effect Transistors (MOSFETs) are on at a specific time. If the motor is to turn forward, the one transistor is pulsed and the other transistor is kept at 5 V and vice versa. Short pulses on the base of the appropriate transistor means that the motor is running slowly and longer pulses will make the motor run faster. Pulse width modulation is used to control the amount of current flowing through the motor [4]. The P-channel MOSFETs on top can source power and the N-channel MOSFETs at the bottom can sink power [5].

An H-bridge circuit can be constructed with relays, transistors or Field Effect Transistors (FETs). By using transistors or FETs, it is possible to increase the control of the motor using

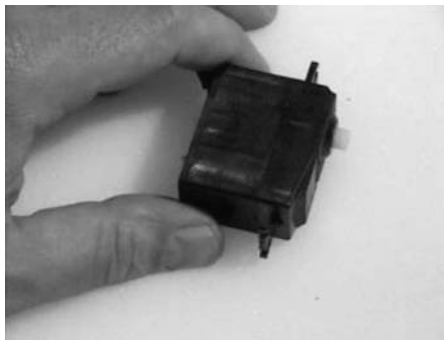
PWM. FETs and transistors can switch higher currents more reliably than relays. When using transistors, diodes should be connected across each transistor (collector emitter) to protect the transistors from the back emf that is generated by the motor's coil when the power is switched on and off. These diodes are called flyback diodes. MOSFETs are much more efficient than transistors as they can provide much more current without over heating. MOSFETs usually have the flyback diodes built in [6].

Motors cause electrical noise. This can be overcome by using capacitors. The capacitors must be connected between the motor terminals and the case of the motor. These capacitors help to reduce spikes at the motor. The capacitors must be mounted directly onto the motor; if it is placed on the circuit board the leads from the motor to the capacitors become antennas that will induce electro-magnetic interference (EMI) [3]. The value of the capacitors must be in the nF range, up to 100 nF and breakdown voltages of 300 V. The capacitors will absorb the energy stored in the inductive windings of the motor.

An AGV needs a controller to coordinate all the inputs and provide the appropriate outputs. Since there will be a lot of different inputs to monitor, a CAN-bus (Controller Area Network) system would eventually be utilized.

A microcontroller (PIC16F876) from Microchip will be used to control the motors and steering of the AGV. This chip was chosen since it has three Timers, USART and it is rewritable. The timers are needed for driving the motors. The USART is needed for RS232 communication between the PIC and the Bluetooth module (HPS-120).

The initial high current drawn by the motor cause the PIC to reset. It was therefore necessary to use two batteries. One battery is used to power the motor and H-bridge circuit and the other to power the control unit and the servo motor. A Futaba S-148 servo motor is used and is shown in Figure 4.



*Figure 4: Futaba S-148 Servo motor*

There are three basic ways to control the speed of a motor, namely:

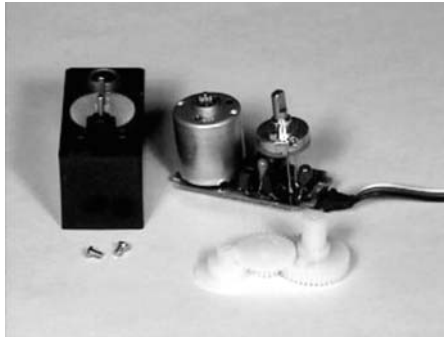
- By using mechanical gears to achieve the desired speed.
- Changing the motor voltage with a series resistor. Using this method reduces the torque and the motor might even stall due to the fact that the motor will draw more current. More current will result in an increase in voltage across the series resistor and thus less voltage across the motor.

- PWM. The amplitude stays constant and the width of the pulses is varied.
- Pulse frequency modulation (PFM). Amplitude constant, turn on time of transistors varied.

One of the biggest problems in delivering power to a load (in this case the motor) is the amount of power that is lost and the heat generated. Since this AGV works with batteries, power loss causes shorter battery life. PWM decreases this power loss. When using PWM instead of applying all the power all the time, a pulse train with a fixed amplitude and frequency is applied. Only the width of the pulses is varied. This will cause the average output voltage to be the same as the input voltage, but with reduced power loss.

For this project PWM will be used by using the Timers of the PIC. Due to the fact that both the DC motor and the servo motor must be controlled from the PIC and that both needs to be pulsed with different duty cycles, it was not viable to use the PWM function of the PIC16F876 since it only has one PWM module.

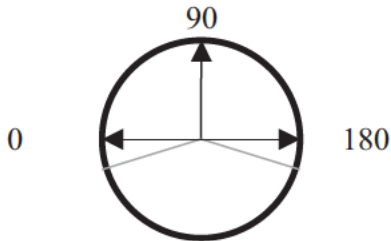
A servo motor is used to direct the AGV. The shaft of the servo can be positioned to a specific angular position by sending a signal to the servo motor. The servo motor is smaller than the DC motor and it has built in control circuitry. The servo motor draws power proportional to the mechanical load. The inside of a servo motor is shown in Figure 5 [7].



*Figure 5: The inside of a servo motor.*

As seen in Figure 5, the inside of the motor consist of the control circuitry, the motor, a set of gears and the case. There are three wires going to the servo, one is for power (+5 V), the ground and a control wire. The amount of power applied to the motor by the control circuitry is proportional to the distance that it needs to travel. This means that if the shaft needs to turn a large distance, the motor will run at full speed and when it needs to turn only a little, the motor will run at a slower speed. This is called proportional control.

The control wire is used to give the commands to the servo motor. The angle is determined by the duration of the pulse applied to the control wire. The length of the pulse will determine how far the motor turns. A 1.6 ms pulse will make the motor turn to the 90 position. If the pulse is shorter than 1.6 ms then the motor will turn the shaft closer to 0 and when the pulse is longer than 1.6 ms the shaft turns closer to 180, see Figure 6. In the RC car the mechanical layout is designed so that when the shaft turns to the 0 position the wheels will turn right and when the shaft turns to the 180 position the wheels will turn left.



*Figure 6: Shaft positions.*

It is simple to control the servo motor with the PIC since, at the beginning it has only three settings: straight, left and right. The servo motor is powered from the control unit (PIC board) with 5 V and one input/output (I/O) pin from the PIC is used to send the pulses to the servo.

The motor on the other hand is different since the speed must vary according to the situation the AGV finds itself in.

## 5. COMMUNICATION

A communication method is needed between different AGVs and between AGV and the user as well as AGV and destinations. Different possibilities are available:

- Infra red communication
- Laser communication
- Radio frequencies
- Bluetooth, etc.

In this project the method used for communication between the different entities is radio signals.

The ideal radio signal should have high speeds, use as little as possible energy and travel far distances. This ideal wave will make data transfer fast (millisecond range) at great distances and will use very little battery power [8]. In reality this is impossible due to the fact that the faster the data travels and the greater the distance, the more energy is needed. It is impossible to achieve the above mentioned simultaneously.

This is why different methods were developed to transfer data, each method with its own advantages. The characteristics of different Wireless Area Networks (WAN) can be seen in Table 1 and typical examples in Table 2 [9].

Table 1: Characteristics of different Wireless Area Networks

Wireless Area Network (WAN)	Range	Power Drain	Transmit speed
Wireless Personal Area Network (WPAN)	10 m	Low	800 Kbps
Wireless Local Area Network (WLAN)	100 m	Medium	11 Mbps
Wireless Wide Area Network (WWAN)	2 - 3 km	High	14.4 - 56 Kbps
Wireless Metropolitan Area Network (WMAN)	30 km	Very High	1.5 Mbps
Wireless Global Area Network (WGAN)	500 - 1500 km	High	64 Kbps

Table 2: Examples of different Wireless Area Networks

WAN	Example
WPAN	Bluetooth
WLAN	Wi-Fi
WWAN	GSM, CDMA, GPRS, CDPD, TDMA
WMAN	Sprint fixed wireless
WGAN	Satellite

Since AGVs are powered by batteries, one of the most important issues to consider was power consumption. In Table 1 it is clear that WPANs uses the least amount of power. This means that Bluetooth should be the obvious choice.

Bluetooth is a wireless technology intended for short range wireless radio links. The primary features of Bluetooth can be summarized as follow:

- Voice and data capabilities
- Robustness
  - Low complexity
- Low power consumption
- Low cost

Bluetooth operates in the range of 2.4 to 2.48 GHz. The advantage of this is that these frequencies will be the same worldwide and any Bluetooth device can connect to any other Bluetooth device in range. Each Bluetooth device can communicate with up to seven other devices. A Bluetooth network is called a piconet. One Bluetooth device can be part of many piconets [8].

The fact that Bluetooth has low power consumption is the only thing that is limiting the range. The only way to have low power consumption is to transmit weak signals, typically in the range of 1 mW. Although this signal is very weak it can still transmit through walls.

In this project the following Bluetooth modules were used (see Figure 7):

- HPS-120 Handywave Version 2
- MSI 6970 Bluetooth dongle



Figure 7: Bluetooth modules

Table 3 shows some specifications of the MSI 6970 Bluetooth dongle [10].

Table 3: MSI 6970 Bluetooth dongle specifications

Baud rate	Up to 723 Kbps
Coverage	Up to 30 m Line of sight
Connection	Point-to-point and point-to-multipoint
Hardware interface	USB
Standard	Bluetooth specification version 1.1
Frequency	2.4 to 2.48 GHz
Modulation	GFSK, BT=0.5
Tx power	6 dBm
Rx sensitivity	-82 dBm
Antenna interface	SMA female
Power supply	+5 V from USB interface
Operation temperature	0 to 75 C

Table 4 shows the specifications of the HPS-120 [11].

Table 4: Specification of HPS-120

Baud rate	Up to 115 Kbps
Coverage	Up to 100 m Line of sight
Connection	Point-to-point
Signal	DCD, TxD, RxD, GND, CTS/DSR, DTR, RTS
RS232 interface	D-Sub 9 pin female
Standard	Bluetooth specification version 1.1
Frequency	2.4 to 2.48 GHz
Hopping	1.6/sec 1 MHz channel space



Modulation	GFSK, 1 Mbps, 0.5BT Gaussian
Tx power	Max 20dBm / typical 16 dBm (class 1)
Rx sensitivity	-84 dBm
Antenna interface	SMA female
Antenna gain	Max 2 dBi
Power supply	+5 V ~ 12 Vdc
Current consumption	Max 110 mA
Operation temperature	-20 to 75 C
Size	35 mm (W) x 65 mm (D) x 16 mm (H)

The HPS-120 is equipped with an antenna and this is the reason for the increased distance. The HPS-120 was fixed to the AGV base and the dongle was placed in the USB port of the PC.

To establish a connection between two Bluetooth devices, the one device must request a connection and the other must accept. Security is very important. The AGV should receive its commands from one point or person only. If the security level was low, any Bluetooth device will be able to communicate with the AGV, this could have a safety risk. Bluetooth has the following methods for security.

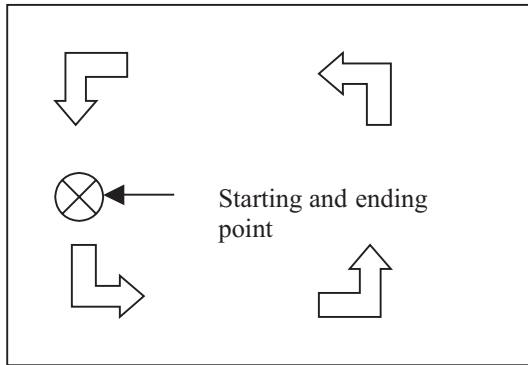
- Authentication is used to verify the identity of the other device; it requires a passkey from the remote device.
- Authorization is a Yes-or-No security, authorization is limited to “yes you may connect” or “no you may not connect”
- Every Bluetooth device has a unique identity or device address. This address is assigned to the device during manufacturing; the Bluetooth Device Address (BDA) is usually displayed in hexadecimal format.
- Link Key is a unique, internally generated, access code. Link keys are generated automatically when devices connect.
- Connected devices share a unique Link Key, which they exchange each time they connect.

The system was setup and tested and reached a distance of 30 m through walls.

## 6. HOW DOES IT WORK?

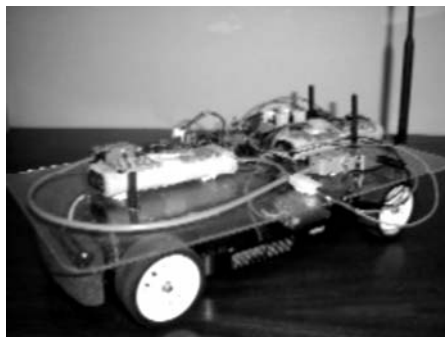
A program was written in C++ for the PIC microcontroller. In the program certain keys on the keyboard were assigned to certain routines. For example “T” was assigned to driving in a square (see Figure 8). The Bluetooth module on the AGV is connected to the PIC circuit with RS232 communication.

When the two Bluetooth devices are connected and the “T” is pressed on the keyboard, the data is transmitted via the Bluetooth link to the AGV. The instruction is decoded and the PIC gives the appropriate outputs to the motors.



*Figure 8: Illustration of the command "T".*

In Figure 8, the AGV starts at the X and travels as indicated by the arrows and then stops again at the X. Any predetermined routine can be programmed into the memory of the PIC and just be activated as required. Another feature is adjusting the speed of the DC motor manually. At this stage the AGV is manually controllable from the keyboard and it can do preprogrammed routines. Figure 9 shows a picture of the current state of the AGV base.



*Figure 9: AGV base*

## 7. BATTERIES

As mentioned, the AGV is powered by two batteries. The one battery was used for the DC motor and H-bridge circuit and the other battery for the servo motor and the control unit. The batteries used are two 7.2 V 1500 mA AH NiCad batteries. If a battery is rated at 1 AH, it means that the battery will be able to supply 1 A for one hour or 0.5 A for two hours [7].

## 8. FUTURE WORK

Further research is necessary to successfully change this base into an AGV.

As additional sensors are added for object avoidance and intelligent navigation, the Bluetooth interface is only going to be utilized for system monitoring and as a safety measurement; manual stop or manual override.

Further work will entail the following:

- Adding sensors for object avoidance
- Finding a method of navigation.

## 9. REFERENCES

1. JH Cohn, Distributor's Edge, AGVs: An unbeatable choice for warehouse operations, November, 2004.
2. C Svård, D Vikenmark, P Saidra, LARS, Robotics and Autonomous Systems, Stockholm, August, 2003.
3. Silicon Valley, HBRobotics Club Builders Book, HomeBrew Robotics Club, 2004.
4. M Barr, Introduction to Pulse Width Modulation, Embedded.com, [www.embedded.com/showArticle.jhtml?articleID=9900283](http://www.embedded.com/showArticle.jhtml?articleID=9900283), 2001.
5. C McManis, H-Bridges: Theory and Practice, Robotics Notebook, [www.mcmanis.com/chuck/robotics/tutorial/index.html](http://www.mcmanis.com/chuck/robotics/tutorial/index.html), 2002.
6. J Brown, B Jordan, Brief H-Bridge Theory of Operation, 2002.
7. Seattle Robotics Society, What is a servo?, [www.seattlerobotics.org/guide/servos.html](http://www.seattlerobotics.org/guide/servos.html), 2004.
8. LXE Inc, Bluetooth Basics, EMS Technologies Company, 2001.
9. M Mann, Bluetooth and Wi-Fi, Socket Communications, March 2002.
10. Micro-star International, BToes Bluetooth USB Dongle, 2003.
11. Handywave Co, HPS-120 User Manual, Republic of Korea, 2001.