

**KELVIN: A Second Generation Land Vehicle**  
2002 Florida Conference on Recent Advances in Robotics  
May 23-24, 2002, Florida International University

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**Keywords:** Autonomous Navigation, Robotics, Linux

### Abstract

*Kelvin is a four-wheeled land-based robotics research platform in development at the Machine Intelligence Lab at the University of Florida. The purpose of this project is to design a robust control and navigation system capable of both autonomous and semi-autonomous operation. The vehicle is about the size of a golf cart and is designed to operate on moderately flat terrain. It is highly agile with its adapted Ackerman's steering system, and can sustain speeds greater than 10mph. Kelvin is an electric vehicle carrying independent power supplies for both its motors and computer systems. The controlling on-board computer runs Linux and coordinates the operation of the entire system. It is interfaced directly to the actuation computer and the sensors. Two cameras, a digital compass, and global positioning system are the primary navigational sensors.*

### 1. Introduction

Autonomous vehicles have applications in all walks of life. The challenge of creating a vehicle that can perform simple driving tasks and complete goals without any human intervention is a difficult one. Along with these the vehicle must also be safe, reliable, and able to deal with unpredictable stimuli. Kelvin is being developed at the Machine Intelligence Lab at the University of Florida as a proof-of-concept vehicle. It shows that we can build human sized vehicles capable of simple driving tasks that are reliable, safe, and highly portable.

Kelvin's control systems are modular and can be broken down into three major categories: the sensor system, the actuation system, and the communication system. These systems are coordinated and controlled by a central computer running the Linux operating system. The control system is designed to be scaleable and portable. These systems are also modular and easily modified.

In addition to navigation and computer vision, modules for complex path planning and terrain mapping technologies can be readily integrated into the system.

From a mechanical standpoint, Kelvin is a road-based vehicle about the size of a golf cart. It uses a simple Ackerman's steering model, electric drive motors, and an electro-magnetic braking system. Kelvin has all of the features of an on-road vehicle including signal lights, brake lights, and headlights.

### 2. The Mobile Platform

#### 2.1 Frame

Kelvin's frame, shown in Figure 1, is constructed of welded steel bars. Sheet metal is used to line the underside and the otherwise open areas of the frame. The back end of the vehicle is mounted on a center axis swivel, which allows 40 degrees of tilt in either direction. The electronics are mounted in a cradle in the bottom of the frame. The systems are on two different levels within this cradle.

Two batteries systems are used in Kelvin. The motor battery system is a bank of two 12-volt marine batteries in series to produce 24 volts. The integrated systems battery is a 12 volt 17.3 amp-hour power source. This battery powers all of the computer systems and the steering servo.

Kelvin uses rubber golf cart tires, directly connected to the two 24 volt motors. The motors pull current through microprocessor controlled motor drivers. The motor drivers provide speed regulation and also control direction of the motors.

#### 2.2 Steering System

Kelvin's steering system uses a servo that has a stall torque rating of 27 ft-lbs of torque. The actuation computer using standard Futaba servo

control signals drives the steering servo. This servo requires an external 12V power source. The power to the servo is provided from the computer power supply independent of the motor power.

A steering linkage system was reconstructed to adhere to the Ackerman's steering model using parts from a 1985 Toyota Corolla. The steering servo is connected to the molded steel linkages by an aluminum flange. This flange is intentionally low tolerance. A weak link in the steering linkages was created so in the event of a collision the fault location would be predictable, and could be planned for.

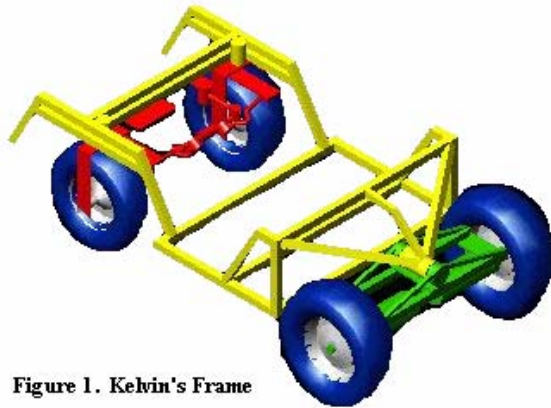


Figure 1. Kelvin's Frame

### 2.3 Ackerman's Steering

Ackerman's configuration, shown in Figure 2, is a mechanical system which allows the inner turning wheel to turn at a larger angle than the outer turning wheel. Geometrically the front wheels of a car, if both are following a circular path around a common center point, must turn at slightly different angles. The inside wheel must angle in more than the outside wheel. If the turning wheels are not properly aligned they will fight each other causing increased friction and wear. By increasing the inner wheels turning angle steering agility is greatly increased.

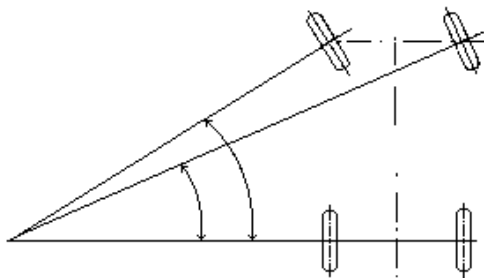


Figure 2. Ackerman's Model

### 2.4 Drive Motors

Two 24V planetary gear motors are bolted onto the rear of Kelvin's frame. The motors are capable of both forward and reverse operation. Each motor contains a shaft encoder and a tachometer. These two features are not being used at this time because the other navigational systems are far more accurate for the applications of the vehicle.

## 3. The Integrated Systems

### 3.1 Control Computer

Kelvin's onboard computer is the control center for the robot. The onboard computer provides fast processing, large amounts of data storage, and a means for remote monitoring. This control computer is interfaced directly to the control systems and fully capable of autonomous operation. Kelvin's control systems, shown in Figure 3, are modular and can be represented in three different categories: the sensors system, the actuation system, and the communication system.

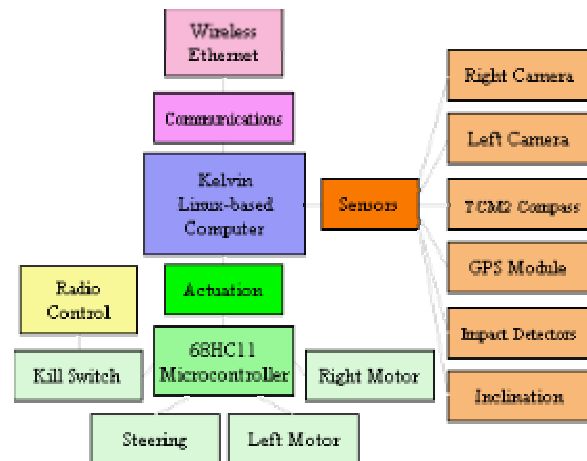


Figure 3. System Integration

#### 3.1.1 Hardware

The control computer is based on the AMD K6-3 processor. The system has 64 megabytes of RAM and a 2 gigabyte hard disk drive. The computer provides 4 serial ports, 2 USB ports, and a parallel port. It also has an onboard video device and 2 PS/2 ports. The wireless ethernet capability comes from PCMCIA cards, which use a PCI bridge adapter. They are ZoomAir 4105 cards based on the Intersil Prism II chipset. These cards have external antennas.

#### 3.1.2 Linux

Linux was chosen to operate Kelvin's control computer because of its stability, easy customization, simple network integration, true multi-tasking, and its near real-time precision. The

control computer runs Mandrake Linux version 8, and is using Linux kernel 2.4.3. The kernel was custom compiled to reduce its memory footprint. Much effort was taken to optimize the loaded daemons and various other parts of the start-up scripts. The rest of the Linux core and system customizations are beyond the scope of this paper.

Kernel modules are used extensively to add and remove support for devices on the fly. The supported devices are the video frame buffer, the serial ports (GPS, Compass, Actuation Computer Interface), the USB ports (Digital Cameras), and the PCMCIA bridge (Wireless Ethernet).

Portability was also a very important factor when choosing Linux. All code built on this platform is portable to almost any \*nix based system.

### 3.1.3 Independent Power Supply

All of the integrated systems of Kelvin have a common power supply which is separate from the motor power supply. The independence of the power supplies provides a method for remote access to the computer systems in the event that the power electronics must be shutdown. This is also a safety measure and a feature to provide for data integrity in the event of a catastrophic failure of the actuation systems.

## 3.2 Sensors

Two cameras mounted on the front of the vehicle provide the primary inputs along with a digital compass and a GPS receiver. The compass has a built in sensor for inclination and temperature. Impact detectors are also used to detect collisions. The images sent back to the computer from the cameras are analyzed to extract relevant information. Both the GPS and the compass provide static navigational references. It is the eventual goal of this project to provide the ability to map terrain topology through the use of stereovision and precise navigational techniques.

### 3.2.1 Cameras

Two cameras are mounted on the front of the vehicle. The cameras can function in two modes. They can operate as video cameras and spool real-time information, or they can operate as frame grabbers, only taking pictures when requested.

The cameras are Kelvin's primary close range navigational sensors. Obstacle avoidance and recognition will be performed with the cameras.

Ezonic EZCam USB cameras are being used. They are based on the ST Microsystem's CPiA Vision chipset and provide high color 352x288 resolution images at 24bpp. The CPiA chipset is well supported in Linux.

### 3.2.2 TCM2-50 Digital Compass

The TCM2-50 is a high performance, low-power electronic compass module. In addition to compass heading, the TCM2 also supplies highly accurate pitch (up to +/-50 degrees), roll (up to +/-50 degrees), magnetic field data and temperature information.

Ferrous metals have a tendency to exhibit magnetic properties over time when in the presence of constant magnetic fields. Kelvin's frame is constructed of metal and can cause interference by misdirecting and possibly magnifying the magnetic compass readings.

The TCM2 uses advanced electronics and correction algorithms to counter the effects of hard and soft iron interference, enabling it to maintain a high degree of accuracy.

### 3.2.3 Rand-McNaly GPS Receiver

Kelvin's control computer is going to use waypoints as a means of implementing goal based navigation. These waypoints correspond to a latitude and longitude somewhere on the within its realm of operation.

The Rand-McNaly GPS receiver outputs NEMA data in 6 standard formats every second. NMEA-0183 data is transmitted as comma-delimited ASCII at 4800 baud. Messages are limited to 79 characters. These messages start with a "\$" character, and end with a carriage return line feed pair. GPGGA and GPRMC are different messages output by the GPS receiver. The output is parsed from the serial port. GPGGA provides the current time, latitude, longitude, and number of visible satellites. GPRMC data is used as verification of GPGGA data. It provides a second source of location data.

The location data provided by the GPS receiver is accurate +/-5 feet. This amount of error is small enough that once the vehicle has reached its location other close range sensors (the cameras) can be used to reach the more accurate goal if one is specified.

### 3.2.4 Impact Detectors

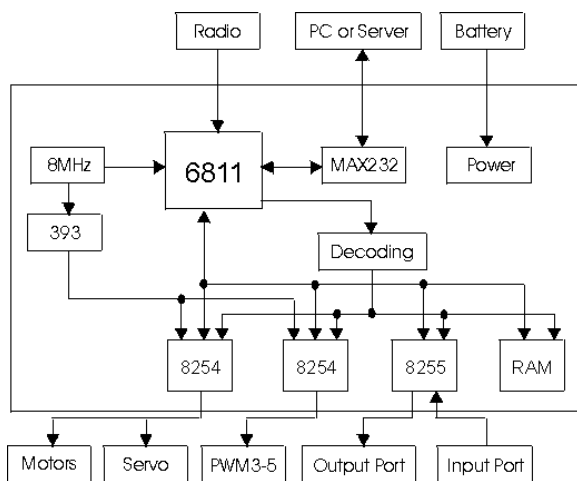
The impact detectors that line Kelvin's frame are essentially reinforced switches, which will trigger if the vehicle comes in contact with another object. They are basically interrupts that trigger reaction by the control computer.

## 3.3 Actuation System

The actuation system is built around a Motorola 68HC11 microcomputer. Although this processor has the ability to directly drive and monitor external hardware, additional hardware was added to supplement the 68HC11 and free the processor for

other tasks. Along with 64k of non-volatile SRAM and efficiently written C code the 68HC11, 8254 timer and 8255 PPI chips provide an abstraction layer to the low-level hardware of the system.

The 68HC11 microcomputer is interfaced via a serial port to the control computer. The 68HC11 receives commands over the serial link and responds with confirmation. The 68HC11 then passes control to the 8254 and 8255 for direct interface to the motor drivers, (which control the speed and direction of the motors) the steering servo, and the kill switch. Figure 5 shows a block diagram of the subsystems.



**Figure 5: Actuation Block Diagram**

All of the various components will be placed on a printed circuit board. Most of the chips can be purchased as surface mount devices, which will reduce the size considerably.

### 3.3.1 8254 - Programmable Interval Timer

The 8254 timers can be programmed for six modes of operations. Two of the modes can generate the required PWM signals. One of the counters generates the period of the remaining counters. Sending data to each counter's control register controls the duty cycle of the remaining counters. An additional digital output signal from the 8255 and the PWM from the 8254 control not only the speed of the motors but the direction of each motor as well.

### 3.3.2 8255 – Programmable Peripheral Interface

The I/O interface consists of a 8255 PPI chip. The 8255 can be programmed to make various pins on the chip either inputs or outputs. Killing Kelvin's motors occurs whenever one of the inputs is active high. One the outputs drive an LED showing the status of the motors. The outputs are also used to drive programming signals to the 8254 timer chips.

### 3.3.3 Kill System

The kill switch exists as a fail-safe measure against dangerous situations. By default and in the event of signal loss the switch is disconnected. This classifies the kill switch as a dead man's kill switch. The switch allows Kelvin's users to disconnect the motors and engage the brakes remotely stopping the vehicle, but leaving all of the control systems running. This remote radio signal is independent of the vehicles wireless communications system.

An R/C radio was used as the kill switch. When the radio is on, a steady 21.25ms PWM signal is detected by the receiver. When the receiver is out of range or turned off, the receiver signal becomes random and erratic.

The algorithm for finding the state of the kill switch is simple. The 68HC11 detects the 21.25ms pulse from the radio using the Input Capture system. When 3 periods are calculated the 68HC11 determines if two of the periods are the same. If all periods have different elapsed times then the car's motors are killed. If the motors are killed a red LED signal is generated on the PCB. The board can be reset without disturbing the current state of Kelvin's main computer.

### 3.3.4 Interfacing the Actuation Computer

The actuation computer is interfaced directly to the control computer through a serial link. This computer has its own instruction set. The instruction set is composed of 4 byte instructions. The actuation computer continuously monitors its serial link looking for the two start bytes of a new command. The two start bytes are then followed by a system byte and a command byte. Once a full instruction is received the actuation computer parses the input stream for the command details and sends a signal back to the control computer. This acknowledgement could be requested data or an echo to confirm an important command.

### 3.3.5 Motor Drivers

Kelvin's motor drivers, shown in Figure 4, were designed in house at the Machine Intelligence Lab using printed circuit board software and a circuit prototyping machine. The motor drivers use 24 volt relays rated at 40 amps each to change polarity at the motor terminals and thus the direction. Motorola 75N03 Power MOSFETs, rated at 75 amps, are employed to amplify the pulse-width modulated and digital signals from the 68HC11 actuation computer. These two signals control speed and direction, respectively.

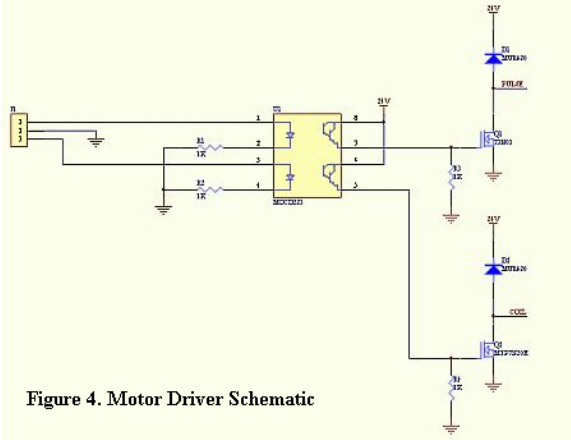


Figure 4. Motor Driver Schematic

The signals originate from the actuation computer as TTL levels. An opto-isolator is used to both protect the actuation microcontroller connected to the motor driver and to raise the voltage of the digital TTL level signals to 24 volts. External protection diodes are present to protect the MOSFETs from high voltage swings cause by constant switching of the motors.

### 3.4 Communication

Communication with Kelvin is established through ad-hoc wireless Ethernet using the 802.11b standard. With a theoretical maximum throughput of 11 Mb/s and an average throughput of about 4Mb/s remote administration and monitoring is possible. The range of the wireless signal is about 50 meters indoors and about 100 meters outdoors.

Remote command and monitoring is done through TCP/IP networking. A control program running on a host machine with a wireless connection must initiate a connection with Kelvin through a specified remote port. After a connection has been negotiated a channel is open for communication with the vehicle. Commands can be issued, and system status can be monitored.

Remote administration is accomplished by logging into the vehicle using a protocol such as SSH or telnet. Linux provided remote access to any system resources. Individual systems can be shutdown or restarted if necessary. Also data can be retrieved manually by FTP or another transfer protocol.

### 4. Control Software

The software which runs on Kelvin uses a client/ server model. The server daemon when running accepts TCP/IP commands and is in control of all of the running hardware systems. This server can accept multiple remote connections

simultaneously. This is useful for observing the system while it is being operated.

The client software is both command-line and GUI based. The GUI portion is written using GTK+. The GUI client provides all of the organized sensor data, including the camera image. It also uses buttons to start and stop the running systems. This basically functions as a remote control panel. The command-line client was designed for testing, or for issuing single, simple commands to the system.

Since we are using standard TCP sockets client software could be developed for many platforms. Web-based control software is being developed to make CGI calls to the command-line client.

### 5. Conclusion

The challenge of creating a robust control and navigation system to drive a vehicle without human intervention is a difficult one. Kelvin is a successful autonomous and semi-autonomous land-based robotics research platform, which is presented as a solution to that challenge.

Kelvin's system architecture is robust and easily portable. Along with this the vehicle is also safe, reliable, and able to deal with unpredictable stimuli.

Kelvin is the foundation on which other vehicles constructed at the Machine Intelligence Lab will be based upon.