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M3S SYSTEM PROTOTYPE – A COMPREHENSIVE SYSTEM WITH STRAIGHTFORWARD IMPLEMENTATION

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Abstract—**There is a growing demand for powered wheelchairs to provide mobility for people with upper-limb impairments, i.e., individuals suffering from cerebral palsy, paraplegia, or multiple sclerosis, and others who may depend on a human-friendly wheelchair to conduct their daily activities. The design of the Multiple Master Multiple Slave ("M3S") architecture provides a flexible system in which individual devices can be added or removed to accommodate specific needs. The M3S provides a two-level safety system for each device. The two levels are a central safety monitor and the two independent wired-OR safety lines connected to each device on the bus, and the system is configured such that in the event of failure, system shutdown can be independently enabled at each separate safety level. We have implemented a prototype with DSP cores and additional circuitries that provide safety enhancements to the M3S protocol, and configured the input subsystems and output prime mover to fit into this novel system.**

Keywords—**M3S, safe mobility, powered wheelchairs**

I. INTRODUCTION

ADVANCES in medical technology and improved medical care have drastically reduced the death rate but have resulted in an increase in the number of individuals that require use of autonomous wheelchairs. These intelligent and autonomous vehicles provide the severely handicapped with easier mobility, thus enabling such individuals to overcome physical challenges and leading to significant improvements in their physical, cognitive, commutative, and social skills.

M3S is an international standard recognized by the International Organization for Standardization (ISO). It is an integrated system based on a modular architecture that provides the option of putting together a variety of electronic modules in a mobility system (Fig. 1). The open architecture M3S bus makes it possible to hook up various output devices such as wheelchair motor controllers, environment control units, manipulators [6], or wireless devices to a wide range of input devices like joysticks, keypads, head-control modules, speech recognizers, and allows extensions to laptops and home-busses if desired.

The "modular" feature [1] of the M3S system allows designers of such systems to meet the varying demands of a wide range of users and to accommodate users with varying degrees of handicap or whose gradual recovery or deterioration of health might require corresponding decrease or increase in system capability.

The main theme of this paper is to present a viable alternative to simplify the process of modifying or expanding an M3S based system via addition or removal of wheelchair components [2-5]. The procedure allows flexible use of wheelchair components to make various adaptations to the M3S system to meet the specific needs of an individual user while maintaining optimal control and high levels of safety and reliability.

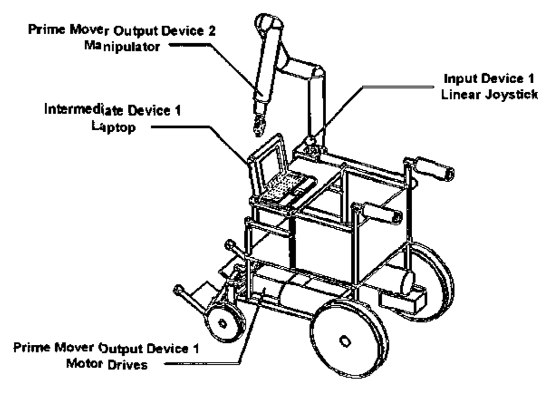

Fig. 1. An integrated system based on modular architecture

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II. System Architecture

An M3S system is based on a bus and several devices. The bus is composed of three components: a CAN bus with two lines for digital communication [7], a SAF bus with two lines for additional safety and a POW bus with two lines for power support. This bus is then linked to M3S compatible devices including the system monitor, a control and configuration module (CCM) (Fig. 2).

1) CAN bus:

The controller area network (CAN) bus uses a multi-master serial protocol that was originally developed for automotive applications. It has a very high level of data integrity and sophisticated error detection mechanisms, which permits efficient support of distributed real-time control functions and fast transmission speeds of up to 1 Mbps for data communications within a 40-meter range.

The CAN bus uses an arbitration protocol that does not communicate with nodes by directing messages to specific physical addresses but instead broadcasts messages each with an identifier code that can be recognized by all nodes. This identifier determines whether a transmitted message will be received by any particular module on the CAN bus as well as the priority of message transfer when two or more nodes are simultaneously competing for transmission. Data is now processed and digitalized locally before being sent through simple twisted two-wire lines. Prioritized messages of up to eight bytes in data length can be sent.

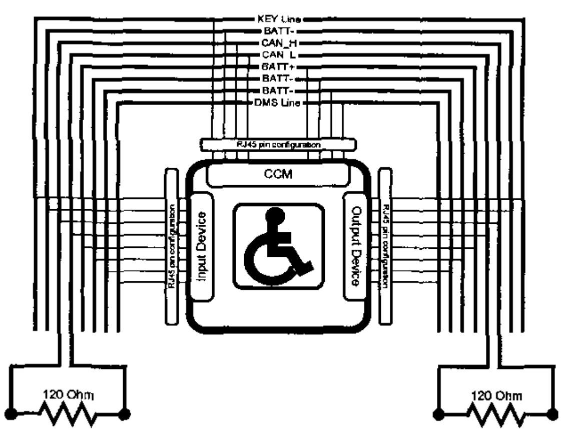

Fig. 2. M3S System Architecture

2) SAF bus:

The SAF bus consists of two signal lines (KEY and DMS) that are coupled to the basic CAN two-line communication channel for extra safety. These lines function independently of the CAN bus and microprocessors of all terminal devices. Set forth below is a description of their functions:

1. Key Switch Function: The key switch function oversees the power supply for each device; it consists of the KEY line, KEY_ON and KEY_OFF switches and the circuitries in the devices. The KEY_ON switch is used for starting up the entire system. When enabled, limited current is supplied to the key line, which signals the local power circuitry of each device to operate. When the KEY_OFF switch is activated, it connects to the negative power supply terminal, cutting off power to all devices. The KEY line makes it possible to turn the whole system on or off by means of any input device with a key switch, however, only one should be active at any time. This allows the user to regain control of the system quickly in the event of a mistake and a helper to turn the system on or off immediately in case of emergency.

2. Dead Man Switch Function: All safety-critical motion control devices are equipped with the dead man switch (DMS) function. This functional module consists of the DMS line, dead man switches and the circuitries for power supply management of safety critical devices. The DMS line is activated upon receiving positive feedback in the form of an action. When the action returns to neutral, the DMS line deactivates, cutting off the power supply to safety critical devices such as motor drives. The DMS module requires a higher safety level than the key switch as turning the DMS module off does not require a positive action on the part of the user. The DMS signal should be independent of the drive signal and like the key switches; only one DMS should be active at any time. There should be no interconnection between the DMS line and KEY line.

3) POW bus:

The battery device supplies power to each device on the M3S bus through the two power lines (POW), namely, the BATT+ and BATT-.

4) CCM:

The control and configuration module (CCM) is responsible for configuring the system and for monitoring safety. Each device on an M3S bus should contain a stored system configuration, which describes the specific behavior of each device in a format that can be understood by the CCM. The CCM also transfers data to and from other devices through the CAN bus. A fully functional CCM controls the system at initialization, task management and device activation/deactivation. We are working on a pre-configured CCM for a general M3S system with the following features:

1. Task Management: The configuration and control function of the CCM has the proficiency to start different tasks within the M3S system, for example, to operate a wheelchair using voice control. The CCM uploads the configuration information from the devices involved, inputs or outputs are matched with the relevant degrees of freedom (DOFs) and then transferred to data signals that devices could communicate on the M3S bus. The CCM also determines the priority status for each task.

2. *Safety Monitoring:* The system safety monitor CCM checks for overall safety status and receives confirmation from individual device safety monitors as to whether each individual device is in its proper condition. The CCM checks the status of disabled devices once per second and enabled devices each tenth of a second and will take proper action to halt the system when serious faults occur. The CCM also monitors the status and connections of the DMS and KEY lines (Fig. 3).

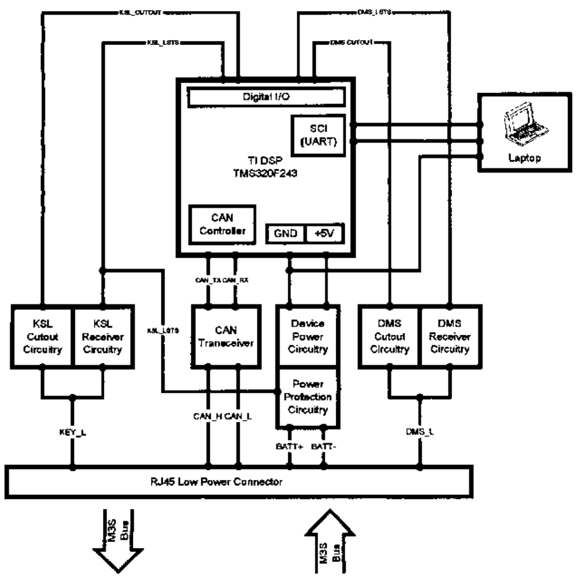

Fig. 3. CCM connections with KSL and DMS circuitries

III. Circuitries For M3S Physical Medium Attachment

Input and output devices with circuitries that allow correct attachment to the M3S Physical Medium are utilized for this application, along with the Texas Instrument TMS320F243 DSP controller as the core processor [8].

1) Input Devices:

Joysticks are often used as input devices for powered wheelchair systems, and can either be discrete or linear [9]. Like switches, discrete joysticks give digital commands in response to discrete outputs. The output of a linear joystick depends on how far the joystick is pushed away from the center position. A pair of variable resistances or inductances is used to signal the position, and a dead-zone is incorporated to differentiate desired input signals from undesired tremors or any other involuntary movements [10].

Most users are able to operate the wheelchair with a joystick, however, for quadriplegic users or users with severe spasticity, an alternative control method should be considered [11], for example, head-control [12]. Head movements are coded as the following commands: forward, backwards, left, right, forward left, forward right, backwards left, backwards right, idle. Commands are sent to the DSP, which generates CAN signals for bus transmission and is received by the target output device. A centrally located dead-zone area allows the user to rest and relax properly after prolonged movement.

The block diagram shown on the next page is the operation of an M3S input device (Fig. 4). Pushing a KEY_ON switch sets the key switch latch, directing BATT+ to supply a limited current through a protection circuitry to the KEY line of the M3S bus. The key switch latch status is read from the KSL_SW_STS signal and isolated from the KEY line so that the CCM can detect faults and turn off the system when the KEY line is short-circuited to BATT+ while no KEY_ON switch is set on any device of the whole system. A C2D_KSL_RESET message is sent through the CAN bus to reset the key switch latch of that certain device. When a KEY_OFF switch is set or the KSL_CUTOUT signal is applied, the KEY line is short circuited to BATT-, which calls for the system to shut down.

A LCD panel connected to the Serial Communication Interface will show the working status of a device.

2) Output Devices (Prime Movers)

A general output device is the safety critical prime mover, which contains, in addition to proper M3S compliant circuitry, an integrated H-Bridge configuration to provide better control of and power efficiency for the motor drive [13] (Fig. 4). The optical encoder block consists of a slotted disk to scan the movement of the motor and interface with the quadrature encoder pulse (QEP) circuit of the DSP to obtain position and speed information.

To control the speed of the motor, the locked anti-phase PWM consisting of variable duty-cycle signals that encode both direction and amplitude information is applied to a single input logic gate of the H-Bridge circuitry. The current sensing feedback mechanism measures the load of the motor and will switch it off if the rotor jams. An embedded watchdog timer monitors the DSP function, and will reset the system upon disruption of the CPU. The DMS transmitter circuitry supplies a limited current from the BATT+ when both the KEY line is active and the input DMS is on, the prime mover device is then enabled by the C2D_ENABLE_DMS message from the CCM.

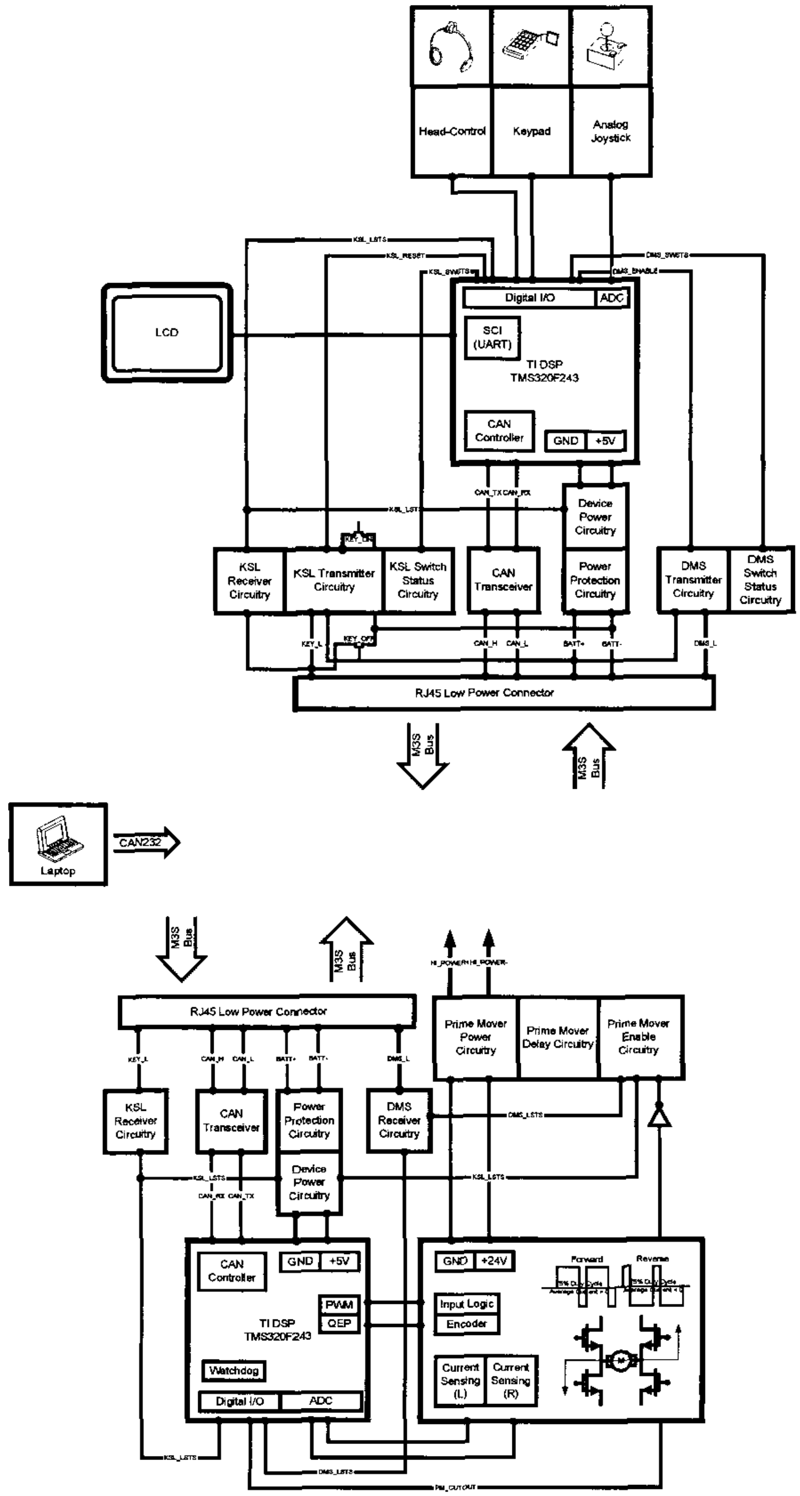

Fig. 4. Design of input and output devices

IV. RESULTS

The physical layer for each device and the attached signal medium retain the properties specified in the CAN standard ISO/DIS 11898 and the specifications of M3S enhancement on safety lines [2]. Signal monitoring is conducted using a LAWICEL CAN232 dongle, which provides the laptop COM port with CAN connectivity. We developed a CAN monitor software with M3S message responses to send and receive standard CAN frames of M3S at various transmission speed. (Modified from freeware by John Dammeyer, COM port Library by Dejan Crnila) (Fig. 5, Table 1).

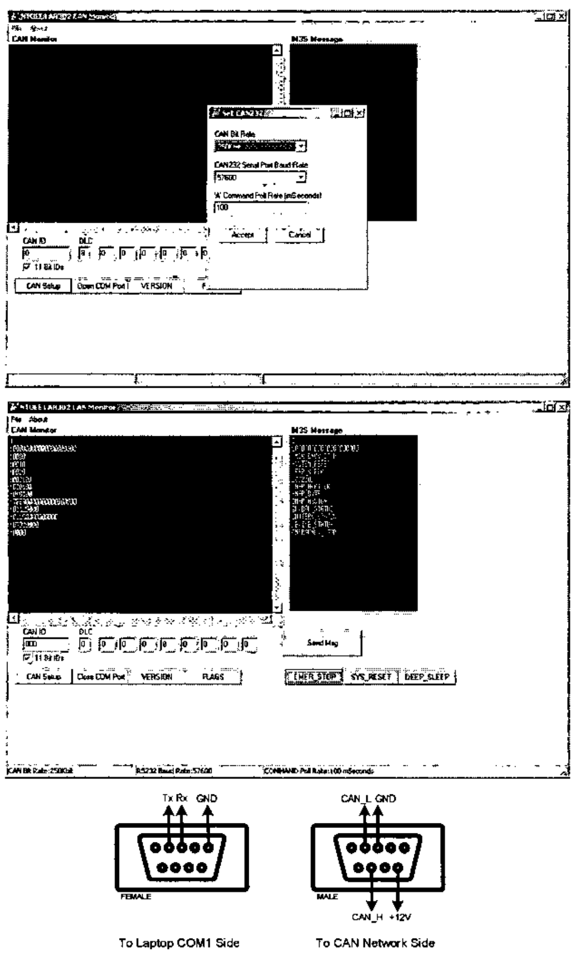

Fig. 5. The M3S monitor with CAN232 dongle

The device power test verifies if the power supply reaches the nominal battery voltage of 24V (lead-acid batteries), a power supply of less than 20V would register as being inactive. KEY and DMS circuitries have been modified for full compliance with each physical layer on the M3S bus.

TABLE I

M3S MESSAGE TRANSFER ON CAN BUS

	NAME	CAN ID	DATA LENGTH CODE
1	EMERGENCY_STOP	0x000	0
2	SYSTEM_RESET	0x001	0
3	DEEP_SLEEP	0x002	0
4	SNAP_ARBITER	0x020	1
5	SNAP_STEP	0x7EF	1
6	SNAP_BYTE	0x040 ~ 0x07F 0x0C0 ~ 0x0FF 0x140 ~ 0x17F 0x1C0 ~ 0x1FF	0
7	SNAP_ASSIGN	0x7EE	8
8	GLOBAL_STATUS	0x021	2
9	BATTERY_STATUS	0x022	5
10	DEVICE_STATUS	0x080 ~ 0x0B9	2

The CAN network-wiring topology suggests that stub connections should be avoided and devices should be kept as close as possible to a single line structure to reduce cable reflected waves. The 120Ω terminating resistors are kept separately from the terminal devices to avoid bus disturbances when one of the two devices is to be disconnected

V. CONCLUSION

The prototype has been designed with the objective of building a versatile base model to allow addition or removal of modules by individuals with minimal technical expertise. Communications take place via the bus by means of head movement controls and preprogrammed analog joysticks. Safety-critical devices are hardwired with DMS circuitry to provide additional safety mechanisms independent of the CCM CAN bus control and the DSP watchdog.

Users that suffer from greater degrees of disability are more likely to use input systems that allow discrete commands to be issued via a tree menu, which provide greater control over the user interface. Such systems may be designed by means of a generic device without complicated adaptations. User-dependent isolated word recognition will also be developed with a DSP core.

Navigation tasks under development include developing a number of intermediate devices having dual characteristics of input (sensory) and the output (response) communications, which will allow disabled users to partially decouple from the system.

The M3S system can also communicate with other bus systems and devices through wireless links and can easily be utilized to maintain a domotic network [2,14].

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