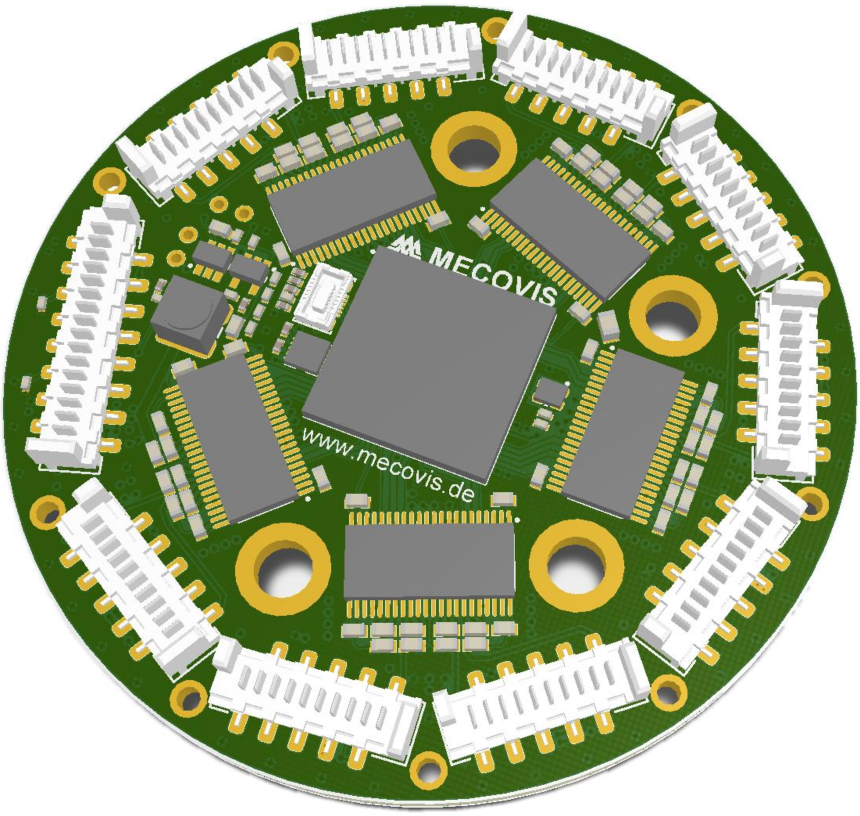


Mecovis S5FH-Controller

User's Guide

Contents

Introduction

The Mecovis S5FH-Controller is a highly integrated electronics, which has been specifically designed to control the SCHUNK 5-Finger Hand. It contains power electronics for driving the motors, sensor interfaces for reading position feedback, a high-performance motion controller, and a communication interface to a host PC. All components are integrated on a circular-shaped board which fits into the wrist of a robot.

By using the Mecovis S5FH-Controller, the wiring harness to the robot hand is significantly reduced. Only a single power supply and a communication link need to be wired to the hand.

The communication between host PC and control electronics uses a simple packet-bases protocol. The communication protocol is described in detail in this documentation and can be implemented in any programming language.

Features

9 power outputs (5x 24V, 4x 12V), very high switching frequency, high dynamics for haptic devices, over-temperature protection

9 differential encoder inputs

5 A/D-converters to connect additional sensors, e.g. force sensors

communication by RS485 (up to 3 MBps full-duplex), high control loop rates for haptic devices

single supply voltage (24V), internal DC-DC converters

integrated FPGA, high speed, quasi-continuous control, floating point precision

Hardware

This chapter provides information about the mechanical, electrical, and functional properties of the Mecovis S5FH Controller.

Overview

The Mecovis S5FH Controller integrates nine power stages, nine encoder receivers, five analog inputs, an RS422/485 communication interface, several DC/DC-Converters, and a powerful controller on a small circular-shaped board.

In Figure 1, a block diagram of the S5FH Controller is shown. The connectors on the left-hand side must be wired to the host, while the connectors on the right-hand side are internally wired to the SCHUNK 5-Finger Hand. The individual blocks are described in detail in the following sections.

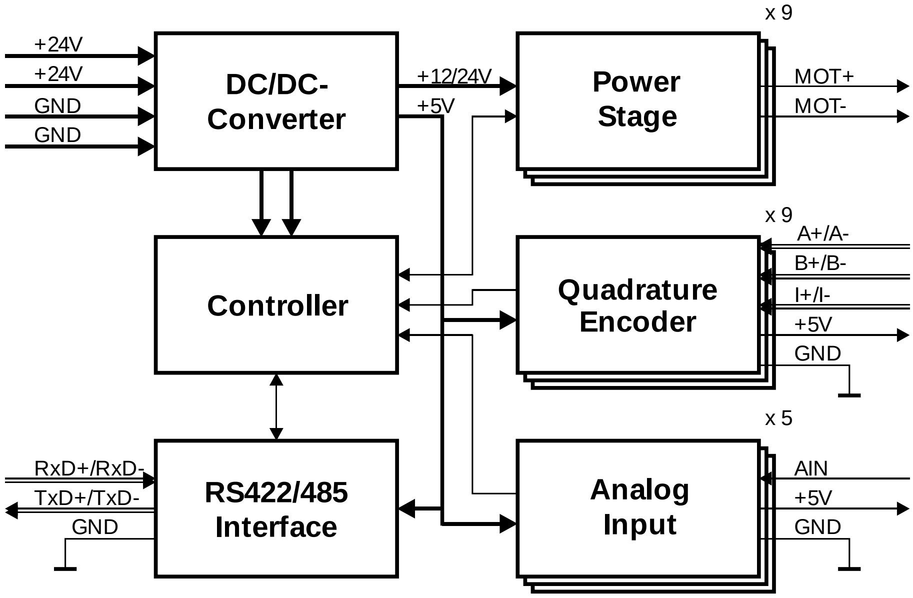


Figure 1: Block Diagram of the Mecovis S5FH controller

Power Stage

The Mecovis S5FH controller has nine power stages in total. Five are directly connected to the externally provided 24 V power supply; four are connected to the internally generated 12 V power supply.

A simplified schematic of a single power stage is shown in Figure 2. The power stage has a full-bridge configuration implemented with four monolithically integrated MOSFETs and anti-parallel diodes.

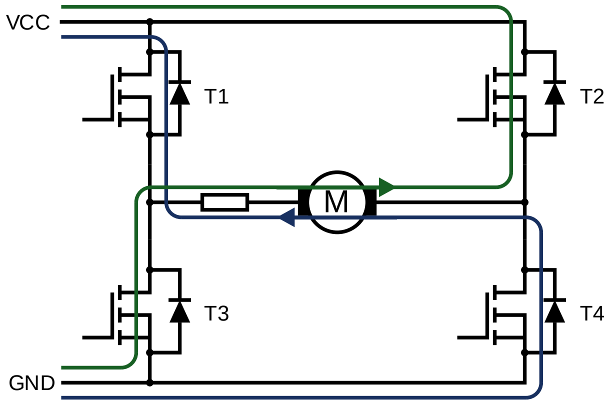


Figure 2: Block Diagram of a single power stage

By activating either the pair T1-T4 or the pair T2-T3, current can be driven in both directions through the motor. The MOSFETs are activated using pulse-width modulation in order to control the magnitude of the current in the motor windings. Due to the very high switching frequency of the power stage, the ripple current can be held small even with small motor inductance.

A series current shunt resistor is implemented to allow measuring the motor current.

Quadrature Encoder

Quadrature Counter

Quadrature Encoders are a type of incremental rotary encoders. They use two square waves which are 90 degrees out of phase in order to track the motion of a motor shaft. Additionally, an index signal is provided, which can be used as absolute reference.

The working principle is illustrated in Figure 1. The two binary signals A and B form four states which are repeated in a cyclic sequence. From each state, two transition to neighboring states are possible. One of these transitions occurs in case of movements in positive direction, the other one occurs in case of movements in negative direction. By observing the transitions and counting the positive and negative steps, the position of the shaft can be exactly tracked.

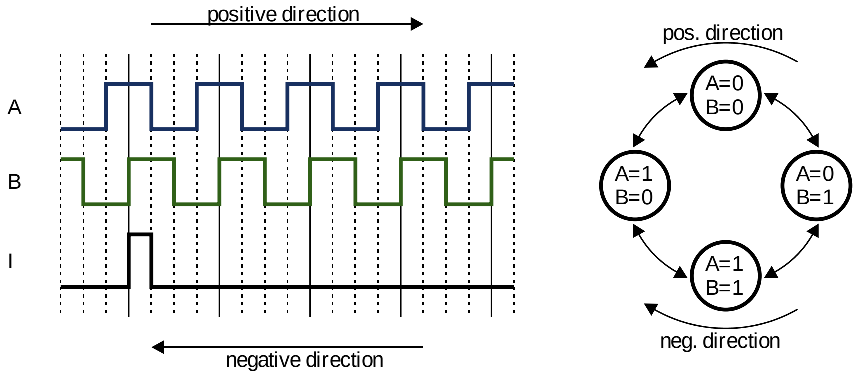


Figure 3: Signals of a quadrature encoder

Failure Detection

As the encoder signals are run close to the motor supply cables, they are prone to disturbances. Most of these disturbances can be cancelled out by using differential signaling. Instead of using only one signal, the positive signal A is complemented by its inverse signal $\overline{\mathrm{A}}$. As disturbances usually affect both signals in the same way, the difference between A and $\overline{\mathrm{A}}$ remains undisturbed.

In addition to its high reliability, the use of differential signals provides a means to detect signal faults. When A and $\overline{\mathrm{A}}$ are not complementary, e.g. in case of a short-circuit, the signal receiver detects a fault.

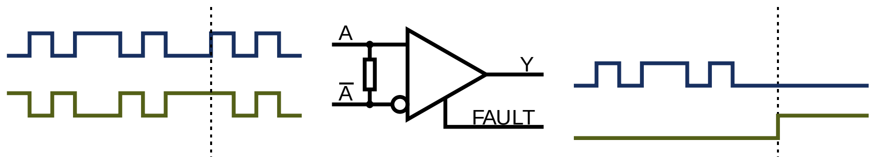


Figure 4: Differential signaling and fault detection

Analog Input

The Mecovis S5FH controller provides five analog inputs, which can be used for arbitrary feedback signals such as force feedback. The analog values can be read by the host PC, but they are not used by the internal controller.

A schematic of the analog inputs is shown in Figure 5. The five inputs are fed to an analog multiplexer, which connects one of the signals with the input of the analog-to-digital converter. The multiplexing is performed automatically in a cyclic way.

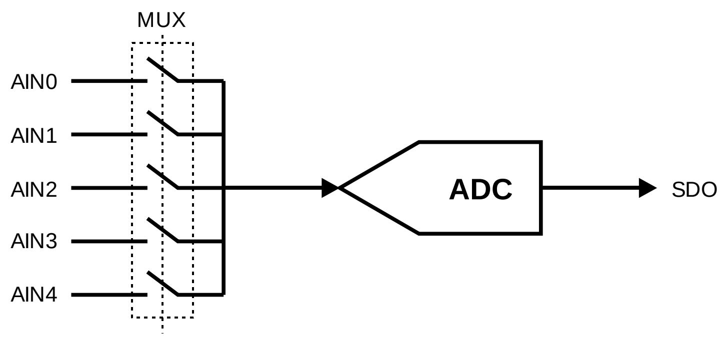


Figure 5: Analog Multiplexer and A/D-Converter

Electrical Specifications

PARAMETER	REMARKS	MIN	TYP	MAX	UNIT
POWER STAGE					
Number of channels			9		
Supply voltage	all channels	21.6	24.0	26.4	V
Supply current	all channels			3.0	A
Output current	per channel	-1.0		1.0	A
PWM frequency			250		kHz
QUADRATURE ENCODER					
Input frequency				32	MHz
Supply voltage	power supply output for encoder	4.75	5.0	5.25	V
Supply current				100	mA
Differential threshold		-200		200	mV
ANALOG INPUT					
Number of channels			5		
Input voltage		0		5.0	V
Supply voltage	power supply output for sensor	4.75	5.0	5.25	V
Supply current				100	mA

Mechanical Dimensions

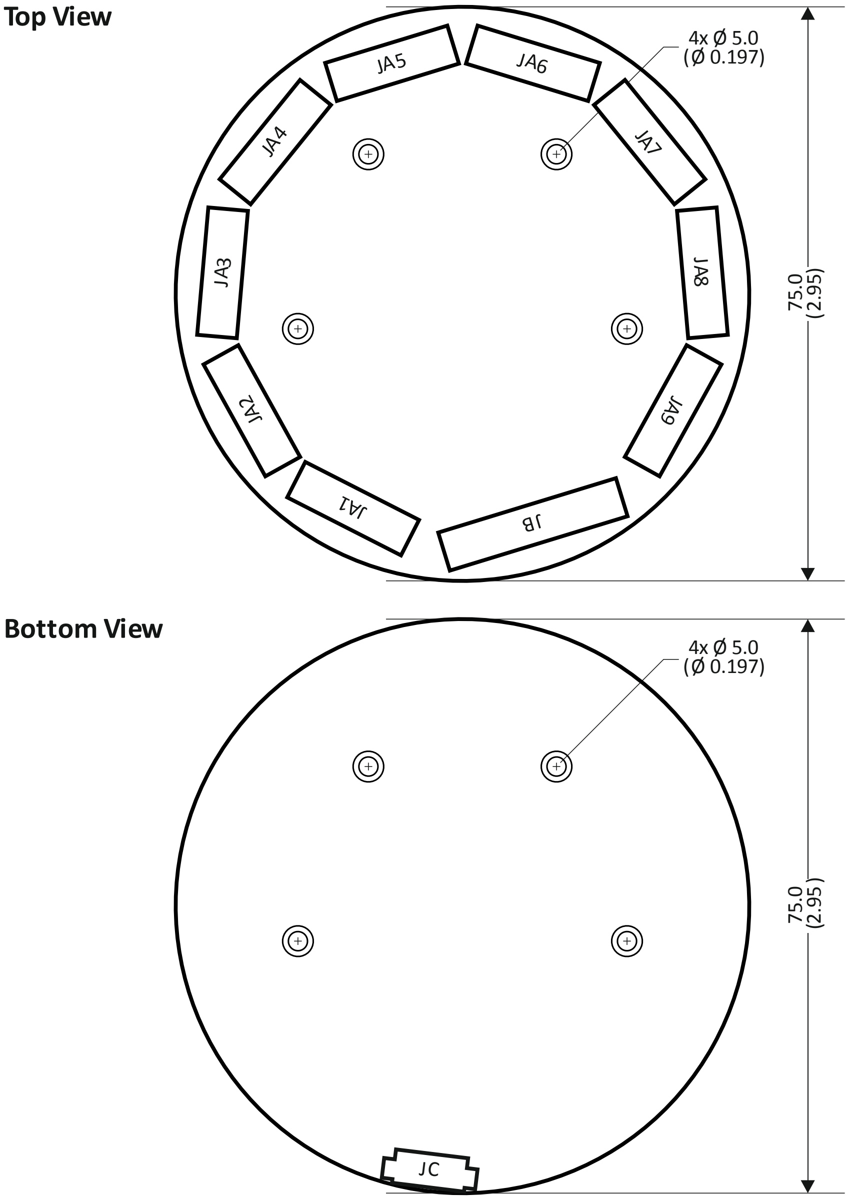


Figure 6: Mechanical dimensions and connector placement

Connector Pin-Out

Motor Connectors JA1 … JA9

The motors are connected via ribbon cables with 10 wires. Molex low-profile connectors are used to save space. The ribbon cable transfers the motor power (MOT+/MOT-), the encoder power (+5V/GND), and the differential quadrature signals (A+/A-, B+/B-, I+/I-).

JA1 … JA9

MOT+	1
+5V	2
GND	3
MOT-	4
A-	5
A+	6
B-	7
B+	8
I-	9
I+	10

Analog Connector JB

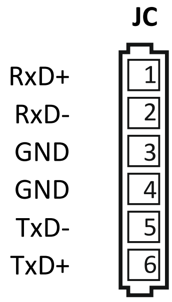
Five analog signals, e.g. force sensors, can be connected via a ribbon cable with 16 wires. A Molex low-profile connector is used to save space. The ribbon cable transfers power (5V/GND) and analog signals (AIN0 … AIN4).

JB

GND	1
AIN0	2
+5V	3
GND	4
AIN1	5
+5V	6
GND	7
AIN2	8
+5V	9
GND	10
AIN3	11
+5V	12
GND	13
AIN4	14
+5V	15
GND	16

RS485 Connector JC

The RS485 communication is established via a ribbon cable with 6 wires. The ribbon cable transfers the differential receive and transmit signals (TxD+/TxD-, RxD+/RxD-).



Firmware

This chapter provides information about the functional blocks of the Mecovis S5FH Controller and their programming.

Overview

The Mecovis S5FH Controller uses a field-programmable gate array (FPGA) to implement the functionality of the firmware. The FPGA technology provides high flexibility and computational performance.

The functional blocks comprise:

- hardware access functions
- controller (position, current)
- communication engine

Hardware access functions

The firmware contains the functionality to interact with the on-board electronics components. For the power stages, the necessary PWM signals are generated, and the current measurements are read back from the current sense amplifiers. The quadrature encoder signals are also evaluated by specific functional blocks. Furthermore, the analog inputs are automatically sampled by the firmware.

Position Controller

The position controller is implemented as PID controller with anti-windup. The control input has software programmable upper and lower limits as well as a rate limiter, i.e. position and velocity can be limited.

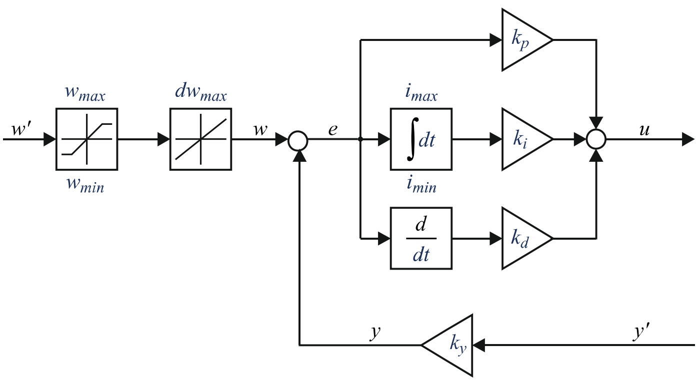


Figure 7: PID position controller with limiters

Figure 7 shows a block diagram of the position controller. The reference signal w' is first limited to the range w_{min} … w_{max} and then the rate of change is limited to dw_{max}. The measured signal y' is scaled by k_y to obtain the feedback signal y. The error signal e is calculated as the difference of w and y. Following the classic PID scheme, the error signal is fed into an integrator and a differentiator. In order to avoid a windup of the integrator, its value is limited to the range i_{min} … i_{max}. The respective signals are scaled with the proportional gain k_p, the integral gain k_i, and the derivative gain k_d, and summed up to form the control output u.

The reference signal w' can be set via the communication interface, and the scaled feedback signal y can be read back. The control output is internally fed to the reference input of the current controller.

Current Controller

The current controller is implemented as PI controller with anti-windup. The control input is fed by the output of the corresponding position controller and has software programmable upper and lower limits.

A block diagram of the controller is shown in Figure 8. The structure is similar to the position controller, except for the missing rate limiter, the missing derivative, and the output limiter. The constrained output u is connected to the bidirectional PWM generator.

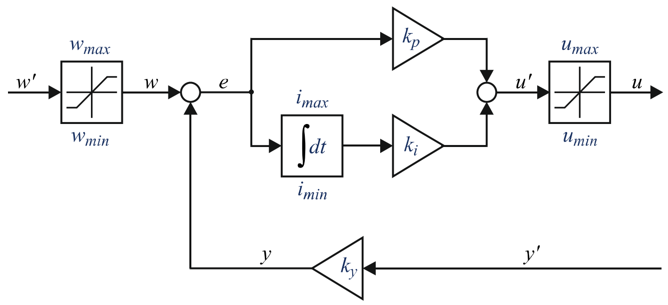


Figure 8: PI current controller with limiters

Communication Engine

The communication engine transfers data between the Mecovis S5FH Controller and a host computer via a serial interface. It implements a packet-based protocol which can read and write values to and from the process memory of the controller. A detailed description of the communication protocol can be found in the following chapter.

Communication

The communication between host computer and controller electronics is established by means of an RS485 interface. It provides sufficient data rates and robustness. The interface is used in full-duplex mode as point-to-point interconnect.

Protocol

Communication is always initiated by the master (host computer) by sending a command packet to the slave (controller electronics). Each command packet is responded to by a status packet from slave to master.

Packet Structure

Packets consist of the raw data itself and synchronization, addressing, and check information.

In Figure 9, the layout of a packet is shown. The packet starts with two synchronization bytes SYNC1 (0x4C) and SYNC2 (0xAA). These are followed by an index, which should be continuously incremented by the master, and an address which defines the meaning of the data. The header is completed by a 16-bit length value, which defines the number of data bytes. The header is followed by the raw data of defined length. The footer contains the two checksums CHECK1 and CHECK2, which are calculated from the raw data. CHECK1 is the byte sum of all data bytes. CHECK1 is calculated by xor'ing all data bytes.

SYNC1	SYNC2								
INDEX	ADDR	LENGTH							
DATA	DATA	DATA	DATA	DATA	DATA	DATA	DATA	DATA	DATA
…	…	…	…	…	…	…	…	…	…
CHECK1	CHECK2								

Figure 9: Packet Structure