# Smart paddleboard and other assistive veyances

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***Abstract*—As a contribution to the new field of WaterHCI (Water-Human-Computer Interfaces), we proposed and developed a smart SUP (Stand-Up Paddleboard) to assist a person with a disability (shoulder + back injury) to continue paddling and cross-country swimming (pulling a paddleboard to carry cargo while swimming). The paddleboard technology consists of two thrusters (motorized propellers) driven (1) in proportion to the flex of a paddle, to maintain the same feeling as normal paddling but with easement on shoulder strain, or (2) in proportion to the tension of a tow line attached to a waist strap around a swimmer's waist. We also propose a controller for controlling a throttle using paddle flex or the tension of a pull cord. We also propose the use of our throttle control technology in transporting the paddleboard by way of a pulled wagon or an electric cargo bicycle (loaded up with the paddleboard and related supplies), at times when it is necessary to push it up steep hill. The wagon has a pull cord similar to the paddleboard, and the bicycle consists of a handlebar equipped with force sensors to provide the similar effect to pulling the paddleboard or wagon.**

***Index Terms*—Humanistic intelligence, wearable technology, electric machines, WaterHCI, Humanistic Intelligence, HIntelligence, HIntel, HInt, HI, BOC-plane, BOC-space.**

## I. Intro and Background

Fundamental technological breakthroughs are giving rise to new kinds of electric (con)veyances such as vehicles, and new micromobility solutions as well as "cyborg" technologies and wearables (smart clothes, smart shoes, smart rollerblades, etc.) broadening the concept of conveyances/deconveyances as *veyances*. Many of these widely-used technologies can be applied to assist persons with disabilities, e.g. in design of electric wheelchairs, mobility scooters, etc.. Most present-day efforts in this area are aimed at assisting persons with lower limb disabilities, e.g. inability to walk.

In this paper we address the needs of a paddleboarder and cross-country swimmer who recently (Jan. 2022) sustained a workplace-related injury. Our system allows the subject to continue paddling, cross-country swimming (i.e. swimming that requires pulling of heavy cargo), and transporting the equipment to and from the beach.

We propose and explore a vehicle/vessel/veyance to assist a person with upper-body disability, e.g. shoulder injury and back injury. In particular, we consider a smart SUP (Stand-Up Paddleboard) that uses electric motors and a special control system to help a person with a shoulder injury in 2 ways by providing:

- paddle assist when the board is being paddled;
- propulsion assist when the board is being towed.

The latter case (2) occurs when the paddleboard is used as a towfloat by a swimmer who uses the board as a safety-visibility marker so as to avoid being struck by boats.

Many swimmers use a device called a "towfloat" or "safety visibility buoy" which is a brightly-colored floating object that is towed behind the swimmer. It is secured by a rope or cord or webbing to a strap around the waist of the swimmer. Many towfloats can also carry a small amount of cargo, such as a smartphone, keys, wallet, towel, and clothes, in a sealed airtight (dry) cargo compartment. However for greater safety and greater visibility to other vessels, swimmers are often accompanied by vessels such as paddleboards or swimmers will tow a vessel, such as a paddleboard, behind them when they swim. Towing a paddleboard also facilitates carrying large amounts of cargo such as a tent, sleeping bag, or provisions for longer cross-country swims (e.g. hiking and swimming).

## II. eSUP

The word "cyborg" was coined by Manfred Clynes in 1960 [1] and his favorite example is a person riding a bicycle [2]. The world's first cyborgs existed more than a million years ago, as our ancestors (hominids) upon rafts or similar vessels, e.g. vessels not unlike paddleboards. Growlerboarding (standing on growler-sized ice fragments while paddling) pays homage to how humans might have traveled thousands of years ago, and cyborg-growlerboarding has also been reported in the literature [3]. Cyborg-growlerboarding is an example of WaterHCI (Water-Human-Computer Interaction) which has existed for 54 years (since 1968) and as an academic discipline for 24 years (since 1998) [4], [5].

We now propose "eSUP" = **e**lectric **S**tand-**U**p **P**addleboard, a WaterHCI system as assistive technology for:

1) stand-up paddling;
2) helping a swimmer tow a paddleboard.

In a manner similar to how micromobility (ebikes and escooters) have many uses to help the disabled, the eSUP also has potential for many assistive uses. It is more than just recreational equipment, it is a truly enabling assistive WaterHCI cyborg technology.

### A. Assistive technology for stand-up paddling

Initially we created a smart "ePaddle", i.e. a smart paddle with a truster built into it, as shown in Fig 1. We built a flex-sensor into the paddle, with a control system to drive the thruster in proportion to the flex, thus creating a natural-user-interface[6], i.e. no additional instructions need be given to the user in order to understand how to use the ePaddle.

We encountered the following 2 drawbacks: (1) the thruster places additional load upon the shoulder joints of the user, whereas putting the thruster on the paddleboard would alleviate this extra loading; and (2) the system only works when

Fig. 1: ePaddle: Thruster in paddle.

paddling. Putting the thruster on the board would make it easier to use the system for swimmers towing the board, i.e. the system would work when not using the paddle at all.

Thus we propose a smart paddleboard using electric thrusters (electric motors driving propellers) driving the board. The propellers were mounted in safety shields. Whereas other electric paddleboards are available, they use motors that are controlled by a throttle-like mechanism, e.g. a remote control that the user can operate much like a traditional motorboat's throttle. What we propose is (1) a smart paddle that senses force of paddling and remotely operates the paddleboard-mounted motors (thrusters) in direct proportion to the amount of force on the paddle or (2) a smart pull cord / cable for swimmer-towing that runs the thrusters in proportion to tension on the pull cord / cable. In this way the user experiences a situation that is very much like paddling a normal paddleboard, or towing a normal paddleboard, but with less shoulder strain in either case. Fig 2 shows the paddle flex system in actual use. We built our own paddle – a smart paddle with sensors which transmit wirelessly to a control system on the paddleboard driving two thrusters, one on each of the 2 side fins, as shown in Fig 3 and Fig 4.

One feature of paddleboards is the ease with which one can jump off and get back onto the board. Unlike a kayak or canoe which takes some effort to climb back into, a paddleboard lends itself well to a mixture of swimming and paddling. Especially since beginners frequently fall off paddleboards, the idea of swimming alongside the board is quite natural. We found that users of the smart paddleboard enjoyed some time swimming as well as some time paddling, easily switching back and forth between these two modes of operation.

Because of the tendency of paddlers (users of paddleboards) to fall off their boards, it is common practice to have a safety tether connecting the board to the user. Almost all paddleboards come with a safety tether that is usually a stretchy (springy) material with a band that attaches to one of the ankles or to the waist of the paddler. Thus when falling off the board, and into the water, the paddleboard remains tethered to the paddler by way of the elastically extensible ("stretchy") cord.

Experienced paddlers also sometimes deliberately jump off their boards and swim for a while, towing the board by way

Fig. 2: Functioning e-sup paddle assist where thrusters are driven in proportion to paddle flex.

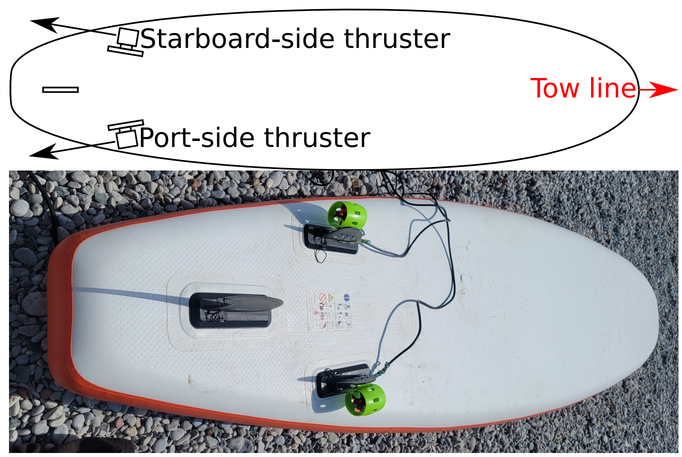


Fig. 3: Bottom view of paddleboard. Thrusters provide support to paddler in proportion to paddle flex, or to swimmer in proportion to force exerted on a tow cord / cable.

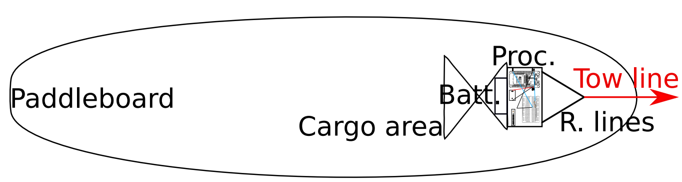


Fig. 4: Top view of paddleboard, ESP8266 and rubber stretch resistors ("R. lines") attached to Tow line to measure increase in pull of cable and send value wirelessly to motor control by way of an ESP32 microcontroller.

Fig. 5: eSUP (electric Stand-Up Paddleboard) as a towfloat to help a swimmer pull (tow) a heavy load. Assist from motors mounted to fins (underwater and therefore not visible in photo) is used to maintain a constant tension in the tether and alleviate force required to tow the paddleboard.

of the cord, and then climb back on the board to paddle some more (e.g. to cool off if overheating, or just for the pleasure of a mixture of swimming and paddling).

To facilitate a cybernetic feedback experience of swimming while towing a board, we constructed a smart tow line that includes 2 rubber cords ("R. lines" in Fig. 4) each impregnated with conductive material so that their electrical resistance (inverse conductivity) varies with tension. We built a control system that uses this change in electrical resistance to control the acceleration of the thrusters on the board in proportion to the tension on the tether. In this way a swimmer can tow a heavy load of supplies and provisions, such as when going on a long trip, while being able to swim totally unencumbered. See Fig 5.

## III. eSUP CONTROL SYSTEM

### A. Electronic speed controller (ESC) control with ESP32

*1) Motor and speed controller setup:* Two FAgdsyigao thrusters, each having a 12V 20A 3-phase motor, were mounted to two detachable paddleboard fins. First they were tested to measure actual thrust which was found to be quite a bit less than their optimistic rating, but sufficient to assist a disabled user in paddling or towing the board.

For motor control, one 20A ESC (electronic speed controller) was connected to each motor, both powered by a 12V waterproof battery mounted on the paddleboard. Each ESC was controlled by a 3.3V, 50Hz PWM (Pulse Width Modulation) signal supplied by a NodeMCU 32S board with an integrated ESP32 controller chip[7].

*2) ESP32 wireless PWM control:* For this application three pins on the ESP32 were used, one being the ground connection for both PWM signals (port side thruster and starboard side thruster), the remaining two being the outputs for these signals using digital output pins 32 and 33. The PWM (Pulse Width Modulated) signal controlled the rate at which 3 pairs of MOSFETs (Metal Oxide Semiconductor Field Effect Transistors) within the ESC energized the stator coils within the motor, rotating the rotor.

To determine the duty cycle of the PWM signal sent to the ESC, the ESP32 wirelessly received packets of data from other microcontrollers using ESP-NOW (private wireless network using integrated 2.4GHz radio transceiver modules allowing for 250 byte data packets to be sent). This was sufficient to pass an integer value for throttle control. This also allowed the system to be modular, with any sensor connected to an ESP board able to provide an assist to the user given the initiator (transmitter) board is equipped with the responder (receiver) board's MAC (Media Access Control) address.

### B. Paddle flex-proportioned thrust + paddleboard

A system is proposed to proportion the amount of force from the thruster motor throttle to the flex (bend) of a paddle, indirectly correlating the thruster force to the force exerted by the paddler on the paddle. This provides paddling with the appropriate magnitude of the assist given, similar to pedal assist on electric bicycles[8][9]. See Fig 2 where thruster PWM duty cycle is changed in proportion to paddle flex, giving the user direct control of thrusters simply through the effort chosen to be used in paddling.

This was initially accomplished by affixing a strain gauge to the shaft of the paddle, but because a disabled subject would typically swap paddles frequently with changes in weather condition, we would have to have affixed strain gauges to a large number of different paddles. A person with shoulder disability will often own a regular paddle, a small-blade paddle, and a slotted-blade (Thurso Surf) paddle, etc..

Therefore we decided on a modular solution that could be clipped quickly to any paddle. The system consists of detachably mounting two 9-axis MPU9250 modules (each one of these two is a 3-axis accelerometer, 3-axis gyroscope and 3-axis magnetometer) to two points of the paddle on opposite ends of the main shaft of the paddle. The MPU9250 itself is a sensing unit consisting of an MPU9250 MEMS (Micro Electro-Mechanical System) chip which collects all accelerometer, magnetometer and gyroscope data, and sends the data to a receiver ("slave") board via an inter-integrated circuit (I2C) bus after establishing a default state via a pull-up resistor[10]. The 3.3V and GND pins on the ESP32 were split to accommodate the corresponding pins on both accelerometers, and in order to accommodate being slave to multiple masters. A .ino (Arduino's C / Java-like language) script was written to repeatedly switch the clock and data pins scanned to obtain the 7-10 bit master address for the I2C bus, obtaining the x-axis accelerometer reading from each MPU9250 and storing these readings in an integer variable.

As both MPU9250s were placed in the exact same orientation on the paddle, any difference in the x-axis accelerometer value (x-axes of both sensors being parallel to one another) was the result of a deformation (flex) of the paddle's shaft, thus the absolute value of the difference between these values was calculated and normalized between 0 and 100 to represent the PWM duty cycle then sent over the pre-established ESP-NOW network to the adjacent ESP32 connected to the 12V motor ESCs.

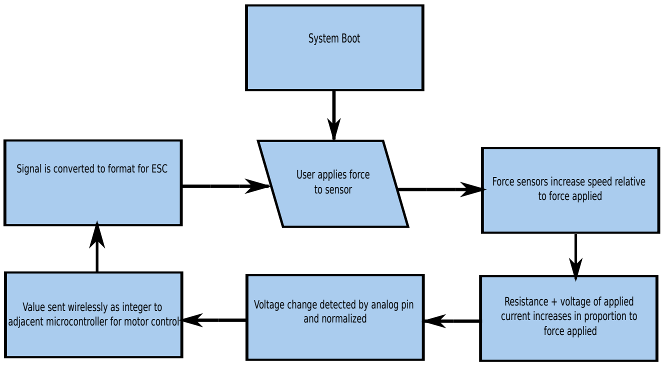


Fig. 6: Flowchart of feedback loop for rope-pull paddleboard control system.

### C. Rope-pull proportioned thrust + paddleboard

Another system was implemented in which a swimmer towing a paddleboard via a harness and tether receives an assist from the paddle's fin motors in proportion to the force exerted on the tether connecting the swimmer to the paddleboard (paddlers almost always wear a safety tether that connects them to their board). To accomplish this, an Adafruit conductive rubber stretch sensor was utilized which increases resistance as the length of the cord increases with user-applied force. See Fig 6.

*1) Rubber cord stretch sensor with ESP8266:* The rubber cord stretch sensor was tied to an equipment housing laid across the width of the paddleboard (affixed to the board's cargo area which is near the front of the board), and had 3.3 volts applied to it by a NodeMCU ESP8266 board's power regulator [11] through two 10K Ohm resistors wired in series. The opposing end of the stretch cord was tied to the opposing end of the wood plank forming a loop, at the apex of which the swimmer's tether was tied while the voltage difference (and hence, change in resistance) was measured by analog pin A0 on the ESP8266 board. The voltage detected increases in linear proportion to the force applied by the swimmer. Similarly to the difference in accelerometer x position, the voltage was then normalized between 0 and 100 from 0 to 1023 (default maximum analog input value on ESP8266 representing 3.3V with 10-bit resolution and onboard voltage divider to both moderate and return precise enough values for input voltage). Once again, the MAC address of the adjacent ESP32 was supplied and a private wireless network was spawned with the adjacent ESP32 being a client receiving 250 byte data packets of integer values every 50ms to consistently alter the duty cycle of the ESC PWM signal[12]. This feedback loop is visually illustrated in Fig 6.

### D. Pull-cord control system

A conductive rubber pull cord is used for controlling the motors in towing the eSUP. A voltage divider was constructed with a fixed pullup resistor and the pull cord was a pulldown resistor. As the cord is stretched and its resistance increases, the voltage at the junction of the two resistors increases. This

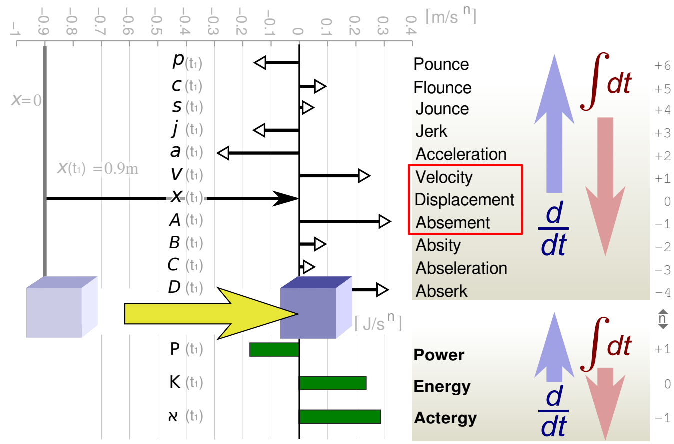


Fig. 7: Time integrals and derivatives of position, reproduced from [17]. The three quantities of the PID controller (absement, position or displacement, and velocity) are boxed in red.

varying voltage is fed to a "throttle" input of the ESCs which varies from 1 to 5 volts DC. This control mechanism is simple but rather crude in terms of overshoot, undershoot, oscillatory behaviour, instability, etc., so after some quick initial testing we implemented a PID (Proportional, Integral, Derivative) controller[13][14][15].

The PID controller, if applied to the position of a throttle, involves the throttle's absement[16], position, and velocity, as in the table below:

| | | |
|---|---|---|
| $(\frac{d}{dt})^{-1}$ | Integral | Throttle absement |
| $(\frac{d}{dt})^{0}$ | Proportional | Throttle position |
| $(\frac{d}{dt})^{1}$ | Derivative | Throttle velocity. |

Absement is a well-known quantity as the time-integral of position or displacement or distance, as shown in Fig 7, where the three quantities of the PID controller (absement, position or displacement, and velocity) are boxed in red.

Existing cruise control systems most commonly use PID controllers to control the accelerator of a vehicle[18], [19], [20], [21], [22].

The result of using a PID controller to control the accelerator control input of a vehicle gives rise to the scope of control on the vehicle's velocity, acceleration, and jerk, as outlined leftmost in Fig. 8. Assuming the vehicle (or vessel) has a constant mass, the acceleration is linearly proportional to the force of the motor on the vehicle. On an electric vehicle, the force is proportional to the current in the motor, and thus the accelerator input is easily implemented by way of a control system that controls motor current.

With cruise control, the desired quantity is velocity or speed, and this is done by control of the vehicle's accelerator, so for cruise control there is only an "off by one" error in the above table, i.e. controlling the accelerator for achieving a desired velocity. In this sense, PID controllers work well for

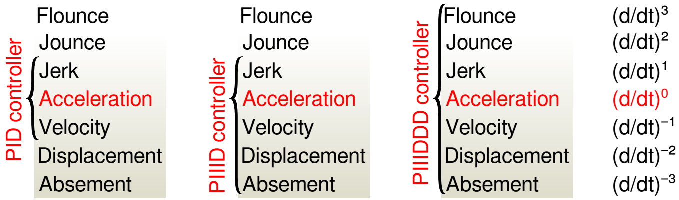


Fig. 8: (left) Scope of influence of a PID controller in controlling the accelerator input of a vehicle or vessel. (center) Proposed PIIID controller. (right) proposed PIIIDDD controller.

cruise control, because the PID controller allows for an off-by-one error in the order of the derivatives of position of the controlled quantity (e.g. velocity controlling acceleration or position controlling velocity).

In our case, however, we wish to achieve position control or displacement control of a vehicle or vessel by way of controlling its accelerator. This is an off-by-two error in the degree of the derivative of what we're trying to control and the control mechanism, i.e. we're trying to control position which is the 0th derivative of position, with an accelerator input to the thruster, which is proportional to the 2nd derivative of position.

### *E. PIIIDDD and PIIID controllers*

The throttle is often called the "accelerator" for good reason. The position or displacement of the accelerator controls the acceleration of the vehicle / vessel, i.e. the "P" term in the PID controller is associated with the acceleration of the vehicle whereas the "I" term with the velocity, and the "D" term with the jerk (time-derivative of acceleration).

We wish to have at least one term in the controller be associated with the position of the eSUP, thus we propose a PIID (Proportional, Integral, double Integral, and Derivative) controller, and in fact if we wish to have a term associate with the position of the vessel, it is advantageous to introduce an extra integral[23]. Thus we extend as per the table below:

| | | | |
|---|---|---|---|
| $(\frac{d}{dt})^{-3}$ | Triple integral | Throttle abseleration | Vehicle absement |
| $(\frac{d}{dt})^{-2}$ | Double integral | Throttle absity | Vehicle position |
| $(\frac{d}{dt})^{-1}$ | Integral | Throttle absement | Vehicle velocity |
| $(\frac{d}{dt})^{0}$ | Proportional | Throttle position | Vehicle acceleration |
| $(\frac{d}{dt})^{1}$ | Derivative | Throttle velocity | Vehicle jerk. |

We initially extended the degree of the derivatives and integrals of a PID controller from $\pm$ 1 to $\pm$ 3, i.e. Proportional, Integral, double Integral, triple Integral, Derivative, double Derivative, and triple Derivative, as indicated rightmost in Fig. 8, but found that the two extra D terms often drifted toward zero in training, so we decided on a PIIID controller (center column of Fig 8).

The parameters of the PIIID controller are determined using the same simple machine adaptive filter / machine learning algorithms used for existing PID controllers, simply tuning the additional parameters as well as P, I, and D[24], [25], [26], [27].

## IV. Assistive technology to carry paddleboards

It was found that transporting the paddleboard to the beach was made difficult for a person with a shoulder injury since the nearest parking lot was about 1km (1000m) away from the beach, resulting in a need to carry the paddleboard and associated equipment and supplies (pump, food, water, emergency blankets, safety equipment, extra clothes, drybag, etc.) over this distance. Therefore it was decided that the equipment be carried by a cargo bicycle so that the weight could be borne by the wheels of the bicycle for the entire trip all the way to the beach, securing the bicycle to the railing by the water, using a seat lock, and two wheel/frame locks.

Electric bicycles are becoming very common in mass production, and are operated either with a throttle like a motorcycle, or with pedal assist to make the pedaling easier which is especially welcome for many people with physical impairments such as knee problems[28], [29]. With an electric bicycle there are situations like getting to the water's edge on a pebble beach where it is impossible to ride, where it is necessary to dismount the bicycle and push it while walking next to it. On rough terrain like a pebble beach, pushing a heavily loaded bicycle up hill can be onerous for a person with a shoulder injury.

Although many bicycles have a "walk" setting that uses the motor to help with walking the bicycle, these settings usually only operate at a fixed speed. Alternatively a continuously variable throttle may be used to walk the bicycle, but this requires the user to continuously vary the throttle up and down and remain conscious of this action, to avoid the risk of accidentally losing control of the bicycle.

### *A. Handlebar push proportioned E-Bike throttle ("Pushbike")*

We propose a cybernetic handlebar system that senses pressure on the handlebars as a user pushes the bicycle along the ground, and activates the throttle in proportion to pressure applied to the handlebars. As the bicycle propels itself forward under motor control, if it goes faster than the user is pushing, the pressure drops to zero and so does the throttle. The result is a closed-loop feedback system that feels as if the bicycle is easy to push along, without any conscious thought or effort in regards to managing the throttle.

This system is illustrated in Fig 9. Note the similarity between this system and the pull cord system of the paddleboard towfloat. Both of these systems make use of our proposed PIIID controller.

To better understand how this system works, consider as a metaphor, pushing a car up a hill with a push stick that presses down upon the accelerator of the car, as shown in Fig 10. It is easy to comprehend here how the position of the accelerator controls the vehicle but with an off-by-two error in the "spectrum" of derivatives of position outlined in Fig. 7. Thus it is easy to see why we require or proposed PIID or

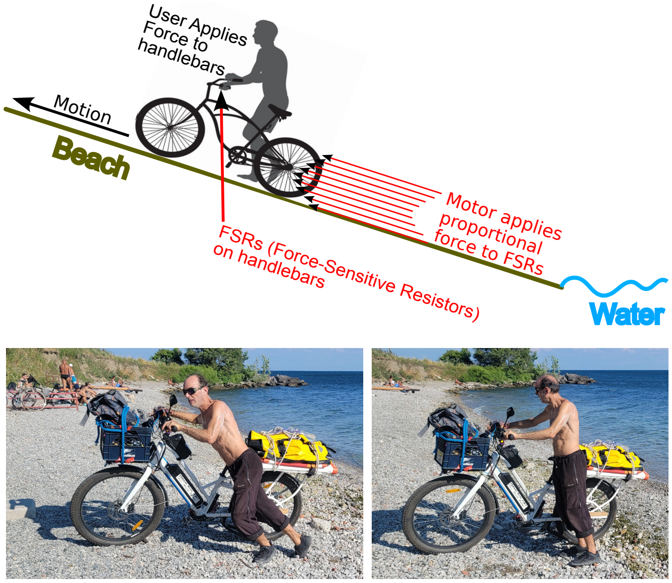


Fig. 9: Cybernetic control of electric cargo bicycle while pushing it up a steep incline on a pebble beach, loaded with paddleboard, safety equipment, drybag of food, and other provisions, etc.. (Left) without cybernetic assist; (Right) with cybernetic assist.

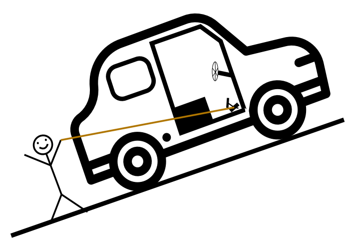

Fig. 10: Conceptual metaphor: pushing a car up hill with a push stick pressing against the accelerator.

PIIID or PIIIDDD controller, i.e. a controller that includes additional orders of derivatives and integrals of position.

Therefore an assist method is proposed for usage with electric bicycles ("e-bikes") wherein a throttle voltage applied to control the motor (central rear wheel motor or mid-drive motor) is proportioned to the force exerted by the rider upon the handlebars of the bicycle. To accomplish this, a Kodiak Voltbike was chosen, owing to its simple modular construction (e.g. separate 3-phase motor controller, easily accessed and modified, in contrast to other bicycle motors Stromer or Bosch which are highly integrated and more difficult to modify).

The Kodiak Voltbike was purchased and outfitted with a large frame to enable it to transport larger amounts of cargo (paddleboard, swimming dry bag, food, safety equipment, etc.) to demonstrate the performance of the system under increased load, for use in cross-country swimming trips where the vessel (eSUP) is to be transported to a beach area and across beach terrain.

By default, the throttle applied to an e-bike (directly applied by the user, without pedal assist) is controlled by a simple

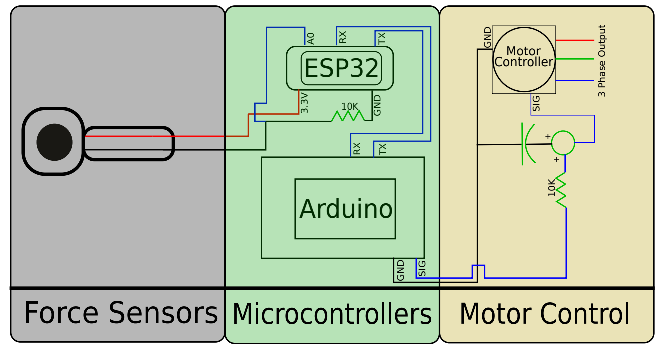


Fig. 11: Circuit diagram of "Pushbike" controller in which ESP32 takes input from force sensitive resistors, normalizes their values, passes them to Arduino which uses them to change the duty cycle of a PWM output signal to the bike motor controller, then converted to analog by lowpass filer

analog input signal between 0 and 3.3V whose voltage is divided by a potentiometer mounted to the starboard (right, drivetrain-side) handlebar of the bicycle, imitating the throttle control of a motorcycle [30].

However we wished to create an illusion of superhuman strength for the user, and allow the bicycle to simply be pushed, while sensing the force on the handlebars, as shown in Fig 9, where the system is used to alleviate the force required to push a heavy electric cargo bicycle up a steep slope of pebbles on the beach.

*1) E-bike throttle ESP32 control:* To provide an identical voltage division able to be controlled by .ino code, the signal and GND wires to the throttle were severed and connected to digital output 9 and GND pins on an arduino UNO, respectively. However, output signals from the arduino digital pins come in the form of a PWM signal with the value indicated in the .ino code changing the duty cycle not the voltage of the signal (default voltage being 5V, past the 3.3V limit of the motor controller). This was found to have no notable effect on the motor output. In order to have a proper effect the PWM output was fed to a simple low-pass filter. The filter was constructed by splitting the GND wire of the UNO, at one end to the GND wire for the e-bike controller, the other being a connection to a 63V, 47 microfarad capacitor soldered to the signal input of the e-bike controller. Also soldered to the wire for this input was the signal output of the UNO, divided by a 10K Ohm resistor which converted the PWM signal output of the UNO to an analog signal between 0 and 5V, controlled by the built-in arduino analogWrite() method with integer argument 0 representing 0V output and 255 representing maximum 5V output.

*2) Hardware and force sensor setup:* Due to the proximity of the handlebars and the motor controller wires, wireless communication between two microcontrollers was not required. However two microcontrollers were required to handle input from the force sensors while updating the analog output to the motor controller simultaneously and in a manner that made the bicycle feel like an extension of one's body. To accomplish this, in addition to the aforementioned UNO, a NodeMCU 32S was mounted to the center console of the handlebars of the e-bike connected to two 5" diameter force sensitive resistors mounted to the handlebars' port (left) and starboard (right) extremities. Each of the resistors consist of a conductive polymer which decreases resistance as one steadily applies pressure which, similarly to the rubber stretch sensor (but with reversed sense, i.e. decrease rather than increase of resistance), had one of its two leads connected to the GND pin of the ESP32 via a 10K Ohm resistor as well as ADC (analog-to-digital conversion) pin number 0, and its other connected to the 3.3V output pin of the microcontroller.

This circuit applied a steady 3.3V current to the resistor which linearly changes the voltage from 0 to 3.3V as pressure is applied by the user and resistance decreases, measured by the ADC pin and represented by a digital integer value from 0 to 4095. ADC pins 0 and 6 were used (GPIO 36 and 34) and GND and 3.3V pins were split to accommodate both sensors. Once integer value for voltages read from both sensors were obtained, the median between the values was found as to not allow one to engage the maximum power on the motor by applying significantly more force to one handlebar than the other, as one does when making a turn. This value was then normalized between 0 and 160 as within the arduino UNO, integer value of 255 passed to the analogWrite() represents 5V analog output signal, thus a limit of 160 was set (equivalent to 3.1V) as to obtain maximum throttle without risking overheating the motor ESC (diagram of completed circuit shown in 11)[31][32].

*3) UNO and ESP32 serial communication:* To pass values to the arduino UNO, a Universal Asynchronous Receiver/Transmitter (UART) connection was established between the UNO and the ESP32 microcontrollers. This was done due to the relative ease in setup (TX pin on UNO was connected to RX pin on ESP32 and vice versa) as well as the fact that UART converts parallel data to serial data for transmission before being converted back to serial data all asynchronously, meaning that data could still be continuously sent to the motor controller and received from the force sensors, and a clock pin connection to indicate the receiving board when to begin reading the start bit of a data packet would not be required. A serial port was opened on both devices with a 9600 baud rate to which the ESP32 would continuously wire the normalized median sensor value and the UNO would decode (from bytes) this value to an integer and pass it as an argument in the analogWrite() method, setting the amplitude of the analog output signal on pin 9[33]. Entire process illustrated in flowchart within figure 6.

The same PIIID controller was used for the pushbike as was used for the pullcord throttle control on the eSUP.

### *B. The Freehicle*

Problems arose with the cargo bike when, for example, wishing to stop at a grocery store to buy a watermelon on the way to the beach. Leaving a bike with expensive cargo parked outside is risky due to possible theft. And bikes are often not allowed in stores. So we came up with the "Freehicle", a 4-wheeled veyance with a cargo box that the user can ride on, or pull like a wagon. See Fig. 12. It uses the same throttle-control concept as the paddleboard with the same rubber stretch cord when it is used as a wagon.

Fig. 12: The Freehicle is a vehicle for freedom of mobility. A person can ride on it or pull it like a wagon.

## V. Results and discussion

Paddle flex was successfully proportioned to motor throttle (Fig 2), providing a natural user-interface, i.e. providing superhuman paddle stroke strength with no little effort required in the stroke. Likewise in 5 a swimmer was able to maintain a constant tension in the tow line without constantly altering their speed simply by exerting some force on the tow cable, engaging the system and allowing the motor to run in proportion to force exerted, alleviating the strain and additional effort required when towing heavy cargo. Two FAgdsyigao thrusters each having a 12V 20A 3-phase motor intended for RC (remote control) boats within the range of 0-40lbs were used, provided a nice gentle assist, resulting in a subtle but helpful assistance when paddling or swimming the paddleboard as a towfloat.

A system for transporting the paddleboard across the beach terrain was also developed, consisting of a pushbike that could be pedalled normally once pushed across the beach onto the road. The pushbike used the same control system principle as the paddleboard.

## VI. Conclusion

In order to assist a person with a shoulder disability continue to go on cross-country swimming and paddling adventures we invented and successfully implemented various new systems: a paddle-driven eSUP (electric Stand-Up Paddleboard), a swimmer-towed eSUP, and a pushbike for transporting the eSUP or other heavy equipment across rough terrain where the bike must be dismounted and pushed. We also created the Freehicle as an alternative to the pushbike. For the latter three systems we developed a new controller, the PIIID controller.

Several systems were proposed in which the disabled or physically challenged person was able to receive a cybernetic assist to boost their abilities in operating or transporting a variety of small single-user electric vehicles and vessels. Such vehicles and vessels include a SUP (Stand-Up Paddleboard) via using it as intended, a SUP via towing it while swimming, an electric bicycle (e-bike) for transporting the SUP, in pushing the bicycle via its handlebars in rough or difficult-to-navigate terrain, and a new kind of wagon. A cybernetic assist was given to a paddleboarder with a shoulder injury, negating the injury and allowing the user to operate the vessel without any hindrance, paddling, or swimming to carry heavy loads, to swim long distances while pulling over 100kg of cargo with a cybernetic assist, despite the shoulder injury. In regards to safety, the system provided a safe and easy way for a disabled person to transport the heavy equipment to the water over rough terrain, in a natural and easy-to-control nature, rather than having to use a throttle which can be dangerous and unwieldy over rough ground.

The proposed system has far-reaching implications beyond helping the disabled. We envision a program of rehabilitation from various injuries, learn-to-swim programs, and new aspects to recreation yet to be created, as well as practical solutions such as creating an alternate mode of commuting for communities built on lakes and waterways.

These systems represent successful embodiments of H.I. = Humanistic Intelligence = "HIntelligence" = "HIntel" = "HInt", a new concept in human-computer interaction (HCI) or human-machine-interaction (HMI) [34].

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