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EDAN: An EMG-controlled Daily Assistant to Help People With Physical Disabilities

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***Abstract*— Injuries, accidents, strokes, and other diseases can significantly degrade the capabilities to perform even the most simple activities in daily life. A large share of these cases involves neuromuscular diseases, which lead to severely reduced muscle function. However, even though affected people are no longer able to move their limbs, residual muscle function can still be existent. Previous work has shown that this residual muscular activity can suffice to apply an EMG-based user interface. In this paper, we introduce DLR's robotic wheelchair EDAN (EMG-controlled Daily Assistant), which is equipped with a torque-controlled, eight degree-of-freedom light-weight arm and a dexterous, five-fingered robotic hand. Using electromyography, muscular activity of the user is measured, processed and utilized to control both the wheelchair and the robotic manipulator. This EMG-based interface is enhanced with shared control functionality to allow for efficient and safe physical interaction with the environment.**

I. INTRODUCTION

In our everyday life, activities such as eating, drinking, or taking a walk outside are so elementary that we perform them without thinking. However, conducting these activities can become a huge challenge or even impossible at all, due to accidents, injuries, or diseases. Given the demographic change in the industrialized states, the number of age-related diseases such as stroke is growing steadily. Fortunately enough, improvement in first aid leads to a decrease in the mortality rate for stroke patients. However, about 20% of stroke survivors suffer from significant motor impairment. In severe cases, even simple activities of daily living, and thus, a self-determined life in one's own home may become impossible, and people require personal care around-the-clock. Moreover, stroke is certainly not the only reason for disability. Spinal cord injury as well as neuromuscular diseases, e. g. *Amyotrophic Lateral Sclerosis* (ALS), *Spinal Muscular Atrophy* (SMA) or others, can strongly inhibit the functionality of the limbs.

Assistive Technologies (ATs) for people with motor disabilities have been available for a while now and provide help and relief in daily life. One relevant example are power wheelchairs which can, to a large extent, restore the mobility of the individual. For people with upper-limb impairment, ATs are also available. Research on these kind of devices started with passive and active arm support systems, which provide help for people with remaining but weak arm and hand function, early on, as stationary devices [1], later also as an add-on component for wheelchairs [2]. For people without sufficient hand function or arm movement robotic arms are investigated as manipulation aids for quite some time already, with early research on this topic dating back to the 1960s [3]. Initially, such systems of the latter kind were meant as stationary robots, which were designed for highly specific tasks such as turning the pages of a book, or feeding [4], [5]. Research on wheelchair-mounted robotic manipulators started in the 1970s [3], the first commercially available system was the MANUS manipulator released in the 1990s [6]. Nowadays, there are a few wheelchair-mountable robotic manipulators available, e.g. the MANUS successor iARM [7] or the JACO arm [8].

Fig. 1. From concept to realization: the evolution of EDAN.

While these systems provide a lot of help to the people affected, controlling them can be cumbersome and difficult, especially because motor impairment also limits the users ability to manipulate the interface. Furthermore, it is notable that there are many developments in state-of-the-art robotic research, which these systems could benefit from. For one, this relates to autonomous functions, which may ease the usability of assistive robotic arms. Secondly, available systems are developed as add-ons and thereby not fully integrated with the wheelchair. Consideration of the wheelchair as a mobile base of the robot could allow for more flexibility and improved capabilities in control and thereby increase usability of the system.

With this in mind, we introduce EDAN, the EMG-controlled Daily Assistant. EDAN is a fully integrated wheelchair-based manipulation aid. It can be controlled by a joystick, or via electromyographic (EMG) signals and is designed to perform activities of daily living supported by shared control capabilities in combination with whole-body impedance control.

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The main contribution of this work constitutes an overview of the EDAN robotic assistance system and its features and capabilities. Accordingly, Sect. II describes the hardware design including the mechanical and electronic components. In Sect. III we introduce design requirements for EDAN's interface. The software framework, including the shared control capabilities as well as the controller concept is described in Sect. IV. Eventually, Sect. V exemplarily demonstrates EDAN's functionalities and presents future work, before Sect. VI concludes the paper.

II. HARDWARE DESIGN

EDAN is based on a state-of-the-art power-wheelchair for people with severe physical disability, namely the F5-Corpus VS built by Permobil. This wheelchair is equipped with a front-wheel drive and pivot-rear-wheels. The actuated seat of the wheelchair allows for elevation, tilt, recline and even standing seat configuration. Furthermore, the UniTrack rail system, which is originally used for mounting of medical devices, serves well to mount the mechatronic components.

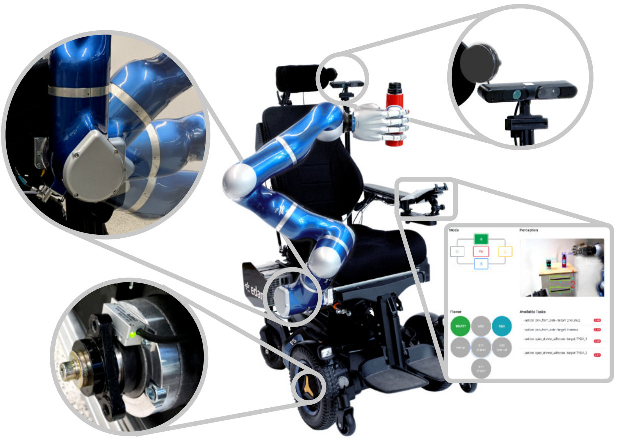

Fig. 2. Picture of the EDAN system including a closeup of the upgraded wheel-encoders (bottom left), the range of motion of the additional, eighth axis of the DLR LWR-III (top-left), the head-switch and the RGB-D Camera (top right) and the tablet interface (bottom right).

1) Manipulator: To provide EDAN with manipulation capabilities, a DLR Light-Weight Robot III (LWR-III) is mounted on the right side of the wheelchair. The LWR-III is a torque-controlled robotic arm, equipped with joint torque sensors, and can therefore be controlled in torque-based (Cartesian) impedance control mode [9]. In order to provide reachability in the complete surroundings of the wheelchair, we extended the LWR-III with an additional eighth axis at the base, see Fig. 2. A specifically designed aluminum structure is fixed to the seat in order to safely mount the manipulator. The eighth axis is built such that its rotational axis points laterally out of the seat. This expands reachability in the *sagittal plane*. That way, the manipulator can reach down to the ground as well as reach areas directly in front of the user, e. g. for drinking. The kinematic reachability [10] is depicted in Fig. 3, which also shows that the 8th axis largely increases general manipulability in the area in front of the wheelchair. In combination with the possibility for elevation of the seat height, the reach space of EDAN's arm is comparable to that of a human. EDAN is equipped with a 5-fingered DLR-HIT (right-)hand which allows for grasping and manipulation of objects.

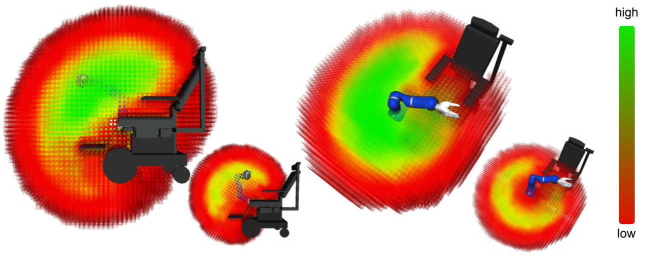

Fig. 3. Kinematic reachability of the EDAN system with the 8th axis (large) and of the standard DLR-LWR3 when mounted to EDAN's wheelchair (small) from two different perspectives.

2) Computing: To perform all computation tasks on board, EDAN is equipped with two Linux-based Intel Core I7 PCs. One of these, mounted next to the arm, is dedicated to run the control software for the robotic arm, the hand and the wheelchair. Furthermore, it receives and processes the digitized EMG signals (see Sec. IV-C.1). To comply with the timing requirements, this computer is patched with a Linux Real-Time Kernel. The second computer, mounted to the left of the seat, is used to run all the high-level software required to realize EDAN's functionality, such as shared control and task management (see Sec. IV). Furthermore, this computer is connected to a 5GHz Wifi-Bridge, which allows the programmer to access EDAN from an external Linux Desktop PC for debugging purposes. Additionally, an Nvidia Jetson TX2 embedded GPU is available on the system, in order to process vision data on board[1]. To allow the user for configuration of the system and visualize its states, an Android-based tablet computer is mounted on the left armrest of the wheelchair.

3) Power supply and I/O: All of EDAN's components are supplied from the internal battery (lead-battery with voltage of 24V and capacity of 36Ah), which allows for approximately five hours of operation. A power-supply-box is mounted to the rear of the backrest. This box contains the DC-DC converters needed to provide the various working voltages for the individual components combined with fuses to ensure electrical safety. Interfacing the proprietary internal control system of the wheelchair is achieved via an R-NET Input-Output-Module (IOM). R-NET is a control-system for power-wheelchairs, which is used in many commercially available rehabilitation devices. The IOM allows to create individual user interfaces to the wheelchair. In our case it is configured to use proportional input signals to specify continuous velocity commands to the wheelchair in 2D (forward/backward and rotation).

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[1] Currently, vision processing is still running on an external computer, connected through WiFi, software integration to the Jetson GPU is ongoing.

In order to be able to realize advanced shared control features, which combine wheelchair and arm motions (whole-body-control), we upgraded the standard drive system of the wheelchair with magnetic ring encoders to precisely measure the wheels rotations (see Fig. 2). We used two LM13 encoders manufactured by RLS®. These sensors provide 82000 increments per wheel revolution, allowing for a stable differentiation of the signal. The encoders operate in a temperature range of -10°C to +80°C and have water-proof sealing in accordance with IP68.

Interfacing the R-Net, the wheel-encoders as well as additional user interfaces, like e.g. a head-switch, of EMG signals, is achieved using a set of industrial input and output modules which communicate via an EtherCAT-Bus. More specifically, these modules, manufactured by Beckhoff, consist of 16 channels of 12Bit AD-converters to read the analog signals, 4 channels of digital input and 4 channels of analog output used for interfacing the R-NET communication of the wheelchair, a relay-interface to switch the power state of the wheelchair, and 2 analog inputs as well as a CAN interface to acquire additional status information from the wheelchair. The wheel encoders are interfaced via an SinCos-Encoder-Interface Module. The EtherCat Master Node is implemented on the real time Linux computer running at a 1kHz sampling rate.

Finally, we use an Asus Xtion Pro Live RGB-D camera to perceive the environment. This camera is attached next to the head rest of the wheelchair. The camera covers the workspace of the robotic manipulator in front of the user and makes it possible to detect, classify, and localize objects to interact with.

To summarize, Table I provides an overview over EDAN's hardware features:

TABLE I
EDAN FACT-SHEET

Overall	DoF	27
	Weight	150kg
	Height	1.6m
	Footprint	1.1m x 0.8m
	Powersupply	36Ah at 24V
Manipulator	DoF	8
	Control Modes	Torque, Position
	Reach	1.33m
	Weight	17kg
	Payload	7kg
Hand	DoF	15
	Control Modes	Torque, Position
	Weight	1.4kg
	Payload	1kg
Wheelchair	DoF	4
	Control Modes	Velocity
	Weight	120kg
	Payload	100kg

III. INTERFACE CONSIDERATIONS

EDAN is supposed to assist people with severe motor impairment and allow them to interact with their environment again. That requires a performant mobile robotic system. Yet, the question of how to provide impaired users with control over such an assistive device has to be answered. Currently joysticks of different kinds [11] are the most commonly used devices to control assistive technology such as wheelchairs or robotic manipulators [8]. Typically, the signals recorded from the joystick control the velocity of the target device. If the degrees of freedom (DoF) of the input device are lower than the DoF of the AT, subsets of the output DoF can be sequentially selected (input-mapping).

Fig. 4. The DLR LWR-III as an assistive device. Left: Footage from the Braingate2 Clinical Trial [14]. Right: Footage from our study on sEMG-based interfaces for people with severe muscular atrophy [17].

For many people in need of assistive technology a joystick may not be an option, due to their limited motor-capability. One solution to this problem is the use of Brain-Computer Interfaces (BCI), which is a steadily growing research area. Comparing non-invasive to invasive BCIs, it is evident that the former mainly allow for decoding of discrete control commands [12], [13], while the higher bandwidth of the latter enables the decoding of continuous signals [14], [15].

This decoding of continuous control signals best resembles the functionality of a joystick, and therefore allows for an intuitive control over the velocity of an assistive device. Analogously to joystick applications, interfacing a device on velocity level is the preferred method. With respect to BCIs, this is also analyzed in [16], showing that commanding on velocity level is superior to position- or goal-control, irrespective of the input modality. The authors argue that this is due to errors in the velocity commands being averaged out within the integration process. Furthermore, the application of velocity commands allows for easier correction of the position of the AT by the user over time.

Using the DLR LWR-III as an assistive device, we have previously investigated various approaches to create continuous interfaces, either based on the recording of neural signals or on the use of surface Electromyography (sEMG). In [14], we showed how a participant with high-level tetraplegia was re-enabled to reach and grasp targets or serve herself a drink, using a DLR LWR-III robotic arm in combination with the Braingate Neural Interface System. In case muscular signals are still available, sEMG can serve as a method to create the interface. In [17] and [18], we showed that people with SMA can use an EMG-based interface to control a robot in 3D and perform delicate functional tasks.

Based on this analysis we decided to design EDAN's control interface such that it can be used with the interfaces investigated precedently. As a result, a 3D continuous velocity command is used to control the motion of EDAN. In addition to this velocity command, one binary trigger signal is required to switch between subsets of the controllable task-space DoF. Furthermore, another trigger signal is used to switch between the actual device to be controlled, i.e. robotic arm or the mobile base.

To allow for investigation of our sEMG-based interface, EDAN is equipped with EMG signal acquisition capabilities based on Delsys Trigno wireless EMG-sensors. The Trigno system provides a differential recording of up to 16 EMG-signals on the surface of the skin. The sensors are attached using medical grade double-sided adhesive and their battery allows for operation of approximately six hours. The EMG-signals are wirelessly transferred to the Trigno base-station through the 2.4GHz ISM-Band. The base-station is mounted to the rear of the backrest of the wheelchair and provides the EMG-recordings as analog signals. The EMG-based interface is extended with a head-switch, which serves as a second trigger signal, used to switch between controlled devices.

As such, the sEMG-based interface in combination with input-mapping and the head-switch allows the user to command all DoF of EDAN and thereby recreate manipulation or mobility-capabilities. Additionally, we integrate EDAN with shared control capabilities, in order to improve usability of the system in recurring activities of daily living (see Sect. IV-B).

IV. SOFTWARE DESIGN

This section introduces the software structure and capabilities of EDAN in a bottom-up perspective, starting from the robot control, via high level software and finishing with the user interface. The main software components and their interactions are depicted in Fig. 5. The entire communication between the software components of EDAN is managed via DLR's Links and Nodes (LN) middle-ware. LN provides real-time-capable communication between software modules based on a publisher-subscriber concept. A central high-level State Machine deals with coordination of EDAN's functionalities, i.e. setting tasks and control parameters, organizing where is the command coming from (autonomy, sEMG- or joystick-based user commands) and where it is applied (manipulator, wheelchair, tablet, nowhere).

A. Real Time Processes

As described in Sec. II, one of EDAN's computers is configured with a real-time operating system (RT-Linux), in order to suffice the real-time constraints required to run the control algorithms. Development and implementation of the control modules is carried out using Matlab-Simulink and the Simulink-Coder. The interfacing from Simulink to the EDAN hardware is achieved using DLR's Robotkernel framework, which provides a hardware abstraction layer, to allow for efficient interaction in heterogeneous hardware and software systems like EDAN. As such, the Robotkernel provides access to the LWR-III, the DLR-HIT-Hand, and the EtherCAT-Modules which interface the wheelchair and acquire the EMG-signals.

1) Whole-Body Impedance Control: EDAN's mechatronic subsystems are heterogeneous in terms of their control interfaces (see Sec. II). The light-weight manipulator provides a joint torque interface, which is a prerequisite to implement torque-based Cartesian impedance control [9].

User interfaces of state-of-the-art robotic wheelchairs feature component-wise control so far. That is, either the wheelchair *or* the manipulator is commanded but not both simultaneously. With the ability to measure the wheel velocity using EDAN's wheel encoders, a torque-based whole-body control concept [19] can be achieved to take advantage of simultaneous coordinated arm and platform motion. This control scheme in combination with the resulting kinematic redundancy w. r. t. the Cartesian end-effector task provides the means to implement additional control objectives simultaneously, which follow a given task hierarchy [20].

The following subtasks and control modes are realized on EDAN:

a) Cartesian Impedance Control of the End-Effector: The light-weight robot arm can be controlled in Cartesian impedance mode to provide a dedicated compliant contact behaviour at the end-effector.

b) Finger Joint Impedance Control: The five-fingered hand is equipped with joint torque sensors which allow for joint impedance control in order to provide versatile and compliant grasping capabilities, which supports stable grasping of a variety of objects.

c) Soft Robotic Features: The torque sensing in combination with a dynamics model of the robot arm allows for realization of soft-robotics features [21] including observation of external forces, collision detection, as well as virtual workspace limitations [22] all of which provide safety in assistive robotic scenarios.

d) Subtask Control: Several subtasks are implemented to be realized in parallel to the main objective at the end-effector, but without disturbing this higher-priority task. This includes singularity avoidance w. r. t. the Cartesian coordinates of the end-effector in order to optimize the manipulability, reconfiguration at the elbow to maintain adequate arm configurations, and null space damping for safe, reliable, and efficient operation.

e) Platform Motion Control: The augmented wheelchair provides the means for high-performance motion control of the mobile base. Via an admittance interface similar to [23], the kinematic motion controller of the wheelchair is integrated into the whole-body impedance control framework of EDAN. Extended with geometric activation thresholds (cf. Fig. 6), a predictable whole-body control concept is realized, enhancing the manipulation capabilities of the system [24].

2) Motion Generation: The control algorithms which realize the desired motion of the system are executed within a control loop running at 1kHz rate. As EDAN's higher level software is running at lower rates and does not necessarily comply with real-time requirements, a motion generation process is needed to guarantee continuous desired poses to be sent to the controller. Essentially, two different modes of motion generation are realized, one for pure manual control of the robot's end-effector, the other to run the shared control approach.

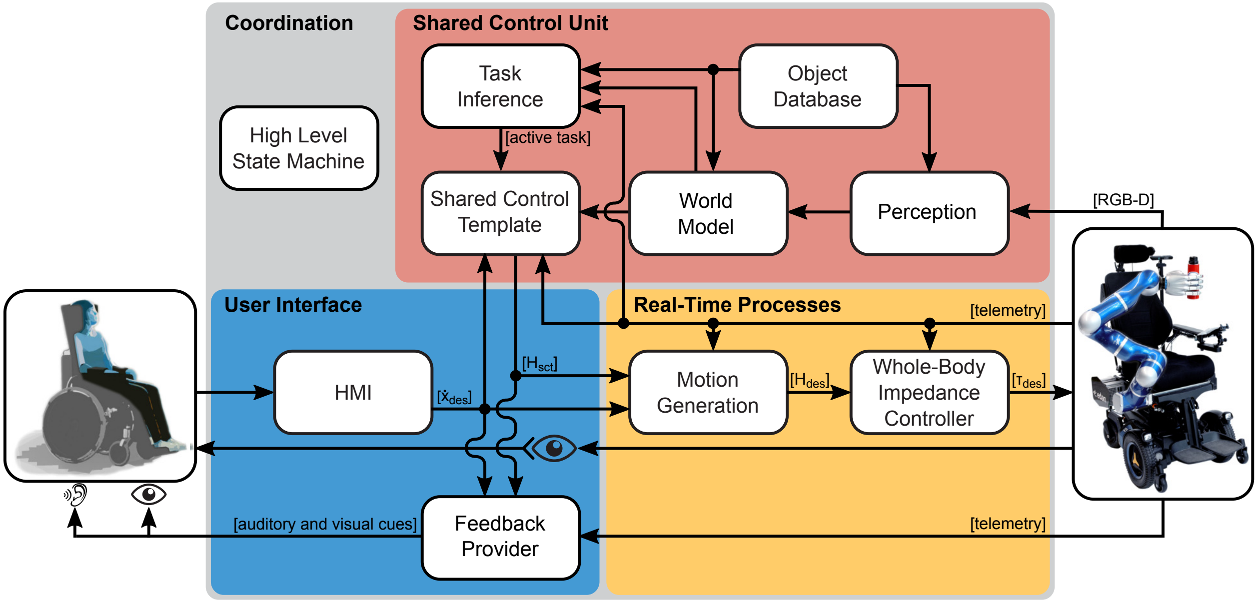

Fig. 5. Reduced scheme of the main software components and their interaction. Software modules are clustered in *Real-Time Processes*, *Shared Control Unit* and *User Interface*. The overall behavior is coordinated by a High Level State Machine.

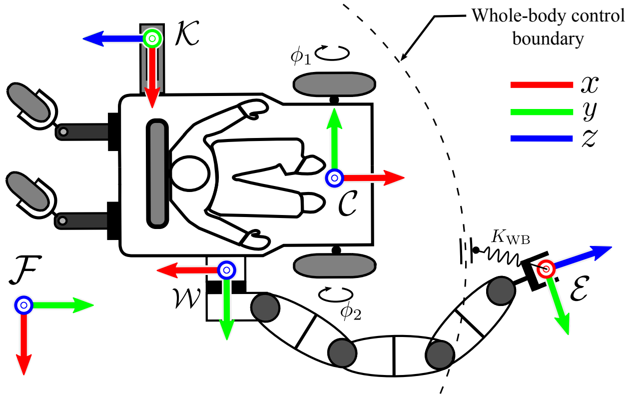

Fig. 6. Schematic representation of the EDAN system illustrating the different coordinate systems. The mobile platform position and orientation are defined with frame $\mathcal{C}$ w. r. t. the fixed frame $\mathcal{F}$, $\mathcal{E}$ is the end-effector frame, $\mathcal{W}$ is the manipulator base frame, and $\mathcal{K}$ denotes the camera frame. ϕ_1 and ϕ_2 are the front wheels positions measured using digital encoders.

In manual control, the velocity commands originating from the interface are first filtered and then integrated either in translation $\boldsymbol{x}_d = \boldsymbol{x}_0 + \int_0^t k_{\mathrm{trans}} \dot{\boldsymbol{x}}_{\mathrm{des}}$ or in rotation $\boldsymbol{\phi}_d = \boldsymbol{\phi}_0 + \int_0^t k_{\mathrm{rot}} \dot{\boldsymbol{x}}_{\mathrm{des}}$, starting from the current robot position $\boldsymbol{x}_0$ and orientation $\boldsymbol{\phi}_0$. Here, k_{trans} and k_{rot} are scaling factors to map user command $\dot{\boldsymbol{x}}_{des}$ to the respective control space. This way, a homogeneous transformation of the desired end-effector pose H_{des} can be generated.

While in manual mode continuity of the desired pose is guaranteed from the integration process, this can not be guaranteed for the shared control mode. As described in section IV-B, the shared control module calculates a desired pose H_{SCT} based on user input and a set of constraints at a rate of approximately 100Hz. To provide a continuous desired frame and stay within safe velocity limits, a trajectory towards this generated target pose is calculated at real-time using the approach presented in [25]. Essentially, this approach performs a linear interpolation for the translational and a spherical linear interpolation for the rotational component of the target frame. This allows for easy realization of a velocity limit, both in translation and rotation. The resulting pose is filtered with a 2nd order filter to get a smooth trajectory, the goal of which can be updated by the shared control module at any time.

B. Shared Control Unit

Even though users appreciate controlling the manipulator themselves [26], the manual control capabilities can be difficult to use in some applications. For example opening a door while switching between wheelchair and manipulator control (translational, rotational and fingers) is challenging. Another example is pouring water into a glass: here, one has to constantly alter the interaction mode in order to execute a curved pouring motion. However, it is possible to map those complex motions to a lower dimensional task-space. We therefore built a Shared Control Unit to assist users in their activities of daily living.

1) Object Database: Our shared control skills are based on a known-objects database, using the concept presented in [27]. This object-centric world view uses object classes and inheritance, e. g. the class thermos derives from the virtual class `_bottle` which derives from the virtual class `_container`. This brings flexibility to task inference, e. g. it is only possible to pour liquid into a object inheriting from `_container`. For every object, the database stores information such as 3D meshes, parameters like weight or symmetries, and interaction information like `tool_frame` (drill bit of a drill or tip of a bottle) or `grasp_frames` (where to grasp the object).

2) Perception: To detect and localize known objects an online perception algorithm is used. Based on the RGB data available from the camera, a bounding box detector pre-trained on ImageNet and fine-tuned on our objects of interest is applied. This is followed by a pose estimator algorithm [28] combined with an Iterative Closest Point algorithm using depth data. For objects with support plane like door or drawer handles, the plane equation is estimated from depth data and intersected with the object bounding box for a more refined pose, cf. [24]. Additional scene grounding limits instabilities caused by partial observability.

3) World Model: Objects detected by the perception module are instantiated in a centralized world representation [27]. This world model describes the robot belief of the current state of the world. Our shared control approach exploits this world model and hence is independent from the online perception, providing stability at the expense of reactivity. The world model is visualized using OpenRave [29].

4) Shared Control Template: To provide the user with support from shared control skills, we use our concept of Shared Control Templates (SCT), introduced in [30]. SCTs are linked to object classes, e. g. the skill ‘Pour liquid’ is available for all instances of the class `_bottle`. An SCT skill is written in a human readable YAML file and describes a Finite State Machine. Transitions between states can depend on distances between poses of interest, like the `tool_tip` of an object and the origin of a target. They can also depend on manifold boundaries, timeouts or thresholds on the estimated external wrenches applied on the end-effector of the manipulator.

In each state Input Mappings as well as Active Constraints (also called Virtual Fixtures) can be defined. Input Mappings describe how the low dimensional input commands, originating from the sEMG-interface or from a joystick, are mapped to displacements of the manipulator. Similar to the manual mode, default mappings are translational or rotational controls, but more elaborate mappings are useful for more complex tasks. For example, while pouring it is useful to map commands to rotate around the tip of the grasped object in the direction of the target, and not around the end-effector. Additionally, command scaling is available to improve control by favoring commands along task-relevant directions of motion.

Active Constraints apply geometric constraints on frames of interest, as the end-effector pose or the `tool_frame` of a grasped object. These constraints help the realization of the task, like keeping a grasped object above a table, guiding the end-effector within a cone toward the `grasp_frame` of a target object or constrain it in a vertical cylinder to stay on the trajectory of the handle when opening a door.

5) Task Inference: To identify available tasks to the user, we use a library of SCT skills and adapt concepts originally built for high-level autonomy as used in [27]. In particular we use PDDL [31] to provide preconditions and effects, which, when coupled with our world model and object instances, allows to infer a list of possible tasks at any given moment. For example, the skill ‘pour liquid’ can be used on the condition that a `_bottle` instance has been grasped by the manipulator and that a `_container` target is present in the world model. If fully executed, the pouring skill has the effect to fill up the target container, which makes the ‘drinking from target container’ task available. Tasks are selectable on the tablet interface and ordered heuristically, primarily via adequate distance measures.

Auto-activation of specific shared-control skills based on distance thresholds is available for the user’s convenience. To further increase the autonomy spectrum available to users, a trigger signal given during a task execution will autonomously complete the current task following a sampling based planner which is working along the SCT skill constraints. This way, the user can actively decide on the desired level of autonomous support.

C. User Interface

As described in Sec. III, EDAN is designed to be operated via a 3DoF velocity signal in combination with two trigger signals. Accordingly, any human machine interface (HMI) meeting these requirements can be used. Furthermore, in order to keep the user informed about the system state, a feedback provider is used to present this information on the tablet computer mounted to the arm rest.

1) HMI: At the highest level of the HMI, EDAN offers four modes of operation to be selected, corresponding to the device that the user actually wants to control. The user can cycle through the available devices (Arm – Tablet – Wheelchair – None) by using the head-switch. This way, the user can easily activate the device to be controlled, or pause control by selecting *None*.

In the current state of implementation, two options are implemented on EDAN to provide the remaining control commands: a joystick-based, and an sEMG-based interface as introduced in [17]. Both interfaces provide 3D continuous velocity signals and a binary trigger signal. When operating the arm, the default control-mode is manual-mode, in which the HMIs velocity commands are mapped to translational movement of the arm’s end-effector. Here, using the trigger signal allows for cycling between translation – rotation – and hand configuration control (cf. Fig. 7).

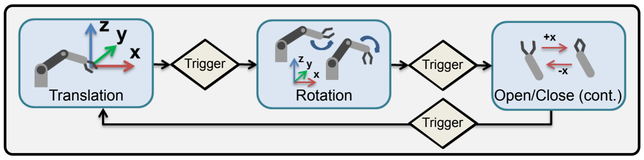

Fig. 7. Scheme of command mapping implemented for manual mode.

In wheelchair mode, two DoF of the velocity command are mapped to forward/backward and rotational movement respectively, while the third DoF and the trigger signal have no use. When in control of the tablet, the continuous commands are discretized and allow to select items on the tablet application. Here, the trigger signal is used to activate the selected item.

2) Feedback Provider: The tablet application is intended to inform the user about the current state of the system and present available options in terms of control modes and

Fig. 8. Picture series of the task *open drawer*. The task is automatically activated, as soon as the user moves the end-effector close to the drawers handle. Once the handle is reached, motion is limited to opening the drawer. Afterwards, the object is picked from the drawer using manual control.

potential tasks to be performed. To this end, it illustrates which device is currently active (i.e. manipulator, wheelchair or tablet), and depicts the current control mode (i.e. manual or shared control). Other contents to be displayed are state dependent. In case of manual mode, the currently active input mapping is shown. Furthermore, a set of grasp configurations (e.g. power, pinch or tripodal grasp) is available, to allow for grasping of various objects. In shared control mode, the currently available tasks are listed, ordered according to the priority assigned by the inference module. Additionally, the current result of the perception module is shown, depicting the RGB image of EDAN's camera enhanced with highlights and labels of localized objects (see Fig.2).

V. AREAS OF APPLICATION AND FUTURE WORK

The EDAN system is intended to allow people with severe motor disabilities to physically interact with their environment again. Essentially, it shall increase the user's mobility and allow for execution of activities of daily living.

A. *Exemplary Applications*

Several submodules of the EDAN system have been successfully tested already. For one, we could show in our previous work that the EMG-based interface in combination with manual mode enables users with SMA to perform delicate grasp tasks of the action research arm test (ARAT) [18]. In [30], we analyzed the functionality of the shared control mode in three exemplary tasks, while in [24] the whole-body functionality is demonstrated and analyzed.

As described above, we have now integrated all this functionality into the EDAN system, in order to empower the user to select the functionality which best fits the current task. In Fig. 8, a typical action is exemplarily demonstrated. Using a joystick-based interface, the user is opening a drawer supported by the shared-control skill and whole-body control accordingly. After successfully opening the drawer, the control modality is switched to manual mode and an object is retrieved from the drawer.

Several further skills are available from the shared control unit (see Fig. 9). E.g. grasping and placing of objects is available for a set of cups and bottles. Additionally, the shared control unit can support in pouring from a bottle into a cup, as this task requires simultaneous motion in translation and rotation. The most sophisticated task currently available is the opening of a door and passing through it. In this task the coordinated whole-body control is essential, as it expands the reachability of the arm to perform the task in a continuous manner.

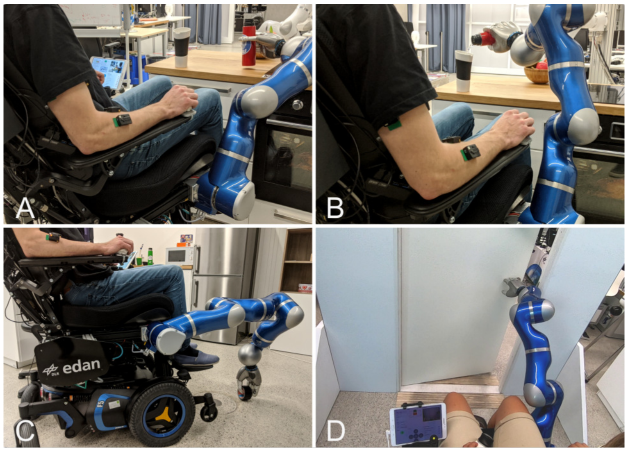

Fig. 9. Footage of various tasks executed with sEMG-based control. A/B: Grasping of a bottle and pouring to a mug supported with shared control. C: Grasping an object from the floor using manual mode. D: Opening a door and passing through supported with shared control and whole-body-control.

B. *Future work*

Given that the current state of the system allows for execution of many activities of daily living, the next step will be to run a pilot experiment with impaired users.

Additionally, the available set of skills will be continuously extended in the near future, to allow for support in more activities of daily living. To this end, we are also investigating the use of machine learning approaches, in order to learn the skill description of the shared control template from demonstrations of the task. In the long run, the goal is to allow the user to extend the skill-set of the system based on demonstrations using the manual mode.

Given an increasing skill-set, the current state of task inference is going to be expanded beyond purely geometrical measures, e.g. by using the available semantic information to calculate a more accurate likelihood of a task. Moreover, we are also planning to add a voice-based user interface, to interact with the tablet application and thereby simplify selection of control modes and tasks.

VI. CONCLUSION

In this paper, we have presented EDAN, the EMG-controlled Daily Assistant. EDAN is a research prototype of an assistive robotic system, to restore mobility and manipulation capabilities for people with motor impairment. EDAN is combining several robotic techniques to create a versatile and powerful system. The core components are the sEMG-based interface, the coordinated whole-body control and the shared control skills to support execution of complex tasks.

We are building our autonomy spectrum with a focus on flexibility, providing users with the possibility to set the autonomy level on a task dependent basis. In particular, we envision that user driven autonomy levels allow to explore EDAN's autonomous functions at the users own pace, thereby increasing transparency of the system. Our approach keeps the user in control and provides a transparent robot behavior which, according to [32], is essential to build up trust into the system and its autonomous capabilities.

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