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DUAL ARM ROBOT GRIPPERS' TEACH-IN AND CONTROL ARCHITECTURE FOR HANDLING OF SMALL OBJECTS WITH COMPLEX SHAPES TOWARDS ELDER CARE SERVICES

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Abstract: *Actual demographic projections are raising concerns about aging population and governments' abilities to deliver adequate care services. Introducing service robots for assisting elder care activities is an envisaged solution. First part highlights Romanian demographic projections and population acceptance of robots for care activities compared to EU. Second part presents authors vision for introducing robots in elder care facilities and the conceptual framework towards development of elder care services based on high level of intuitiveness. In third part an experimental glove type device for controlling robot grippers, its interface with robot and brief control logic are presented. An experimental application where developed device was employed is detailed in fourth part and in last part conclusions and further research directions are presented.*

Key words: teach-in device, rapid prototyping, industrial robot, tele-control.

1. INTRODUCTION

Over the last decades trends like increased life expectancy, reduced birth rated were observed within in all over the world. These trends, combined with economical facts, personal beliefs, political and geopolitical decisions are leading towards an accentuated aging process of world population.

This phenomenon is even more accentuated in developed and under-development countries and European Union (EU) states are not making an exception [1, 2, 3, 4].

Aging population has been highlighted as one of the EU major issue since directly affects the three pillars of a sustainability society: social, environmental and economic [3].

According to EUROSTAT projections EU will experience an increase in over 65 years individuals by 12% and a decrease of working force by over 10% by 2060 [1, 2, 3]. Over 65 years individuals will count up to 15% of global population by 2060 [4].

As part of EUROSTAT projections the old-age dependency in Romania will reach by 2060, 64.8%, the second highest level from EU [1, 2].

Consequences of such circumstances can be concluded as a high number of over 65 years individuals with age specific characteristics, social and medical requirements being taken care of, from medical, financial and social perspectives, by a reduced working force.

Therefore, issues related to the ability to provide adequate and sustainable care of elder individuals are rising from social and economic point of views. The major cost driver of elder care facilities are staff costs, approximately 70% [5].

One of the envisioned and emerging solutions for reducing costs and involving less work force with elder care activities and services in order to deliver a boost and leverage effect by concentrating society resources (people, training, education) towards jobs generating real added value and wealth would be the introduction of service robots in elder care and related activities [8].

This solution is already undergoing and financially supported by Japan government, mainly due to the competitive research advantages in the field of robotics and positive feedback from population towards robots [6, 7].

Over 60% of EU citizens are against using robots when it comes to children or elderly care as shown in Euro barometer 382 [9]. Comparing robots acceptance results, Romania can be considered a better environment for introducing robots for elder care since only 51% of citizens are against using robots for care activities, a percentage under the EU average.

In order to successfully introduce robots in elder care activities, beyond gaining society confidence one of the main function that elder care robots should provide is high intuitiveness in robot task learning in order to easily overcome the huge diversity of requirements that have to be faced as fast as possible by the operators.

Presented, within this paperwork is authors' vision and one of the first experimental stages of a solution which aims to develop the hardware and software framework for providing assisted handing functionalities for small objects with complex surfaces. It is envisioned that the proposed solution will act as an enabler in rapid task development and learning towards elder care services.

2. PROPOSED CONCEPT

Proposed solution consist out of the design, development and testing of custom built hardware devices, software environment and modules for controlling a robot and its grippers in order to provide assisted handling and manipulation of small objects with complex surfaces.

The first phase of the proposed solution concept consists in developing an affordable input device for a custom architecture consisting of a dual-arm Motoman™ robot and two grippers by employing embedded systems and rapid development tools.

Proposed concept architecture for the first development phase can be observed within figure 1. Its architecture consists out of two embedded systems that are exchanging data by means of wireless communication.

One embedded system uses sensors and data processing algorithms to read hand gestures, process information and send it to its partner. A second embedded system is used to interface with robot controller, read processes data and de-multiplex it on robot IO board. After which, a robot routine is required to process received data and control the fingers of the two grippers in accordance with operator hand gesture.

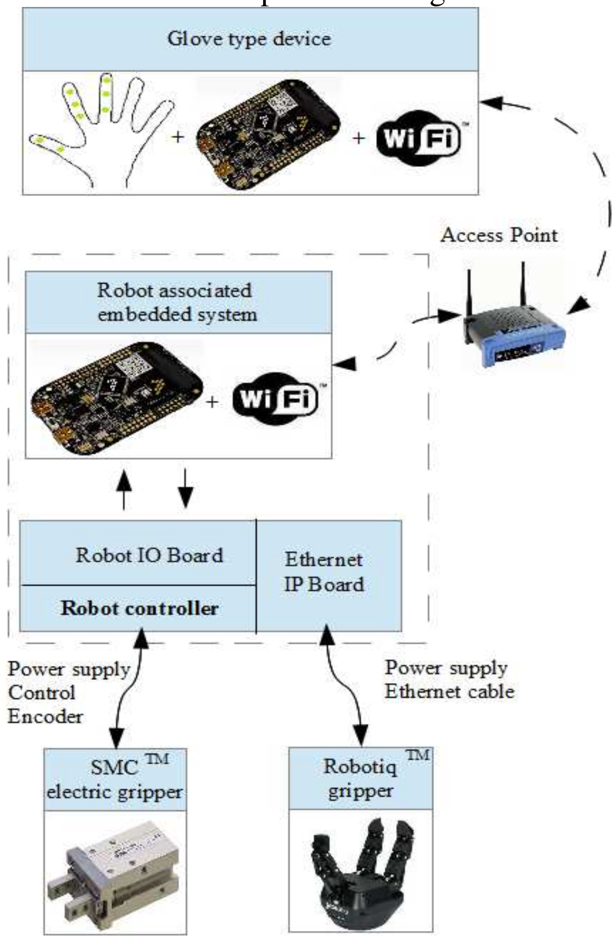

Fig. 1. Proposed concept phase one architecture

Even if, development of input devices able to read human hand gesture, process and send the acquired data for achieving different tasks dates back to 1980's [10]. Since then, various robotic hands, input, haptic devices and control methodologies and algorithms were developed considering latest technological developments and the increasing number of fields in which they can be used starting from: virtual reality, entertainment, tele-operation, interaction up to medicine and rehabilitation [11, 12, 13]. A comprehensive survey and brief classification of these devices was done by Dipietro [14].

One of the most advanced glove type device available on the market is the CyberGlove consisting of up to 21 sensors and Wi-Fi technology, still being very expensive. Beyond costs, another drawback is the compatibility or the required software and hardware interfaces to interact with industrial robot controllers.

Even if proposed device performances cannot match CyberGlove and additional robot jobs are needed it shall be able to interact with all robot controllers by means of robots IO board to perform required tasks.

Second phase of proposed solution concept consists in development of the online environment and creating plug-and-play software functionalities and services. Also within this phase standardization of hardware equipment and operations which are planned to be used is required for seamless interface and operation. Second phase is not part of this paperwork.

3. EXPERIMENTAL TEST-BENCH

The glove type pure input device should be capable to transpose finger gestures into useful data, interface with Motoman™ robot controller hardware and control two grippers: a three fingers adaptive gripper from Robotiq™ via an industrial communication protocol and another electric gripper manufactured by SMC.

Within this experimental phase a cost effective input device able to assist human operators in teaching or operating a dual-arm robot to smoothly handle small to medium size objects with complex surface is presented.

A wireless control device for a three-finger adaptive gripper from Robotiq™ and a two-finger electrical gripper is set up for the experimental bench.

Complex handling operations can be approached by the three-finger gripper due to its adaptive characteristics, while the two-finger gripper is mainly used for auxiliary functionalities in relation to the handling operations.

As can be observed in the proposed architecture of this phase, figure 3, it consists out of two major parts: the glove type device and the robot associated embedded systems which are exchanging data using a wireless network.

3.1 Glove type device

The glove type device, presented in figure 2, is a pure input device intended to be wearable by the operator which desires to control the robot grippers accordingly to its hand gestures. From hardware point of view it consists out of:

- three flex sensors from Spectra Symbol mounted on the thumb, index and middle fingers,
- one rapid prototyping Mbed enabled hardware platform from Freescale FRDM-KL25Z,
- one custom designed bottom board with five push-buttons,
- a wireless communication module from Roving Networks RN-171ek.

From software point of view an online programming platform with built-in compiler is employed to orchestrate the required algorithm for gripper's control (mbed.org).

Fig. 2. Developed glove type device

Controlling the three-finger gripper is achieved as follows: the software algorithm reads, filters, digitizes and processes the analog signals delivered by the flex sensors of whose properties are influenced by the position of the operator's fingers.

The second gripper is also controlled by the operator by swiping its fingers over a touch sensitive area available on the top of the hardware platform. The processed data is sent at short time intervals via the Wi-Fi module to the embedded system connected to the robot controller. Wi-Fi is module is connected to the Freescale development board by a serial connection.

In gripper teach mode, by means of pressing the available push-buttons, the operator can increase or decrease sensitivity and save or delete values corresponding to specific gripper positions which are going to be used in robot running mode for handling and manipulating specific objects for which values were saved

3.2 Robot associated embedded system

The robot associated embedded system, presented within figure 5, is a custom built embedded system of whose inputs and outputs are connected and optically isolated to inputs and outputs of robot controller's IO board as described in table 1.

Eight robot inputs are used to receive 8-bit data regarding human hand position, and speed, another three inputs are specifying which finger to be moved at the corresponding position with the calculated speed.

Information about basic status of interfacing systems is shared via inputs and outputs.

Controlling the second gripper is done using two robot outputs connected to the second gripper control unit.

The software algorithm of the embedded system reads data sent via the communication module of the glove type device which de-multiplexes and decodes received data and sequentially activates inputs of the robot controller's IO board while reading the status of the robot controller or triggers other internal predefined procedures.

For this purpose, several software procedures and tasks are specially designed and loaded in the robot controller.

A software procedure created in the robot controller reads the inputs, interprets information and data regarding human hand position and the speed of moving fingers is sent to the Robotic adaptive gripper via the Ethernet IP communication protocol or controls the second gripper by sending signals to the control unit of this gripper.

The glove type device requires calibration with robot adaptive gripper for every new user. A raw calibration software procedure for each finger movement was developed as part of service operations of the glove type device. The operator has to extend and compress to a maximum each finger and by using the pushbuttons available on glove type device to "tell" the device that these are anatomical limits of user hands.

Table 1

Inputs and outputs mapping and description.

Motoman IO board	*Signal type and address*	*Description*
CN306-B1	Input (20040)	If 20056 False - 8 bit representation of a human hand finger and the position where gripper finger must go. If 20056 True - 8 bit representation of the speed for moving the corresponding finger at the specified position.
CN306-A1	Input (20041)	
CN306-B2	Input (20042)	
CN306-A2	Input (20043)	
CN306-B3	Input (20044)	
CN306-A3	Input (20045)	
CN306-B4	Input (20046)	
CN306-A4	Input (20047)	
CN307-B1	Input (20050)	Depending on its state it shows what kind of data is received at addresses: 20040-20047.
CN307-A1	Input (20051)	According to decimal representation of bits: 20051 – 20053: 0 – SMC gripper selected, 1 – Thumb finger selected, 2 – Index finger selected, 3 – Middle finger selected
CN307-B2	Input (20052)	
CN307-A2	Input (20053)	
CN307-B3	Input (20054)	False – Embedded design busy
CN307-A3	Input (20055)	For further development
CN307-B4	Input (20056)	False – position value, True – speed value
CN306-B8	Output(30040)	Robot busy
CN306-A8	Output(30041)	Robotiq Gripper busy
CN306-B9	Output(30042)	Control second gripper (0 – Open, 1 – Close)
CN306-A9	Output(30043)	Robot job type (1 – teach, 0 – play)
CN306-B10	Output(30044)	Trigger event 1
CN306-A10	Output(30045)	Trigger event 2

CN306-B11	Output(30046)	Trigger event 3

Afterwards, the glove type device will use a linear scaling function to provide an 8 bit data value between 0 and 255, as requested by Robotiq adaptive gripper: 0 – meaning full open and 255 – meaning full close.

The developed device is capable to deliver a certain degree of modularity and re-configurability since it is possible to add up to five flex sensors, therefore being able to control grippers with five fingers.

In authors vision the robot associated embedded system shall be able to be loaded from a cloud service or taught by the operator with the required software for handling a specific part or object.

3.3 Process logic

This chapter presents briefly presents the control logic of interconnected systems: glove type teaching device, robot associated embedded system, robot job.

Within figure 3 a brief overview of glove type device control logic is presented.

After applying power to the device, a raw calibration process, presented at the end of section 3.2 is required if a new operator is using the glove type device. Otherwise, if user has already done a calibration process he selects his calibration ID and calibration data is loaded.

Afterwards the device connects to a pre-configured wireless network and attempts to connect to the robot associated embedded system which acts as a server in this application.

The glove type device enters automatically in teach mode, where the operator can control three fingers Robotiq adaptive gripper by hand gestures and the SMC gripper by interacting with the touch sensitive area of the board.

Within this mode the operator can save, delete or modify several grippers' positions, together with their speed and force. When teaching process is done the device shall upload data to a cloud service and the functionality can be created and later used (this features marked with dashed red line on figure 6 are underworking).

Being driven by a stepper motor the second gripper, control units allows saving several open or close positions which can be selected afterwards.

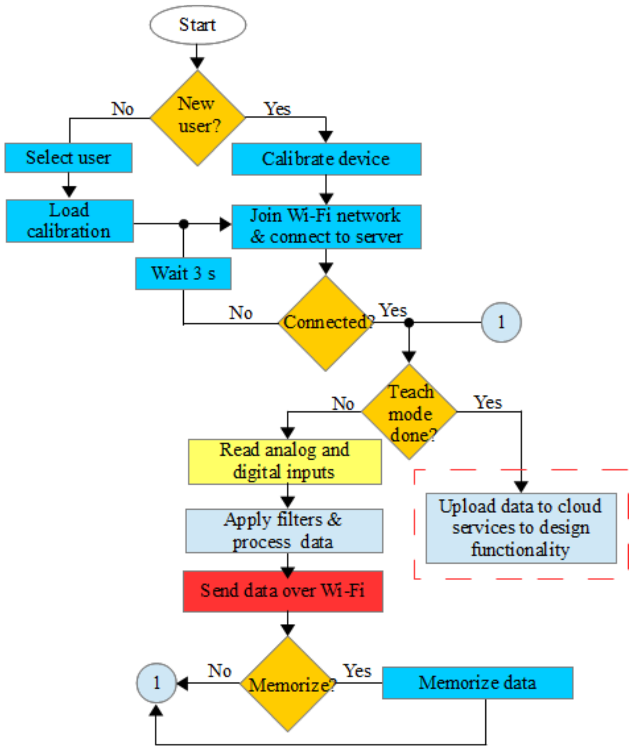

Fig. 3. Brief overview of glove type device control logic

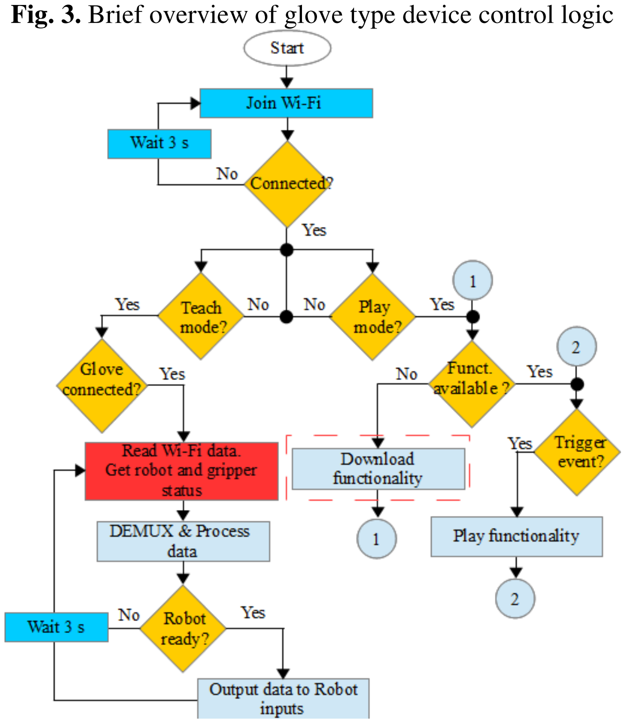

Fig. 4. Brief overview of robot associated embedded system control logic

After joining to the pre-configured wireless network, the robot associated system is listening for clients. This embedded system is designed to run in two modes: teach mode and play mode as can be observed in figure 4.

When in teach mode it receives data from the glove type device regarding fingers position speed of movement and force. Received data is de-multiplexed and if robot and grippers are ready the data is sent to robot IO board according to table 1 signal mapping in order to control the grippers.

When in play mode, the robot runs an already developed functionality for a specific handling and manipulated task (under development, marked with dashed red line in figure 4). Robot associated embedded systems controls grippers by driving them to learned positions in correlation with robot job.

The robot main job has two sections. Teach section is used by the operator when is jogging grippers to handle specific parts and memorize gripper position accordingly to manipulated objects. When in play mode a robot procedure is reading at specific time interval the status of robot associated embedded system and the IO board inputs that are activated by the robot associated embedded system corresponding to gripper selection, position and speed.

Afterwards IO board outputs are updated in order to control the grippers as desired by the operator.

In order to test functionalities available on the robot associated embedded system, the operator has to previously create a robot job, and make use of instructions that are writing the outputs corresponding to the desired functionality that is desired to be triggered, as presented in table 1.

4. EXPERIMENTAL APPLICATION

In order to test the first phase of the proposed solution, functionalities for grapping and releasing specific type of water bottle and water can were created.

These functionality were downloaded into the robot associated embedded system and a robot job was created and orchestrated for pouring water to the water can.

The picture within figure 5 is part of the teaching process for grabbing a bottle.

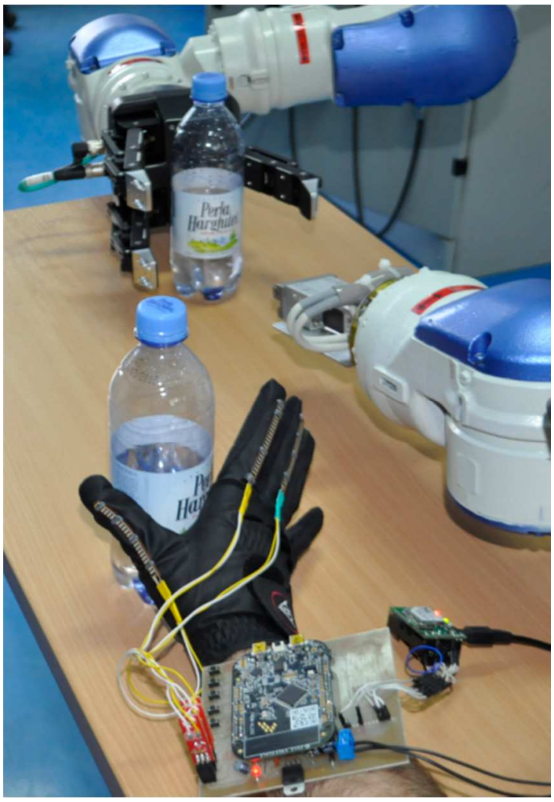

Fig. 5. Teaching a robot to grab a bottle

Fig. 6. Running a robot task

Figure 6, is depicted from a robot job intended to pour water in a can. The robot job is created by the robot operator and where grabbing the water bottle functionality is needed the operator has to activate the output corresponding to the de-sired event within the robot associated embedded system (e.g. output 30044 which triggers event with number 1 on the embedded system side).

In big lines, when the event is activated, a robot procedure is reading the inputs activated by the associated embedded system and controls the grippers accordingly.

An application example where the proposed solution could be employed is within an elder care center where an operator could remotely teach a robot how to prepare and deliver breakfast to bed at early hours, therefore reducing the number of involved care personnel required during nighttime.

5. CONCLUSIONS

Phase 1 of the approach delivered a low price (approximately 200 euros) glove type input device and basic method for controlling one of the newest products on the market interconnected with a Motoman DX-100 controller using the Ethernet IP communication protocol and an on/off electric.

Rapid prototyping of applications, functionalities and services for elder care can be enabled by the proposed solution.

Nevertheless, the device requires better data process algorithms and good calibration in order to replicate human hand gesture more precisely.

Implementing authors' vision, as presented in chapter 2, several major constraints should be considered (e.g. standardized orienting and positioning equipment for grasping the objects for which the software modules were uploaded).

Also, the development of the phase 2 of the concept is impetuously required in order for this concept to be effective.

Several issues were identified and presented below:

- Different users must have the same type of equipment available in order to use the uploaded functionalities, unless virtualization of available equipment and software "harmonization" is previously done.
- Feasibility of the solution is depended on robot type and its technology, since performance, workspace and other important parameters cannot be replicated on all types of robots, constraints might occur.

Some of the identified technological performances:

- Average response time: < 2 sec,
- IoT connectivity,
- Rapid prototyping using the online Mbed compiler,
- Satisfying hand gesture replication,
- Objects with complex shape and different size (17 cm) can be safely gripped and manipulated by Robotiq gripper.

Further research activities will be focused towards:

- Glue the flex sensors to the glove type device for a better response to human hand gestures,
- Introduce force sensors in order to control the force applied of Robotiq gripper,
- Implementation of advanced software algorithm in order to filter and process sensors signal,
- Use the onboard accelerometer and develop the required software in order to rotate the last joint in accordance with wrist rotation.
- Reduce the size of the wearable device and development of a mechanism to attach the device to operator arm.

8. ACKNOLEDGMENT

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Platforma de control a griperelor unui robot de tip umanoid pentru manipularea obiectelor mici cu forme complexe in scopul dezvoltarii de functionalitati pentru servicii de ingrijire a varstnicilor

Rezumat: Una din problemele generate de evolutia demografica prevazuta pentru urmatoarele secole referitoare la gradul de imbatranire populatiei este problema asigurarii de servicii de asistenta si ingrijire adecvate in special pentru varstnici. Unul din scenariile posibile este introducerea robotilor de servicii pentru a asista in activitatile de ingrijire a varstnicilor. Prima parte a lucrarii evidentiaza proiectiile demografice pentru Romania si gradul de acceptare a populatiei fata de introducerea robotilor in activitatile de ingrijire in comparatie cu media in Uniunea Europena. A doua parte prezinta viziunea autorilor asupra introducerii de roboti in centrele de ingrijire a varstnicilor impreuna cu prezentarea conceptualui unei platforme de cooperare pentru dezvoltarea de aplicatii specifice ingrijirii bazate pe un nivel ridicat de intuitive si usurinta in dezvoltare. Un dispozitiv experimental de control al griperelor unui robot de tip umanoid, interfatarea cu sistemul robotic si logica de control sunt prezentate in a treia parte. A patra parte prezinta o aplicatie care utilizeaza dispozitivul de control pentru realizarea de operatii specifice. La final, concluziile si o serie de aspecte tehnice impreuna cu viitoarele directii de cercetare sunt prezentate.

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