ISSN 1590-8844
International Journal of Mechanics and Control, Vol. 16, No. 01, 2015

AN APPLICATION OF LARM CLUTCHED ARM FOR ASSISTING DISABLED PEOPLE

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ABSTRACT

This paper addresses attention to an application of LARM Clutched Arm for feeding process aiding disabled people. The research core is focused on experimental kinematic analysis of the robotic arm with high-speed video analysis equipment for validating its functionality. Originally the arm was designed for humanoid robots, but the reported results demonstrate that this arm can be also used in service human food feeding applications.

Keywords: Service robots, Robotic arms, Clutched systems, Assistive Food feeding robots, Experimental kinematics.

1 INTRODUCTION

Several solutions have been developed for helping disabled people to walk, to feed, to carry objects or to perform different tasks. These solutions are based on robotic systems or mechanical devices that are specifically designed for types of tasks.

In the particular case for human feeding process, there are several robotic systems already available as outlined in [1-9]. The meal assistance robot My Spoon (in Fig. 1a) is characterized by a manipulator arm with 5-DOF and an end-effector that is controlled by a joystick, with a spoon/fork of 1-DOF [1]. The assisting robotic system Handy 1 (in Fig. 1b) has a 5-DOF robotic arm that is installed on a non-powered wheeled platform to assist in very specific activities of daily life such as eating, drinking, and make-up application. During the eating application a scanning system of lights has been included into its tray section which helps the user to select food from any part of the dish [5].

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Another example of an assistive robotic system is Neater Eater [3], which has two versions: a manual one and an automatic one. It consists of 2-DOF arm with a dish, as shown in Fig 1c. The manually controlled Neater Eater comes with a handle with damping mechanism which absorbs tremor. The electric programmable device can be controlled by using switches, in light-touch finger or head switches and foot switches.

The Meal Buddy in Fig 1d [4] has a three-DOF robotic arm and three bowls that can be mounted on a board using magnets.

The Winsford feeder robot in Fig. 1e, [5] is a mechanical system with a pusher, which moves the food onto the spoon, and a pivoting arm which raise the spoon. The height of the feeder can be adjusted with a command by a switch. In the case of the system Fig. 1f [7], the food is placed in three bowls, which rotate until the desired food is located under the spoon. The spoon dips into the bowl, scoops up the food, and presents a rounded spoonful of food very near the lips of the user. The user must lean forward slightly and remove the food from the spoon. Other assistive robots for feeding applications are described in [8] to [10].

In general these systems use a large number of actuators and the command and control unit cannot be

easily accessible to a disabled person. Considering human feeding robots or mechanical devices developed for this purpose, one can note that most of them cannot be readapted in order to fulfil multiple or combined tasks such as grasping objects and feeding process or writing and feeding process.
By taking the above considerations into account, this design has been aimed to readapt a clutched arm that was specifically designed for humanoid robots, to the case of feeding process. This clutched arm has been used for research purposes at LARM laboratory [11-16]. The functions of this arm is reported in [11] with some numerical examples and test results, while its functioning for humanoid robot's arm are described experiment tests in [12]. In [13] ADAMS simulations are reported for single motion of arm, and the simulations for combined motions of LARM clutched arm are reported in [14]. The design, capability and experimental validation of this arm are described in detail mainly in [15]. In [16] the characteristics and functionality of arm are described for different applications as industrial robot's movement, an assisting movement and pick and place of the objects.
This paper is organized as follows. In the first section the existing solutions that are designed for disabled human feeding process are shortly presented. A prototype of LARM Clutched Arm is described from a general viewpoint in the second section. Based on the desired task and by considering the existing prototype several adjustments are presented in the experimental setup on third section of the paper.
Tests for assisting the disabled people on feeding process were performed by setting up different functionality modes. The obtained results are comparable with the ones acquired in case a feeding process by a healthy human subject as reported in section four.

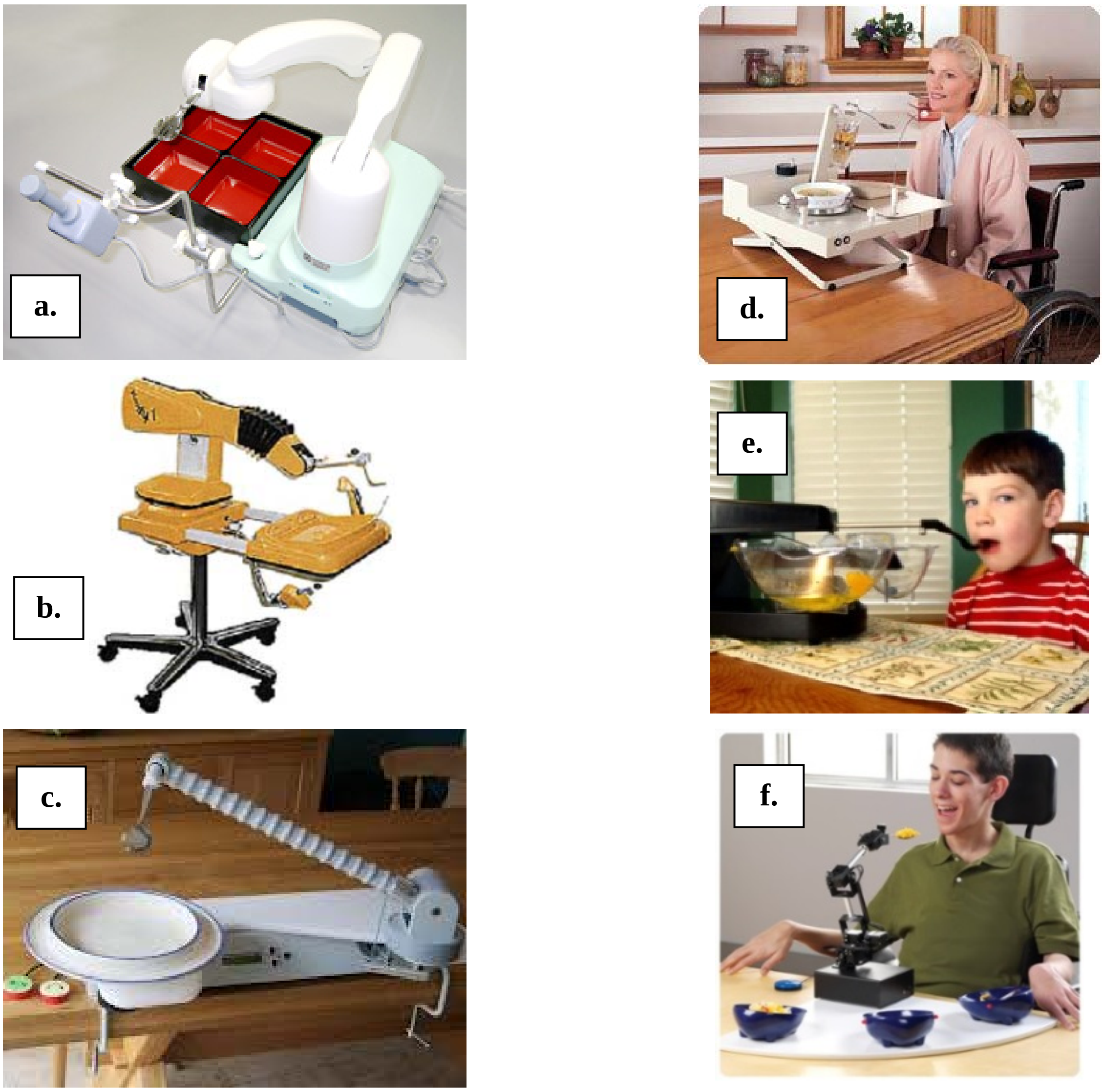

Figure 1 Examples of assistive feeding robots [1]-[9]; a) My Spoon, b) Handy 1, c) Neater Eater, d) Meal Buddy, e) Winsford feeder, f) Mealtime Partner Dining System.

2 LARM CLUTCHED ARM

LARM clutched arm [11-13] is a robotic arm with single actuator from which the motion is transmitted to joints with the help of gears and electromagnetic clutches. These components make possible the arm's movement in a 3D space by using only one electric motor. The design with the motor in the shoulder has been conceived to have most of the weight far from arm links that can be in contact with human users. This is for safety purposes with light weight design for low-inertia impacts.

Because of a single actuator, LARM clutched arm can be controlled fairly easily also by no expert users. Furthermore this arm is characterized by light weight structure, which ensures safety when a collision occurs between the robotic arm and a human. The single actuator implies a low cost design as compared with respect to other traditional robotic arms. Other aspect of this arm is that the motor works only when there is a movement of arm and there is no energy consumption when arm stops with energy saving. The size of all components are designed to give it an anthropomorphic aspect with specific cover.

The arm has a parallelogram-based mechanism for the limb part which makes to drive the upper arm and forearm from the shoulder. The main idea is to use a proper clutch system to obtain three sub-motions from the source motion of a single motor as shown in Fig. 2, [14].

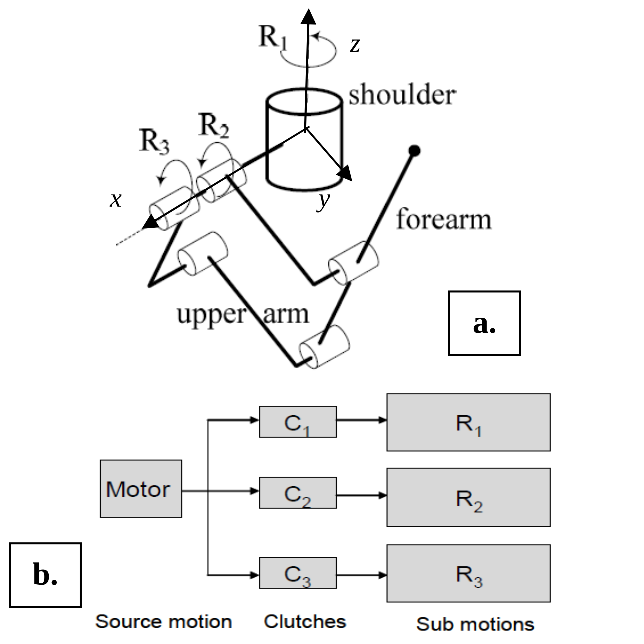

Figure 2 The design model of LARM clutched arm [14]; a) a kinematic scheme, b) an actuator scheme.

The shoulder is the main powered component of entire arm, because the motion for arm's functioning is given by it. The shoulder part gives output for three rotations R1 to R3. Rotation axes R1 and R2 are orthogonal to each other, while the axes for R2 and R3 are coaxial. Gearing systems are used to construct the transmitting lines for the required rotations. The entire structure is made up of light aluminium alloys which gives the light weight property.

In Fig. 3a the mechanical design of the shoulder is shown in which the z axis is orthogonal to R2 and R3 axes, while Fig. 3b shows a CAD model of the shoulder. The output shaft for R2 and R3 is a double cylindrical shaft, within which a full cylinder outputs the R2 rotation. Coaxial to this shaft there is a hollow cylindrical shaft which outputs the R3 rotation.

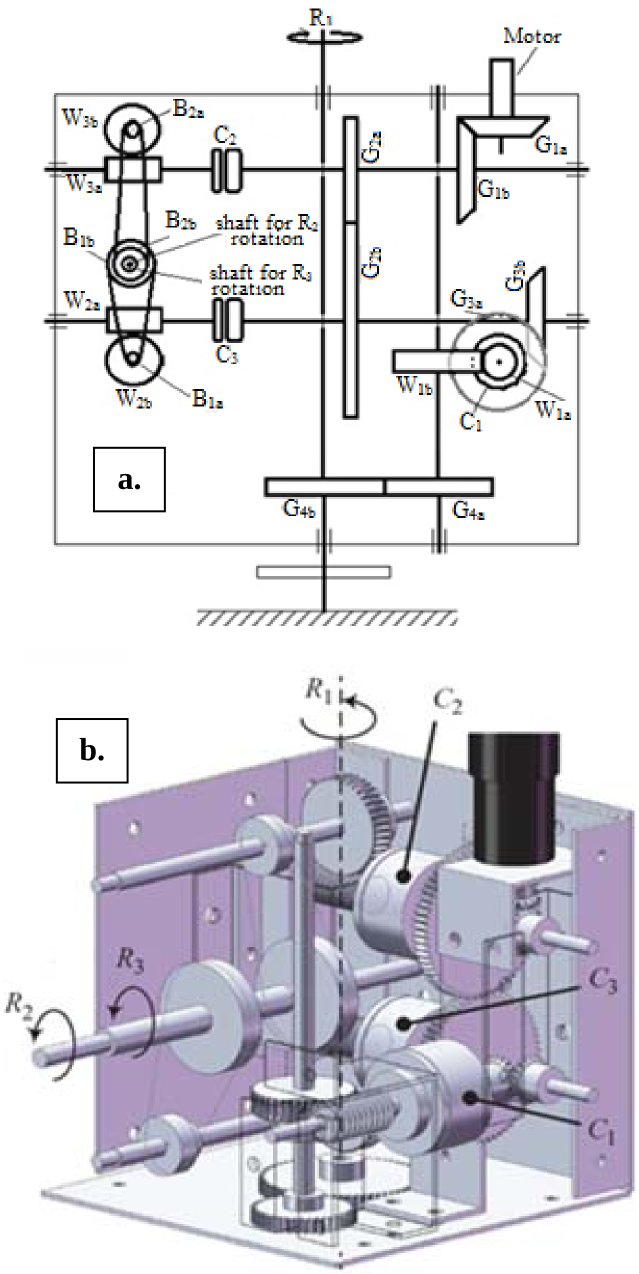

Figure 3 The mechanical shoulder design of LARM clutched arm; a) a kinematic scheme, b) a CAD model.

As referring to Fig. 3 (a), the components of the design can be identified in:
- $B_{ia/b}$ (i=1,2) represents belt wheels;
- W_{ia} and W_{ib} (i=1,2) represent the worm and the worm wheel respectively;
- C_i (i=1-3) are electromagnetic clutches assembled along the rotation axis;
- $G_{2a/b}$ represent cylindrical gear;
- $G_{1a/b}$ is the main conic gear;
- $G_{3a/b}$ is the secondary conic gear.

Fig. 4 shows a photo of the shoulder prototype of LARM clutched arm at LARM in Cassino. This figure shows how the gears and three electromagnetic clutches that are marked as C1, C2 and C3 are combined in the shoulder for the three rotations. The motion of joints can be transmitted or stopped by changing the state of clutches. With the three clutches there are eight possible modes of different combination of operation state, as summarized in Table I where 0 means the clutch is deactivated and 1 means the clutch is activated.

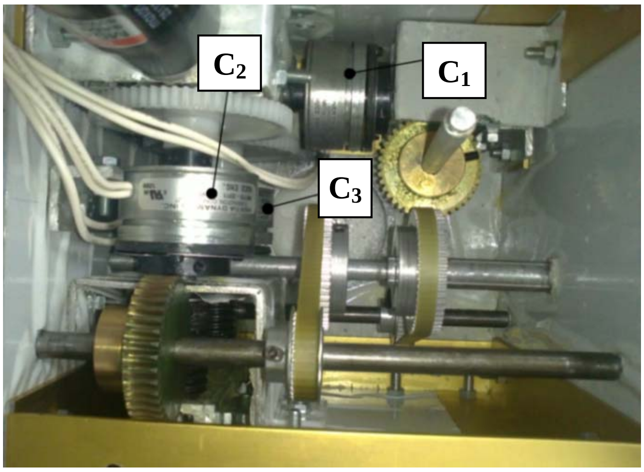

Figure 4 Mechanical design of the shoulder prototype of LARM clutched arm.

Table I - The operation modes for LARM clutched arm as function of clutches activation

Operation mode	Rotation	C_1	C_2	C_3
OP0	0	0	0	0
OP1	R1	1	0	0
OP2	R2	0	1	0
OP3	R3	0	0	1
OP4	R1 and R2	1	1	0
OP5	R1 and R3	1	0	1
OP6	R2 and R3	0	1	1
OP7	R1, R2 and R3	1	1	1

In Table 1 OP0 is a stationary mode, i.e. there is no rotation during this operation mode; while OP1 to OP3 are single operation modes, during which there is only one rotation at a time. OP4 to OP7 are multi-rotational operation modes, since during these operation modes there are more than one rotation simultaneously.
Figure 5 shows a photo of the prototype of LARM clutched arm at LARM in Cassino in a lab setup for tests. This arm can be attached to a wheel chair to help disabled persons for assistive movements like for example in food feeding. In this case a spoon is attached perpendicularly to the forearm as an end part with the aim to perform the food feeding action.

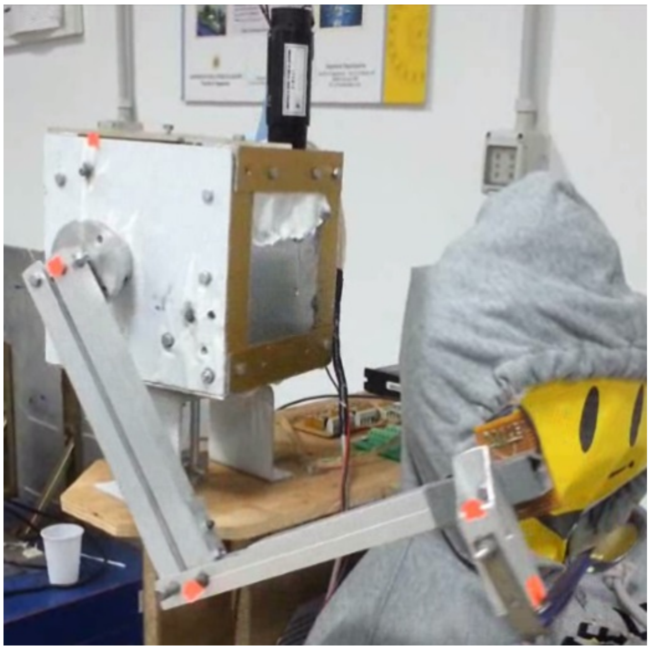

Figure 5 The prototype of LARM clutched arm in a lab setup for testing.

3 EXPERIMENTAL SETUP

Components of the prototype for lab tests are listed in Table II, and they are connected to each other as shown in the block diagram of Fig. 6.
A clamp handling the spoon with a three directional accelerometer is used as an end-effector. Further information on used components is given in the following.
In LARM clutched arm a 24V DC motor is used with information of motor speed and current given from a servo-amplifier. From the tests in [13] a maximum needed value of motor torque has been determined as 1.6Nm. Three equal 24V DC frictional electromagnetic clutches are used from Inertia Dynamics production with maximum transmissible torque of 1.7Nm. The control unit is composed of a PLC, a NI-PCI, and a servo amplifier as shown in the block diagram of Fig. 7, where C1, C2 and C3 represent the three clutches, respectively.

Table II - Components in the prototype of LARM clutched arm in Figures 4 and 5

Components	Characteristics
DC motor	70 watt, maximum speed 3000 (degrees/second)
Clutch	Maximum transmission torque (1.7Nm)
PLC	8 inputs and 4 outputs
PCI	6024E to communicate computer and periphery
Accelerometer	A three axis, measure range (±4g)
Worm	1 module, 20 (degrees) pressure angle, material: steel
Worm wheel	1 module, 40 teeth, material: brasses
Spur gear	1 module, 40/64 teeth, material: plastic
Bevel gear	1 module, 16 teeth, material: plastic
Belt wheel	32/60 teeth, material: aluminium

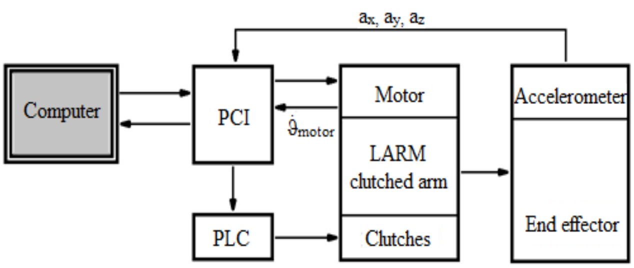

Figure 6 A block diagram for connection among components in lab layout in figure 5.

For a generic movement of LARM clutched arm, the CLANCONS program, elaborated in LabView, sends the signal to outer components with the help of PCI. This PCI sends a digital signal to an amplifier (with lines indicated as DIO), which regulates the current to pass in the PLC. The clutches state can be modified by changing the current value from PLC through a suitable command data [14]. The motor informations acquired by the servo-amplifier are analogical and they are sent to the PCI through ACH14 and ACH15. Comparing this information on motor's measured angular position with a prescribed value as in operation the program, an analogical signal created by the PID is sent to the servo-amplifier from PCI through DAC0OUT. The servo-amplifier gives current to the motor through commands for + motor and – motor as indicated in Fig. 7.

In order to control the arm operation, a GUI interface (Graphic User Interface) has been elaborated in LabView with the name CLACONS (CLutched Arm CONtrol System). It has two modes: Adjust mode and Control mode. The Adjust mode can be used to control the arm manually to reach on a desired position; while Control mode can be used for automatic function of arm. Through suitable programming during a controlled motion the system reads a text file in which the path is written for arm movement. For safety considerations, there is an emergency STOP button, which terminates the arm function leading the operation mode to OP0. Three virtual meters monitor the motor state while three LED lights indicate the state of three clutches, respectively. For arm's movement CLACONS sends a signal through the PCI to other components. The PCI sends a digital signal to an amplifier, which regulates the current that is given to the PLC. On the base of current value, PLC regulates the state of clutches by opening and closing the circuit through which the current passes to produce the electromagnetic field in the clutch. The servo amplifier receives a command signal from PCI, amplifies the signal and transmits electric current to the motor in order to produce a motion proportional to the command signal. An accelerometer as shown in Fig. 8 is attached at the end of the forearm to measure the acceleration of arm's end point along three directions.

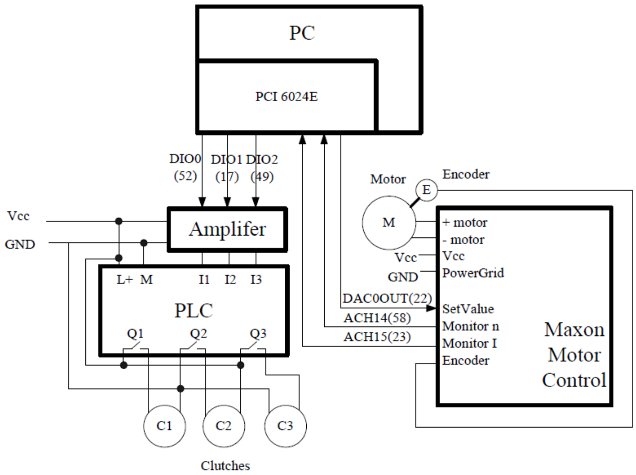

Figure 7 A block diagram of proposed control unit.

Figure 8 The accelerometer used at arm end point.

In order to compare the operation of food feeding achieved by the LARM clutched arm with a similar human operation, a video recording has been acquired through an ultra-high speed equipment CONTEMPLAS [17]. The CONTEMPLAS application layout is illustrated in Fig. 9 as was used for a motion analysis on a human subject and LARM clutched arm to study human upper limb motion

during feeding process. This equipment uses two ultra-high speed cameras which can track special markers with reflexive properties during motions. These markers are usually attached on joint centres of the interest mobile system by tracking and measuring certain characterization of a system motion. In our case, the mobile system it is firstly represented by the human upper limb and then by the LARM Clutched Arm. The equipment is capable to track automatically desired trajectories in real time or to analyze them after a video is recorded and stored in its computer host. The equipment is provided with software created by the CONTEMPLAS Company, and in our case this is the Templo Standard General Motion basic software.
The lab layout configuration is the following: TEMPLO Module, Ultra high speed cameras, C-Mount Objective, Tripod, Gigabit Ethernet ExpressCard, Gigabit Ethernet CAT6 cable, Charger, Special laptop, as summarized in Figs 9 and 10. The motion analysis processing is based on the scheme in Fig. 10.

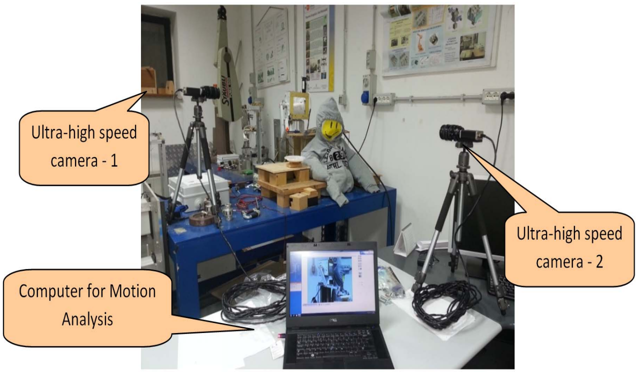

Figure 9 Lab layout of ultra-high speed video analysis equipment (CONTEMPLAS) for experimental tests.

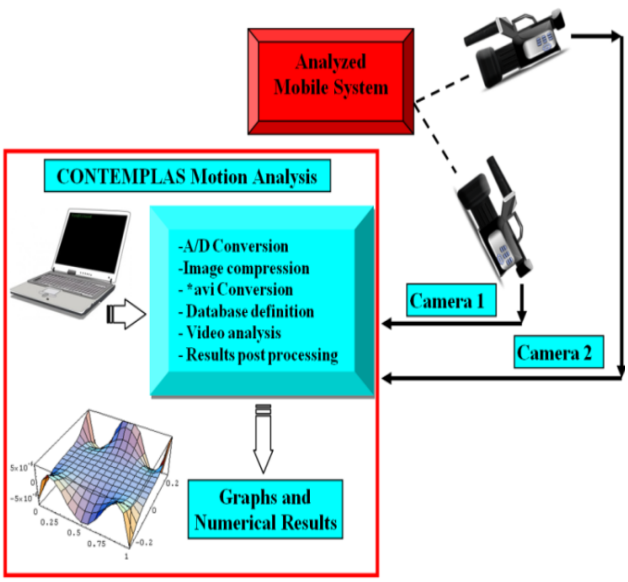

Figure 10 A processing scheme for video analysis by using CONTEMPLAS Motion Analysis Equipment as in figure 9.

4 TESTS FOR ASSISTING DISABLE PEOPLE

A lab layout has been settled at LARM in Cassino to perform tests, to check the feasibility and to characterize the performance characteristics of the proposed application with LARM clutched arm. By using combination of three clutches states, it is possible to obtain a desired movement for food feeding. In order to verify the functionality of the LARM clutched arm, a mannequin has been used as a disabled person and a macaroni food is used as the feeding food. The mannequin is located at the distance from arm which should be same as the distance between the arm and a disabled person sitting on a wheelchair. In Fig. 11 a photo sequence of arm's positions is reported during an experiment.

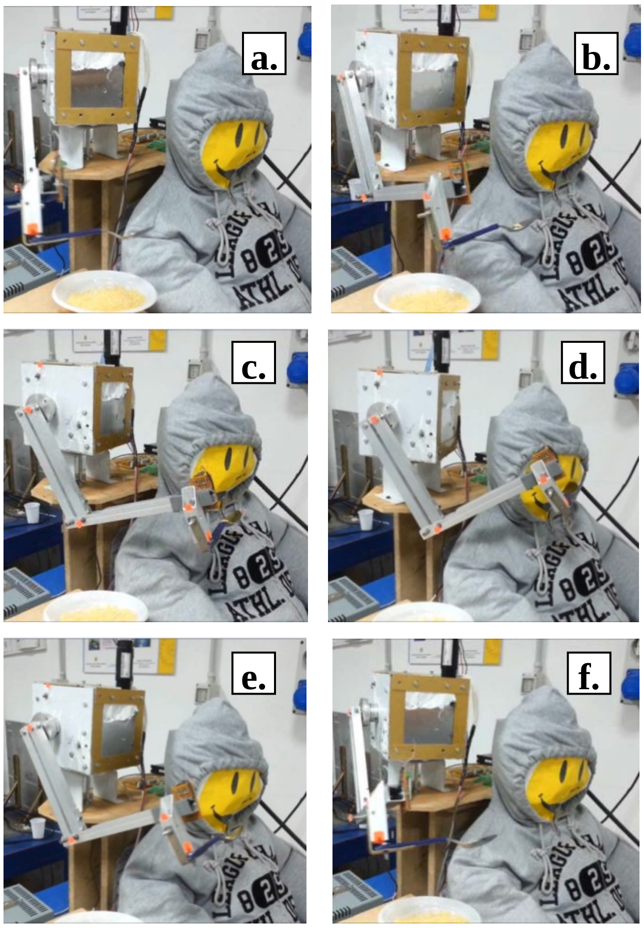

Figure 11 A photo sequence of arm's movement during an experiment at LARM.

The trajectory for the arm movement during the food feeding action is planned in joint space as in the plot of Fig. 12, where θ1 [degrees] is angle which characterizes the shoulder movement, while θ2 [degrees] and θ3 [degrees] are the angles characterizing the arm and forearm's movements, respectively.
At the beginning and returning movement of arm, there is a small time delay when there is no motion as due to the need

of time to load the food. The measured acceleration magnitude of arm's end point is plotted in Fig. 13. The acceleration components along the coordinate systems are shown in the plots on Figs 14, 15 and 16. These values of acceleration look very similar to the values of human arm's acceleration during a similar action of food feeding.

Referring to Figs. 12 and 13, the obtained 3D trajectory of the robotic arm through clutches combination can be explained as follows:

- the generated path between points 1 to 2 corresponds to the activation of clutch C3, Fig. 11a;
- next path between points 2 and 3 corresponds to the activated clutch C2;
- a combination of one pair of clutches, respectively C1 and C2 corresponds to the generated path from points 3 and 4, Fig. 11b;
- when the spoon is raised up, the clutch C3 is activated and a path is generated between points 4 and 5;
- another combination of a paired clutches, respectively C2 and C3 corresponds to the path between points 5 and 6, Fig. 11c;
- for path between points 6 and 7, clutches C1 and C3 are activated, Fig. 11d;
- during the path between points 7 to 8, the clutch C3 is activated and the spoon is situated near the mannequin mouth, Fig. 11e;
- after retracting the spoon from mannequin mouth, the path between points 8 and 9 is generated and it corresponds to the activation of the clutch C2.

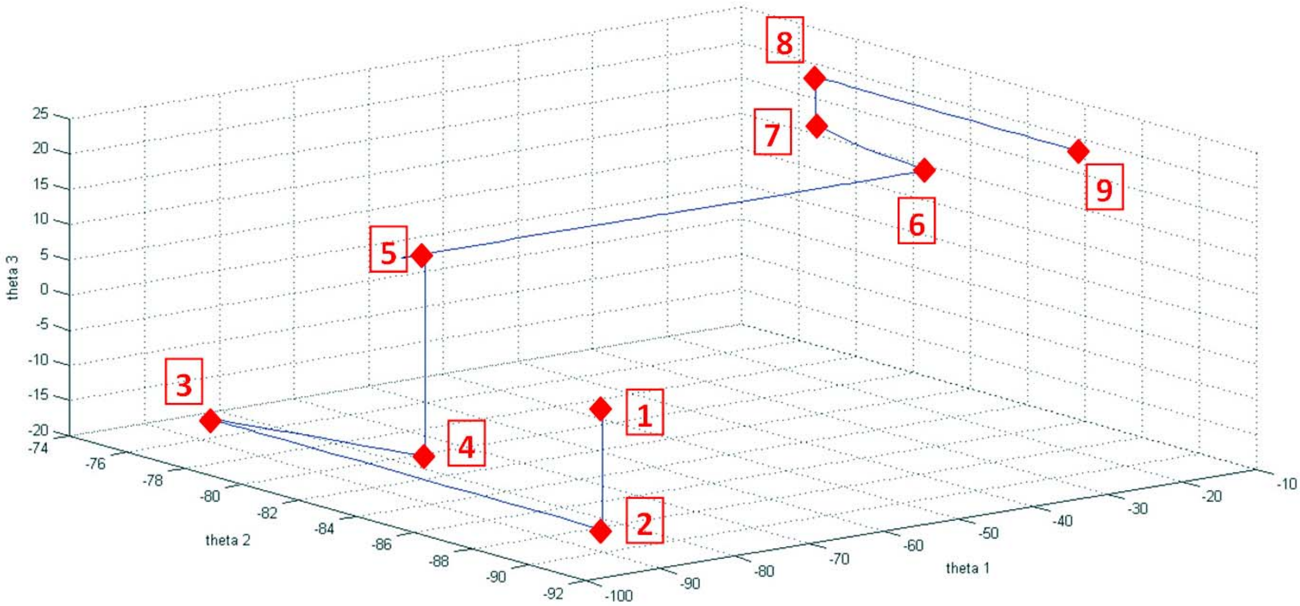

Figure 12 The chosen trajectory for arm's movement in the joint space.

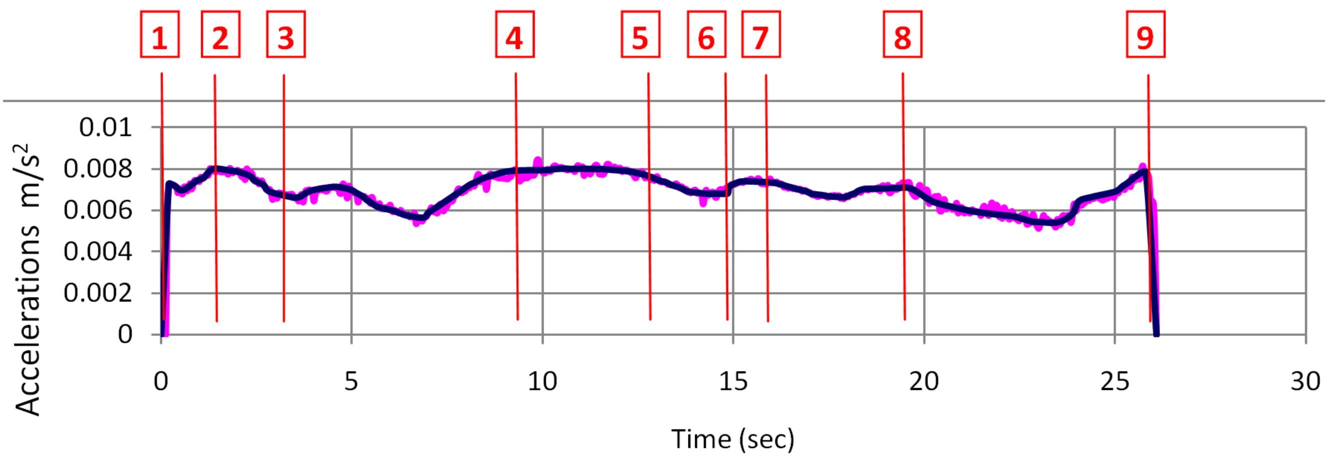

Figure 13 Acquired acceleration magnitude of LARM clutched arm end point during a test (Magenta line represents the acquired data, blue line represents the filtered data).

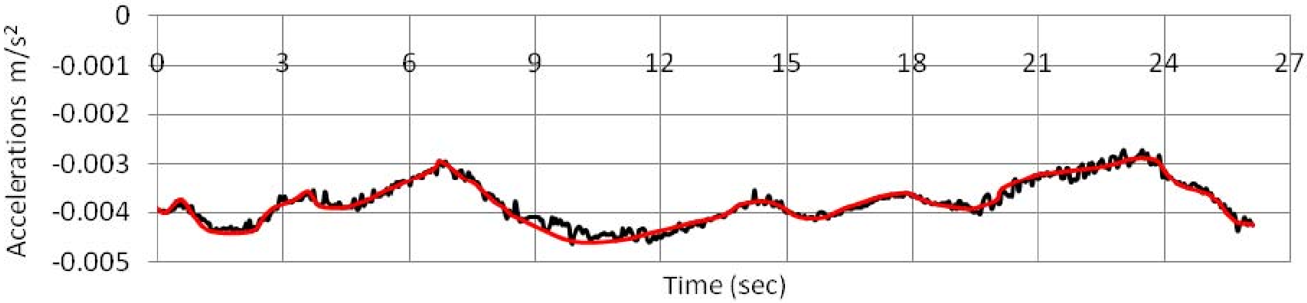

Figure 14 Acquired acceleration component in X direction of LARM clutched arm end point for test result in figure 13 (black line represents the acquired data, red line represents the filtered data).

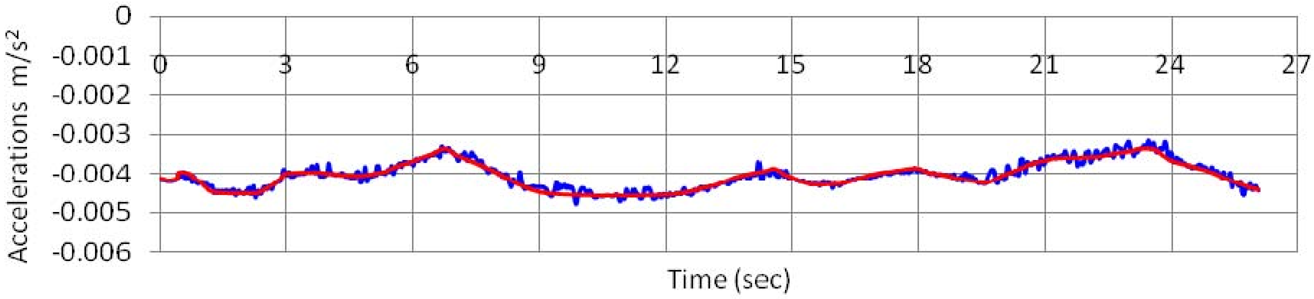

Figure 15 Acquired acceleration component in Y direction of LARM clutched arm end point for test result in figure 13 (Blue line represents the acquired data, red line represents the filtered data).

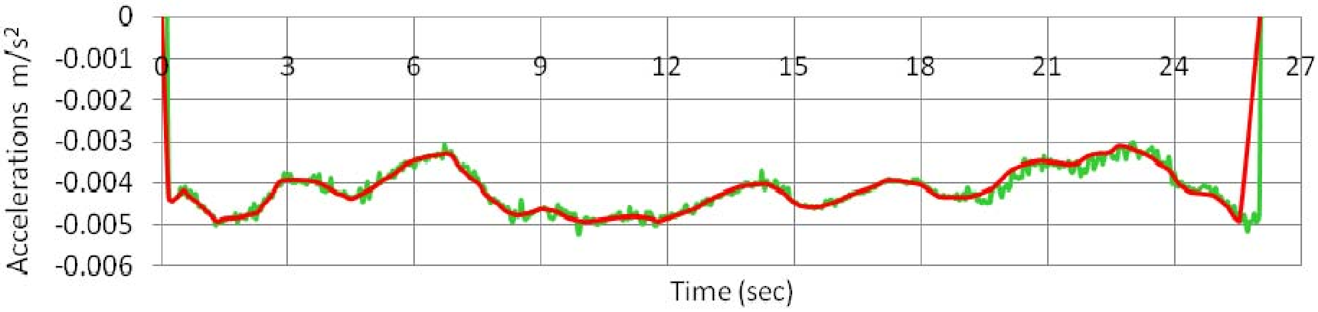

Figure 16 Acquired acceleration component in Z direction of LARM clutched arm end point for test results in figure 13 (green line represents the acquired data, red line represents the filtered data).

The video experimental analysis process has used special markers on shoulder, elbow and wrist joints. These markers are automatically tracked by the CONTEMPLAS equipment during a feeding process when a human performs a motion with a spoon. Moreover the trajectories can be used as a starting point for creating reference paths for a robotic system. First of all it is monitored the movement of a healthy person during the food feeding. After this it is monitored the LARM clutched arm during a similar motion. The experimental test conditions in this case were the same as the ones from the LARM clutched arm motion analysis. After this analysis a database was obtained and a comparative study was performed. The measured displacements are shown in Fig. 17 as obtained by analyzing the complete motion for food feeding action in both cases.

The time history variation of elbow position is almost the same in both cases. In human case the position variation has a value of 1m, and in the case of the LARM clutched arm reaches a value of 1.8 m. This larger value is due to the programmed path as in Fig. 12 and also to the plate position between mannequin position and LARM clutched arm.

For wrist position in Fig. 17b, the time history between human and robotic arm is different yet. But the obtained values are almost the same. The maximum measured displacement has a value of 2m in both cases.

The data provided by the accelerometer is useful to obtain displacement through numerical double integration. This was computed by a numerical elaboration by using the data in Fig. 13. The obtained values are shown in Fig. 18.

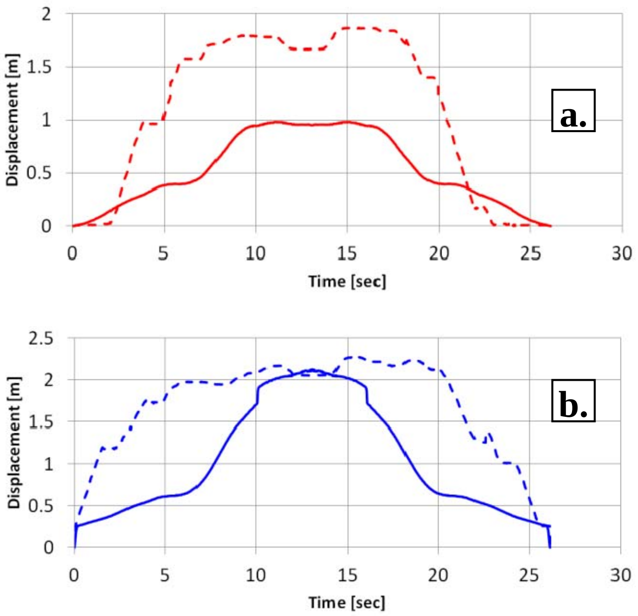

Figure 17 Results of experimental tests with a human subject and LARM Clutched Arm (Continuous line for human elbow, dotted line for LARM clutched arm);
a) Elbow position, b) Wrist position.

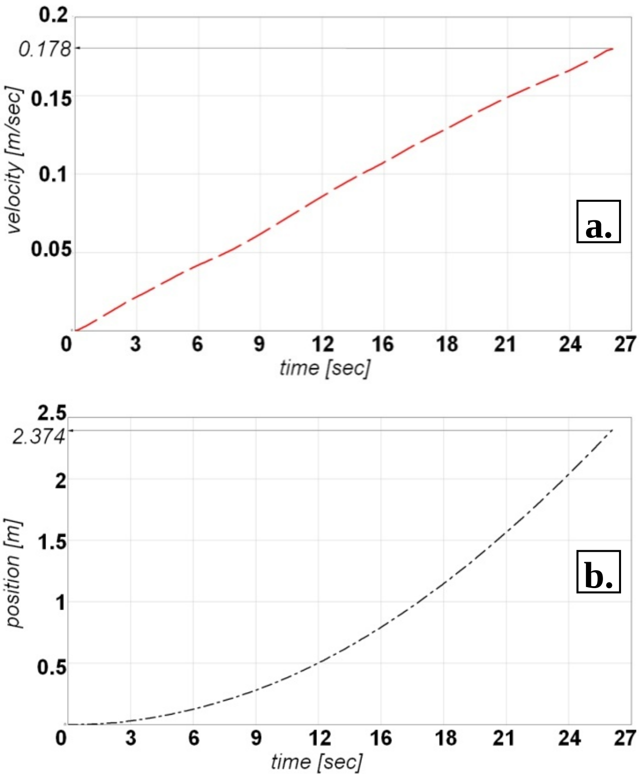

Figure 18 Wrist position numerical processing by acceleration's double integration from figure 13:
a) Velocities variation; b) Position variation.

The acceleration during food feeding process is almost constant with values from 0.005 m/s^2 to 0.008 m/s^2. Thus, the velocities show a quasi-linear variation and the displacement curve looks with a quasi-quadratic shape, but with smooth evolution. The obtained displacement value is about 2 meters. In addition, joint motion has been evaluated by monitoring the shoulder and elbow joint in a human subject and LARM clutched arm for a test of Fig. 12. Results are shown in Figs. 19 and 20.

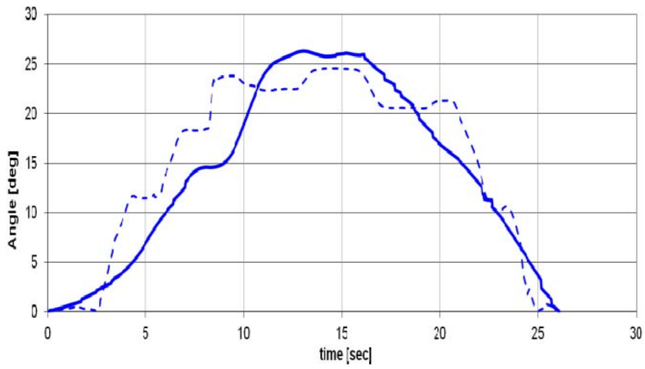

Figure 19. Measured shoulder angles of the human arm and LARM arm (Continuous line for human elbow, dotted line for LARM clutched arm).

The shoulder angular amplitude is from 0 to 26 degrees in case of a human subject, and in the case or LARM clutched arm this is from 0 to 24.95 degrees. In case of elbow joint the angular amplitude obtained in both cases are between 0 and 24 degrees as shown in Fig. 20.

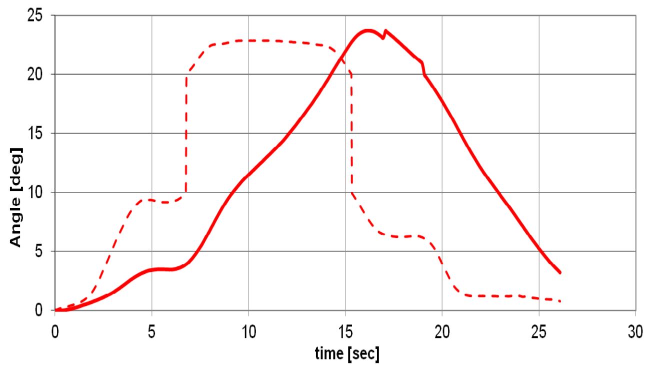

Figure 20. Measured elbow angles of the human arm and LARM arm (Continuous line for human elbow, dotted line for LARM clutched arm).

For the shoulder joint the time history is quite similar in the two arms, while the elbow joint shows difference that is very likely due to the intermittent motion due to clutch activation/deactivation. Nevertheless, it is to note that even in the joint angles, the motion looks enough smooth as to ensure a safe user-friendly action of the robot in the food feeding task.

5 CONCLUSIONS

In this paper, the characteristics and functioning of an anthropomorphic clutched arm built at LARM, in Cassino (Italy) are analyzed through an experimental experience for an application in assisting disable peoples for food feeding.

The robotic LARM clutched arm has only one actuator, from which the motion is transmitted to joints with the help of gears and electromagnetic clutches. Tests have proved the movement of this robotic arm as suitable for food feeding action, because it behaves like the human arm during the same action in terms of trajectory and acceleration.
In a near future, this arm can be modified in order to be adapted on a wheel chair and to assist disable persons. Also its functionality can be modified and can perform multiple tasks such as hand writing or carry on movable objects.

REFERENCES

[1] R. Soyama, S. Ishii, and A. Fukase. The Development of Meal-Assistance Robot My Spoon. *Proceeding of the 8th International Conference on Rehabilitation Robotics*. Daelon, Korea, pp.88-91, 2003.

[2] M. Topping. An Overview of the Development of Handy 1, a Rehabilitation Robot to Assist the Severely Disabled. *Journal of Intelligent and Robotic Systems. Kluwer Academic Publishers*. Vol. 34, pp. 253–263, 2002.

[3] NEATER. *User Manual Instructions*. [2013 – 11-15], http://www.neater.co.uk/brochures

[4] Hermann, R., Phalangas, A., Mahoney, R. & Alexander, M., Powered Feeding Devices: An Evaluation of Three Models. *Arch Phys Med Rehabilitation*. Vol. 80, pp.1237–1242, 1999.

[5] Topping, M. & Smith, J., The Development of HANDY 1, a Robotic System to Assist the Severely Disabled. *Proceedings of International Conference on Rehabilitation Robotics*. California, USA, pp.95-105, 1999.

[6] Kobayashi H. Development of Feeding Support System and its Quantitative Estimation. *Proceedings of the 2006 IEEE/RSJ International Conference on Intelligent Robots and Systems*. Beijing, China, pp.717-722, 2006.

[7] Guglielmelli, E.; Lauro, G.; Chiarugi, F.; Giachetti, G.; Perrella, Y.; Pisetta, A. & Scoglio, A., *Self-feeding Apparatus*. US Patent2009/0104004, 2009.

[8] Pourmohammadali, H.; Kofman, J. & Khajepour, A., *Design of a Multiple-user Intelligent Feeding Robot for Elderly and Disabled People*. Master Thesis, University of Waterloo, Ontario, Canada, 2007.

[9] W. K. Song and J. Kim. Novel Assistive Robot for Self-Feeding. *Robotic Systems - Applications, Control and Programming. InTech*, USA, pp.43-60, 2012.

[10] Song, W.-K.; Kim, J.; An, K.-O.; Lee, I.-H.; Song, W.-J. & Lee, B.-S. New Dual-Arm Assistive Robot for Self-Feeding. *Second International Symposium on Quality of Life Technology*. Las Vegas, USA, pp. 152-159, 2010.

[11] M. Ceccarelli, H. Gu. Trajectory planning for a 1-dof clutched robotic arm. *Robotica, Cambridge University Press*, Vol. 29, pp. 745-756, 2011.

[12] H. Gu, M. Ceccarelli, G. Carbone. Design and simulation of a 1-dof anthropomorphic clutched arm for humanoid robots. *International Journal of Humanoid Robotics*, Vol. 7, pp.157–182, 2010.

[13] Hao Gu and Marco Ceccarelli. A Multiobjective Optimal Path Planning for a 1-DOF Clutched ARM. *Mechanics Based Design of Structures and Machines*. Vol.40:1, pp.109-121, 2012.

[14] Copilusi C., M. Kaur, Ceccarelli M. Lab Experiences with LARM Clutched Arm for Assisting Disabled People. *New Trends in Mechanism and Machine Science Mechanisms and Machine Science* . Vol. 24, pp.603-611, 2012.

[15] Klippel S., Seeholzer T. *CONTEMPLAS, User Manual*. Kempten, Germany. 2013.