56TH INTERNATIONAL SCIENTIFIC COLLOQUIUM
Ilmenau University of Technology, 12 – 16 September 2011
URN: urn:nbn:gbv:ilm1-2011iwk:5

DESIGN AND DEVELOPMENT OF A FEEDING AID DEVICE TO ASSIST PEOPLE WITH DEFICIENCY

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ABSTRACT

The present work intends to design new devices of aid to the feeding for individuals with deficiency. Like this, along this paper they are referred the most relevant pathologies, which affect the autonomy of the patient's feeding, as well as some existent devices in the market. Based on the characteristics of these devices, this research was performed with the main objective of finding the most appropriate actuation system. Furthermore, it was made the analysis and discussion of the performance specifications, essential stage in the design process of the feeding aid device for this to assure all the demanded requirements. Afterward, they are pointed some possible solutions, in the sense of creating more and better on behalf of the patient's need. Finally, for the solution selected, it was being later developed a model, in the advanced software Working Model for the simulation of the mechanical system of aid feeding.

Index Terms **-** Technical aid, Biomechanical project, Multibody modeling systems

1. INTRODUCTION

To reduce the potential healthcare costs arising from a rapidly aging industrial world population, the problem of sustaining independent living for the elderly and persons with low to high levels of disabilities must be addressed.

There are many examples of assistive devices for people with manipulative and locomotive disabilities. These devices enable disabled people perform many activities of daily living thus improving their quality of life. Disabled people are increasingly able to lead an independent life and play a more productive role in society [1]

Eating process is one of the most important activities in everyday life. Eating activity influences many aspects of our overall medical, physical, and social well being. Gustafsson [2] evaluated the psychological effects of self-feeding and found that disabled individuals who attained their goals of self-nourishment had a heightened sense of control, security, and hope for the future. The inability to feed oneself has been linked to shame for human incompetence, decreased self-esteem, and feelings of panic or fear. This information supports attempts to study feeding devices that assist individuals unable to feed themselves.

With this motivation, in this paper it is present the design and development of a new feeding aid device. To achieve this goal, the following section is devoted to the presentation of the conceptual design, the next two sections discusses, respectively, the adopted solution development and the device modeling. Further; section discusses the obtained simulation results concerning the requirements to study and, finally, last section, presents some conclusions, in this field.

2. CONCEPTUAL DESIGN

The process of the conceptual design includes descriptive and prescriptive models. The descriptive models work as a sequential description of the activities that the conceptual design includes, enhancing the need to generate a solution conceptual in the beginning of the process. On the other hand the prescriptive models are ruled by a structure-base of three phases: Analysis - listing of requirements and their grouping in performing specifications -, Synthesis - elaboration of solutions for each specification to obtain complete solutions - Evaluation - verification of the requirements fulfillment for all considered solutions, before the selection of the final solution [3, 4].

The methods used in the design process in this phase are divided in two main groups, the creative and rational approaches.

There are several design methods which are intended to help stimulate creative thinking, for instance, the Brainstorming and the Synectics methods. In general, they work by trying to increase the flow of ideas, by removing the mental blocks, or by widening the area in which a search for solution is made. On the other hand, the rational methods have as base a systematic approach in the resolution of the problem, being subdivided in several stages: Clarifying objectives; Establishing functions; Setting requirements; Determining characteristics, Generating alternatives; Evaluating alternatives; and finally, Improving details [3].

In the conception of an equipment it is advisable the use of rational methods and, due to that, the mentioned design stages will be described in the next subsections for the case study of the feeding aid device developed in this research work.

2.1. Clarifying objectives

In general, the needs of the customer's specifications are subjective, due to his lack of technical knowledge of the device that intends to acquire. This subjectivity becomes a difficulty for the obtaining of objectives well structured in all of the design phase's process, which is indispensable to control adequately its development. However, it can be highlighted, that the initial objectives are susceptible to be altered, during the conception design process [3, 5].

One very important point to take in consideration in the design process is the relevance of each identified objective, then the high importance of being built a hierarchical objectives "tree". As the main objective of this work is the conception of feeding aid device for individuals with deficiency, this objective is in the top of the objectives "tree".

With the main purpose of this device to present a significant more value relatively to the comparable devices available in the market were considered the following secondary objectives: reliability, functionality, easy operation, adaptability, minimum cost, and ecologic design.

2.2. Establishing functions

The method of analysis of functions has in consideration the essential functions. These functions should be capable to allow the materialization of the conceptual objectives of the device, without considering the physical components that they can be used. With the definition of the global function, the method only concentrates on what has to be achieved and not on how it is to be achieved.

Using this methodology, it is obtained a global function (fig. 1), commonly named for Black Box, as a result of the conversion of entrances (restrictions) in outputs (products or objectives).

Fig. 1: Flowchart of the global function.

In this phase, the global function is much enlarged, being necessary to divide it in sub functions, as explained to proceed. To begin the process, the patient has to press a button to activate the feeding device. The first device operation it will be take the spoon to the container for be possible the patient select the food that intends to ingest. After being complete the food selection it will be performed the food capture and drag operation, and afterwards it will be made the elevation of the spoon to give the food in the patient's mouth.

Fig. 2 shows the overall flowchart of the sub functions considered in the conceptual design of the feeding aid device.

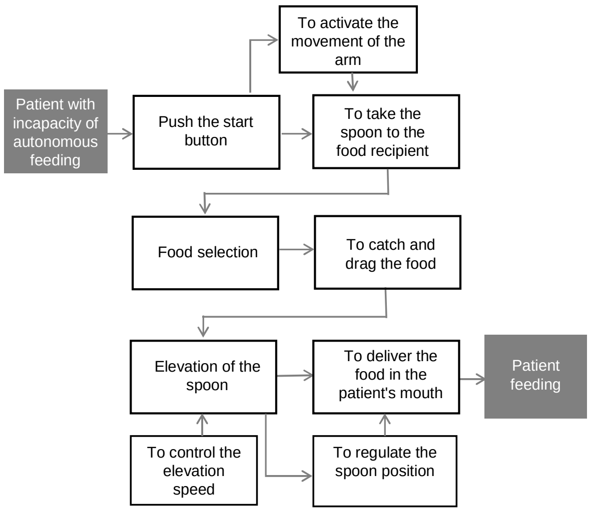


Fig. 2: Flowchart of the sub functions adopted.

2.3. Setting requirements

Usually, the setting requirements considered in the design process of equipments are related with the following specifications: Safety, Durability, and Comfort. Based on these specifications, as should result a list of requirements, in the which is crucial to distinguish among those that constitute "desires" - symbolized by W (wishes) - or "obligations" - expressed for a D (demands) [3].

This way, based on the previous design stages, it was obtained a list of requirements (tab. 1) essential to guarantee a good performance for the device of feeding aid developed.

Tab. 1: Setting of the feeding aid device requirements.

D or W	*Requirements*
	A. Structure
D	1. Maximum volume of 0,060 m^3
D	2. Maximum height of 0,4 m
D	3. Maximum base area of 0,25 m^2
D	4. Maximum weight of 5,5 kg
W	5. Conical geometry of the food container
	B. Operation parameters
D	6. Active system
D	7. Arm angular velocity: 60 e 100 degrees/s
	C. Functionality e operationality
D	8. Easy operation
W	9. Multi driven system
W	10. Easy wash and cleaning of the components
	D. Adaptability and comfort
W	11. Possibility of container substitution
W	12. Possibility of cutlery/silverware substitution
D	13. Module construction
W	14. Support base for different surfaces
W	15. Head and arms supports.
D	16. Adjustment of the supports position
	E. Security
D	17. High accuracy of movements
D	18. High precision of movements
D	19. “Round” ends edges
	F. Durability
D	20. Materials with mechanical, thermal, and corrosion resistance
W	21. Useful life greater than 15 years
	G. Cost
W	22. Price less than 2400 Euros
	H. Ecology
W	23. Material biodegradable and/or recyclable

2.4. Generating and evaluating alternatives

The main objective of the development of alternative solutions is the obtaining of better characteristics for a new device, when compared with other existent ones in the market.

This is a fundamental phase because it looks for a reasonable satisfaction of the specifications identified in the previous phase of the design. Although, this process can implicate an alteration and improvement of the requirements, in order to obtain an optimization of the performance of the new device.

In the elaboration of the morphologic maps, related with the alternative solutions, for almost all of the functions, the possible considered resources were buttons or sensor (automatic operation), manual execution or joystick (it demands expertise of the operator).

The resource to springs, in the case of the delivery function of the food to the mouth, is due to the consideration of a shock-absorbing effect, because this function demands a softness of movements, avoiding any damage on the patient. In what it respects to the selection and drag of the food, in fact, the pliers or the existence of a cutlery/silverware of aid would be susceptible to resources to make this function in a correct way. However, the existence of these components is not appropriate for guarantee the patient integrity, when the delivery of the food to the mouth happens (silverwares as forks and knives and even the pliers contain sharpened surfaces, beaked and cutting), in addition not all of the foods are possible of catching (liquids and all of the non solids).

Based on these considerations, the fig. 3 presents the morphologic map of the alternative solution that presents the most appropriate resources for the optimization of the defined main functions.

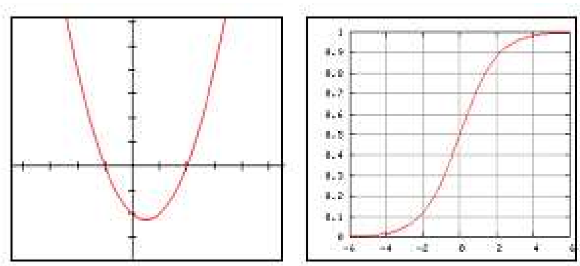
FUNCTION	RESOURCES		
To activate the movement of the arm	**Push the start button/Sensor**	Manual	
To take the spoon to the recipient	**Automatic**	Manual	Joystick
Food selection	**Push the start button/Sensor**	Manual	Joystick
To catch and drag the food	To push with aid of another cutlery	Pliers	**To collect the food for projection against wall of the container**
To deliver the food in the patient's mouth	**Automatic**	Spring	Joystick

Fig. 3: Morphologic map of the selected solution.

3. ADOPTED SOLUTION DEVELOPMENT

To be possible to develop the mechanical system of an aid device, it is of paramount importance to know the natural feeding trajectory.

For that reason, an experimental analysis of the feeding movement was performed, and concluded that the trajectory is not linear; it approaches to a parabola or even of a Sigmoid function (see fig. 4).



a) b)
Fig. 4: a) Quadratic function; b) Sigmoid function.

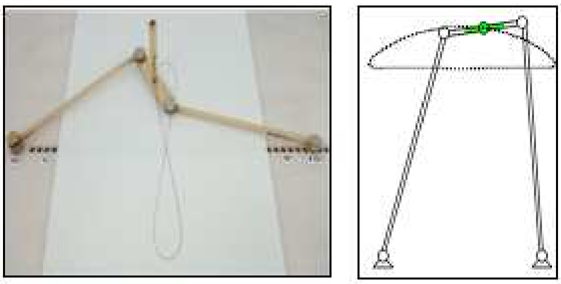
This path is the most appropriate for the use in a mechanism with just a motor, since it transmits a continuous and progressive movement. However, it is essential to find a suitable mechanism to replicate this trajectory with a driven motor only. Besides, it is fundamental that can be possible stop the mechanism in a specific point to allow the patients' feeding. It is still desirable that the described trajectory is cyclical and allows incorporating in one of their points the individual's mouth.

For that it was necessary to select the most appropriate mechanism than it could accomplish these requirements.

3.1. Alternatives Analysis

It was first considered the Watt mechanism (see fig. 5a). This four bars linkage returns a trajectory in form of "eight", which could satisfy the initially imposed conditions. However, the Watt mechanism presents two problems: first, the point that describes the intended trajectory it is the medium point of the central bar (coupler link), which represents a physical obstruction for placing the spoon; second, this mechanism is driven by a bar with alternate motion (input link), which requires the change of the direction of the motor, this aspect does not satisfy the needed requirements. Despite these problems, the difficulty of maintaining to maintain the horizontal position the spoon during the whole trajectory still exists.

Further, it was studied the possibility to use of the Chebyshev mechanism (see fig. 5b). This returns a “half moon” trajectory that is much easier to maintain the horizontality required for the spoon during the trajectory. However, this mechanism presents the same problems as the previous one, because the point that describes the trajectory is the medium point of the central bar (coupler link), also requiring an alternate driven motor.

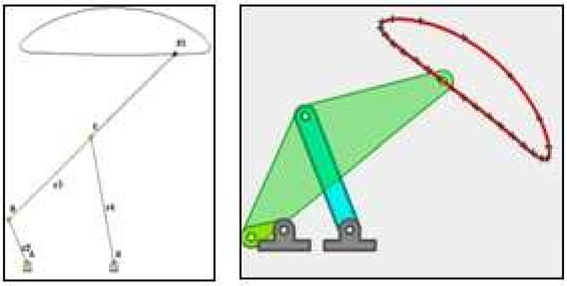


a) b)

Fig. 5: Mechanisms, a) Watt; b) Chebyshev.

In this project, the Hoekens mechanism (see fig. 6a, a variation of the Chebyshev mechanism), was also analyzed with the advantage of having the trajectory defined by the end of one bar (point P1 of the fig 6a). With this mechanism it is possible to fulfill the two main system requirements: to perform the trajectory with the intended end point, while the mechanism is driven in only one rotation direction, since the driven bar carries out a motion of 360°.

Finally, the four bars linkage selected was the Burmester mechanism (see fig. 6b) which is similar to the Hoekens mechanism. The orientation of the fixed body in this mechanism relatively to the obtained trajectory is different and, due to this reason, it was considered more appropriate to the aid feeding system to be developed. The following section presents the mathematical formulation of the equations of motion of this multibody system.



a) b)

Fig. 6: Mechanisms, a) Hoekens; b) Burmester.

3.2. Equations of motion for a constrained multibody system

When a configuration of the multibody system is described by *n* Cartesian coordinates $\mathbf{q}$, then a set of *m* algebraic kinematic independent holonomic constraints can be written in a compact form as [6],

$$\mathbf{\Phi}(\mathbf{q}, t) = \mathbf{0} \quad (1)$$

Differentiating equation (1) with respect to time yields the velocity constraint equation. Behind a second differentiation with respect to time the acceleration constraint equation is obtained,

$$\mathbf{\Phi_q}\dot{\mathbf{q}} = \boldsymbol{\upsilon} \quad (2)$$

$$\mathbf{\Phi_q}\ddot{\mathbf{q}} = \boldsymbol{\gamma} \quad (3)$$

where Φq is the Jacobian matrix of the constraint equations, υ is the right hand side of velocity equations, and γ is the right hand side of acceleration equations, which contains the terms that are exclusively function of velocity, position and time.

The equations of motion for a constrained multibody system of rigid bodies are written as [6},

$$\mathbf{M}\ddot{\mathbf{q}} = \mathbf{g} + \mathbf{g}^{(c)} \quad (4)$$

in which $\mathbf{M}$ is the system mass matrix, $\ddot{\mathbf{q}}$ is the vector that contains the state accelerations, $\mathbf{g}$ is the generalized force vector, which contains all external forces and moments, and is the vector of constraint reaction equations.

The joint reaction forces can be expressed in terms of the Jacobian matrix of the constraint equations and the vector of Lagrange multipliers as [7],

$$\mathbf{g}^{(c)} = -\mathbf{\Phi}_{\mathbf{q}}^{T}\boldsymbol{\lambda} \quad (5)$$

where λ is the vector that contains m unknown Lagrange multipliers associated with *m* holonomic constraints. Substitution of equation (5) in equation (4) yields,

$$\mathbf{M}\ddot{\mathbf{q}} + \mathbf{\Phi}_{\mathbf{q}}^{T}\boldsymbol{\lambda} = \mathbf{g} \quad (6)$$

In dynamic analysis, a unique solution is obtained when the constraint equations are considered simultaneously with the differential equations of motion with proper set of initial conditions [6, 7]. Therefore, equation (3) is appended to equation (6), yielding a system of ordinary algebraic equations that are solved for $\ddot{\mathbf{q}}$ and $\boldsymbol{\lambda}$. This system is given by,

$$\begin{bmatrix} \mathbf{M} & \mathbf{\Phi}_{\mathbf{q}}^{T} \\ \mathbf{\Phi}_{\mathbf{q}} & \mathbf{0} \end{bmatrix} \begin{Bmatrix} \ddot{\mathbf{q}} \\ \boldsymbol{\lambda} \end{Bmatrix} = \begin{Bmatrix} \mathbf{g} \\ \boldsymbol{\gamma} \end{Bmatrix} \quad (7)$$

In each integration time step, the accelerations vector, $\ddot{\mathbf{q}}$, together with velocities vector, $\dot{\mathbf{q}}$, are integrated in order to obtain the system velocities and positions at the next time step. This procedure is repeated up to final time will be reached.

The set of ordinary algebraic equations of motion (7) does not use explicitly the position and velocity equations associated with the kinematic constraints, equations (1) and (2), respectively.

Consequently, for moderate or long time simulations, the original constraint equations are rapidly violated due to the integration process. Thus, in order to stabilize or keep under control the constraints violation, equation (7) is solved by using the Baumgarte stabilization method, and the integration process is performed using a predictor corrector algorithm with variable step and order [8-11].

The use of numerical algorithms with automated adjust step size is particularly important in contact problems whose dynamic response is quite complex due to the suddenly change in kinematic configuration. In such events, the use of a constant time step is computationally in-efficient and the system could be overlooked due to insufficient time resolution. Thus, auto-mated time step size adaptability is therefore a crucial part of the dynamic solution procedure. Moreover, the abrupt configuration changes caused by rapidly variation of contact forces are source of stiffness, since the natural frequency of the system is widely spread. Thus, the time step size must be adjusted in order to capture the fast and low components of the system response.

4. FEEDING DEVICE MODELING

After the selection of the mechanism that best fits the intended trajectory, a 3D CAD model was built to permit its analysis, as shown in fig. 7. It was necessary to consider the maximum height of the movement that allowed the correct feeding of the individual, as well as the minimum height to make possible the filling of the spoon.

Using AutoCAD®, from Autodesk, it was possible to find the appropriate relationships between the lengths of the bars that can describe the required trajectory using the Burmester mechanism. It was obtained a length ratio of 2:1 between the fixed bar (B1) and the driven bar (B2) and of 1:2 between the fixed bar (B1) and the remaining bars (B3, B4 and B5). For the bars linkage was used rotation joints (four in the main mechanism and one in the rotation system of the food container).

It must be emphasized, that having been used five bars, the Burmester mechanism is a mechanism with only four bars; the bar of different geometry was replaced by two bars (B4 and B5) linked together.

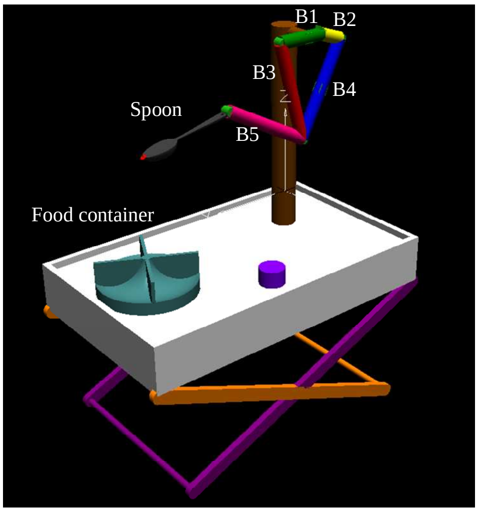


Fig. 7: 3D Model of the developed feeding aid device.

5. SIMULATION RESULTS

Finally, in order to evaluate and validate the proposed feeding aid device, the motion of the mechanism was also analyzed by using a commercial software specially dedicated to these type of mechanical systems. The computational program Working Model 4D (by MSC Software) was used to carry out the kinematic analysis of the displacement of the spoon, to determine the performance of the feeding system.

After positioning all components (bars, spoon, food container and other components), the mechanism is completed with all its characteristics, that is, the kinematic pairs, the generator of the movement, the friction and restitution coefficients, etc. Once defined the characteristics of the four bar linkage mechanism, it was possible to carry out the kinematic analysis where, for the present simulation, the output variables are the position, velocity and spoon acceleration. The obtained results are presented in the fig. 8, using a graphical form, according to the displacement movement of the spoon mechanism.

Based on the obtained simulation results, it can be concluded that the developed mechanical system is appropriate as a feeding aid device, because it enables to obtain the required spoon trajectory in a continuous motion.

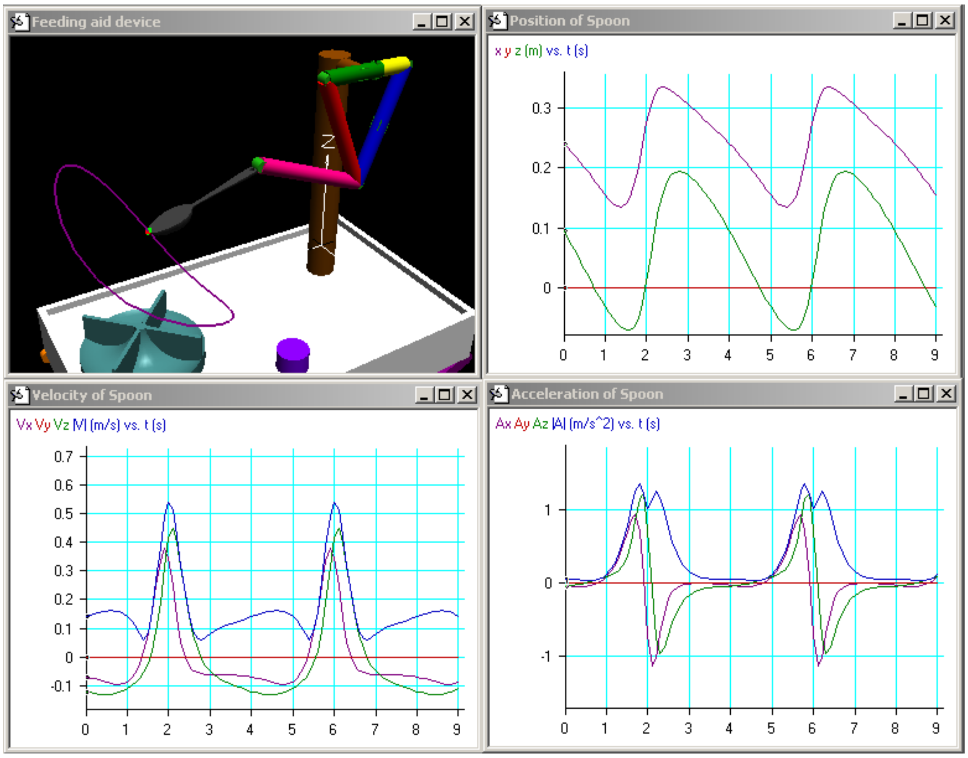


Fig. 8: Kinematic analysis of the developed feeding aid device.

6. CONCLUSIONS AND FUTURE WORK

The design of a feeding aid device to assist people with deficiency has been developed and proposed in this paper.

The present research proved to be successful using an four bars linkage to obtained the natural feeding trajectory in continuous motion. After having analyzed several types of systems of this type it was concluded that the Burmester mechanism is the most appropriate to fulfill the requirements of the feeding aid device developed.

The software Working Model 4D proved to be successful in order to obtain simulation models of complex mechanical systems.

This paper highlighted the design phase carried out so far, and future work will be focused on the detail design and analysis, as example, regarding the spoon and food container, as well as, to the implementation of the overall (electronics hardware and software) systems architecture to control the device.

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