MAGIC-HAND: A bottle and jar opening machine for people with severe disabilities

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U. Lorentzon, G. Bolmsjö, M. Doyle, D. Carus. MAGIC-HAND: A bottle and jar opening machine for people with severe disabilities. Gerontechnology 2007;6(2):79-88. This paper describes the development of a prototype product named MAGIC-HAND that has been developed to open bottles, jars and packages that require a twisting action. Its intended users are people with severe disabilities, who are not capable of using the current range of package opening tools. MAGIC-HAND is a kitchen accessory device that fits into standard kitchen furniture. The machine uses novel design approaches applying human-centred virtual prototyping methodology. It is highly automated so users need only place the package in the machine, close the door and activate the machine with a single touch of a button. The machine automatically centres the package, grips its base, senses the height of the closure, grips it and twists it open. Safety features are provided to ensure fingers cannot get trapped accidentally. User trials have highlighted both the advantages and disadvantages of the machine. A comparison with current jar and bottle opening machines is provided. Routes to commercialisation are discussed.

Keywords: jar opener, bottle opener, assistive technology, smart homes

The global packaging industry is one of the world's largest and most diverse manufacturing sectors, valued at over US$ 400 billion. Estimates from the World Packaging Organization suggest the industry employs over five million people in about 100,000 companies worldwide[1]. The industry cooperates with food manufacturers to supply products that are packaged for hygiene, safety, storage and convenience, but it is recognised that some packages are difficult to open, particularly for the elderly population, for whom muscle weakness, joint pain and neurological disorders are common.

As life expectancy increases, so does the time living with age-related changes and disabilities. The US Administration on Aging (AoA) reports that about one in every eight Americans is aged over 65, and the older population continues to increase dramatically over the next 30 years[2]. Those aged 85 and over represent the fast-

est growing segment of the population. The European Commission reports that of all developed countries, Europe and Japan experience the most pronounced ageing trends up to 2050[3]. The share of the over 60 age group will be around 37% in Europe and even more in Japan, compared to only 27% in North America, where population growth will continue to be relatively strong.

The old-age dependency ratio is an indicator that the availability of assistance to older people is likely to diminish. This ratio is the total population aged 60 and over divided by the population aged 15 to 60. In 2002, these ratios were 0.39, 0.36 and 0.26 for Japan, the European Union and North America respectively. In 2025 the ratios are predicted to be 0.64, 0.56 and 0.44. In other words, in 2025, Japan can expect to have 64 people aged 60 and over for every hundred people aged between 15 and 60. These ratios are used to forecast financial implications of pension policies, but they are also useful for those concerned with management and planning of caring services[4]. The reduction in the availability of support promotes the development of assistive technology (AT).

The aims of the work described in this paper were, first, to develop a sophisticated home appliance named MAGIC-HAND that would open jars and bottles and secondly, to conduct a user evaluation. The machine would be suitable for people who find the task of opening these packages either extremely difficult or impossible, even with the aid of existing opening devices. The work was undertaken within the EU PACKAGE project (**P**rovision for improved lifestyles via **A**ccess to **C**onsumer pack**AGE**s), funded by the European Commission's Information Societies Technology (IST) Programme. Full details of the project are described in its final report[5].

MAGIC-HAND was developed to promote independent lifestyles. Its users would need multiple AT devices, so it is therefore better described as smart home technology, a term used for the electronic and computer-controlled integration of devices in the home[6]. They include controls for doors, windows, curtains and blinds; heating, lighting and security systems; communication aids; water taps; cookers and bed warmers, but currently do not include opening machines for food packages.

The target users are people with impaired upper limb function who have major difficulty in opening packages with screw-top closures, even with the aid of the variety of openers available on the market. Their impairments include reduced strength and dexterity, pain and paresthesia, and their conditions (in no specific order) include rheumatoid and osteo-arthritis, cerebral vascular accident (stroke), Parkinson's disease, cerebral palsy, multiple sclerosis, muscular dystrophy, motor neurone disease, mal-united fractures, carpal tunnel syndrome, arthrogryposis and cervical 5 level spinal cord injury.

A number of inexpensive non-powered jar and bottle opening devices are available from retail stores and supermarkets. They include semi-rigid cone shaped rubber mouldings with finger grips, flexible rubber mouldings to grip small tops, fan shaped openers with serrated inside edges, and rubber straps which self-tighten around a closure when a handle is turned in the opening direction. In addition, there is a number of tools to break vacuum seals, and also holders that grip containers prior to opening. These simple devices are unsuitable for the target users, who need powered openers. Two commercially available powered jar and bottle openers were identified. LIDS-OFF™ is supplied by Applica Consumer Products, a licensee of Black & Decker household products. It is a portable device that is intended for one-handed operation and requires no hand strength. To operate, the user places

the jar on the machine's bed, rotates the bed to hold the jar in place, lowers the top of the jar opener to the top of the jar and presses a button. It is designed to be accessible to people of all levels of dexterity and strength, and to work with a wide range of jar and lid sizes. Its market is the general population, especially women, who have difficulty in opening jars, particularly lids on vacuumed sealed jars.

OPEN UP™ is the second jar and bottle opener for the general consumer market. It is a battery-powered device that fits to the underside of a kitchen cabinet. It operates when a jar or bottle is pushed into an opening cone to activate a pressure switch. The cone rotates slowly, applying a frictional torque to the closure. The user is required to hold the bottle's base and exert a reaction torque.

The JAROMATIC™ is a prototype device, similar in concept to LIDS-OFF and has been designed to open jars and bottles. It also has one-handed operation and no hand strength or effort is needed. Its owner and inventor, Jerry Russell, developed his original prototype in 1998 to meet the needs of a friend. It is not yet a retail product due to production delays.

Method

Human Centred Virtual Prototyping

The definition of MAGIC-HAND's functional specification was done within the framework for the Human Centred Virtual Prototyping (HCVP). This is a methodology for designing and manufacturing prototypes using computer tools as an aid during the entire design process. Lorentzon and Bolmsjö have provided a full description of this methodology[7], for which an important aspect is information integration, not only between computer tools, but also primarily between human resources and their different expertise areas. It is a holistic approach that places human resources at the centre of the development process.

To implement the HCVP methodology, a User Group Forum (UGF) was established early in the PACKAGE project, comprising potential users of MAGIC-HAND recruited from care and charity organisations in the town of Stoke, Central England. Its members were invited to comment upon the existing range of non-powered opening devices. People with arthritis reported that manual opening tools were painful to use due to twisting actions, wrist rotation and squeezing movements. They complained they could not position their fingers and wrists correctly because of joint deformities and pain. Plastic handles were often regarded to be too rigid and many preferred longer handles. People who had suffered a stroke were able to use only one hand effectively, whereas some tools require two hands, one to hold the jar and the other to use the tool. It was quite common for people with tremor to have difficulty in positioning opening tools, for instance, people with cerebral palsy who make uncoordinated jerky movements. Lack of dexterity was a general problem. Comments such as some tools are 'too fiddly and awkward', 'difficult to handle' and 'keep falling off' were common. Some concern was expressed that tools with sharp or serrated edges might cause injury, especially to those with poor eyesight. Others reported the contents might be spilled because it is difficult to apply high torque in a controlled manner. The jar and bottle holders were popular and it was not unusual for users to say that they were indispensable. Members of the UGF participated in the development of the functional and technical design specifications of MAGIC-HAND and later in the testing of prototypes.

Specifications

The criticisms and concerns of the members of the UGF were considered in the development of the functional specification. It was decided that MAGIC-HAND would be a functional aid within a suitably modified kitchen environment. A ma-

jor reason for rejection of AT is the stigma attached to an assistive product, so it was decided that MAGIC-HAND would be fitted inside a standard kitchen unit, hidden from view. The unit could be fitted at either floor or shoulder level for a wheelchair user. The opener would have a very high level of functionality; the only tasks required of the user would be to place the bottle or jar on a tray that would slide in and out of the cabinet (motorised if necessary), close the door and push a start button. The process of removing the closure would be fully automatic. It would not matter if the user were unable to position the jar or bottle accurately in the centre of the tray, because the machine would centre it prior to opening.

The principal functional specification criteria for MAGIC-HAND were (i) simple and intuitive controls; (ii) a grip range for jars and bottles with diameters between 30 and 100 mm; (iii) a clear opening height of 380 mm; (iv) an opening torque in excess of 5 Nm; (v) outer dimensions less than w = 350 mm, h = 660 mm, and d = 520 mm, so it could fit inside a standard 400 mm wide kitchen unit; (vi) an aesthetic 'non-orthopaedic' appearance, (vii) virtually silent operation; (viii) a variety of handle sizes and locations; (ix) a mass centre close to the bottom to facilitate safe installation. Excluded from the specification were features to (i) open products with child resistant closures (CRCs) that require lateral pinching action; and (ii) reapply closures, because of the likelihood of cross-threading.

MAGIC-HAND differs from LIDS-OFF, OPEN UP and JAROMATIC in a number of critical aspects and is not a direct competitor. MAGIC-HAND is specifically intended for people with severe disabilities, whereas LIDS-OFF, OPEN UP and JAROMATIC are for the general consumer market, albeit with emphasis upon people with reduced strength. MAGIC-HAND is a permanent fixture, hidden within a kitchen unit; LIDS-OFF and JAROMATIC are portable machines with aesthetic de-

Table 1. Functional features of some jar and bottle openers; some data is taken from marketing literature

Characteristic	Brand of jar or bottle opener			
	MAGIC-HAND	**LIDS-OFF**[13]	**OPEN UP**[14]	**JAROMATIC**[15]
Target market	disabled people older people	general consumers older people	general consumers older people	general consumers older people
Level of disability	severe - complete	mild - moderate	mild - moderate	mild - moderate
Type of package	jars and bottles	jars	jars, some bottles	jars
Location	inside kitchen unit; non-portable due to size	countertop & portable	wall or surface mount	countertop & portable
Hands-free operation	yes	yes	no	yes
Limitations	expensive	not intended for tall slim bottles	requires user to apply resistive torque	not yet available
Secondary features	incorporates tractrix grippers; centring feature	for opening jars but also includes a can opener		
Grip range	30 – 100 mm	from 115 mm	13 – 100 mm	7 – 140 mm
Jar / bottle height	380 mm	200 mm	no limit	25 – 260 mm
Dimensions (mm)	350 x 660 x 520	215 x 250 x 200	140 x 127 x 230	178 x 230 x 366

signs intended to be attractive appliances on kitchen work surfaces and OPEN UP is a fixed unit but can be re-located easily. Finally MAGIC-HAND has the highest level of functionality, since it is able to open the largest range of sizes of jars and bottles, it can open plastic bottles that are easily distorted and it has a centring feature (*Table 1*).

None of the machines offers all the functionality that might be needed by users; for instance, bag slitters, cork pullers, openers for flexible cellophane wrapped packages and cartons, though a version of LIDS-OFF includes a can opener.

Development of MAGIC-HAND

Preliminary technical tests with a prototype machine showed that the task of opening jars and bottles is considerably more difficult than it initially appears. Smooth sided vacuum-sealed jars are difficult to grip securely and twist open; grippers suitable for one jar diameter might be unsuitable for other diameters; plastic bottles are distorted by crushing forces. The solutions adopted in MAGIC-HAND to these problems were first, to use only lateral forces to grip the base and closure of a package prior to opening and thereby avoid the application of compressive forces and second, to use the segment of a tractrix curve as the gripping surface for the base of the container. This curve has two advantages; it has self-locking characteristics and it is suitable for a wide range of container diameters. The final 3-D model of a finger formed a base for the generation of Numerical Control-milling programming[7].

Description

MAGIC-HAND (*Figure 1*) comprises three units, namely the base unit, a vertical linear actuator and the top unit. The base unit has two functions, to move the bottle or jar to the centre of the base plate and to grip it. These functions are achieved with four fingers that are rotated by a belt that turns a plate to which are connected ball joints on the finger shafts. A screw-driven linear actuator, encased in an aluminium extrusion, moves the top unit with respect to the base plate. The actuator was supplied by Warner Tollo, Sweden, and was

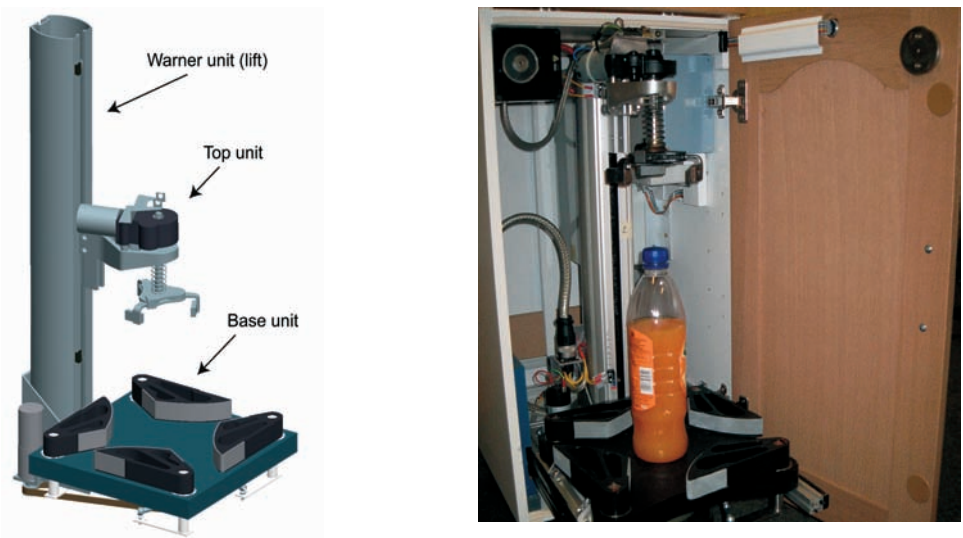

Figure 1. MAGIC-HAND; Left: Computer design drawing of the bottle and jar opening mechanism comprising a base unit, a vertical linear actuator and a top unscrewing unit; Right: The assembled opening mechanism is secured on a sliding tray inside a standard 400 mm wide kitchen unit; The electromagnetic lock is shown at the top-right corner of the door

chosen for its good reliability, structural stiffness and strength, reasonable size and low noise.

The top unit is required to both grip and rotate a closure. In order to avoid the necessity of having to use two motors, coupling between these two degrees of freedom is achieved in the following way. The top unit is supported on a spring that is lightly compressed when the actuator lowers it onto the top of a jar or bottle. The pressure that is created generates frictional torque between the top unit and the package that closes the unit's grippers when it starts to unscrew the closure. This arrangement ensures only one motor is needed, not two. The gripper is based upon an oil filter wrench, modified to give a larger gripping range. Its main component is a 12 Vdc geared motor with an output torque of 22 Nm.

The control unit comprises two printed circuit boards (PCBs), the driver card and the logic card. These cards drive the motors and provide the logic for the unit. The driver card outputs a pulse width modulation (PWM) signal to the appropriate motor. System control is achieved with a Motorola MC68376 microcontroller chip and flash memory. Two separate power units are used for the 12 Vdc and 24 Vdc supplies. Five sensors are used for the position control of the lift unit (top and bottom positions), the infrared photodiode for the top unit, closure detection of the cabinet door and the start button.

Kitchen Unit

The base unit, vertical linear actuator and top unit are assembled together and secured on a sliding tray that fits inside a standard 400 mm wide kitchen unit. Wheelchair users can access the tray from the side (*Figure 1*). Besides disguising the opener, the kitchen unit is a safeguard to prevent finger entrapment and provides protection for children. For safety purposes, an electromagnet locks the door and a light detection circuit checks the door is fully closed before the machine can operate.

Operation

A light touch of the user's finger upon a capacitance charge switch on the outer surface of the cabinet door operates the machine. This switch is not recessed and can be positioned at the user's preferred height. A ring of light emitting diodes (LEDs) illuminates the switch to assist users with impaired vision. The base unit fingers centre & grip the base of the container and current sensing in the controller detects when the fingers have firmly gripped the package. The linear actuator moves the top unit down until it touches the top of the bottle or jar. The shaft in the spring-loaded unit is pushed up, its spring is compressed and the height detection element is activated, stopping the downward movement of the actuator.

Rotation applies a torque to unscrew the closure. The opening unit then rotates in reverse, thus opening the fingers. The top unit moves up to its top position, leaving room for the user to remove the package from the machine. A piezoelectric sounder is incorporated to provide audible indications to the user. A series of short sound beeps indicates that the system is commencing a cycle of operation; a series of longer beeps indicate the machine is ready and the door can be opened. For safety, commercially available EU standards compliant power supplies are used and all power cables are shielded to avoid the generation of high frequency electromagnetic fields.

Accessibility

MAGIC-HAND meets key recommendations of the Rehabilitation Research and Training Center on Independent Living Management (RRTC-ILM) team in Buffalo, NY, to promote accessibility within the kitchen[8] (*Table 2*).

User evaluation

User evaluation of the machine was conducted at the Innovation centre in Housing for Adapted Movement (In-HAM) at Gits, Belgium. There were forty-two participants (21 male, 21 female) with an average age of 39 (minimum 21, maximum 59), who had been selected on the basis of their disability. All but one required assistance to open packages. They were given unlimited time to evaluate MAGIC-HAND with a variety of jars and bottles and were invited to provide spontaneous comments upon functionality, usefulness, appearance, size, practical issues such as installation, cost and maintenance. Their responses were grouped into positive and negative comments, as well as suggestions for further improvements. This was the first round of user testing and no statistical analyses were attempted. It could not be described as Beta testing.

Positive reactions

MAGIC-HAND would promote independence and is suitable for people with severe disability because it has a high level of functionality and a single switch control. It is easy to use, intuitive and can be operated at the user's own speed (no hurry, no pressure). It has an acceptable non-stigmatising appearance. Difficult packages such as large glass containers can be opened. The design had focussed on cylindrical packages but the trials showed that it works for square and oval packages as well. The internal light and LEDs were helpful for people with poor vision. A number of variants could be provided to suit differing needs (height level, position of control, etc). Every participant considered the noise level satisfactory. Finally, the participants were not aware of any comparable product on the market.

Negative reactions

The size of the machine was a concern, particularly for people with small kitchens. Some opening operations required a second attempt if the first attempt was not fully successful. Some closures are damaged and difficult to reapply. Spilled fluids

Table 2. Accessibility features of MAGIC-HAND within the kitchen as compared to RRTC-ILM recommendations[8]

Recommendations	MAGIC-HAND
Additional lighting	Internal light provided in kitchen unit
Open cabinets for wheelchair accessibility/ cabinets with removable fronts	Kitchen unit door can be fitted to open about either a vertical or horizontal axis
D-ring cabinet handles/large knobs	Fitted
Easy glide drawers	Fitted – could be motorized if required
Height adjustable cabinets	Kitchen unit can be fitted at preferred level
Appliances designed for accessibility - controls in front or side (installed 762 mm x 1067 mm high)	Charge capacitance switch operated with a light touch of a finger. It can be positioned at any preferred level
Consider turning radius for wheelchair manoeuvrability (minimum 1525 mm x 1525 mm)	Should be provided in kitchen design
Matte surfaces / avoid glare and specular reflection	Kitchen unit can be selected to suit
Push button, large knobs/visual/tactile cues on controls	A light touch of the user's finger upon a capacitance charge switch operates the machine; switch not recessed and placed in preferred position; ring of LEDs around the operating switch
Automatic control faucets	Audible indication when machine is working and ready

would be a problem for cleaning; components should be removable, so that they can be cleaned in a dishwasher. It would be an expensive product and views varied considerably on how much people would be prepared to pay. The majority expected the cost to be € 250. It would be a specialist product, not likely to be available from supermarkets and main street retailers. It is not a complete solution because other openers are needed for packages that do not have screw-top closures.

Further improvements

A sizeable number of participants commented upon the value of a window in the door so that they can see when the machine has finished, like a clothes washing machine. A motorised tray would assist some users. Ideally, the functionality should be extended to open wine bottles and cartons.

The fact that the kitchen unit can be positioned at any height is an advantage and the majority of trial participants opted to use the machine at desktop level. Although it is not necessary for a user to position the jar or bottle accurately in the centre of the tray, it is clear that upper limb dexterity is necessary to place containers, retrieve them and avoid spillage. Some users with joint pain were able to perform these tasks by holding the bottle or jar between the forearms thereby avoiding hand use, though the task is precarious. In the longer term, a flexible robot arm that moves between docking stations and can work in a smart home environment would be an advantage. A robot of this type is being developed in the EU MATS project[9].

Discussion

The market

In order to classify potential users of MAGIC-HAND, the authors have used the World Health Organization's International Classification of Functioning, Disability and Health, known more commonly as ICF[10]. In 2001, the 191 WHO member states agreed to adopt ICF as the basis for the scientific standardisation of data on health and disability world-wide. It provides a standard language and framework for the universal classification of disability and health for health and health-related sectors, including assistive devices. The principal ICF descriptors are (i) body functions, (ii) body structures, (iii) impairments, (iv) activity, (v) participation, (vi) activity limitations, (vii) participation restrictions and (viii) environmental factors. The predicted impairment, activity and participation limitations for MAGIC-HAND users

Table 3. Predicted activity and participation limitations for MAGIC-HAND users. Impairment = Problems in body function or structure such as a significant deviation or loss. Activity limitation = Difficulties an individual may have in executing activities. Participation limitation = Problems an individual may experience in involvement in life situations

Health conditions	Impairment	Activity limitation	Participation limitation
Arthrogryposis Carpal tunnel syndrome Cerebral palsy Cervical 5 spinal cord injury Mal-united fractures Motor neurone disease Multiple sclerosis Muscular dystrophy Osteo-arthritis Parkinson's disease Rheumatoid	Joint movement restrictions Cerebral vascular disease Joint pain Limited coordination Paraesthesia Tremor Weakness	For opening bottles For opening (vacuum sealed) jars	Embarrassment Reduced care for family members Social life restrictions Social status reduction Unable to prepare a full range of meals

are listed in Table 3, in accordance with ICF recommendations.

Although the ICF classifications provide some assistance in classifying potential users, the market (as opposed to users with perceived needs) for assistive technology such as MAGIC-HAND is difficult to define. There is a wide range of profiles of potential users, so it is difficult to target purchasers solely on the basis of disability. For instance, a person who is severely disabled might gain major improvement in his or her quality of life through the ability to occasionally prepare a meal for the family, but would such a person buy MAGIC-HAND for occasional use? On the other hand, a person who prepares all the meals for the household but has painful arthritis might be satisfied to ask a family member or neighbour to open jars and bottles. Would such a person buy MAGIC-HAND for daily use? Sales would be affected by life-style factors such as the support of family members as well as quality of life expectations, but regulations, healthcare prescriptions and quality assurance demands would not affect them.

Long-term commercial potential

The authors consulted manufacturers, retailers, charities and government bodies to promote MAGIC-HAND as a commercial product and concluded there are major obstacles. There will be a long haul to market for the following reasons. First, there is a lack of clarity about funding models. Assistive technology has a low priority in health and social care strategies[11], so public and insurance funding schemes are severely limited. Potential purchasers of MAGIC-HAND are likely to be private individuals, who would have to find the product in catalogues or from the very small number of specialist retailers. An individual who is likely to benefit from MAGIC-HAND would also need multiple AT devices for tasks such as washing, toileting, door and curtain opening, security and environmental control, and so on, so the total cost of a 'complete package' could be daunting. Second, the market demand for such a product is unlikely to be high because it is a specialist product and would not have the benefits of large market volume and hence reduced manufacturing costs. Marketing costs for the LIDS-OFF product were estimated at $ 1.5 million[12] but expenditure of that scale could not be expected for MAGIC-HAND. Third, the authors encountered significant resistance from mainstream kitchen appliance manufacturers who are reluctant to enter the 'disability market' in which they have no previous marketing experience. Finally, there is a brand image issue; some manufacturers approached by the authors stated that their brand images must remain associated with lifestyles that can be projected as modern and attractive. Their advertising is targeted at youth and vitality, not age and fragility.

Conclusions

The machine offers a high level of functionality for people with severe disabilities but it is only one of a range of devices required for independent living. The current design was focused on providing a high quality prototype for demonstration and trial purposes, so its cost is high. It is currently believed that the machine is most likely to be used in communal kitchens in sheltered housing, where its shared cost and availability would support higher levels of independence but within a supported environment.

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